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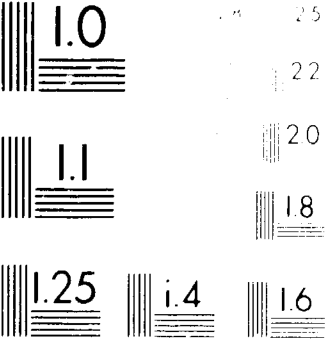

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UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION

Advances in Materials Technology: MONITOR

14551

Issue Number 3 December 1984

Dear Reader,

This is the third issue of UNIDO's state-of-the-art series in the field of materials entitled Advances in Materials Technology: MONITOR. This issue is devoted to fibre optics and is addressed to a select target audience of policy makers, scientists, technologists and industrialists in developing countries.

In each issue of this series, a selected material or group of materials will be featured and an expert assessment made on the technological trends in that field. In addition, other relevant information of interest to developing countries will be provided. In this manner, over a cycle of several issues, materials relevant to developing countries could be covered and a state-of-the-art assessment made, hopefully every two years.

The first issue was devoted to steel and dealt in particular with high strength, low alloy (HSLA) steels. The second issue was devoted to new ceramics, also known as fine ceramics, high-performance ceramics and advanced ceramics. UNIDO has received good response on the content of these issues as well as on the idea of a monitor on materials.

This issue is devoted to fibre optics and contains two articles written by experts in this field. A current awareness section includes information on new products, new processes, applications and market trends. A list of publications and information on meetings in this field are also contained in this issue.

The UNIDO secretariat would welcome information on materials and suggestions on the format and content of this issue from readers.

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CONTENTS

CURRENT AWARENESS

New Products

NTT develops light-powered telephone equipment

"Nippon Telegraph and Telephone Public Corporation's (NTT) Yokosuka Electrical Communication Laboratory has recently succeeded in introducing an experimental basic light-powered telephone system; terminals in this system consume only one milliwatt compared with 88 for conventional electrically powered telephone equipment. Two optical cables for transmitting and receiving voice signals and optical power connect the telephone terminal with a central office system; the office system is equipped with two semiconductor diodes, each capable of transmitting optical power of up to 25 mw in a 0.83 micron wavelength and of transmitting call signals in a 0.89 micron wavelength. The telephone terminal has one light-emitting diode (LED) for transmitting signals, a Ga-Al-As photodiode for receiving optical power, and a silicon photodiode for receiving signals. Laboratory experiments showed that when the length of the optical fiber cables were no more than 100 m the new light-powered telephone terminal performed as well as conventional ones." (Extracted from Fiber Optics and Communications Newsletter, April 1984, p. 10.

The Spectran Corporation develops single-mode fibre

"Spectran Corporation, a developer and manufacturer of optical communication fiber located in Sturbridge, MA announces immediate availability of medium and high performance single mode optical fiber. Prior to this, Spectran has been a major producer of large core, high NA, multi-mode optical fibers for short distance data communication. The fiber is available for operation at first window (1300 nm) and dual window (1330 and 1550 nm), medium performance is 0.7 dB/km and 0.5 dB/km at 1300 and 1550 nm respectively with a maximum total dispersion of 3.5 pico seconds/nm-km. High performance is 0.5 dB/km at 1300 and 1550 nm respectively with the same dispersion characteristics. The advantage of single mode fiber is in the transmission pattern: it has greater information-carrying capacity and allows longer distances between repeaters than multimode systems. Single mode systems will routinely be able to transmit without regeneration by a repeater up to 200 million bits of information per second over 80 to 100 kilometers. The SG102 version at a cladding of 125 micrometers with a buffer coating of 250 micrometers and has a proof stress level of 50kpsi. The SG100 version has a buffer of 500 micrometers and has proof stress level of 100Kpsi. A variety of buffer coatings is available including a high-temperature coating." (Extracted from Fiber Optics and Communications Newsletter, May 1984, p. 12.

Sumitomo Electric's new single mode fibre

"Sumitomo Electric Industries, Limited, Japan has been actively involved in the development of single mode fibers containing fluorine for some time. A paper on single mode fiber consisting of a core containing GeO_2 and a cladding layer containing fluorine was presented at the 9th European Conference on Optical Communication in Geneva last year. Since then Sumitomo Electric has established mass production techniques for the fiber and has been delivering this type of fiber optic cable for commercial use. Further, Sumitomo Electric has been developing a single mode fiber consisting of a pure silica core and cladding layer containing fluorine. At this time, Sumitomo Electric announces the successful development of such a single mode fiber by the VAD (Vapor-phase Axial Deposition) method. This type of single mode fiber, manufactured by the mass production method (VAD), is a world first. Currently the transmission loss of the new fiber [illegible] dB/km at [illegible] anti-radiation property and has no loss increase in the atmosphere of hydrogen gas (H_2). With respect to transmission loss, a fiber having a core containing GeO_2 has an inherent absorption loss due to the GeO_2 and a comparatively greater scattering loss than the fiber having a pure silica core which has no inherent absorption loss and has a lesser level of scattering loss. Sumitomo Electric expects that extremely low transmission loss at the longer wavelength regions will be achieved by improved developments of the new fiber in the very near future. Sumitomo Electric is currently refining the improved characteristics of the new single mode fiber and preparing to supply the product on a mass production basis." (Extracted from Fiber Optics and Communications Newsletter, April 1984, p. 9.

Heat-resistant optical fibres

Mitsubishi Rayon of Japan has developed optical fibres that are capable of withstanding 100 degrees Celsius. The fibres are made from polymethyl metacylate. The material is used to transmit switch signals in door locks, speed controls and radio tuners in such high-quality automobiles as Toyota's Century and Nissan's Cedric and Leopard models, replacing primarily the bundles of wires within the passenger compartment. In the future, Mitsubishi predicts that optical fibres will be used in the engine compartment of automobiles. The engine compartments are hot due to exhaust-gas treatment. To meet this demand, Mitsubishi is progressing with the development of fibres capable of withstanding 130-135 degrees Celsius. (Extracted from Kagaku Kogyo Nippo (in Japanese), 30 March 1984, p. 2.

Light guides around the driver's seat in automobiles

Mitsubishi Rayon is supplying General Motors and the Chrysler Corporation with polymethyl methacrylic resin (PMMA) optical fibre which is used as light guides to illuminate the necessary parts of the instruments around the driver's seats. In the future, Mitsubishi Rayon intends to use the PMMA fibres for signal controls by connecting the wires with the microcomputer installed in automobiles in order to automatically open and close doors and windows. These optical fibres are thin and lightweight as compared with the electrical wires, which will reduce automobile weight. (Extracted from Nikkei Sangyo Shimbun (in Japanese), 21 January 1984, p. 9.

High-precision optical connectors that reduce leakage

The Sumitomo Electric Corporation of Japan has developed a detachable optical connector for use in connecting single-mode optical fibre. Optical connectors are important parts than can connect or form relays with like optical-fibre components. If precise connections are not obtainable, light losses increase. In order to hold the light loss to 1 decibel, the ferrule, which is the critical part in a precise connection, must have a slant of less than 0.7 microns with respect to the outside circumference of the ferrule. The optical connectors developed by Sumitomo have a precision of 0.7 microns of slant. Sumitomo achieved this slant by using ceramic capillaries in addition to the stainless steel that heretofore was used in making ferrules. (Extracted from Kagaku Kogyo Nippo (in Japanese), 24 April 1984, p. 3.

Nippon Sheet Glass's selfoc fibres and lenses

Nippon Glass has developed a microlens, called the Selfoc microlens (SML), which is made by cutting Selfoc optical fibre glass into appropriate lengths, which was jointly developed by Nippon Sheet Glass and Nippon Electric. This lens has a small calibre (about 1 mm in diameter) and can attain the desired focal distance. It also demonstrates excellent capabilities to disperse, gather and receive light. At present only Nippon Sheet Glass has the patent rights to sell this lens and AT&T

has decided to use the SML in converting its telephone and telegraph networks to optical transmissions, a project jointly undertaken by Bell Laboratories and Western Electric, an affiliate. To produce microlenses in the United States, Nippon Sheet Glass has purchased a plant site in New Jersey in the United States. AT&T is installing optical fibre communications trunk lines on both the East and West coasts. SML will be used at relay and exchange stations. SML also has uses beyond that of optical-fibre communication parts. It can be utilized in optical switches and detectors used in robotized, unmanned processing plants and in video discs and medical equipment.

Nippon Sheet Glass also wants to make a full-scale advance into markets in the United States with Selfoc fibre, optical fibre used for short- and intermediate-distance communications in plants and buildings, and the Selfoc lens alley, a lens used in duplicating and facsimile machines and in computers. (Extracted from Nihon Sangyo Shimbun (in Japanese), 5 November 1983, p. 3. Copyright © Nihon Keizai Shimbunsha 1984.)

Sensitized optical fibre

Battelle Memorial Institute's Research Center in Switzerland has plans to develop an optical-fiber cable sensitive to external perturbations along its whole length. "This sensor basically will be an optical fiber sensitized to external perturbation by an operation that can be as simple as wrapping a wire around it to increase microbending when disturbed. The cable could serve as an intruder alarm or as a sensor for automatic opening of doors. It even could be used as a readily accessed telecommunications line, because a piezoelectric transducer can be clipped on to the outside at any point to modulate the light in the fiber." (Extracted from "Sensors exploit optical fiber's physical sensitivity," Electronics, 21 April 1983, p. 86. Copyright © 1983, McGraw-Hill Inc.)

Improved photodiode

Researchers at Siemens AG have redesigned the photodiode at the receiving end of a glass-fibre transmission link. The researchers attained a 7-decibel improvement in receiver sensitivity, which extend the repeater-to-repeater distance by at least 5 kilometres for a link operating at wavelengths between 1 and 1.6 micrometres. An indium gallium arsenide/indium phosphide avalanche photodiode with an intermediate InGaAsP layer was used. (Extracted from "Avalanched diode extends glass-fiber transmission link", Electronics, 3 May 1984, p. 85. Copyright © 1984, McGraw-Hill Inc.)

Fibres to withstand low temperatures

Sumitomo Electric Industries, Ltd. of Japan, in co-operation with Osaka Gas, has developed an optical fibre that can be used in very low temperatures. The new fibre uses a special acrylic resin for the primary coating that reduces transmission losses to between one and two decibels down to 200^{o} C below zero. In order to prevent shrinkage due to the low temperature, the fibre is also housed in an aluminum spacer with spiral grooves cut into it. External damage is kept to a minimum. Conventional optical fibre uses silicon for the primary coating and nylon for the second. However, under low temperatures the nylon coating tends to shrink, causing fibre distortion and transmission losses. For temperatures below 40°C below zero, transmission losses increase from between one and two decibels for every kilometre. For temperatures under 60°C below zero, the silicon coating crystallizes, making transmission of information impossible. Applications include such areas as LNG, which requires early detection of gas and liquid leaks and of abnormalities in the condition of tanks, and in aircraft computers that must function under extremely low temperatures. (Extracted from Nihon Kogyo Shimbun (in Japanese), 27 February 1983, p. 4. Copyright © Nihon Kogyo Shimbun Tokyo Honsha 1983.)

Mitsubishi Rayon uses plastic optical fibre for a LAN

Mitsubishi Rayon and Nippon Electric have developed a local area network (LAN) information system utilizing plastic optical fibres. The fibre is 1 mm in diameter, a fraction of the diameter of conventional electric coaxial cable, which simplifies the wiring of offices. The plastic fibre costs less than half that of quartz optical fibre and is bend-resistant. Mitsubishi will install five working stations in its New Products Division, each station consisting of a word processor, a monitor, a floppy diskette, a keyboard and a display. The stations, about 70 metres apart, will form a network connected by the plastic optical fibres, which are capable of reaching 180 to 200 metres, a world record. Mitsubishi Rayon will use the LAN system to handle orders, production, sales and inventory of its new products and plans to introduce the system to its management division and its branch offices. It will market the system after the software has been developed in conjunction with Nippon Electric. (Extracted from Nikkei Sangyo Shimbun (in Japanese), 20 December 1983, p. 11. Copyright © Nihon Keizai Shimbunsha 1983.)

[illegible] Japanese produce new light-emitting diodes (LEDs)

Toshiba has produced a LED that is ten times brighter than what is now available on the market by putting several positive and negative layers together to emit 3,000 millicandela from a single diode. Because the light comes from a very small area, this LED is well suited to the task of sending signals down an optical fibre.

Sharp has produced a LED that only emits light when it is fed a voltage of exactly the right level, making this fibre suited to checking batteries, e.g. in [illegible]table computers that may lose their memory if the voltage falls below a certain [illegible]shold. (Extracted from "A brighter light at the end of the fibre," New [illegible]tist, 6 September 1984, p. 26. Copyright © 1984, IPC Magazines.)

[illegible] Electric Corporation develops a 85-milliwatt laser diode

[illegible] Electric Corp. has developed a high output long wavelength laser diode which [illegible] produce a maximum 85-milliwatt laser beam at room temperature and a [illegible]-milliwat[illegible] the hitherto difficult temperature region of over 100 degrees [illegible] the output of such devices announced up until now [illegible] around 50 to 60 [illegible]ts (at room temperature), introduction of the new [illegible] will greatly increase the transmission range of optical fibre systems and [illegible] building of "[illegible]" [illegible]unications networks, separating the [illegible] light source for mul[illegible] usage. Long wavelength laser diodes [illegible] beam [illegible] 1.3 microns (one [illegible] one thousandth of a millimeter) have [illegible] indium-gallium-arsenic-phosphorus or indium-phosphorus compounds. Compared [illegible] short wave-length type using aluminum-gallium-arsenic as the base, the indium diodes are sensitive to temperature rise, having a maximum output of only [illegible] milliwatts at room temperature and are hardly transmittable at temperatures of over 100 degrees C." (Extracted from Fiber Optics and Communications Newsletter, October 1984, p. 6. Copyright © Information Gatekeepers, Inc. 1984.)

[illegible] Systems develops a single-fibre optic transceiver module

"A single-fiber optic transceiver module has been announced by [illegible] Systems, [illegible]der, CO that is a direct plug-in replacement for ARCNET[R] coax drivers and enables manufacturers of ARCNET[R] products to add fiber optic ports to their products without circuit redesign. The 3191 also expands the [illegible] distance between [illegible] to 4,000 feet, as compared to 2,000 feet when [illegible]. The ability to add fiber optic ports to existing equipment [illegible] advantages of fiber [illegible] ARCNET[R] system user[illegible] planning to [illegible] area networks or to upgrade or expand their existing local area networks. These advantages include immunity to EMI/RFI, ground loops, and power surges; data security; cost effective resource sharing and greater marketing flexibility. This flexibility is of great interest to users of ARCNET[R] in business and industry, office automation, medicine, military and multi-building installations." (Extracted from Fiber Optics and Communications Newsletter, November 1984, p. 1-. Copyright © Information Gatekeepers, Inc., 1984.)

Fibre-optic link kit

"A fibre-optic link kit is available from Pilkington Fibre-optic Technologies of Rhyl, North Wales. The kit comprises of 35 metres of cable, four connectors, two Y joints and two line drivers terminated ready for use with two optical line drivers. Designed to demonstrate to potential users the ease with which fibre-optic systems can be implemented, the kits will retail at £299.00 plus VAT - a saving of £100 on the normal list price of the equipment. An additional £5.00 post and packaging charge will apply to orders for delivery. The kits will be of particular interest to data communications managers and will enable all of the major benefits of fibre-optic systems to be realized. These include high integrity data transmission, ease of cable routing in cluttered environments, freedom from the effects of EMI (electro-magnetic interference), and high security of transmitted data - fibre-optic cables cannot be tapped without detection. Pilkington Fibre-optic Technologies informs us that only a limited quantity of the kits are available and that these can be obtained from them at the following address: Sales Department, Pilkington Fibre-optic Technologies Limited, Kinmel Park, Bodelwyddan, Rhyl, Clwyd, LL18 5TY." (Extracted from Fiber Optics and Communications Newsletter, April 1984, p. 11. Copyright © Information Gatekeepers Inc., 1984.)

New processes

New process for GI multimode and SI monomode silica glass fibres

Philips has developed a process for the manufacture of graded-index multimode and step-index monomode silica glass fibres. This process is different from others in the method of inducing the reaction: a microwave resonator, not a gas flame, is passed along a quartz glass tube. The tube is not rotated but is inserted in the middle of the resonator, which brings about ionization of the gasses as a result of the magnetic field. A non-isothermic (cold) plasma is thus formed - in which the electron temperature is several tens of thousands of degrees higher than the temperature of the ions - in which the desired reactions take place. Both the tube and resonator are located in an oven that maintains a temperature of 1100 degrees Celsius in order to prevent the formation of hair cracks in the layers of glass deposited. In the MCVD (modified chemical vapour deposition process), the temperature is much higher. This temperature, much lower than that to which the tube is exposed in the MCVD process, reduces the deformation of the tube. The pressure within the tube is 2500 Pascal, which eliminates the powdery intermediate stage.

The PCVD increases the control and replicability, but the speed with which the resonator can be moved is the most obvious advantage, due to the fact that energy is released directly in the plasma and does not have to pass through the tube wall, which continues to increase in thickness. The separate layers can be thin (0.5 micron) as a consequence and their composition is determined with great accuracy. The desired profile can be approximated to close tolerances in a large number of very small steps. In the time required to build up 30-50 layers with the MCVD process, the PCVD process deposits about 1000 layers. Since the temperatures occurring during the process remain much lower than the melting point of quartz glass, the preforms obtained have an excellent geometry, which is of great advantage during the drawing process which follows. (Extracted from Electrotechniek (in Dutch), June 1984, pp. 509, 511-513. Copyright © 1984 Electrotechniek.)

New production techniques developed by Sumitomo and Furikawa

"Fiber technology is one area where the Japanese had not mounted a serious challenge until recently. Now Japan's leading optical fiber makers, Sumitomo Electric Industries Ltd. and Furukawa Electric Co., are putting the finishing touches on a new production technique that they confidently predict will give them a strategic cost advantage over U.S. suppliers. Called VAD, for vapor axial deposition, it promises continuous production for the first time: As the thin filament is pulled from one end of a hot glass rod, the rod is replenished at the other end. The process has yet to run continuously, and only 10% of Japan's optical fibers are made with it, but Sumitomo plans to double its capacity, to 60,000 mi. of fiber annually, each year for the next few years - all using VAD." (Extracted from "Fiber Optics: The Big Move in Communications - and Beyond," International Business Week, 21 May 1984, p. 70. Copyright © 1984 McGraw-Hill Inc.)

New crystal-growth technique

"Epitaxx Inc. is a newly formed "high-tech" company in Princeton, NJ which will conduct research and light manufacturing of semiconductor materials and "chips" for optoelectronic devices such as lasers, light-emitting diodes (LED's) and light detectors. The primary application of these devices will be in fiber optic communications although a number of infrared applications such as detectors and emitters for rangefinding and satellite imaging are also envisioned. The optical communications industry is undergoing rapid growth - over 90% of all telephone information should be tramsmitted optically by 1990. The unique feature of Epitaxx is the use of a crystal growth technique known as vapor phase epitaxy (VPE), whereby thin films of semiconductor materials are deposited from gases. Vapor phase epitaxy is a low-cost mass-production process for the production of high-quality crystalline semiconductor wafers. "Epitaxy" is a crystal growth technique whereby the deposited films adopt the crystal structure of the substrate wafer upon which they are deposited. Dr. Gregory Olsen, who serves as its President, and Dr. Vladimir Ban, Senior Vice President, are co-founders of the company. Both are former research scientists at RCA Laboratories in Princeton, who have extensive experience with the technique. The VPE technique has been used to grow alloys of indium gallium arsenide phosphide which are used to make emitters and detectors in the 0.6-3.5 micron spectral range. Located along the Trenton-New Brunswick, NJ Route 1 corridor, Epitaxx is a precursor for a whole new wave of high-tech businesses which will accompany the explosive growth of optical communications. Unlike the integrated circuit/computer chip industry which sprung up and matured in "Silicon Valley" near San Francisco, the new optical communications industry is primarily an East Coast/New Jersey phenomenon, having been developed mostly at large laboratories such as RCA, Bell and Lincoln Laboratories. Initial production of detectors is planned by early summer. Subsequent products will include LED/s lasers and microwave materials." (Extracted from Fiber Optics and Communications Newsletter, May 1984, p. 10. Copyright © Information Gatekeepers, Inc. 1984.)

AT&T's new optical-fibre coating method

"Researchers at AT&T's Centre in Hopewell, New Jersey, have developed a method of drawing and coating optical fibres at a speed of 12m/sec, while maintaining the same mechanical and optical properties as those achieved at conventional speeds. The development was announced at a conference on optical fibre communication held in New Orleans recently. Using a high draw tower, Un-Chul Paek, the researcher responsible for developing the process, and his assistant, Charles M. Schroeder, drew, and simultaneously coated with a polymer, long lengths of optical fibres. During the drawing process, fibre diameter was constantly monitored and controlled to maintain uniformity. The standard deviation of the diameter was less than 0.5 µm-thick, single-layer coating throughout a 7 km length of fibre, with the fibre properly centered within the protective outer sheathing. The fibres were then proof-tested at two different stress levels - 100,000 and 200,000 psi. The results showed that their strength was comparable to that of fibres coated at lower speeds." (Extracted from Fiber Optics and Communications Newsletter, April 1984, p. 4. Copyright © Information Gatekeepers, Inc. 1984.)

Better coatings for optical fibres

The Ube Nitto Chemical Corporation of Japan, in conjunction with some leading manufacturers of electronics equipment, has developed the technology to produce coverings for optical fibres made from fibreglass-reinforced plastic (FRP). Until now, optical fibres have been protected by coatings of such materials as nylon. Light-transmission losses are reduced to an absolute minimum. The FRP coverings are produced by a process of drawing out before the substance hardens. The coatings have proven highly effective in avoiding the effects of external heat to the greatest possible extent, and especially in solving problems related to tensile strength in the first stage of the drawing-out process. The FRP coverings avoid the effects of electromagnetic induction and permit the use of entirely non-metal cables in uses where magnetic induction cannot be avoided, e.g. electric power and electric railways. (Extracted from Kagaku Kogyo Nippo (in Japanese), 29 March 1984, p. 2. Copyright © Kagaku Kogyo Nipposha, 1984.)

Fiber-optic holograms

AT&T Bell Laboratories in New Jersey, United States of America, has developed a technique for transmitting three-dimensional photographs, called holograms. "In holography, an object is illuminated with laser light in such a way that an interference pattern is recorded on a photographic plate as a hologram. When the hologram is later illuminated, a three-dimensional image of the original object is reconstructed in space. Holography interferometry, a branch of holography that monitors the position of interference fringes on the hologram, is useful in precisely measuring vibrations and strains." This technique can be used to observe remote or otherwise inaccessible objects, such as hostile environments or equipment in operation. (Extracted from "Fiber-optic holograms," IEEE Spectrum, August 1984, p. 18. Copyright © 1984 by The Institute of Electrical and Electronics Engineers, Inc.)

The Ortel Corporation develops new laser technique

"For the high-capacity systems that beckon for solid-state lasers, a new technique is making it possible to modulate gallium aluminum arsenide lasers at much higher rates than had previously been attempted. In addition, a tuned laser of high spectral purity has increased the potential of single-frequency devices for appearing in multiplexed, high capacity systems. A related goal, that of achieving truly coherent light beams over long distances, is coming closer to success, permitting frequency mixing and other established techniques that are possible with conventional rf systems. Until recently, practical fiber-optic systems using laser diodes were confined to bandwidths of no more than 2 GHz because of what were thought to be the theoretical limits of the laser's semiconductor properties. To isolate the factors limiting the data rate, Ortel Corp. (Alhambra, Calif.) re-examined the theory of modulation as it relates to lasers and was able to raise the existing limit threefold in its standard cavity-type lasers.... More specifically, they shortened the resonant cavity of a buried heterostructure laser, [illegible] decreased photon lifetime (as opposed to increasing photon [illegible] modulation bandwidth [illegible] injection-class devices, which are mounted on a semi-insulating GaAs substrate, exceeded 6 GHz at room temperature and can go as high as 8 GHz when applied power reaches the device's limits. With a continuous-wave output of 3 mW and a threshold current of only 10 mA, Ortel's laser has been effective in sending data 1 km or so at 840 nm over a single-mode fiber. It remains stable in its single-frequency mode when modulated at depths as high as 80%. The primary design use of the laser will likely be in short-range radar and delay-line applications." (Extracted from "Fiber-optic parts burn a wider, brighter path," Vincent Binacomano, Electronic Design, 8 March 1984, p. 97. Copyright © 1984, Hayden Publishing Company, Inc.)

Cable jacketing

"Cable jacketing is as important as the fiber itself, since the latter can be easily destroyed by exposure to hostile environments. Indeed, the jacketing not only affects the cable's protection and resistance to wear, it also can even affect the fiber's optical performances. Resistance to abrasion, chemicals, and moisture, as well as flame retardancy, are all factors that can affect the choice or a cable. Some materials, such as vinyl, are suitable for general-purpose, or indoor, use. Nylon, in comparison, improves a fiber's physical properties and is generally used with single-fiber conductors. Hypalon can withstand extreme environments and is flame retardant as well. It is more thermally stable than neoprene and resists oxidation and the effects of ozone. Another tough coating, Kynar (polyvinylidene fluoride), is a natural choice for use in factory installations. It is self-extinguishing, resists the corrosive action of most chemicals, and has been approved for low-smoke applications. Its inherent stiffness, however, limits its use. Polyethylene, which is flammable, is less than desirable for electronic applications. The tough and low-cost material has been put to work in some telephone cables. Polyurethane also resists abrasion and remains flexible at low temperatures, to boot. Thermoplastic elastomer, or TPE, is a relatively inexpensive material that has many of the characteristics of rubber. Its good mechanical and chemical properties make it suitable for a jacketing material. Difficult assignments require proven performers, and for fire-alarm signalling systems, Teflon FEP has shown its mettle. It will not smoke, even when exposed to a direct flame, and it can be used even at continuous temperatures of 200°C. Another fluorocarbon, Tefzel, has many of the qualities of Teflon FEP. It is tough, rated for 150°C, and self-extinguishing. Also rated for 150°C operation is irradiated cross-linked polyolefin (ELPE). Because of the cross-linking, it has become a thermosetting material with great resistance to environmental stresses, ozone, solvents and solder." (Extracted from "Focus on fiber-optic cables: Steadily forging the link," Electronic Design, 8 March 1984, p. 180. Copyright © 1984, Hayden Publishing Company, Inc.)

Applications

Plans for new cable facilities for the Pacific region of the United States

"At a meeting with their telecommunications administration correspondents in the Pacific region ... in Morristown, NJ, AT&T Communications and the U.S. international service carriers considered 10 alternative plans for new cable facilities during the 1987-1995 Pacific region facilities planning period, settling on two that would introduce digital fiber optic cables in the region in 1988. The more expensive alternative - "II-A modified" - with an estimated capital investment requirement of $787,000,000, would link the U.S. mainland and Hawaii with a twin-280-megabits-per-second fiber optic pair cable with a capacity of 40,000 equivalent voice circuits. The twin-280 mbps configuration would continue past Hawaii to a deep-sea branching point, with separate 280-mbps cable pairs, each with 20,000-equivalent-voice-circuit-capacity, branching off to Japan and Guam. On the Japan branch, another deep-sea branch past that nation would link Korea and Hong Kong into the loop via a single 140-mbps fiber pair cable. Continuing around the loop, the single-140-mbps pair cable would extend to the Philippines and, from there, back to Guam - closing the loop begun at the first deep-sea branch. The plan also calls for a single 140-mbps-pair cable linking Taiwan and Guam in 1994; with analog cables linking Okinawa to Japan, Taiwan, the Philippines, and Guam, and linking Taiwan to Hong Kong and the Philippines. Another analog link would connect Hong Kong and the Philippines to Singapore, Thailand, Malaysia, and Indonesia. From there, the analog cable would continue on to Australia, New Zealand, and Papua New Guinea, and then continue on to Hawaii and Canada. The less expensive proposal - "III modified" with an initial capital investment of $588,000,000 differs from plan II-A by eliminating the deep-sea branch of the fiber optic cable past Hawaii, substituting a direct twin-280-mbps pair cable linking Hawaii and Japan - but not Guam. Past Japan, the twin-280-mbps-pair link - would again branch at a deep-sea junction with single-280-mbps-pair cables continuing to Korea at a spur, and to the Philippines, where single-140-mbps-pair cables would feed off to Hong Kong, and, in 1994, to Taiwan. Analog facilities available for service during the planning period would be as in plan II-A modified, except that the fiber optic link from the Philippines to Guam, completing the northerly loop, is not included. and Philippines to Guam traffic would transit through Okinawa on analog cables. AT&T-C noted, in its submission to Pacific planning process participants, that mixing voice and data circuits on the computer model for its plans is not possible, and that appropriate adjustments yield an effective capacity for the three cable configurations of 31,000 equivalent circuits for a twin-280-pair, 15,500 for a single-280-pair, and 7,750 for a single-140 pair cable." (Extracted from Fiber Optics and Communications Newsletter, May 1984, p. 3. Copyright © Information Gatekeepers, Inc.)

AT&T set to expand fibre-optic network

"The American Telephone and Telegraph Company will accelerate and extend its high-speed, digital communications system nationwide to increase the capacity and quality of voice and data transmissions, the company announced. 'AT&T will construct the world's largest fiber optic telecommunications network by the end of this decade,' Robert W. Kleinert, president and chief operating officer of AT&T Communications Inc., said at a news conference. AT&T said it would have [illegible],000 miles of optical fiber cable routes in place by 1990. In addition, there will be 9,000 miles of digital microwave routes and 4,500 miles of digital coaxial cable. Together, these routes will offer improved, interference-free communications between most major cities in the country, the company said. The announcement by AT&T is, in essence, the telecommunications equivalent of a plan to widen and upgrade the interstate highway system. The current backbone of the telecommunications system is made up of copper cable and microwave radio designed to carry voice transmissions in the form of analog, or wavelike, signals. The new backbone will be made of optical cables on the most heavily traveled routes, and digital microwave radio on the less traveled routes." (Extracted from Fiber Optics and Communications Newsletter, November 1984, p. 1. Copyright © Information Gatekeepers, Inc.)

Undersea surveillance system being developed by McDonnell Douglas

"Working under a $3 million contract with the US Navy, the McDonnell Douglas Astronautics division in Huntington Beach, CA is developing an undersea fiber-optic surveillance system. The Ariadne Telemetry system is named after the mythical lady who helped Theseus defeat the Minotaur and escape the labyrinth. In the Ariadne system, fiberoptic cables are connected to acoustic hydrophones which pick up undersea sounds. These sensors convert the soundwaves to light signals which transmit back to a ship- or land-based computer for analysis. In an alternate scheme, an aircraft deploys the sensor, spools out the fiberoptic cable, and serves as the computer base. McDonnell Douglas has been involved with research and development on this fiberoptic application since 1977." (Extracted from Fiber [illegible] Communications Newsletter, November 198[illegible]

Artel develops communications systems

"Artel Communications Corporation is announcing a major advance in CAD/CAM communications with the introduction of the industry's first fiber optic system specifically designed to remote Computervision Corporation's widely used Instaview® C color workstations. Artel's new CV103 fiber optic system replaces bulky coaxial and wire ribbon cables with small lightweight fiber optic cables, resulting in:

- longer distance remoting of ultra-high resolution color workstations from the CPU
- cleaner image quality
- greater communications security
- protection against lightning damage
- immunity to noise
- elimination of ground faults and hum

Artel expects the new CV103 fiber optic system to find wide acceptance in large CAD/CAM facilities, such as in aerospace and automotive manufacturing, government laboratories and other applications where color workstations should be located away from the computer room. 'Fiber optics now allow the CAD/CAM workstations to be placed where the activity is happening, rather than forcing the user to visit the computer room,' said Artel Chairman Richard A. Cerny. 'We feel fiber optics should be used whenever the cable runs to the workstation exceed 100 feet. The higher bandwidth of the new ultra-high resolution workstations is starting to obsolete coaxial cables in the longer cable runs, and coaxial cable problems become even more severe when electromagnetic and grounding problems come into play.' The new Artel CV103 fiber optic system is a plug-compatible video/data communications system that connects Computervision Corporation's Graphics Processors and Instaview® C color workstations over hair-thin optical fibers. Video and data signals are multiplexed, processed and transmitted via light beams through the fibers which act as miniature optical waveguides. Used in conjunction with new or existing Computervision Instaview® C installations, this system provides a new dimension in system network flexibility, performance, reliability, and communications security. Workstations may be located wherever they are needed, as far as two miles away from the Computervision Graphics Processor (CGP). (Extracted from Fiber Optics and Communications Newsletter, April 1984, p. 13. Copyright © Information Gatekeepers, Inc.)

Optical communications business in Japan

"Kyocera Corp., Sony Corp., Ushio, Inc., Secom Co. and several other private corporations have decided to venture into telecommunications business in response to the planned opening of this field to private interests following the scheduled restructuring of the government-owned Nippon Telegraph & Telephone Public Corp. (NTT), sources said. The telephone company is now planned to be reorganized to be a quasi-government firm, like Japan Air Lines Co., next year. According to the present idea, these companies as a group will install a large-capacity optical fiber circuit between Tokyo and Osaka and offer data communications and other communications services to other businesses. The new company to be created for this purpose will be the first private long-distance telephone company to compete with NTT, a concept quite new in Japan. The group of companies will first create a joint venture to make a feasibility study of its "second NTT" project immediately after the enactment of the Telecommunications Business Law (tentative), to be presented to the present session of the Diet by the Ministry of Posts and Telecommunications. Actual business is slated to start in or around 1987. The same group of companies has already shown its plan unofficially to both the Ministry of Posts and Telecommunications and NTT. Ever since liberalization of the telecommunications business has become a certainty, several organizations, notably the Japanese National Railways and electric power companies, have been closely studying the possibility of moving into this new field. Concrete plans, however, have never before been formulated. At present, telecommunications business is monopolized by NTT and Kokusai Denshin Denwa Co. (KDD) under the existing Public Telecommunications Law, with the former handling domestic services and the latter international services. Under the new law and the resultant restructuring of NTT, however, a wide range of telecommunications services, including telephone and other basic communications services and value-added network (VAN) services, will be made accessible to private corporations. Kyocera and other companies sponsoring the idea of the "second NTT" believe that new telecommunications business will not only facilitate inter-corporation communications but will also play a key role in restructuring the nation's industry. More than 10 companies including Kyocera, a leading semiconductor maker, and Secom, a security firm, are scheduled to participate in the program. The planned joint venture, which is likely to be capitalized at around ¥700-¥800 million, will wind up a feasibility study of the project in a year or so. The group will recruit additional participants while the feasibility study is underway. The selection of the Tokyo-Osaka route as the business area was motivated by the fact that industrial communications are highly concentrated in this route. The costs for laying a large-capacity optical fiber cable between Tokyo and Osaka are estimated to range from ¥30 billion to ¥50 billion. Des e this huge capital expenditure, Kyocera and its fellow planners believe tnat they can offer telecommunications service networks, not the Tokyo-Osaka channel alone. Kyocera and its group are planning to lay trunk communications circuits along the Tomei (Tokyo-Nagoya) and Meishin (Nagoya-Osaka) Expressway and/or the national railway's shinkansen bullet train line. The trunk lines will be connected to NTT's existing communications networks in Tokyo, Osaka and various cities along the way with revenues from the trunk lines going to the "second NTT" and those from "local" circuits flowing into the new restructured NTT." (Extracted from Fiber Optics and Communications Newsletter, April 1984, p. 8.

Achival network for NASA

The Government Systems Division of the RCA Corporation is constructing a fiber-optic network at the Marshall Space Flight Center in Alabama that will link universities and federal laboratories engaged in land-resource, atmospheric and space-science studies. This optical-storage sub-system is capable of storing 10 trillion bits. "The network began to take shape five years ago, after officials at the U.S. National Aeronautics and Space Administration realized they were being inundated with data from deep-space probes. ...To cope with the heavy data flow, NASA planners designed a fiber-optic bus with seven active ports configured in a star that runs at 100 megabits per second (Mb/s) in bursts and 50 Mb/s continuously. It links three superminicomputers that have been fitted with triple-ported memory. (Extracted from "Juke Box Stores Trillions of Bits of Space Data," Electronics Week, 8 October 1984, p. 17.

Telecommunications system for Singapore's rapid transit network

"A French group made up of Jeumont-Schneider, Halberthal SA, Bouyer SA, Thomson CSF and Steel have been chosen to supply a telecommunications system for the Singapore rapid transit system. The contract amounts to nearly 180 million francs. The system proposed, which is fully integrated, is based on Jeumont-Schneider's time-division electronic PBXs and uses an optical fiber transmission support for handling all information in digital form. The new installation will include communications related to safety, to maintenance, and to alarms, as well as processing information concerning time distribution in the stations, automatic fare collection, public address, telex and radio systems. (Extracted from Fiber Optics and Communications Newsletter, October 1984, p. 4.

Battelle proposes a programme to develop fibre optics

"A major multi-million dollar program to help U.S. industry develop basic manufacturing technology needed for mass producing components for fiber optic networks was proposed recently by Battelle Memorial Institute's Columbus Division. The program, which could lead to a $60 million, seven-year cooperative research effort funded by U.S. companies, is intended to develop generic technology for large-scale manufacturing of active optoelectronic components that interconnect fiber optics in local area communication and process control networks. The program's primary aim is to ensure future U.S. leadership despite mounting foreign competition in the fiber optics field, according to Dr. Robert L. Holman, who will head the research effort. Battelle estimates that by the year 2000 in the United States fiber optics could be a $30 billion market as these materials replace copper wire and microwaves for a wide variety of communication and related purposes. ...Large fiber optic network markets are expected to include office, factory, residential, transportation, and military applications. 'The one crucial factor blocking the effective use and ultimate commercialization of fiber optics systems,' Dr. Holman says, 'is the lack of practical high-performance active components that can interconnect sets of fibers. These components must perform a variety of functions such as switching, splitting, amplifying, and modulating light signals, and processing optical data. 'What's needed is a toolbox of manufacturing technology that companies can use to develop and fabricate these components. The design capability is here, but missing are the generic materials, fabrication, microassembly, and packaging techniques for cost-competitive mass production.' Battelle designed the proposed research program after extensive interviews with U.S. industry and government leaders. The program has three major projects: (1) developing automated microassembly packaging technologies, (2) developing manufacturing processes for fabricating optical circuits, and (3) developing processes for producing optical-grade crystals for guided-wave optics. Each major project, in turn, has two phases. In the first phase, Battelle will develop concepts and reduce these to practice. In the second phase, the Battelle team will conduct scale-up experiments and automated computer-aided pilot demonstrations to evaluate and refine the techniques and needed equipment to the demands of large-scale manufacturing. Completion of the overall program will lead to generic manufacturing technologies companies can use to make devices for connecting multiple fiber systems as well as fiber systems to wire networks. The connectors will need to be easy-to-assemble and highly reliable over lengthy periods of time. When these generic manufacturing technologies becoming available, Dr. Holman says, companies can then develop their own proprietary designs and production specialties to carve their niches in the market. Battelle estimates that, by the year 2000, between 100 and 500 million components will be needed. To carry out the program, Battelle is assembling a multidisciplinary team of internationally known experts in guided-wave optics, physical chemistry, materials science, and manufacturing. Program R&D will be conducted in Battelle's state-of-the-art laboratories devoted to experimental research in guided-wave optics. Currently, Battelle is organizing the first phase of the initial project of the program: to develop concepts and reduce them to practice for automating micro-assembly and packaging technologies. This phase, requiring $12 million in support and three years to complete, is being offered to companies at a cost of $200,000 a year. First phases of the two other major projects of the program are expected to begin six months to one year following the study's initiation." (Extracted from Fiber Optics and Communications Newsletter, May 1984, pp. 1-2. Copyright © Information Gatekeepers, Inc.)

Inter- and intra-building communications

"Large fiber optic applications fall into two categories: interbuilding communication and intrabuilding communication. Interbuilding fiber, used in environments where the buildings are separated by a limited distance (from a campus environment up to about 25 miles), is oriented toward point-to-point, high bandwidth applications combining voice, data, and possibly CAD/CAM or teleconferencing. The primary motives are cost reduction, facilities quality improvement, and the flexibility to quickly add lines or offer new services. ...Intrabuilding fiber optics is oriented less toward identifiable cost reductions and more toward increasing the flexibility and quality of communication facilities. The objective is to simplify communication - by eliminating the need to pull new cable each time a new terminal is installed, and by improving transmission quality." (Extracted from "Out of the Labs and Into the Streets," Peter G. Balbus and Joseph H. Healey, Datamation, 1 September 1984, p. 106. Copyright © Technical Publishing Co.)

Biomedical applications

"The development of glass or plastic fibers a fraction of a millimeter in diameter for in vivo measurements is a relatively new and potentially important endeavor. Fiber-optic sensors can be as small as electrosensors and offer several advantages. A fiber-optic device is safe, involving no electrical connection to the body; the optical leads, very small and flexible, can be included in catheters for multiple sensing; and materials suitable for long-term implantation, such as plastic, can be used. At least some of the sensors are sufficiently simple in their design to be disposable. In the case of chemical sensors there are particular advantages in long-term stability and simplification of calibration because the measurement is equilibrium-based rather than rate- or diffusion-dependent and because the specificity of the measurement is achieved by chemical instead of physical means. Reversible, specific colorimetric and fluorometric reactions are available for most chemical and biochemical constituents of interest." (Extracted from "Fiber-Optic Sensors for Biomedical Applications," Science, 13 April 1984, p. 123. Copyright American Association for the Advancement of Science.)

Fibre-optic cable for television transmission from the Eiffel Tower

Early in 1984, Telediffusion de France (TDF), the State-run broadcasting company, completed the construction of a 2.2 kilometre fibre-optic cable that links TDF's Cognacq-Jay television studios with the Eiffel Tower antenna. This system provides high-quality video and audio transmission for the Ile de France region. Only 54 kilogrammes of optical cable were required for the 300-metre vertical run up the tower, whereas a coaxial cable with the same capacity would have exceeded 1,000 kilogrammes. Lignes Telegraphiques et Telephoniques (LTT) of the Alcatel Thompson group provided the optical cable and transmission equipment for this system, one of the longest vertical systems in the world. LTT has received a research contract for construction of an 18-kilometre cable system linking the Cognacq-Jay station with a tower in Romaineville, which is the starting point of national programmes. (Extracted from "Eiffel Tower Link Operates Successfully," Laser Focus/Electro-Optics, July 1984, p. 50. Copyright © PenWell Publishing Company.)

Long-distance telephone transmission

One of the biggest developments in fibre optics has been the installation of third-generation long-distance telephone systems using 1.3-micrometre laser transmitters and single-mode optical fibres. This development was not expected until about 1985. "... the trend is toward greater use of gallium arsenide indium phosphide (GaAsInP) diode lasers for fiber-optic communications at wavelengths of 1.3 micrometers (the wavelength of minimum chromatic dispersion) and 1.55 micrometers (the wavelength of minimum attentuation). Lasers of aluminum gallium arsenide (AlGaAs), operating at wavelengths in the range of 0.78 to 0.9 micrometers, will continue to serve many other applications, such as optical digital memory, distance measurement, space communications, defense applicatons, high-speed printing, and the like." The MCI Communications Corporation installed a system along the Amtrak railroad right-of-way between New York and Washington, becoming the first long-haul single-mode fibre-optic system to carry telephone traffic. A similar system in England is planned by Mercury Communications along the British Rail right-of-way. The Nippon Telegraph and Telephone Public Corporation of Japan completed a field trial of its F-400M 1.3 micrometre, single-mode optical fibre system in December 1982 and will finish installing this 2,500-km system across Japan by the end of this year. The first use of fibre-optic cable for long-distance transmission of telephone service began in February 1983 between New York and Washington, D.C. The initial fibre link installed by AT&T Communications was 595 kilometres long, including side legs and interconnections to toll-switching offices. Earlier this year it was extended to serve Boston, Mass. and Richmond, Virginia, for a total length of 1,241 kilometres. "Informaton is trasmitted digitally on the fiber at 90 megabits per second. This rate corresponds to 1344 simultaneous voice or to an equivalent mix of voice and data service. Transmission is currently at a wavelength of 0.82 micrometer with an AlGaAs laser as the source. However, the system is designed to be expanded to three times its present capacity if two channels are added at different wavelengths: 0.88 and 1.3 micrometres. Repeaters are spaced 7 kilometers apart, because the fiber follows the route of an existing coaxial telephone cable with repeaters spaced at those intervals. (Extracted from <u>IEEE Spectrum</u>, January 1984, p. 53.

<u>Fibre optics in Australia</u>

"John Wise, fibre optics specialist with consulting engineers Crooks, Michell, Peacock, Stewart in Sydney believes a lack of knowledge of the new technology has held Australia back from using it. But local manufacturers of fibre, cables and associated equipment are gearing up for increased production. ... According to Wise, the next 10 years will see a 50-fold, or perhaps 100-fold increase in the number and size of optical communications systems, with Telecom Australia leading the way. Telecom Australia, which has been field testing optical fibres since [illegible], is currently carrying out major trials in Brisbane and in Melbourne. It plans to install about 50 short and medium-haul systems in the national telecommunications network by 1986. The Brisbane installation is a 24 km cable containing 5 pairs of fibres, each pair transmitting 34 Mbits/s. It carries public telephone traffic between Spring Hill and Strathpine exchanges. One of the Melbourne systems is a 36 km, 34 Mbits/s cable linking the Exhibition and Dandenong exchanges. The other is a 17 km, 140 Mbits/s cable between the Exhibition exchange and the Maidstone microwave terminal, where it will provide a digital radio system entrance link. Work is now under way on an optical communications link which Queensland Railways is installing as part of the electrification of the Kuraby-Beenleigh line. The 20 km, 2 Mbits/s systems will provide communication and control between stations on the way, using "drop and insert" repeaters. The optical fibre cable will share ducts with power and signalling cables. Another railway application now under way is the New South Wales State Rail Authority's electrification of the 47 km Waterfall-Port Kembla line. This system uses a composite cable made of 50 pairs of copper wires and 3 optical fibres carrying 8 Mbits/s. The fibres will provide point-to-point communication between Waterfall and Port Kembla while the copper pairs handle short connections to stations and trackside telephones along the route. A composite cable has been installed by the Northern Territory Electricity Commission as part of its Darwin communications network. The four optical fibres in this cable will provide communications, control and data gathering at up to 34 Mbits/s, while the 50 copper pairs provide transmission line protection. ... The line is likely to be extended in the next few years by another 11 km. But most of Australia's optical communications systems are small or experimental, according to Wise. He thought there was probably about [illegible]0 fibre kilometres in total installed in Australia compared with more than [illegible]00 times this amount in the United States. ... Although Telecom Australia had been involved in fibre optics research for about 12 years, it was only in the past [illegible] years that the work had become oriented towards operation. [illegible] [illegible] reasons why fibres had not [illegible] because of the belief that they were very expensive and the lack of awareness of the technology's advantages and maturity." (Extracted from Fiber Optics and Communicatons Newsletter, October 1984, p. 2. Copyright © Information Gatekeepers, Inc.)

Ballarat, Australia to pioneer new fibre-optic technology

"The provincial city of Ballarat in the state of Victoria, Australia is to play a key role in a switch by Telecom Australia, the Federal Government-owned telecommunications monopoly, to optical fibres. Ballarat will be the first provincial city in Australia to be linked to a metropolitan city with the new fibre and will be used to pioneer the technology. The cable will run from Ballarat to Melton where it will connect with a coaxial system linked to a sophisticated AXE electronic exchange at the Exhibition Exchange, opened in Melbourne late last year. Existing earth and radio communications from Ballarat to Melbourne will be maintained and there also are plans to double the capacity of the radio link between Ballarat and Geelong, a port city on Port Phillip Bay, Victoria. On current planning Telecom Australia is to start laying the optical fibres about January 1985. The fibres will be encased in a protective lining about the thickness of a finger. New transmission equipment will be installed and ready for March 1986 for an anticipated 'cut over' to a high technology AXE exchange also being built in Ballarat. Ballarat was chosen because of the need by Telecom Australia to find a city with the demand for a new communications system with reasonable proximity to a metropolitan capital. Information gleaned from the laying of the cable and its linking up will be used on a more ambitious Melbourne-to-Sydney optical cable planned for completion in 1987-88. The area from Melton to Ballarat will literally be Telecom Australia's testing ground for the cable and new techniques it has developed for its laying. The route - although not finalized - will govern a variety of terrain, with the biggest challenge expected to be the Melton Rock Plains." (Extracted from Fibre Optics and Communications Newsletter, November 1984, pp. 3-4. Copyright © Information Gatekeepers, Inc.)

Telecommunications link between Waverley and Sydney, Australia

"The first commercial installation of locally made optical fibre has joined Telecom Australia's radio tower at Waverley in the eastern suburbs of Sydney to the Haymarket telephone exchange in the downtown centre of the city. Amalgamated Wireless Australia Ltd. (AWA), the local manufacturer of the optical fibre, said the seven kilometre link was also the first fully Australian made telecommunications cable based on optical fibres and could be followed soon by similar installations in the state of Victoria and in Telecom Australia, the Federal Government-owned telecommunications group. The head of the AWA physics laboratory, Don Nichol, said two multi-mode optical fibres, such as the ones between Waverley and Haymarket, could carry as much information as 120 pairs of copper wires." (Extracted from Fiber Optics and Communications Newsletter, November 1984, p. 6. Copyright © Information Gatekeepers, Inc.)

Test of optical ground wire for Australian hydroelectric system

"Canstar Communications and The Manitoba HVDC Research Center jointly announced the installation of a 2600 meter optical ground wire (OPGW) experimental test line at Manitoba Hydro's transmission line test site north of Winnipeg. The test line containing four multi-mode optical fibers in the core of the ground wire is strung in four spans of 488 meters over five transmission towers 40 meters in height. The test system is equipped with CANSTAR CDS-1 Optical Terminal Equipment for data and message transmission at 1.544 Mb/s data rate. The installation is part of a joint project by The Manitoba HVDC Research Centre and Canstar Communications in which Canstar is supplying the complete lightguide system consisting of OPGW lightguide cable, CDS-1 electro-optic terminal equipment, splicing and test equipment and engineering support. HVDC is providing the test site, the research facilities, line installation personnel, mechanical test arrangement and the data collection and processing capability." (Extracted from Fiber Optics and Communications Newsletter, November 1984, p. 7. Copyright © Information Gatekeepers, Inc.)

Market trends

Projections of European market in fibre-optics office links

"Fiber optics is an accepted technology for long-haul telecommunications in Europe today; in the future, fiber optics will be used not only in long-distance data-transmission (telecommunications) applications but also in shorter distance data links. In fact, these short-distance data links promise to be the major market for fiber optics by 1990, according to a new Frost & Sullivan study. Many non-telecommunications uses of fiber optics are expected to grow rapidly before 1990 in Europe, especially those associated with communications and data processing technologies. The total market for non-telecommunications applications of fiber optics will be $404 million in 1990, a healthy increase over 1984's $67.5 million dollar market (both in current US dollars), says the new study. According to "Non-Telecom Fiber Optics in Europe"..., though the current market for components in most of these applications is small, many are expected to grow rapidly during the forecast period. Office and industrial links will show the most rapid growth over the forecast period. Office links will become the largest single category: by 1990 they will have 36% of the total market, and 56% overall average yearly growth is predicted. Office links alone will be a $146 million market in 1990, says the report, up from $18 million in 1984. This increase will be fueled by the increasing use of local area networks, says Frost & Sullivan. Industrial links will experience slower growth to the end of the decade than office links, with a $91 million market in 1990, up from 1984's $18 million market. Frost & Sullivan predicts growth in the five other applications covered in the study: light and image guides, power waveguides, sensors, automobiles, and military-aerospace-marine. Of these, the greatest growth will be in automotive applications. Frost & Sullivan predicts a $15 million market in 1990, an astounding increase over 1984's $1 million market. France, the UK, and West Germany absorb around 70% of the total currently, with the UK being marginally ahead. Benelux and Scandinavian countries equally share the bulk of the remainder, with Italy and other countries accounting for around 10% of the total." (Extracted from Fiber Optics and Communications Newsletter, November 1984, pp. 16-17. Copyright © Information Gatekeepers, Inc.)

Fiber optic electronics sales to the U.S. telephone market

"Sales of fiber optic electronics equipment to U.S. telephone companies will total between $1.062 billion and $1.594 billion by 1988, according to CARRIER TRANSMISSION EQUIPMENT MARKET, a report published by Northern Business Information (NBI), an independent market research firm with offices in New York and Toronto. The size of the entire U.S. carrier equipment market, excluding microwave equipment, will reach between $2.465 billion and $2.778 billion by 1988. Consequently, fiber optics electronics will amount to between 43% and 57% of the total telco purchases for carrier equipment. Conversely, in 1983, sales of fiber optic electronics represented only six per cent of the total $1.785 billion carrier equipment market. AT&T Technologies was the clear leader with a 45% share of the $104 million worth of fiber optic electronics equipment sold to telecos. The market for the traditional types of carrier equipment reached $1.681 billion in 1983 and is gradually declining. NBI projects that by 1988, sales of traditional carrier equipment to telcos will total between $1,184 billion and $1,403 billion." (Extracted from Fiber Optics and Communications Newsletter, October 1984, p. 13. Copyright © Information Gatekeepers, Inc.)

European opto-electronics market

"Optical fibers will shine more brightly than cathode ray tubes (CRTs) in Europe's opto-electronics components market, as telecommunications need help push it to more than twice its present level by 1989, or nearly $1.4 billion. "Opto-Electronic Components in Europe"..., a new study by Frost & Sullivan, shows that while CRTs will dominate the 15 component categories analyzed, due to the burgeoning of microcomputers, they will grow more slowly than the average annual gains of 15% that the market will register through 1989. Optical fibers and fiber-optic connectors and couplers, by contrast, will each exhibit 25% annual increases. The total market will rise from a 1983 base of $585 million (constant 1983 dollars used in projections). Key factors energizing the market, in addition to telecommunications requirements, will be high growth in component demand for industrial controls and instrumentation, in consumer electronics, in the automatic industry, and in data processing. All of these demand areas will outperform the market, the 266-page report says, as solar power and military and aerospace segments show smaller increases. The market is analyzed by major EEC countries (Benelux, France, the U.K., West Germany, the rest of Europe) as well as by industry sector and product type, and profiles and general rankings of manufacturers are also supplied. Opto-electronic components will be used most in telecommunications and communications, which alone accounted for 29% of the market in 1983 and will represent nearly 30% by 1989. Of particular importance will be submarine cables using fiber optics. The interconnection of peripherals and growth of local area networks for computers and office equipment will spur the use of fiber optic links in data processing, the second largest demand area, which will constitute 24% of the market throughout the years discussed. The explosive growth of microcomputers 'will provide a positive impetus for cathode ray tubes and other display devices'. Instrumentation and industrial controls will be the fastest growing sector of the market, averaging gains of more than 16% a year, climbing from 18% of the market in 1983 to 19% of the 1989 total, thanks to growing use of display panels, video display units, opto-electronic sensors as position sensors, and fiber optic links for remote controls". (Extracted from Fiber Optics and Communications Newsletter, October 1984, pp. 13-14. Copyright © Information Gatekeepers, Inc.)

Market trends in U.S. optical fiber products

In an article by David Charlton in Laser Focus/Electro-Optics, September 1984 issue, he estimates the trends in optical fiber consumption by applications for telecommunications systems. Inter-LATA use will decline from 57 per cent in 1983 to 35 per cent in 1990. The large increase will be in the local loop, from 2 per cent in 1983 to 30 per cent by the end of the decade.

APPLICATION	1983	1987	1990
INTER-LATA	57	54	35
INTER-EXCHANGE	33	29	15
FEEDER	8	12	20
LOCAL LOOP	2	5	30

(Extracted from Fiber Optics and Communications, October 1984, p. 14. Copyright c Information Gatekeepers, Inc.)

U.S. industries increase use of optical fibres

The growth in the fibre-optics industry is 40 per cent per year. Both AT&T and Corning Glass hold about a 35 per cent share each of this market. Corning intends to spend $87 million on expanding its production unit in Wilmington, Delaware. Japanese companies are also competing for the U.S. market: Sumitomo Electric Industries plans to build an R + D facility in North Carolina and the U.S.

branch of Tama Chemical will construct a 10,000 square-foot facility near Seattle, Washington. The largest demand for fibre-optics is by the telecommunications branch, which now uses 85 per cent of the optical fibre sold. Computer-data transmissions, private telephone exchanges, local area networks and cable television make up about 30 per cent of the future demand for optical fibre. Companies that supply chemical products are also benefiting from the healthy market. "For all applications, according to John N. Kessler, president of Kessler Marketing Intelligence, U.S. fiber-optic cable sales are expected to jump from $500 million in 1984 to more than $2.2 billion in 1990." ...Companies in the coatings industry, for instance, say they fully expect to keep pace with the 40%/year growth rate enjoyed by the fiber makers. In addition to their polyethelene jackets, fibers also are covered with coating [illegible] UV-curable resins such as urethane and epoxy acrylates. (Extracted from [illegible], Chemical [illegible], 8 August 1984, p. 1[illegible]. Copyright [illegible])

[illegible]

U.S. Department of Commerce figures for optical components, optical [illegible] optical fibre and cable indicate a trade surplus of $6.5 million for the [illegible] months of 198[illegible]. "For the first time in at least five years the United [illegible] exporting more non-consumer optical products than it imports. ... Japan and [illegible] East Asian nations provide most U.S. imports, but western European nation[illegible] most U.S. exports. As a result, the U.S. had a trade deficit of $20.[illegible] million [illegible] East Asia and a trade surplus of $16.5 million with Western Europe in the [illegible] three quarters of last year. Trade with Canada, Latin America, Israel and [illegible] nations was more even." (Extracted from Laser Focus/Electro-Optics, April 1[illegible], p. 11[illegible]. Copyright © PennWell Publishing Co.)

Projection of sales of fibre-optic cable to U.S. telephone companies

"Sales of fiber optic cable to U.S. telephone companies will reach $889 million to $1.334 billion by 1988, according to Northern Business Informatio[n], a research firm. NBI said the entire toll and exchange cable market will tot[al] $2 billion to $2.3 billion by 1988, and fiber could account for between 44 an[d] 59 per cent of those expenditures. The study, Wire & Cable Market, said 198[3] sa[les] of fiber optic cable remained small relative to sales of metal cable. About $87 million worth of fiber optic cable was sold to telephone companies last ye[ar], representing only 6 per cent of the total $1.4 billion telco cable market. AT[&T] and Siecor were the leading suppliers of fiber optic cable in 1983, with market shares of 60 and 25 per cent, respectively, according to the NBI report. NBI note[d] that, over the 1983 to 1988 period, sales of metal cable to telcos will decline about 5.8 per cent per year, and that, faced with the prospect of shrinking met[al] cable demand, suppliers are beginning to more aggressively market fiber optic cab[le] to the regional holding companies (RHCs). AT&T is expected to remain the dominant supplier of wire and cable to the RHCs, retaining about 75 per cent of the market, NBI said, but added RHCs will continue to second-source these products to keep AT&T's prices at competitive levels." (Extracted from Fiber Optics and Communications Newsletter, May 1984, p. 10. Copyright © Information Gatekeepers, Inc.)

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OPTICAL-FIBRE PRODUCTION

Ernst Bonek*, Bernhard Furch** and Heinrich Otruba***

Optical-fibre communications systems

Basic [illegible]

[illegible] carrier frequency of light promises a tremendously wide bandwidth [illegible] transmitting information compared with conventional systems. Whereas line-of-sight transmission through the atmosphere is restricted to some few kilometres because of the absorption of light due to dust, fog and rain, guided transmission of light through glass fibres became attractive in 1970 when Corning Glass Works announced the development of optical fibres with losses less than 20 decibels per kilometre (dB km) [illegible]. Suddenly, long-distance telecommunications on fibre optics seemed possible. The ensuing development of optical-fibre transmission systems grew [illegible] the combination of semiconductor technology, which provided the necessary light sources and photodetectors, and optical waveguide [illegible] which optical fibre is based. In recent years world-wide [illegible] have led to the development and installation of practical and [illegible] feasible optical-fibre communication systems operating as [illegible] the data are sent [illegible] simply turning the transmitter on and [illegible].

The elements comprising an optical-fibre transmission link are presented [illegible] figure 1. The key components are (1) a transmitter consisting of a light source and its associated drive circuitry, (2) a cable providing mechanical and environmental protection for the optical fibre(s) contained inside, and (3) a receiver consisting of a photodetector plus amplification and signal-restoring circuitry.

The light sources suitable for fibre-optic transmitters are semiconductor injection laser diodes (ILDs) and light-emitting diodes (LEDs). They have adequate output power, which can be directly modulated by varying the input current to the device. They have a high efficiency, and their dimensional characteristics are compatible with those of optical fibres. In the 800 to 900 nanometre (nm) region the light sources are generally made of alloys of gallium, aluminium and arsenide (GaAlAs). For longer wavelengths (λ=1100 to 1600 nm), alloys of indium, gallium arsenide and phosphorus (InGaAsP) are the suited material. A major difference between LEDs and laser diodes is that the optical output from a LED is incoherent, whereas that from a laser diode is coherent. Coherence means that the light is highly monochromatic and that the output beam is highly directional. Since a LED has no wavelength selective cavity, its optical radiation has a broad spectral width and a large beam divergence.

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Figure 1. Basic elements of an optical-fibre transmission link

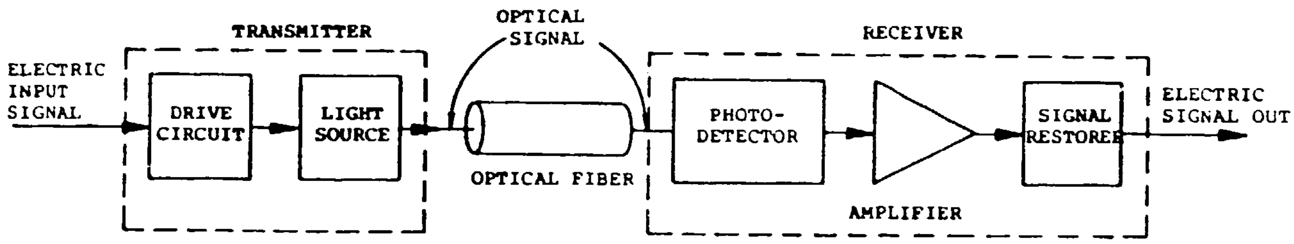


Figure 2. Schematic of a single-fibre structure

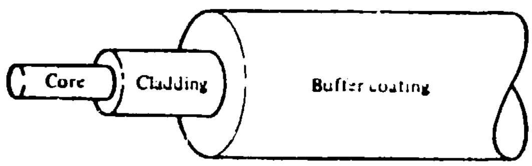
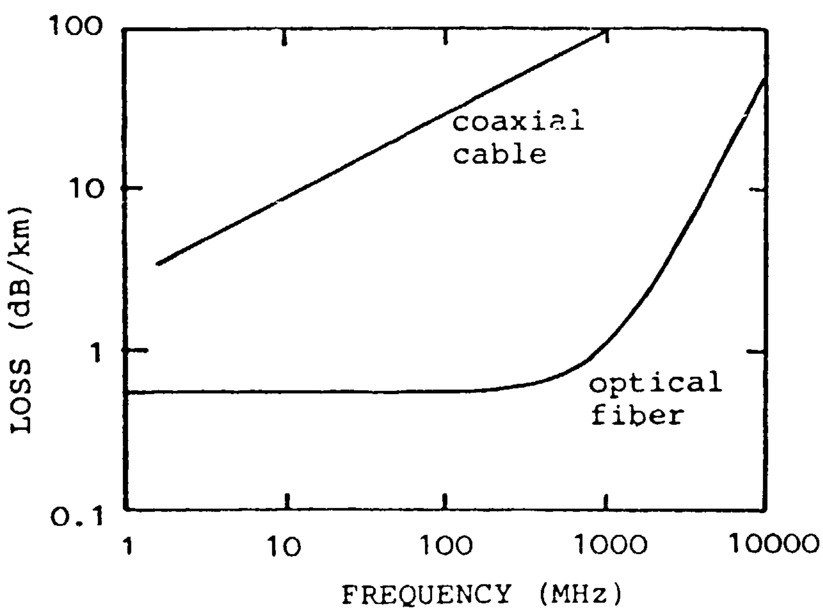


Figure 3. Transmission performance of optical fibres compted with copper cables (attentuation/km vs. frequency)



Source: G. Grau, Optische Nachrichtentechnik (Berlin, Springer-Verlag, 1981).

Generally, the cable contains several hair-thin glass fibres, each of which is an independent communication channel, and, if necessary, copper wires for powering repeaters that are needed for periodically amplifying and reshaping the signal when the link spans long distances. An optical fibre is a dielectric waveguide operating at optical frequencies. Its form is normally cylindrical. It confines electromagnetic energy in the form of light to within its surfaces and guides the light parallel to its axis due to total internal reflection. 2/ As illustrated in figure 2, the fibre consists of a circular solid core surrounded by a cladding that has a lower refractive index than that of the core. An elastic plastic buffer encapsulates the fibre for higher strength and mechanical isolation from the cable structure.

Optical fibre cables can be installed either aerially, in ducts, undersea or buried directly in the ground. As a result of installation and/or manufacturing limitations, individual cable lengths will range from several hundred metres to several kilometres. The complete long-distance transmission line is formed by splicing together these individual cable sections.

The photodetector senses the luminescent power falling upon it and converts the variation of this optical power into a correspondingly varying electric current. Of the semiconductor-based photodetectors, the photodiode is used almost exclusively for fibre-optic systems because of its small size, suitable material, high sensitivity and fast response time. The two types of photodiodes commonly used are the PIN photodiode and the avalanche photodiode (APD). The suitable materials are silicon (Si), germanium (Ge) and indium-gallium-arsenide (InGaAs).

Comparison with conventional telecommunications

The advantages of fibre-optic transmission 3/ as compared with conventional electrical telecommunication (twisted pairs of wire, coaxial cable and microwaves) are:

- An extremely wide bandwidth, permitting a greater volume of information or conversations to be carried over a particular transmission line.
- Very low attenuation, which reduces the number of repeaters, or makes them completely obsolete. Figure 3 compares the transmission performance of optical fibres with copper coaxial tubes.
- Small-diameter, lighter-weight cables because the fibres are hair-thin. Together with the size reduction (easily 10:1) comes an enormous reduction in weight (25:1). This is an important advantage for aircrafts, satellites and space vehicles, ships, and high-rise buildings.
- Negligible cross-talk, even when numerous fibres are cabled together, and almost total immunity to wiretapping, thereby providing greater security.
- Immunity to radio-frequency interference (RFI), electromagnetic interference (EMI) and electromagnetic pulses (EMP).
- Greater safety since light, not electricity, is being conducted and also due to electrical isolation between the transmitter and the receiver.
- High tolerance to temperature extremes as well as to liquids and corrosive gases.

At present the existing price penalty prevents optical fibres from completely driving copper lines out of business.

Applications and trends

Two main tasks can be categorized for telecommunications systems: (1) point-to-point transmission of data and (2) multi-user - multi-service distribution of data. A detailed breakdown of these two main applications is presented in figure 4. Depending on the intended area of use, there are various features of optical fibres that give them an advantage over conventional systems. In transmission systems the main advantages of optical fibres are low attenuation and a large information capacity. For distribution systems the main advantages of optical fibres are price, weight, immunity to electromagnetic interference, and - as long as broadband services have to be distributed - bandwidth.

The challenges facing today's general telecommunication trends are to:

- offer diversified communications services
- integrate services
- integrate components
- digitalize networks
- reduce the cost of transmission

Fibre optics, through vigorous R + D programmes, are meeting these challenges. The aims and relevant activities are summarized in table 1.

Table 1. Summary of trends in general telecommunications

Aims	Activities	Application areas
Avoid repeaters	. Single-mode fibre . 1550-nm wavelength: dispersion-shifted fibre and single-frequency lasers . New materials for 2-5 µm . Low-noise PIN-FET receivers . Coherent detection	. Long-haul links
Make optimum use of installed fibre by WDM a/	. Ultra-broadband fibre . Frequency-stabilized lasers	. Medium-haul links . Subscriber loops
Benefit from electrical isolation, EMI-freedom, weight and volume	. Cheap passive and active components (Lasers, LEDs, photo-diodes, couplers)	. Short-haul links . Local-area networks (LANs)

a/ Wavelength-division-multiplexing (WDM). Light signals at different wavelengths are transmitted simultaneously through the same fibre.

Fibre classifications and standards

Optical fibres can be classified according to the following criteria:

- type of light propagation
- material of the core and cladding
- dimensions of the core and cladding
- transmission characteristics

Figure 4. Classification of tasks in telecommunications

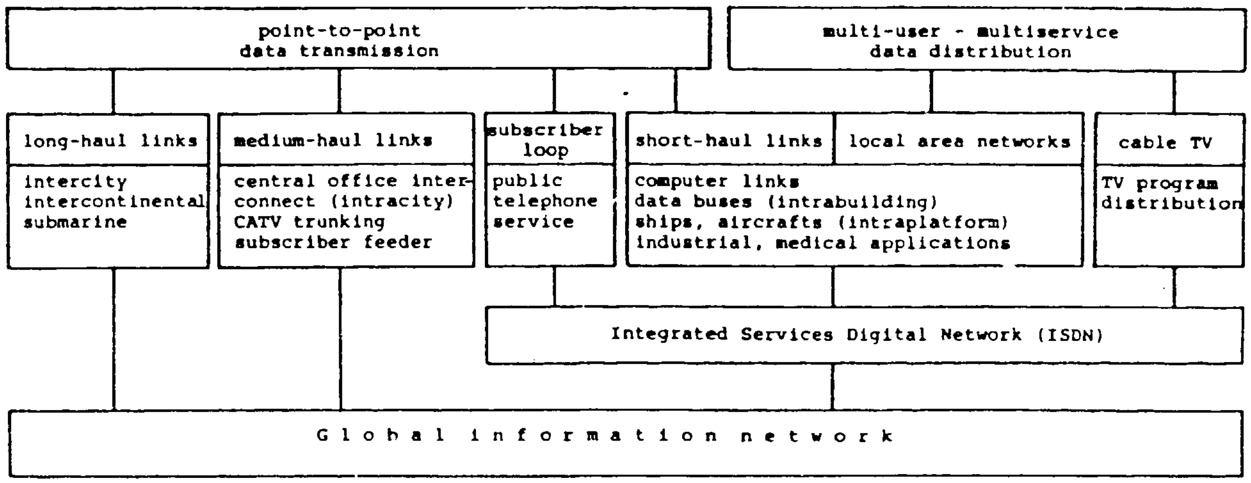
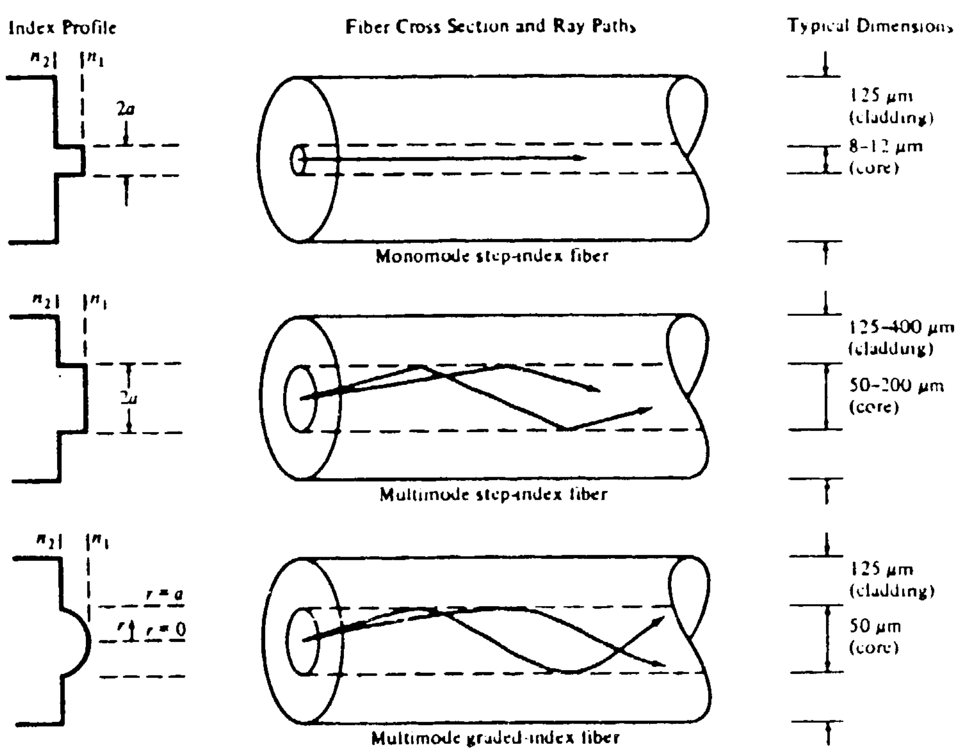


Figure 5. Comparison of step-index (single- and multimode) and graded-index optical fibres



Source: G. Keiser, Optical Fiber Communications (New York, McGraw-Hill Inc., 1983).

Type of light propagation. Two principal groups of fibres can be distinguished according to the manner in which light propagates in them: (1) single-mode (monomode) fibres and (2) multimode fibres. As depicted in figure 5, single-mode fibres usually are called step-index (SI) fibres. In the radial direction the refractive index undergoes an abrupt, step-like change at the core-cladding interface. Due to the core diameter chosen, only the fundamental mode, i.e. electromagnetic radiation pattern, is guided by this fibre type. The dispersion, which causes pulses travelling along the fibre to spread, and the attenuation of the single-mode fibre are the lowest possible, enabling high data-rate transmission over long distances without distortion.

Multimode fibres, according to the refractive index profile of their cores, are either: (1) step-index (SI) fibres or (2) graded-index (GI) fibres. A multimode fibre has a core with a larger diameter than single-mode fibres and carries many hundreds of modes. The dispersion of the SI multimode fibre is high, but is drastically reduced by a nearly parabolic variation of the refractive index profile (GI fibre). The low dispersion characteristic of single-mode fibres can not be obtained by multimode fibres.

The main advantage of multimode fibres is the considerably larger core diameter, making it easier to launch optical power into fibres, especially with LEDs. The large core also reduces the requirements on the tolerances of connectors and splices to join similar fibres. A measure of the information capacity of an optical waveguide is usually specified by the bandwidth-distance product in MHz x km. For a step-index fibre the various distortion effects tend to limit the bandwidth-distance product to about 20 MHz x km. Graded-index fibres exhibit a value as high as 2.5 GHz x km. Single-mode fibres can have capacities well in excess of this.

Material of the core and cladding. The material of core and cladding may be glass or plastic, dividing fibres into four major categories, as presented in table 2.

Table 2. Categories of multimode fibres according to the material of core and cladding

Core	Cladding	Category a/
Glass	Glass	A1 (Graded index) A2 (Step index)
Glass	Plastic	A3
Plastic	Plastic	A4

a/ According to categories developed by the International Electrotechnical Commission (IEC), Subcommittee 46E: Fibre Optics, in its draft "Generic Specification for Optical Fibres-General Requirements," Document 46E (CO) 8, November 1982.

Single-mode fibres always have a glass core and glass cladding. Among the useful glasses, fused silica (SiO_2) in pure and doped form ranks first in production of low-loss fibres. Other glass compounds, made for example by the addition of sodium dioxide plus calcium oxide (Na_2O+CaO) or sodium dioxide plus boron oxide ($Na_2O+B_2O_3$), lower the high process temperatures necessary for pure silica, but usually result in higher optical loss of the fibres. Plastic materials suitable as cladding for glass fibres (plastic-clad silica (PCS) fibres) include low-loss silicone resins and fluoridized polyalkenes and polymethylacrylates. 4/ All-plastic (PP) fibres suffer very high transmission loss (100-1000 dB/km), which is why they are not widely used in telecommunicatons.

Dimensions of the core and cladding. The dimensions of the core and cladding are closely related to the type of light propagation and to the fibre materials (see figure 5). Up to now there existed no complete standardization of the dimensions of optical fibres. The standards of the International Electrotechnical Commission (IEC) standards and the recommendations of the International Telephone and Telegraph Consultative Committee (CCITT) both stress that setting the 50/125 µm standard does not preclude other, future standardized dimensions of A1 fibres. In fact, the dimensions 85/125 µm and 100/140 µm have been recently proposed and are under consideration. 5/ The second standard in effect to date concerns category A3 fibres (plastic clad silica fibres). 6/ Only the core diameter is specified: 200 µm.

No international standards exist for single-mode fibres, but a cladding diameter of 125 µm ± 3 µm has been proposed in a CCITT draft recommendation. 7/ It is not necessary to specify the core diameter; the mode field diameter is the relevant dimension. (For Gaussian light distribution, the mode field diameter is the diameter at the 1/e points of the optical amplitude distribution.) For an operating wavelength of λ = 1300 nm, parameter values of 9 µm ± 1 µm and 10 µm ± 1 µm have been proposed.

Transmission characteristics. The transmission characteristics are (1) attenuation (in dB/km) and (2) bandwidth (in MHz or MHz x km). They depend greatly on the wavelength used to convey the information. Figure 6 illustrates the wavelength regions of low fibre attenuation. Material research and improved fabrication methods (e.g. low hydroxal ion (OH) content) reduced the attenuation, especially at longer wavelengths.

Because of these attenuation characteristics, three wavelength regions are in use today. A fourth one (λ = 1550 nm), where attenuation is a minimum, will be opened as R + D on fibres and components progress. Table 3 gives an overview of these regions. A rough classification of fibres according to their attenuation and bandwidth coincides with material, wavelength, and propagation classifications (see figure 7).

Table 3. Wavelength regions for fibre optics

Wavelength region ("window")	Major use	Typical fibres
Around 630 nm	Short-haul data transmission	Plastic
Around 850 nm a/	General purpose	Graded-index glass, plastic-clad silica, step-index glass
Around 1300 nm b/	Long-haul trunk lines	Graded-index silica, single-mode silica
Around 1550 nm c/	Long-haul trunk lines	High-grade silica (single-mode)

a/ First "window".
b/ Second "window".
c/ Third "window".

Figure 6. Optical fibre attenuation as a function of wavelength

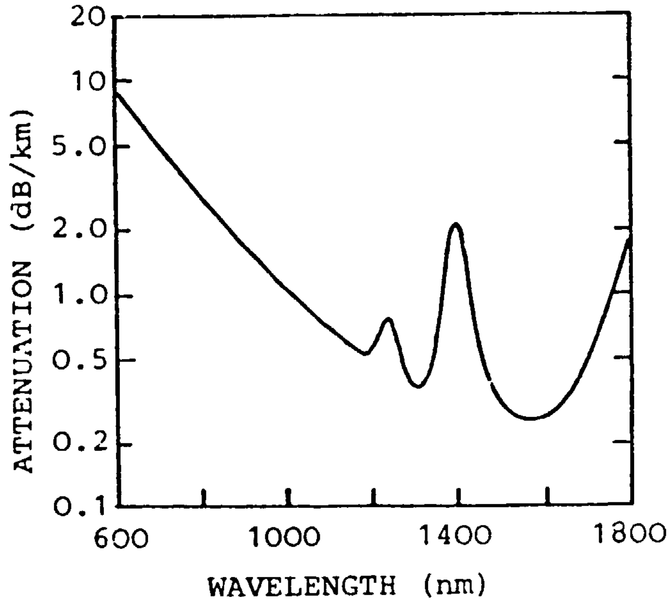
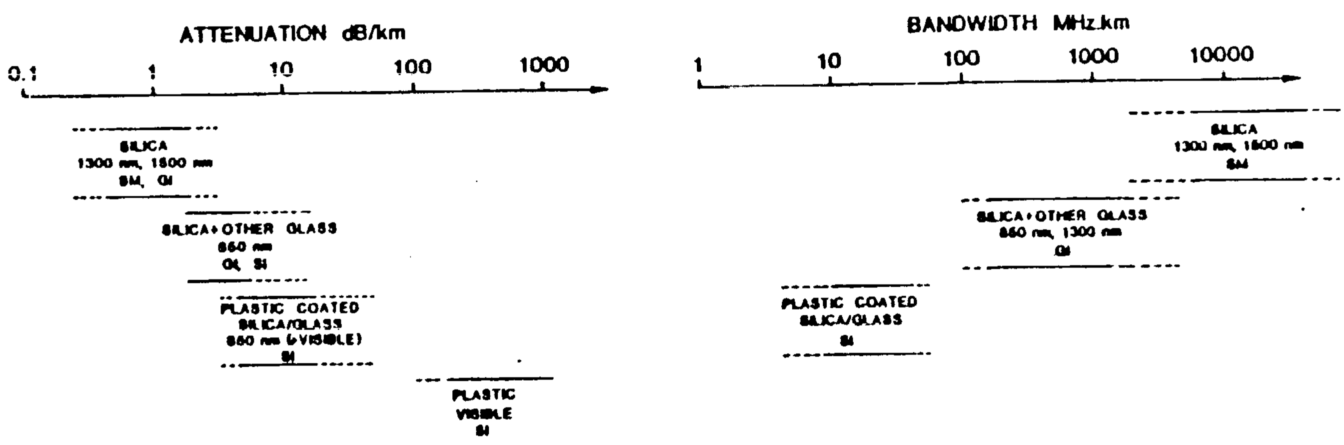


Figure 7. Attentuation and bandwidth of optical fibres



Key

SM: Single-mode fibre
GI: Graded-index fibre
SI: Single-index fibre

Production of optical fibres

Basically, two paths can be followed to produce optical fibres: (1) preform fabrication followed by fibre-drawing and (2) direct drawing from the melt (see figure 8). The first method is today's most widely accepted approach for the production of high-quality silica fibres and plastic-clad silica fibres.

Preform fabrication

The four major preform fabrication processes are based on vapour-phase reaction or chemical vapour deposition, in the general sense of the term. In the narrow sense of the term, two are chemical vapour deposition (CVD) processes: modified chemical vapour deposition (MCVD) and plasma-activated chemical vapour deposition (PCVD). The two remaining processes, outside vapour-phase oxidation (OVPO) process and vapour-phase axial deposition (VAD), are sometimes referred to as "soot processes", since SiO_2 soot is originally formed by oxidation of Si in a hydroxy flame burner. Silica is the primary glass former, additions are made to alter its refractive index and to build a waveguide structure. Vapor-phase deposition and oxidation methods originated in the semiconductor and glass industries and are applied in fibre preform fabrication for reasons of achievable purity and cleanliness. The major raw material for silica fibres is silicon tetrachloride ($SiCl_4$). The portions of the preform designated to form the future fibre core or the adjacent layers of the cladding are doped to increase the refractive index (e.g. with germania (GeO_2) or phosphorous pentoxide (P_2O_5)) or to decrease the refractive index (e.g. with boric oxide (B_2O_5) or fluorine (F). Hard-glass fibre can therefore be said to be based on germanosilicate, borosilicate and phosphosilicate glass.

The modified chemical vapour deposition (MCVD) process. This process, developed at Bell Laboratories 8/ and subsequently applied and improved by many laboratories and factories all over the world, starts from a tube of fused silica that ultimately becomes the outer cladding of the fibre. High-grade silica tubes with a 25-mm outer diameter, a 19-mm inner diameter and 1000-mm in length are standard. The hydroxal ion (OH) content is 150 parts per million (ppm). Heralux WG tubes manufactured by Heraeus GmbH in the Federal Republic of Germany are predominantly used. The tube is then mounted in a glass working lathe to be rotated and heated by one or several oxy-hydrogen torches (see figure 9). A gas stream consisting of a carrier gas and halide vapours is fed into the tube and passed through it. A gas-phase reaction of halides and oxygen in a zone heated from the outside by the torch forms glass particles that are deposited downstream of the torch position. Since the torch is traversed in the direction of the gas flow, the deposited layer is sintered immediately after deposition. Typically, 30 to 100 layers are deposited by as many passes of the torch. The composition of the layer can be varied during each traversal by the addition of dopants to the gas stream. Finally, the tube including the deposit is collapsed into a solid rod, the preform, again by outside heating to silica-softening temperatures (1900-2200°C).

To enhance the deposition efficiency of MCVD, RF-plasma-enhanced MCVD has been proposed. 9/ The "particle deposition" and "consolidation" steps are performed by separate heat sources. It is estimated that a total of 1500-2000 man-years have so far been invested in the development of the MCVD process. This process is well documented. It has found widespread use all over the world and is probably the easiest process to set up.

The plasma-activated chemical vapour deposition (PCVD) process. This process was pioneered by Philips. 10/ The main difference - and advantage - of the PCVD process as compared with the MCVD process is that a non-isothermal plasma initiates a reaction on the inner wall of the tube (see figure 10). No "soot" is formed because the temperature of the furnace in which the process occurs is too low. The

Figure 8. Classification of fibre-production processes

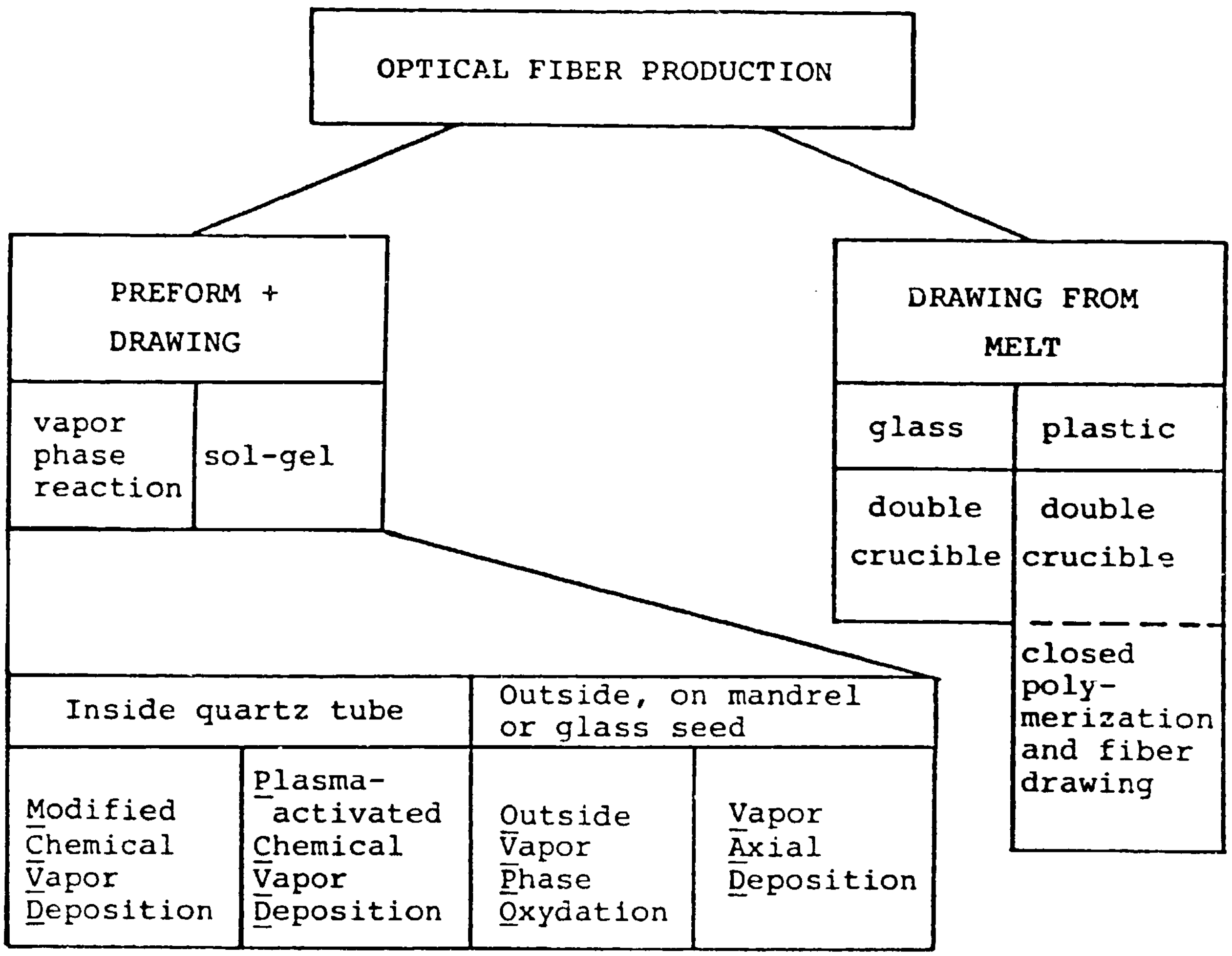


Figure 9. Schematic of the apparatus for modified chemical vapour depostion (MCVD)

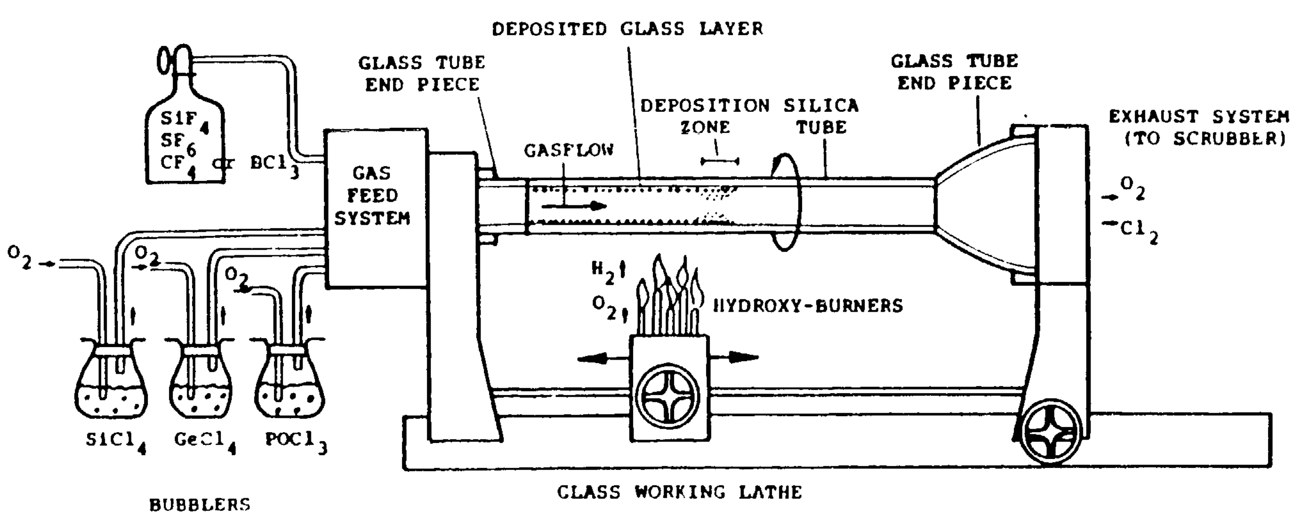


Figure 10. Schematic of the plasma-activated chemical vapour deposition (PCVD) process

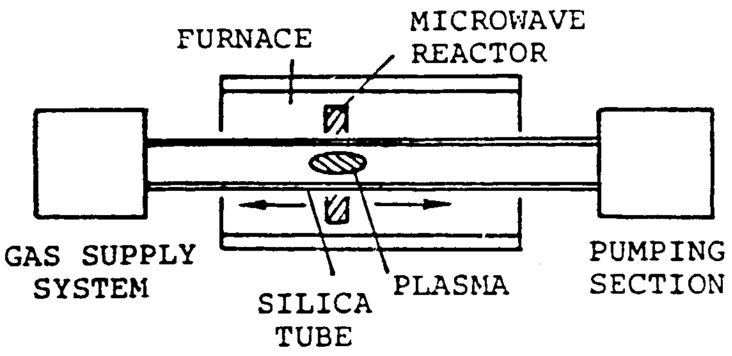
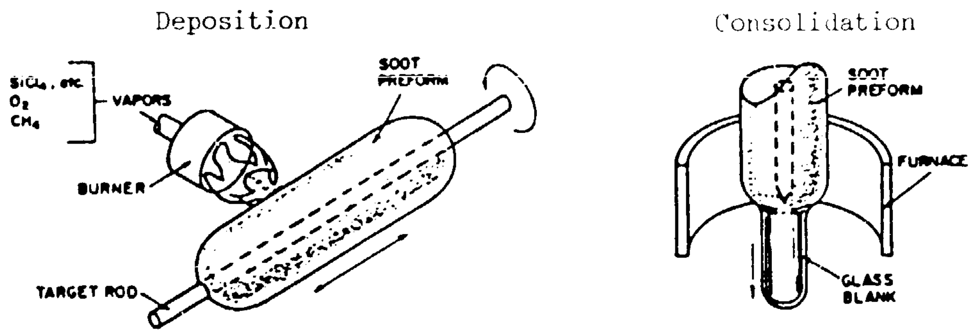


Figure 11. Schematic of the outside vapour-phase oxidation (OVPO) process



Source: P.C. Schultz, "Fabrication of optical waveguides by the outside vapor deposition process," IEEE Proceedings (New York), v. 68, no. 10. Copyright 1980 IEEE.

PCVD process is a "low-temperature" process. Deposition efficiency of SiO_2 and GeO_2 occurs heterogeneously (i.e. only on the tube wall) upon initiation of the plasma. A microwave resonator sweeps past the tube, and very thin layers (~0.5 μm) are deposited with each pass. Several hundred layers are usual, permitting very close profile control. Some 500 man-years have been invested in the development of this process. Control of process parameters is claimed to be easy.

The outside vapour-phase oxidation (OVPO) process. This process was invented by Corning Glass Works. 11/ This company prefers to name the process outside vapour deposition (OVD). Figure 11 is a schematic of the separate deposition and sintering, i.e. consolidation, steps. The essential difference between the OVPO process and the MCVD and PCVD processes is the lateral outside deposition of glass particles. These glass particles (~0.1μm in average diameter) stick together to form a porous preform around the centre starting member of aluminium oxide (Al_2O_3). After removal of this member, a sintering step transforms this porous or soot preform into a transparent glassy preform, from which the fibre is eventually drawn. The investment in total manpower for the development of this process is estimated between 600 and 800 man-years.

The vapour-phase axial deposition (VAD) process. In the processes described so far, glass layers are deposited in a lateral direction. In the vapour-phase axial deposition (VAD) process, glass particles are deposited onto a rotating vertical seed rod from below (see figure 12). As in the OVPO process, glass particles are synthesized in the flame of an oxy-hydrogen burner. In this way a porous preform (soot preform) grows in an axial direction. It is gradually pulled up in accordance with this growth so that the burner position remains unchanged. The soot preform has to be consolidated to the transparent, actual preform for fibre drawing. The VAD process was developed by the Ibaraki Electrical Communications Laboratory (Nippon Telephone and Telegraph Public Corporaton) 12/ and is used by the major Japanese fibre producers Sumitomo, Furukawa and Fujikura. Approximately 1000 man-years have been consumed in developing this process.

A comparison of the CVD processes

The MCVD process

Advantages and potential

- inside tube deposition, resulting in little contamination
- partly porous deposition, making partial OH removal possible
- flexible, well-understood, easy-to-model process

Disadvantages and problem areas

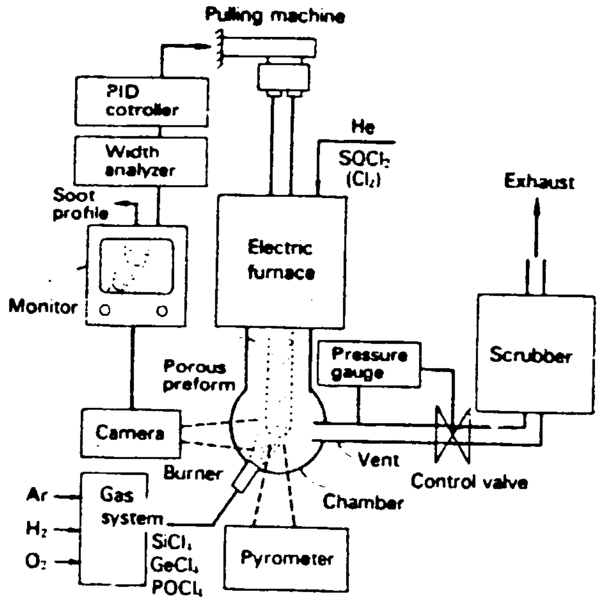
- discontinuous process
- requires high-grade silica substrate tube
- very low GeO_2 deposition efficiency (10-20 per cent)
- length taper of index profile
- central dip of index profile
- preform size limited (fibre length)

The PCVD process

Avantages and potential

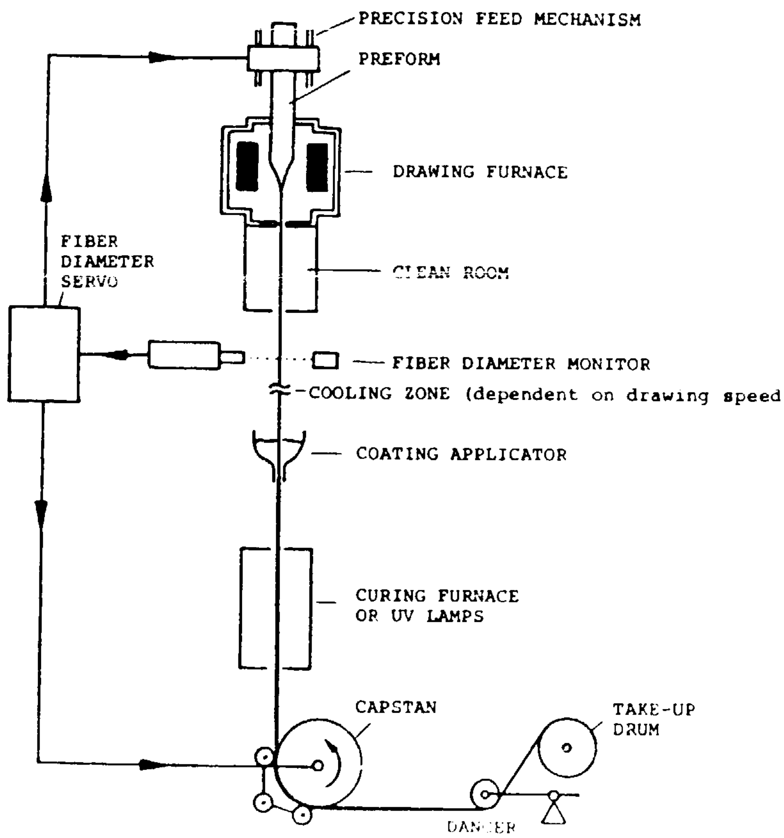
- low deposition temperature
- inside tube deposition resulting in little contamination
- no length taper
- highest deposition efficiency
- relaxed temperature control (± 5° at deposition)
- good dimensional control
- no heating through tube walls

Figure 12. Schematic of VAD apparatus



Source: K. Inada, "Recent progress in fiber fabrication techniques by vapor-phase axial deposition," IEEE Journal of Quantum Electronics (New York), v. 18, no. 10. Copyright IEEE 1982.

Figure 13. Schematic of fiber-drawing tower



Disadvantages and problem areas

- discontinuous process
- limited deposition rate (low-pressure process)
- hydrogen incorporation
- limited preform size (fibre length)
- silica tubes necessary

The OPVO process

Advantages and potential

- good profile control
- no collapse step necessary, but added complexity in drawing
- tolerant to hydrogen contamination in starting materials
- no silica tubes needed
- good dimensional control (tolerances, little ovality and eccentricity)
- high deposition rate possible
- large preforms possible

Disadvantages and problem areas

- drawing with central hole requires control of atmosphere
- built-in stress of preforms (yield?)
- control of deposition complex

The VAD process

Advantages and potential

- continuous process possible
- lowest OH level achieved
- tolerant to hydrogen contamination in startng materials
- large preforms possible (100 km fibre drawn)
- no collapse step necessary
- no silica tubes needed
- high deposition rate possible

Disadvantages and problem areas

- index profile control difficult and critical
- soot density fluctuations
- roundness control
- fluorine doping difficult

The sol-gel process

A glass preform fabrication method entirely different from the CVD processes is the sol-gel process. 13/ It consists of the following steps: (1) hydrolysis of metal alkoxides to make a gel containing water and a solvent (methanol) that is cast into cylindrical glass containers, (2) drying of the gel to form a porous gel body (for one week at 70°C); (3) a chlorination process to reduce the initially high (1000 ppm) OH content; (4) sintering of the porous gel body to produce a transparent glass preform, which is performed at only 1100°C under a helium (He) atmosphere to form a pore-free glass. The main advantages of this method are low temperature and potential mass production. So far, the process has been used only in the laboratory.

Fibre drawing

Irrespective of the preform fabrication method, fibre drawing is achieved on drawing towers, at the top of which the preform is heated to silica-melting temperatures ($\approx$2200°C) (see figure 13). When a refractive index profile has been incorporated into the preform, this profile is preserved in the drawing step. The drawing process includes several separate operations, 14/ all of which have to be carefully controlled:

- heating of the preform
- draw-down of the molten glass
- monitoring and control of fibre diameter
- application of coating
- monitoring and control of coating thickness/concentricity
- solidification of coating
- fibre take-up.

For protection against damage and contamination, one or more primary coatings are applied to the just-drawn fibre. The most common coating materials are acrylates, which become hard upon curing by ultraviolet (UV)light, and silicone polymers, which are heat-treated after application but stay more or less soft (see table 4). The coating process is the limiting factor to fibre-drawing speed. First, the fibre has to cool down to a certain temperature before being ready to be coated. Second, the speed with which the fibre passes through the coating cup or die must be low enough to ensure proper wetting. Third, the coating has to cure. The two important fibre properties that are influenced by the coating and jacketing steps are: (1) fibre strength and (2) fibre loss (microbending).

Table 4. Comparison of coating systems according to coating material

Coating material	Curing	Speed of Coating Process	Diameter of Coating
Silicone polymers a/	Usually by heat	1 - 2 m/s (5 m/s) c/	0.25 - 0.4 mm
Acrylates b/	By UV radiations	1 - 5 m/s (12 m/s) c/	0.25 - 0.5 mm

a/ Poly-dimethyl, siloxane, polymethyl, phenyl-siloxane
b/ Urethane acrylace, epoxy-acrylate polymers, methyl-butadien-acrylate
c/ Laboratory results

Plastic-clad silica (PCS) fibres

PCS fibres are designed as step-index (SI) fibres. The core - a popular choice is natural quartz - has a uniform refractive index. This rod is drawn to a fibre as described above. The cladding is a relatively low-loss polymer with a lower refractive index and is applied preferably by methods similar to the coating process, which require a curable liquid as cladding material. For low-price applications, purely plastic fibres are preferred.

Drawing from the melt

The methods relying on melting basic raw materials and pulling the optical-fibre directly from the melt are applied to both glass and plastic fibres. For glass fibres, various oxides and carbonates are added to SiO_2 to form a multi-component glass with a lower melting temperature than pure SiO_2. Core and cladding melts are loaded into double crucibles with two coaxial nozzles at the base, hence the "double-crucible" method. 15/ A number of major optical-fibre manufacturers have discontinued using this method, since several severe disadvantages outweigh the advantage of basic simplicity.

Plastic fibres are produced by very similar methods, but the crucible material requirements are not very demanding because the melting points of the starting materials are lower than those for glass. A modern variant of plastic-fibre production by this method is the "closed polymerization and fibre drawing method". It considerably reduces contamination of the starting materials and thus fibre loss.

The performance of optical fibres depends largely on the fibre-production process and the materials used. Raw materials should be as pure as possible to prevent light absorption and scattering. Contamination during manufacture should be kept as low as possible to ensure a high-quality end product. As an example, a transition metal concentration of as low as 1 part per million causes an additional absorption loss of 1 dB/km in silica. Even worse, the same OH concentration causes a 35-50 dB/km loss at a wavelength of 1.39 μm.

From a purely economic point of view, yield and production speed are important assessment criteria. Yield is to be understood as the output of fibre of given technical parameters as compared with input raw materials. The main criteria by which the quality of the produced fibre will be judged are: (1) attenuation, (2) bandwidth and (3) mechanical strength.

In the production of hard-glass fibre preforms, which make up the overwhelming share of today's fibre market, several trends towards increasing productivity can be observed:

- increase of deposition rates by combining a high deposition rate with large fibre bandwidth
- increase of preform size, while maintaining high yield
- increase of yield by improving or circumventing critical process steps
- making preform fabrication a continuous process
- elimination or combination of production rate-limiting steps, e.g. collapse
- replacement of costly materials, particularly high-quality silica tubes and germanium chloride ($GeCl_4$)
- improvement of process control in order to yield a consistently high-quality fibre product
- replacement of phosphorous (P) and boron (B) as dopants. Fluorine and aluminium oxide (Al_2O_3) are favourite candidates for lowering or raising the refractive index, respectively.
- elimination of the 1.39 μm OH peak and reduction of OH content in general
- further reduction of fibre attenuation at 1.55 μm wavelength for ultra-long-range fibre systems
- development of entirely different methods of preform production, e.g. the sol-gel process

Production of optical cables

Mechanical fibre properties

Optical fibre, unlike copper wires, cannot be handled straight-forwardly since, compared with metal, glass fibres differ considerably in mechanical properties. Under an applied stress glass will extend elastically up to its breaking strength, whereas metals can be stretched plastically well beyond their true elastic range. Copper wires, for example, can be elongated plastically by more than 20 per cent before they fracture. For glass fibres, elongations of only 0.5 to 1.0 per cent are possible before a fracture occurs. In contrast to strength, which deals with instantaneous failure under an applied load, static fatigue relates to the slow growth of pre-existing flaws in the glass fibre under humid conditions and tensile stress. This gradual flaw growth causes the fibre to fail at a lower stress level than that which could be reached under a strength test.

These typical properties of glass material and the small cross-sectional area of the individual fibres are responsible for their susceptibility to breakage and damage during the cabling and installation procedure. To ensure the invulnerability and ruggedness of the bare fibre, the fibre has to be protected by a jacket and, afterwards, incorporated into a cable structure. In doing so, considerable attention has to be paid to minimizing additional optical losses due to stress that might be introduced during cable making and installation or, after installation, by environmental and mechanical factors.

Fibre jacketing

Despite the primary coating, which is applied immediately after the drawing process and consists of one or two layers of silicone or UV curable acrylate, the optical fibre is very fragile and vulnerable to damage by externally-induced stress or hostile environments. For further protection three packaging methods 16/ have been developed:

(1) The tight-fit jacketing method. A relatively thick secondary coating of plastic is applied over the primary coated fibre, its main purpose being to enhance the tensile strength and to provide radial protection. Adequate mechanical protection is obtainable with nominal coating diameters in the range of 0.8 - 1 mm. A number of high modulus plastics have been used for secondary coatings, including amorphous polyethylene tetrephtalate (polyester), polypropylene, and nylon. For easy identification during installation and repair, the jacket may be colour coded.

(2) The loose-tube method. This method isolates the fibre from strain in the coating process. In loose structures, the optical fibres are incorporated in plastic tubes with a certain amount of slack and can move freely within limits. As a result, they are decoupled from tensile stresses during cable laying and during temperature-driven cable stretching and shrinking. The inner diameter of the tube is much larger than the 250 μm-diameter of the primary-coated fibre. The remaining space is filled with a water-blocking jelly. By stranding up to ten primary-coated fibres and protecting them by an extruded loose-fit plastic tube, a higher fibre packing density can be realized than with only one fibre contained in one tube. For the loose-tube jacketing, only UV curable acrylates can be used since this material ensures low friction of the fibre inside the tube.

(3) The open-channel method. This method is similar to the loose-tube approach with respect to the effect of isolating the fibre from strain in the coating. The difference, however, is that no additional plastic tube

is formed to take up the fibre(s). The protection for the fibres is provided by the cable structure itself in which channels or slots are formed to take up the fibres.

The loose-tube as well as the open-channel construction offer the lowest possible cable attenuation for a given fibre plus a high level of isolation from external tensile forces. This means more stable transmission characteristics under continuous mechanical stress. The tight-buffer construction permits smaller, light-weight design for a similar fibre configuration and generally yields a more flexible, crush-resistant cable.

Cable design

To meet the requirements set by the cable customers (buyers) that converge in the desire to install fibre-optic cables with the same equipment, installation techniques, and precautions as those used in conventional wire cables, special cable designs are necessary to ensure that fibre elongations are limited to 0.1 to 0.2 per cent. 17/ The cable structures will vary greatly, depending on whether the cable is:

. pulled into underground or intra-building ducts
. buried directly in the ground
. installed on outdoor poles (aerial cable)
. fixed to high-voltage lines
. laid on intra-building grids
. submerged under kilometres of water (submarine cable).

In copper cables the wires themselves are generally the principal load-bearing members of the cable. In fibre-optic cables, special strength members have to be added to take up the axial load. The following are examples:

. steel wires
. plastic mono-filaments
. textile fibres (Terylene, Dacron, Kevlar)
. glass fibres
. fibre-reinfored plastics (FRP)

High-modulus materials are inherently stiff in solid form, but flexibility can be improved by employing a stranded or bunched assembly of units of smaller cross section, preferably with an outer coating of extruded plastic, helically applied tape or a braid. Such a coating is particularly necessary if the strength member comes into contact with coated fibres, since a resilient or smooth contact surface is required to avoid optical losses due to microbending. The position of the strength members can be the centre of the cable, or the strength members can be placed around the fibres.

Another factor to consider is fibre brittleness. Since glass fibres do not deform plastically, they have a low tolerance for absorbing energy from impact loads. Hence, the outer sheath of an optical cable must be designed to protect the glass fibres inside from lateral impact forces. In addition, the outer sheath should not crush when subjected to side forces, and it should provide protection from corrosive environmental elements. In underground installations, a heavy-gauge metal outer sleeve may also be required to protect against potential damage from burrowing rodents.

The simplest cable design are called fibre cords, containing one or two fibres intended for indoor use to connect data terminals or measurement equipment. The cable length is a few meters. Usually both ends are provided with connectors. Such cables are called "jumpers". For strength purposes this tube is surrounded by strands of polyaramid yarn which, in turn, is encapsulated in a polyurethane jacket.

In the telecommunications industry, larger cables containing up to thousands of fibres are required. Three different basic cable structures can be distinguished:

(1) The slotted-core cable. Helically wound slots (typically six to twelve) are formed by extruding hot plastic through specially-designed dies around the strength member. Up to twelve fibres are laid simultaneously and tension-free into these open channels. They are kept in place by applying a closely spaced dual binder yarn around the plastic profile (see figure 14). If water-blocking is required, a gel is poured into the void of each slot.

(2) The stranded circular design. Several basic fibre units (loose tube or tight-jacketed) are stranded around a central strength member (see figure 15).

(3) The rectangular ribbon array cable. Twelve coated fibres are embedded in a polyethelene (PE) tape. Twelve of these ribbons are stacked together, producing a fibre array. Then, this stacked ribbon array is stranded together with strength members and is sheathed.

For the cabling of optical fibres, conventional basket cabling machinery, as used in the cabling of metallic wires, has been successfully adapted. Since a uniform tension must be applied to the fibres to be stranded, special fibre-stranding machines have been developed. A new stranding principle is the "SZ-stranding technique". 18/

Testing and quality control

Fibre optics is one of the world's fastest developing technologies and the test equipment and methods are undergoing an equally rapid development. Although there are still some unresolved tecnnical problems associated with transmission measurement methods, some standard test methods for fibres have evolved and international standardization is impending, especially for GI fibres 19/, 20/

Fibre testing

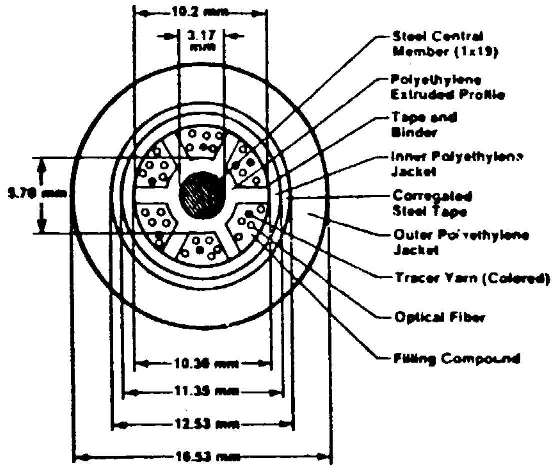
It would be desirable to test only selected specimens of the fibres produced. Inevitable variations of the production process, however, preclude this economical procedure and every metre of fibre produced must be thoroughly tested 21/22/ for:

- strength
- attenuation
- bandwidth (baseband response)
- numerical aperture
- size (core diameter, refractive index peak change Δn, etc.)
- concentricity
- cut-off wavelength (Single mode (SM) fibres only)
- polarization characteristics (SM fibres only)

Strength. Two categories of tests pertain to fibre strength. First, every fibre has to undergo a screening test, whereby the drawn fibre is wrapped - under defined tension - from one reel to another. This test detects and eliminates cracks and other physical defects caused simply by rupture. Second, the tensile failure point of a selected number of fibres is determined as a measure of statistical quality control.

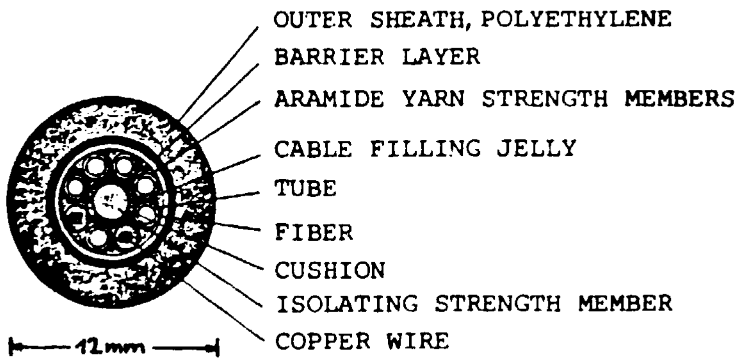
Attenuation. Optical attenuation is measured at the wavelength or in the wavelength region for which the fibre is intended. Pecause of today's low fibre

Figure 14. Slotted-core cable design



Source: C.K. Kao, "Fiber cable technology," IEEE Journal of Lightwave Technology (New York), v. 2, no. 4. Copyright IEEE 1984.

Figure 15. Six-fibre cable based on the loose-fit tube



Source: U. Oestreich, Lichtwellenleiterkabel für Nachrichten-Weitverkehrsverbindungen, v.6, no. 4, 1983.

loss, a measurement uncertainty of 0.1 dB is desired. For consistent measurement results, the conditions of launching light at the fibre input have to be well defined ("equilibrium mode launching conditions"). 23/ Three methods are recommended: cut back, insertion loss and backscattering. 24/

Bandwidth. The bandwidth (baseband response) of a certain length of fibre can be measured either in time domain or in frequency domain. The results of either method can be transformed into each other by a computer. The frequency domain measurement is more common, but it also requires sophisticated equipment, both optical and RF electronic. The optical wave is modulated by the swept baseband frequency. The frequency at which amplitude response is 6 dB (electrical) or 3 dB (optical) below its DC value is called "bandwidth". It is given for a fibre length of 1 km.

Special tests on single-mode fibres. The numerical aperture, the actual core size, and the exact refractive index profile of SM fibres are difficult to measure routinely. Therefore it is customary to specify and to measure the mode field diameter instead. 25/ A parameter defining the useful wavelength region of an SM fibre is the cut-off wavelength λ_c of the first higher order mode (designated LP_{11}). For its determination a spectrally tunable light source is required. The simplest criterion by which to determine cut-off wavelength is bending loss: the fibre is wound around mandrels of 20 and 30 mm diameter and the respective spectral response is measured. 26/

Cable testing

After fabrication each cable has to be tested to ensure tight control of quality. The optical characteristics of the cable, especially the attenuation at the design wavelength, are evaluated using the same measurement techniques as those described for fibres. These measurements are required to be carried out while the cable is subjected to the conditions called for by the specifications. The mechanical tests are concerned with survivability of fibre when the cable is subjected to stre ses at various temperatures and humidities. These mechanical and environmental tests are generally based on standard test procedures used in the copper-cable industry 27/ and are listed in tables 5 and 6.

Quality control

The importance of quality control in optical-fibre production is evident. It should be stressed that there exists virtually no market for low-quality fibres. Quality control measures should be carried out before, during, and at the end of the production process.

Clean room conditions are beneficial for high-strength, high-quality fibre. Preform fabrication, storage, and handling as well as fibre drawing should be performed in a controlled, dust-free atmosphere. Within general areas of Class 10,000, special work places can then be raised to Class 100 by special clean-room booths if so desired.

Incoming raw materials should be inspected. It is sufficient to check the purity of delivered high-purity chemicals only at rather long intervals. For processes requiring substrate tubes, a very important measure of initial quality control is to check the tubes for uniformity of wall thickness, concentricity, ovality and bow.

During production of preforms, microcomputer control of gas composition. temperature, mass flow, burner travelling speed and the like is a good approach toward ensuring consistently high-quality fibres. For every fibre design, there exist proprietary "recipes" which are stored in a master computer. Though modelling of the various processes becomes more and more accurate, these recipes

Table 5. Mechanical characteristics

Test number	Subject of text	Characteristics covered by test method
IEC XXE- 1	- Tensile strength	- Mechanical strength
- 2	- Abrasion	
- 3	- Crush	
- 4	- Impact	
- 5	- Radial pressure	
IEC XXE- 6	- Bend	- Ease of handling
- 7	- Torsion	
- 8	- Vibration	
- 9	- Flexing	
-10	- Fibre constraint in cable	
-11	- Bend under tension	
-12	- Snatch	
-13	- Kink	

Table 6. Environmental characteristics

Test method	Subject of text	Characteristics covered by test method
IEC XXF-1	- High temperature - Low temperature	- Climatic performance
-2	- Temperature cycling	
-3	- Humidity	
IEC XXF-4	- Contamination	- Chemical resistance
IEC 68 Test J	- Mould growth	- Biological resistance
IEC 331	- Fire resistance	- Resistance to fire
IEC 332	- Propagation of fire	
IEC XXF-5	- Smoke emission	
IEC XXF-6	- Internal static pressure	- Pressure sensitivity
-7	- External static pressure	
IEC XXF-8	- Water penetration	- Resistance to water-penetration
IEC 189-1	- Cold bend	- Flexibility at low temperature
IEC XXF-9	- Freezing	- Freezing resistance
IEC XXF-10	- UV radiation	- Solar radiation resistance
IEC XXF-11	- Nuclear radiation	- Resistance to nuclear radiation

are still found largely by trial and error. The preforms for GI fibres are inspected for proper index profile. 28/ As a quality control measure this can eliminate faulty preforms before they are subjected to the drawing process.

A likewise general but effective measure to control and improve quality is an in-house R + D group. The secret of success of leading fibre companies is to involve a large number of people in this activity. For quality control, their contribution is a thorough understanding of the physics and chemistry of the production process.

The most important step in quality control is the final fibre testing. What really counts are the specifications of the fibre. Testing is becoming more and more elaborate, and the number of parameters measured increases. Fibre producers view this development with concern because every additional parameter measured will inevitably decrease yield. It is, of course, a reflection of the buyers' rising quality standards, and again stresses the importance of quality control in fibre production.

Requirements

Optical fibre production has few but highly specific and out-of-the-ordinary requirements. Optical cable production, on the other hand, differs little from conventional cable production and even has relaxed requirements.

Basic requirements for fibre production

The basic requirements for fibre production are:

- ample supply of highly pure gases and other chemicals
- familiarity with clean-room conditions
- chemical engineers to set up and supervise fibre production
- communication and optical engineers to design and test fibres
- general knowledge of the fields of electronic control engineering and computer-assisted automation of fabrication processes

Machinery and installations

The essential pieces of machinery of a fibre production facility are:

- gas feed/distribution system
- glass-working lathes
- fibre-drawing towers
- optical/electronic test equipment
- computers for process control

Exact mass flow control of the pure gases of the burners is crucial for the production process. The feed system must be gas-tight and non-contaminating, and must provide exact mixing ratios and automatic switch-over when a cylinder or container becomes empty. Minute amounts of dopants must be reliably delivered to the carrier gas stream.

The glass-working lathes are the central parts of production units for the fibre preforms. The required length between centres is of the order of 1.5 m. An inner chuck jaw with a maximum diameter of 10 cm is sufficient. Turning speed is uncritical, but an automatic feed for the separate carriage of the oxyhydrogen burners is mandatory. An exhaust system channels solid particles, unreacted chemicals and reaction products to a wet scrubbing system. Besides conventional filters, a water supply and a neutralization station is required. Fibre drawing towers can be purchased "ready-to-use", but in-house designs (or at least modifications) are standard.

The testing of the drawn fibres involves sophisticated and expensive optical and electronic test equipment. Numerous sophisticated sensors and process computers for the control of gas-feed systems, lathes, drawing towers and testing procedures make up a considerable portion of the necessary equipment. The computer also stores the results of the final tests.

Pure gases and chemicals

The requirements for pure gases and chemicals are most stringent and critical for optical fibre production. The purity of the critical constituents ($SiCl_4$, $GeCl_4$, O_2, He, Ar) should be as high as commercially available. The H_2 and water vapour content has to be extremely low. Some gas suppliers specifically manufacture pure gases for the fibre-optic industry. Usually the standard purity grades for CVD processes in the semiconductor industry are suited for optical-fibre production. The cooling water required in the deposition/consolidation step should be reasonably pure so that it neither attacks the glass tube nor the plumbing pipes.

Clean-room conditions/climatization

Although there is considerable controversy about the class of clean-room conditions required, there exists general agreement that cleanliness promotes eventual fibre quality. Preform production can be performed in rooms of Class 10,000 or worse with the glass-working lathes contained in air-tight boxes. Fibre-drawing rooms should range between Class 1,000 and 10,000. The atmosphere around the just-drawn fibre should be of Class 100. An air-conditioning system to control temperature, humidity and dust particles, is required for the factory.

Electrical power consumption

Electrical power consumption is moderate, but electricity must be available permanently. If outages from the public mains are anticipated, an on-plant emergency power supply, e.g. by diesel-powered generators, must be provided.

Labour force

The requirements for a labour force for optical-fibre production, concerning number as well as qualifications, are suprisingly low. For a reference plant the estimate of the total number of employers is between 60 and 100 persons. 29/ This is true for actual, well-running production; in the initial starting-up phase and, also, for the R + D activities going on parallel to production, highly qualified specialists are needed. In addition, craftsmen such as electricians, plumbers, glass-blowers, managers, accountants and typing clerks will be needed. At least one chemical, electronic (control), optical and communications engineer should also belong to the production staff. Training of workers is usually done on the job. Senior workers train their younger or new colleagues. In Japan and the United States of America, a majority of the semi-skilled workers are high school graduates.

Storage capacity

The toughest storage requirement is presented by the pure gases. Not only are large amounts needed, but some of the gases are toxic and some are inflammable. Silicon tetrachloride ($SiCl_4$) and germanium chloride ($GeCl_4$) are liquids that come in specially sealed cylinders, at pressures near atmospheric. Oxygen supports immediate combustion of almost any substance and is particularly incompatible with hydrocarbons. It should be therefore kept outside the factory in a safe place. Hydrogen is highly flammable in air, so storage outside the plant buildings is mandatory.

The silica substrate tubes should also be carefully stored in a dry and clean place and in a manner that precludes breakage and deformation. The finished product, the optical fibre, is wound on spools (with a diameter between 20 and 50 cm and comparable height) and stored until sold. One spool carries between 1 and 10 km of fibre, so that the required space is small compared with conventional copper cables. The spools must also be stored in dry and clean places.

Transport

For the delivery of raw materials and the shipping of the fibre, a production plant should be easily accessible. However, this requirement is not very stringent because only modest masses have to be transported. In contrast to conventional telecommunication copper wires, the transport problem is small.

Fibre-optics markets: characteristics and trends

Products and applications

A brief overview of the most important products and examples of their present applications will facilitate an understanding of the current status and trends of fibre-optics markets. These products are fibre, cabled fibre, connectors and couplers, receivers, transmitters, splicing, and test equipment.

Usually four market segments can be distinguished:

(1) Fibre/cable market: fibre and cabled fibre in many different qualities and specifications
(2) Connector market: connectors and couplers of various types
(3) Transmitter/receiver market: LEDs, laser diodes, PIN diodes, PIN-FETS, APDs
(4) Equipment market: splicers, test equipment etc.

Table 7 gives a schematic overview over the most important application fields in connection with fibre-optics markets and gives some examples of important installations and projects.

Long-haul telecommunication fibre-optic systems predominantly use single-mode fibre, splices, laser diodes, and PIN-FETS or APDs. Bit rates of 280 Mbps (used in the TAT-8 Project and the channel-cross between Marseille and Ajaccio) or even higher (used in the North-Eastern Corridor in the United States and the F-400 M route in Japan) can be achieved with these system configurations. Long-wavelength transmission at 1,300 nm or 1,500 nm is standard.

Fibre-optics applications for central office interconnects are numerous throughout the industrial world and, up to the recent past, were dominated by system configurations of multimode fibres, LEDs and PIN-FETS operating at short wavelength around 850 nm. Recent developments in the United States of America show a growing importance of single-mode (SM) fibre together with longer wavelength. In fact the first single-mode central office interconnects are already in operation. In Japan, there is a marked trend toward using SM-fibre for this kind of installation as well as for long-haul trunks.

As regards the United States of America, fibre-optic links for central office interconnects are standard. In other industrialized countries they are on the way to becoming usual. Some developing countries (e.g. Argentina, Egypt and India) have also reported applications.

In short-distance applications, one observes a rapid penetration of the market by fibre-optics. Applications range from subscriber loops to subway and railway control systems. There is a strong tendency toward applications for broadband

Table 7. Fibre-optics applications

Application	Preferred fibre type	Major fibre joints	Sources and detectors	Important installations and projects
Long-haul telecommunications	Single-mode	Splices	Laser; PIN-FETs (APD)	F-400 M route, TAT-8, North-Eastern corridor, Western corridor, Channel-Cross between Marseille-Ajaccio
Central office interconnect	Graded-index single-mode	Splices	LEDs; PIN-FETs LEDs (Laser); pin diode	Numerous applications in many countries including Argentina, France, FRG, GB, Hong Kong, India, Japan, US; growing importance of single-mode fibre, long wave-length transmission
Short distance (broadband services in subscriber loops, LAN)	Graded- or step-index; (silica and other glass	Connectors	LEDs; PIN-FETs or diodes	LAN in New York City, Sapporo Subway Control
Very short distance (intra-building, factory, ship, airplane, process control, computer links)	Step-index (silica/silica, glass/glass, PCS, plastic/plastic	Connectors	LEDs and pin diodes	Numerous different applications

services: TV, voice, data, and facsimile transmitted by the same system. It is contended that this tendency will also have an effect on system design in long-distance communication to allow all these services to be operated through the long-distance telecommunication network, which also uses these highly efficient light waveguides.

Very short-distance applications demonstrate an even more diversified spectrum in used material as well as in applications. Here plastic-clad silica (PCS) and all-plastic (PP) fibres come in and may have a market in this area. Applications range from computer links and factory control to control systems for aircraft, ships and buildings.

Demand side

This section addresses the following questions:

- Who are the most important users in the fibre-optics industry?
- How do they behave?
- Are there different patterns in different countries?

It can be said that roughly 60 per cent of fibre and cable markets is in telecommunications, the remaining 40 per cent is divided among military, computer interconnection, video and other uses, in descending order of importance. This ranking is found in the most important national markets of the United States of America 30/ and of Japan. 31/ Similar structures prevail in the rest of the industrialized world.

The demand side of the national telecommunication markets is best characterized by the term monopsonistic demand, i.e. one single, very powerful demander dominates the demand side. This powerful position is usually held by the national telecommunication administrations.

In the United Kingdom and in the United States of America, the situation has slightly changed. In the United States of America, the Bell system (AT&T) played very much the role of a national telecommunication authority until its divestiture in January 1984, when patterns changed. There is now emerging an open market for telecommunication services, and some of the most interesting projects in fibre-optics are installed by competitors of AT&T. The most important example in the long-haul segment is MCI's Northeast corridor fibre-optic project. A similar development can be observed in the United Kingdom where a limited opening of the telecommunication markets can be observed, and where Mercury is establishing itself as a competitor of British Telecom. Again more competition is introduced to the telecommunication markets in the United States of America on the regional and local level by the opening of these markets to everyone who can cope with the technical standards. In April 1984, the Japanese Cabinet decided to lift the monopoly of the Nippon Telephone and Telegraph Public Corporaton (NTT) and open, in principle, the national telecommunications market.

Continental European markets are still closed and probably will stay closed. Developing countries and members of the Council for Mutual Economic Assistance (CMEA) show the same pattern: national telephone companies or administrations are the sole suppliers of telecommunication services and, as a consequence, the sole (potential or actual) users of fibre optics for telecommunication purposes in these countries. Traditionally, international projects such as the TAT projects or the channel-cross project between Marseille and Ajaccio are proposed by a consortium of national telephone companies and private investors, who explore the available alternatives for realization and put the chosen one into action.

One important strategy of many national telephone administrations is to rely as much as possible on domestic sources of supply in order to foster a high degree of national value added. This strategy has not been changed fundamentally in the fibre-optics markets. National telephone companies prefer domestic fibres and cables, if possible. There are cases where this strategy has led to the development of new fibre-optic industries or branches of these industries. This strategy has even been adapted by international projects, such as the TAT-8 fibre-optic link between Europe and the United States of America. AT&T will command over 37 per cent of the total capacity of the link and received with $US 250 million the largest portion of the $335.4 million contract. British Telecom (15.5 per cent of the capacity) chose Standard Telephones and Cable, a British affiliate of ITT, as their contract partner for the delivery of $52 million worth of fibre optics. The same happened in France, where the French National Telecommunications Research Center participated in the R + D efforts of the leading French firms CIT-Alcatel and Les Cables de Lyon to create a national submarine fibre-optic system. In 1985, this system will connect Ajaccio (Corsica) with Marseille, technical parameters being very close to TAT-8 requirements. In Japan, the three major cable manufacturers teamed their efforts with the Electrical Communication Laboratories of NTT in optical fibre/cable R + D, either jointly with Ocean Cable Co., Ltd. or bilaterally.

Beyond these general patterns, the demand behaviour of national telephone administrations differ widely. Some buy complete systems, whereas others prefer to design their own systems and buy only the system components, depending on the status of domestic industry.

The next most important market is the military. It accounts for almost 20 per cent of the whole market volume and offers very important stimulation for national suppliers of fibre-optics. However, by its very nature military markets are national markets and are closed to foreign competitors. The remaining portion of the markets consists of a variety of demanders, although up to the present pilot installations have dominated the behaviour of demanders.

Supply side

The fibre-optics industry shows a considerable and still growing number of suppliers in all market segments. Since the markets in the United States of America amount to more than 50 per cent of the international fibre-optics markets, it pays to have a close look at them before turning to the situations in other countries. A very interesting picture emerges: all of the main fibre-optics markets (fibre/cable, connectors and receivers/transmitters) are highly concentrated and interconnected via vertically integrated producers. The most impressive situation is in the fibre/cable market. Figure 16 shows the market share of the most important fibre and cable suppliers in 1983 and projections for 1984. 32/ In both reported years more than 90 per cent of cabled-fibre shipments were supplied by only five companies. Western Electric dominated the market with more than a fifty per cent market share. The role of Western Electric has been somewhat changing since the divestiture of the AT&T system. Until recently, Western Electric shipped almost every metre of fibre and cable to the Bell system, a situation that will definitely change. Western Electric plans to engage in the markets outside of the Bell system and even in the international markets via AT&T International. Since Western Electric is a very large low-cost producer, all other suppliers must compete with Western Electric in the near future.

Table 8 gives a brief account of the degree of vertical integration among fibre/cable suppliers throughout the world. It shows that the majority of firms that produce fibre/cable are in fact vertically integrated. Only 18 out of 93 suppliers make or sell just one item (fibre or cable); all the others engage in other segments of the fibre-optics markets. All major suppliers (excluding Corning Glass Works) are active in more than one market. Corning is a special case: its joint venture with Siemens (Siecor) represents Corning in the other sectors of the market. A large group of firms have unclear production and selling patterns, i.e. they do not regularly supply fibre and cable and other components.

Table 8. Vertical integration among fibre and cable suppliers

Products supplied	Number of suppliers
Fibre only	6
Cable only	12
Cable and fibre	20
Fibre and other components	3
Cable and other components	8
Fibre, cable and other components	14
Unclear production and selling programme	30

Besides Canada (Northern Telecom) and the United States of America, there are at least seven other countries with considerble production capacity in the fibre/cable market: Federal Republic of Germany, France, Great Britain, Italy, Japan, Netherlands and Sweden.

In Japan, the fibre-optics industry co-operates with the Optoelectronic Industry and Technology Development Association, which includes NEC, Hitachi, Fujitsu, Toshiba, Matsushita, Mitsubishi, Oki, Furukawa, Fujikura, Sumitomo and Nippon Sheet Glass as its founders. Japanese suppliers mainly sell on domestic fibre-optics markets, but undertake strong and successful sales efforts in developing countries as well, e.g. Argentina, India and Singapore.

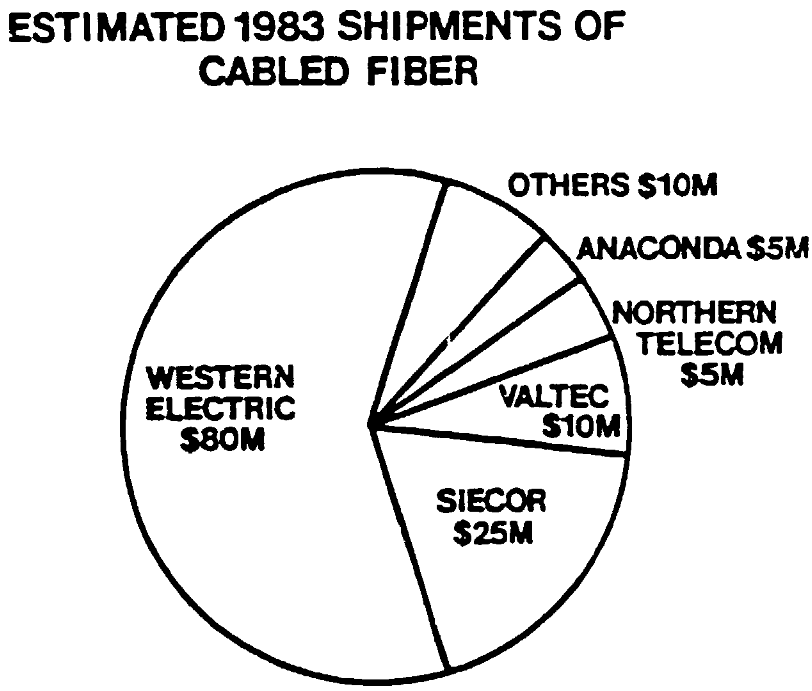
Similar situations, although with institutionally different arrangements, can be found in France, where the Centre National d'Etudes des Telecommunications (CNET) co-ordinates and propagates national efforts in fibre optics. In the Federal Republic of Germany, the so called "Kabelkartell", including Siemens, Standard Elektrik Lorenz, Philips, AEG and Kabelmetall, has put its hands on fibre and cable markets. This situation has recently been successfully challenged by Wacker Chemie, a large supplier of chemicals to the semiconductor industry.

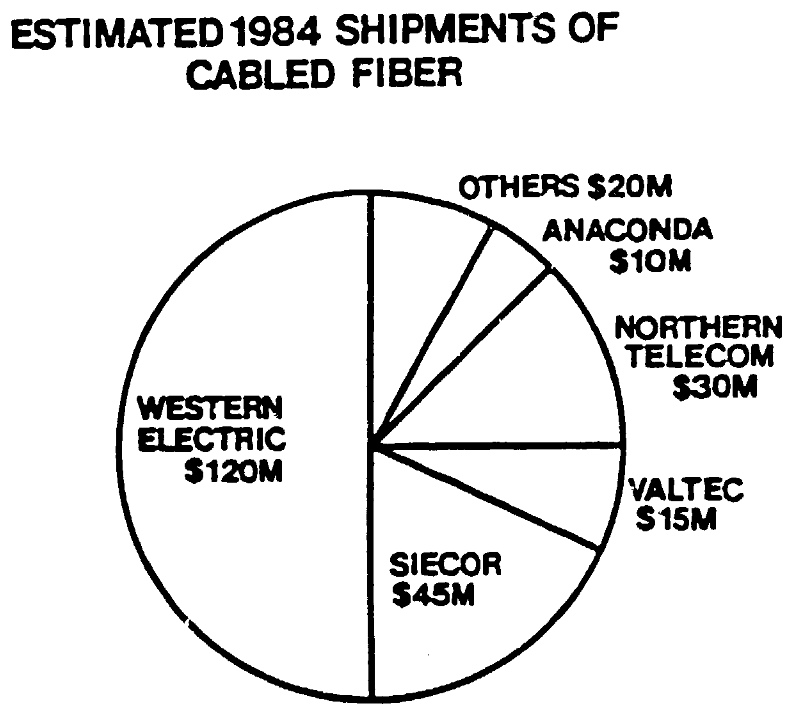
The transmitter/receiver market for fibre-optics accounts for only a minor portion of the market for semiconductor devices such as lasers, photodiodes and LEDs. In many cases suppliers of complete fibre-optics systems do not produce these devices themselves. In other cases LEDs can be put to different uses, and it is very difficult to estimate the market structure of semiconductor devices used in fibre optics. The leading manufacturers in the United States of America are RCA, ITT, Western Electric, Lasertron, and General Optronics. The leading Japanese firms are NEC, Fujitsu and Hitachi. Northern Telecom, Siemens, CIT/Alcatel, and Plessey must be noted as important suppliers outside of Japan and the United States of America.

Table 9. Vertical integration among suppliers of transmitters, receivers and connectors

Products supplied	Number of suppliers
Receivers and transmitters only	24
Receivers, transmitters, fibre and cable	7
Receivers, transmitters and other components	14
Receivers, transmitters, fibre, cable and other components	33
Connectors only	25
Connectors and fibre/cable	12
Connectors and other components	10
Connectors, fibre, cable and other components	16

Figure 16. Shipments of cabled fibre in the U.S. market





Source: D. Hardwick, Worldwide Markets for Fiber Optic Cable-Strategic Issues, Proceedings of the Newport Conference on Strategies for Fiberoptic Markets, October 1983, Newport, Rhode Island, U.S.A.

Table 9 shows the degree of vertical integration among suppliers of transmitters, receivers and connectors. The picture in these two markets is somewhat different. The transmitter and receiver market is dominated by 33 suppliers of systems. The connector market shows a larger number of firms (25) who specialize in connector production; the leading firms are not engaged in all of the fibre-optics markets.

The reasons for the high degree of vertical integration lie in the behaviour of some national telecommunication administrations to demand systems or major parts of systems and in the interest of suppliers. Development of readily usable systems simply makes it easier to sell fibre optics, since many actual or potential users of fibre optics are not at all in the position to design and assemble their own fibre-optics-based communication systems at reasonable cost.

Another point to note is the existence of a large number of market niches for specialized producers. Especially in LANs and very short-distance segments of the market, many highly specialized fibre-optic systems are supplied. This market characteristic gives new entrants profitable chances.

If one combines behavioural patterns and institutional aspects of supply and demand in fibre-optics markets, a very interesting pattern emerges. In all countries using fibre-optics on a broad scale in telecommunications, there exist strong ties between both sides of the markets. The principal users of fibre-optic systems and components usually contract with a limited number of suppliers. These suppliers are sometimes affiliated with the users (AT&T Western Electric) or co-operate through official, institutional channels (France, the German Democratic Republic, Japan), so that, in fact, market entrance is severely restricted in several countries. An open market exists in only short and very short-distance applications.

Finally, there are potential entrants to and drop-outs from the fibre-optics markets. Recent entrants include IBM, Kodak, Olympus and N.V. Philips (a Valtec take-over), to name the most important ones. The list of dropouts is headed by Times Fiber, 33/ which almost totally eliminated its fibre-optics activities.

Prices in fibre/cable markets

As usual in high-technology markets, prices are expected to go down with economies of scale in the production sphere and by falling R + D costs. This is exactly what has been happening in the fibre/cable markets. An excellent example can be found in the decline of Corning Glass Works' prices between 1977 and 1983 (see figure 17). Prices dropped from $US 3.00 per metre of GI fibre in 1977 to approximately 30 cents per metre (attenuation: 5 dB/km, 1977; 1.5 dB/km, 1983).

Table 10 compares 1982 and 1983 prices for different types of fibre for various applications. Unfortunately single-mode fibre prices are usually not published, only the graded/step-index fibre prices could adequately be covered by these figures. The official prices for low-volume produced fibres remained constant whereas prices for high perfomance graded-index (GI) and single-mode (SM) fibres came down appreciably in the very recent past. This is a consequence of world-wide expansion of production capacity. Most notably, the ratio of SM to GI fibre prices, which traditionally has been around 3, is approaching values around unity.

It must be stressed that table 10 gives only an indication of the many different prices. In particular, GI and SM fibres come in vastly different quality as concerns bandwidth, attenuation, etc. Prices range accordingly up to a factor of four within one category.

Table 10. Fibre prices in early 1982 and 1983

Material	Attenuation	Core diameter	Cladding	Bandwidth (MHz x km)	Price per metre (in US dollars) 1983	1982	Type
Silica	1 dB/1,300 nm	8.2 µ	125 µ		6.00 */	6.00	Single mode
Silica	1.5 dB/1,300 nm	50 µ	125 µ	400	0.31	0.39	Graded index
Silica	4 dB/820 nm	133 µ	200 µ	20	1.00	1.00	Step index
Silica	4.5 dB/820 nm	200 µ	300 µ	20	1.50	1.50	Step index
Glass/glass	15 dB	100 µ	150 µ	10	0.60	0.60	Step index
Silica/silicone (PCS)	15 dB/850 nm	200 µ	400 µ	40	0.60	0.60	Step index
Plastic/acrylic	1,200 dB/675 nm	117 µ	128 µ	-	0.013	0.013	Step index

*/ The same fibre from the same suppliers cost $1.00 per metre in December 1983.

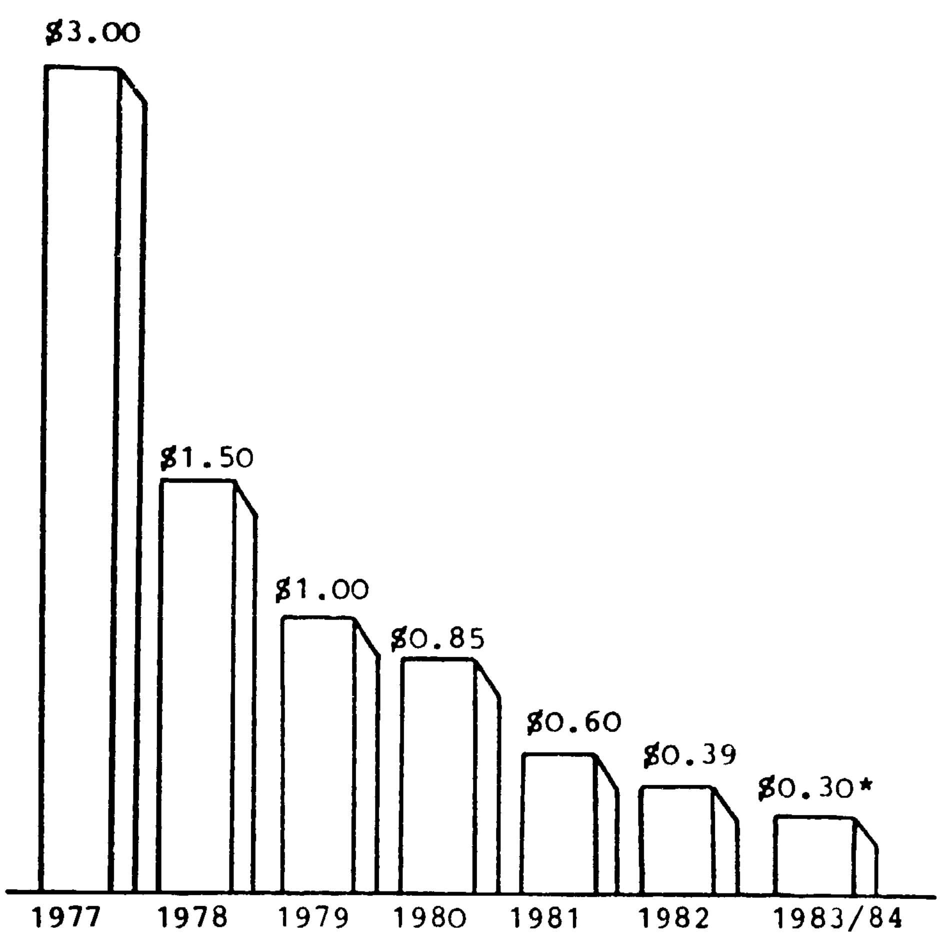
Source: Laser Focus' Guide, 1982 and 1983.

It is harder to survey cable prices in the same manner as fibre prices. There exists a broad variety of cable specifications as regards fibre specifications, number of fibres used, weight, tensile strength, jacketing etc. Furthermore cables are in most cases not publicly available, so nothing can be said directly about the cable-price development. A comparison between fibre and cable prices of the same supplier for indoor cables shows ratios between 3 and 4 and much higher ratios for outdoor cables.

Market volume projections

As of December 1984 approximately 830,000 kilometres of fibre were installed or on the books in industrialized countries. The United States with 650,000 kilometres tops the list. Amost 50 per cent of these installations occurred between 1983 and 1984; the United States is again leading. 34/ The author's investigations of European, Japanese and United States fibre/cable manufacturers confirm this picture. Many of the producers believe there will be strong growth in the market during this decade. The steepest slope is expected in 1988.

Figure 17. Corning fibre prices 1977-1983



*Based upon the authors' investigations

Source: Kessler Marketing Intelligence, Fiberoptic Marketing Intelligence, Newport, Rhode Island, 1983.

Market volume projections for fibre-optics markets are based on valuations and estimates, i.e. they are not really founded on sufficient data and therefore cannot use refined statistical methods. This can be seen from the widely differing estimates of market volumes collected in the recent past. 35/ The authors' judgement is based on the KMI market volume projection for 1983 36/ and some general considerations on the development of world markets in the communication sector.

The volume of investment in communication throughout the world was around \$60 billion in 1980, with a negligible share for fibre optics. The expected annual growth rate for the 1980s is about 4.5 per cent, so that at the end of the decade approximately \$93 billion will be spent on communication investments. The most important technologies competing with fibre optics are terrestrial microwave transmission, satellites, and traditional copper/coaxial cables. Most experts contend that fibre-optics will drive conventional copper/coaxial cables out of the market by the end of the century. The estimates of the expected split of the long-haul communication market between microwaves and satellites and fibre optics range between 60:40 and 50:50. The essence of these general considerations is a much higher growth rate for fibre optics than for the market as a whole. Therefore the annual growth rate of 35 per cent for fibre optics reported by Kessler Marketing Intelligence (KMI) 37/ does not exaggerate the growth of world markets for fibre optics in the 1980s. Japanese producers project that their annual expansion rate will be up to 80 per cent per year.

Kessler's findings are based on a careful collection of data on fibre-optics installations and projects. They fit well into the picture drawn by Gnostic Concepts' 1982 projection of world-wide fibre-optics markets, 38/ predicting a somewhat slower expansion, as presented below in table 11.

Table 11. World markets for fibre-optics 1980-1990
(in millions of U.S. dollars)

Year	Predictions by KMI	Predictions by Gnostic Concepts
1981	177	-
1982	327	335
1986	1 429	1 330
1989	3 044	-
1990	-	2 826

The predictions can be broken down in two ways. One way is to determine national shares. Here one sees a predominance of U.S. markets, with about 50 per cent of the world market. The other way is to look for the volume of the market segments listed above. Fibre and cable markets now constitute the bulk of the world market with approximately 65 per cent, and its share will grow slowly to 75 per cent in the mid 1980s. There are two reasons for this increase: (1) increased repeater spacing, which relates to a move to long wavelength transmission, increased use of laser diodes and single-mode fibre and (2) expected price stability of fibre and cable relative to semiconductor devices and other components. Connectors and couplers will maintain a market share of approximately 5 per cent and the market share of transmitters and receivers will fall from 30 per cent to 21 per cent.

Position of developing countries in optical-fibre and cable production

The central issue of this section is the discussion of advantages and disadvantages of developing countries in optical-fibre and cable production. The position of most developing countries is characterized by severe deficiencies in their telecommunications system. It is typically restricted to urban areas, operates only on a very small scale and places severe restrictions on economic development. It is clearly understandable that many developing countries make strong efforts to get rid of these obstacles to economic and social development. As a consequence of the authors' investigations of the most prominent optical fibre producers in Japan, the United States of America and Europe as well as literature studies, a list was developed of countries in Latin America (Argentina and Brazil) and in the Middle East and Far East (China, Hong Kong, India, Indonesia, Iraq, Saudi Arabia, the Republic of Korea, Singapore and Sri Lanka) that have already received or expect shipments of optical fibre, cables and other equipment from developed countries. This list, by no means complete, contains only relatively rich or technologically advanced developing countries. This indicates that only the most advanced developing countries seem to be capable of installing, operating and maintaining fibre-optic systems for telecommunication purposes. Therefore this narrow subset of developing countries will be the most important demanders in the international fibre-optics market in the near future. This reduces the range of developing countries that could enter the fibre-optics market in the next five years to a very exclusive circle.

Material and energy inputs

Fibre production is not restricted to special locations due to the need for some special natural resources. Most of the material inputs can be produced everywhere, and those which cannot be produced everywhere, i.e. pure silica tubes and germanium, must be imported from abroad, as is the practice of existing fibre producers. If at all, there is only a small transportation-cost disadvantage for developing countries. The real problems for developing countries result (1) from the fact that very high and special quality standards for these inputs must be met and (2) from the economic considerations concerning the cost of raw material inputs. Fibre production requires substantial amounts of H_2, O_2 of technical purity and O_2 of very high purity, as well as other chemicals of very high purity and in small amounts. Efficient fibre production can only be maintained if these inputs are continuously available.

Two systems to assure continuous supply seem viable. One alternative would be to rely on domestic chemical industry, which holds sufficient stocks of the required chemicals with the required qualities. This system places the burden of storage costs on the chemical industries, but makes the fibre-production facility dependent on the willingness and ability of the chemical industry to deliver the required amounts on a steady basis. The other alternative is to carry sufficient stocks of the necessary chemicals and reorder them according to some inventory strategy. In this case, the fibre-production firm carries the inventory costs but is somewhat independent from unreliable sources of supply.

In both cases developing countries are worse off than highly industrialized countries. The main reasons for this disadvantage are economies of scale in chemical industry and higher transportation costs if there is no domestic chemical industry. Optical-fibre production uses chemicals similar to the semiconductor industry. Developed countries with considerable capacities in semiconductor manufacturing can exploit the gain of economies of scale in the production of the required chemicals. Since it is very unlikely that developing countries have command over such capacities in this specialized branch of the chemical industry, these advantages are not readily accessible to developing countries. It is therefore concluded that material costs will be higher in developing countries than in industrialized countries.

Electrical energy must be continuously supplied to guarantee efficient production and safety in the production facility. One can assume that there are no distinctive disadvantages for the developing countries compared with industrialized countries in this respect.

Manpower requirements

The minimum manpower requirements for a 100,000 km fibre/year production facility can be summarized by the following figures:

Highly skilled technicians	8
Skilled workers	4
Semi-skilled workers	26
Unskilled workers	9
Craftsmen	3
Administrative) Others)	13
	63

There can be no doubt that in the case of a country on the threshold of industrialization, such as Brazil, it is perfectly possible to recruit the required personnel. But one has to expect at least the following problems: higher training costs due to the longer training time required, higher fluctuation costs and lower productivity. In developed countries, especially in highly industrialized regions, qualification requirements do not play a significant role in training costs. Newly hired workers usually have a command over various skills that can easily be developed to the level of skills required.

Training costs, though important for the profitability of a firm, are low compared with a situation of a generally low level of education and skills. Fluctuations in personnel can constitute a severe problem if a vacancy due to a resignation cannot be filled in reasonable time. The special labour market conditions in many developing countries, with high unemployment rates for completely unskilled workers and heavy shortages of trained personnel, make this problem very likely. It is a generally accepted fact that a low level of education and skills reduce productivity. These problems become more important if one considers developing countries which are not yet on the threshold of industrialization. In many developing countries it simply will not be possible to recruit the necessary number of skilled and semi-skilled workers to start and maintain production.

These disadvantages are counteracted by the comparably low levels of wages and wage by-costs in the developing countries. Since the wage bill accounts for only 30 per cent of the average costs of fibre production, low wages and wage by-costs are only of limited importance for such capital-intensive production as fibre production.

Capital equipment, technology transfer, research and development

Fibre optics is a new branch of modern telecommunications industry and is now penetrating industrialized countries. Technological knowledge, patents etc. are in the hands of a few companies. Therefore it is crystal clear that any effort directed towards optical-fibre production must rely on a complete technology transfer, or at least on very intensive technological co-operation with one of the leading firms in this market. This means that technological knowledge and machinery (including robotics and electronics) and detailed information on processes and their control must be imported from industrialized countries. This is the main disadvantage for developing countries. They would have to completely depend upon their partners in industrialized countries to get optical-fibre production started and to keep it running.

Building up a production facility is little more than a first step towards a self-sustained technological and industrial development. The concrete disadvantages for developing countries under such an arrangement would be:

- higher production costs (royalties would represent 5-7 per cent of gross revenue)
- technological inflexibility
- high dependency on licenser or international companies owning the facility
- reduced domestic value added and tax revenues

If one includes R + D, cost calculations change profoundly. In the short run, this raises overhead costs with only minor effects on production. In the long run, many positive effects can be expected:

- development of own machinery and equipment
- better production schedules
- smaller dependency on licensers
- specialized fibre designs
- higher yield

All these factors may help to lower production costs and to reduce in the long run the competitive advantage of established producers.

General production and market conditions

Optical-fibre production requires special conditions in the factory: clean room conditions for fibre drawing and/or preform production; electronically controlled, highly automated gas supplies; acclimatization and special waste treatment. Developing countries with adequate industrial experience are not expected to have severe disadvantages in this respect. Some countries may be in the position to provide adequate buildings or even to some extent the necessary equipment from domestic sources.

The situation with regard to market conditions is somewhat different. Despite installations in some developing countries, there is not yet a substantial domestic market for fibre optics in these countries. The great bulk of the optical fibre that is produced is deployed in industrialized countries. Many leading optical-fibre producers recently expanded their production capacity to meet anticipated demand in the near future. If developing countries want to participate in the dynamic development of the fibre-optic markets even in their own countries, strong efforts must be made in order to become suppliers in time. These efforts might be hindered by at least two factors: (1) domestic markets in developing countries tend to be small, so that fibre must be sold on the international market, and (2) the behaviour of national telecommunications authorities or their private counterparts which leads to almost closed markets. Therefore it appears to be very difficult to penetrate these markets without the assistance of an international company.

The advantages of domestic suppliers stem from their familiarity with the general conditions in the telecommunications sector of their country, language, co-operation with national telecommunications authorities etc. Close co-operation with national telecommunications authorities, universities and national and international companies may provide a nucleus for a national industry as well as the necessary international connections to sell these products on the international market. The most advanced countries are Brazil, where strong efforts towards national optical-fibre production have been ongoing since 1974, and the Republic of Korea, where technology transfer is currently taking place.

Optical-cable production in developing countries

Optical-cable production uses basically the same equipment as conventional copper-cable production. Investment costs to adapt production facilities for optical-cable production are quite low, so that conventional cable factories can be used for optical-cable production. Such factories exist in a considerable number of developing countries, in some cases owned by international companies. For example, Sumitomo of Japan owns facilities in Brazil and Venezuela.

The disadvantageous labour market conditions in developing countries and technology deficits are not serious considerations in optical-fibre production, since at least parts of the technology are already used in developing countries. In all other respects, conditions for cable production are not exceedingly adverse in the most advanced developing countries.

Conclusions

It seems in fact to be possible to produce optical-fibre in the most advanced developing countries in the near future. But one must be aware of the following problem areas, which are by no means outweighed by other factors:

- supply of highly pure chemicals
- reliable and well-trained personnel
- higher training costs
- general production conditions
- participation in international markets
- technological and economic dependency
- size of domestic markets

Special attention must be paid to the conditions of the necessary technology transfer in order to avoid the usually unfavourably phenomena. Developing countries with little industrial experience cannot meet the requirements for successful optical-fibre production, except in the case of a complete technology transfer, including manpower and supply of chemicals. This amounts to inviting the construction of a production facility of an established company that will be built up and run under the complete domination of this company. Optical-cable production uses equipment very similar to conventional copper-cable production and can be assembled at any existing cable factory with reasonable cost.

Recommendations

General considerations

How can a developing country enter the international fibre/cable market in the most profitable and easiest way? Two aspects are considered: the purely commercial point of view and the socio-cultural implications. As a starting point, two well-known facts about developing countries should be kept in mind. Developing countries constitute a highly heterogeneous group. In contrast to countries on the verge of industrialization, there are many developing countries that are still struggling to develop basic telecommunications services for their people. Their strategies and positions as to whether and how to introduce fibre-optic production will be vastly different. Several developing countries are confronted with a "dual economy" situation: simple rural lifestyles in sharp contrast with advanced, technology-oriented social patterns.

Factors involved in optical-fibre and cable production

1. Optical-fibre and cable production is a rapidly developing high-technology business.

2. The market is capital-investment oriented.

3. Developing countries have little specific advantages over industrialized countries in optical-fibre production. Labour cost is only a minor factor: the raw materials required are few, but highly refined.

4. Within developing countries, optical fibres have yet to establish a position as a viable transmission medium in competition with satellites and terrestrial microwave and conventional cable.

5. The market for high-quality fibres is vigorously expanding: low-quality fibres are available in surplus quantities.

6. A facility for optical-fibre production should have a capacity on the order of 100,000 fibre kilometres per year to take advantage of economies of scale. Smaller units may not be price competitive internationally unless specialty fibres are produced.

7. The capacity for world-wide installed optical-fibre production is estimated between 2,000,000 and 2,500,000 fibre kilometres per year, which is more than present annual sales.

8. Companies offering optical-fibre systems have competitive advantages over companies offering only fibres and/or cables.

9. Setting up optical-fibre production from the beginning, it takes about two years until high-quality fibres with high yield can be produced.

10. Comparing the various fibre-production processes, highest value added can be achieved with high-quality silica fibres, produced by the "preform - then drawing process".

11. Consistently high-quality silica fibres can only be produced by highly automated, computer-controlled machinery.

12. A minimum of 500 man-years of R + D have been invested in major production processes.

13. The distribution of value added between fibre and cable is approximately 50:50 (including installation and instrumentation/equipment on the cable side).

14. In the field of plastic fibres, there is a single major world-wide supplier that is determined to keep its monopoly. However, even with high-market penetration, plastic fibres will constitute only a small portion of the telecommunications market because the lengths of plastic fibres are rather short.

Strategies to acquire technology

Table 12 shows the principal strategies that can be utilized by developing countries to acquire technology for optical-fibre production. In the independent-development strategy the developing country develops its own technology from scratch, with no or little outside help. Buying patent licenses involves obtaining permission to use patents obtained at low cost from the patent assignee. The bulk of problems in setting up the production rest with the developing country in this approach. Buying a technology package is an approach in which a foreign company sets up a production unit in a developing country, initiates production, and then turns over ownership and responsibility to a locally owned and controlled firm. Joint venture within the context of this article describes a situation in which a company owned by a developing country and in possession of some relevant technological know-how shares ownership, risk and profit with a foreign company, which contributes specific fibre-optic technology. Importing a complete production plant entails the construction of a completely new fibre/cable production unit in a developing country by a foreign firm, e.g. a multinational corporation, that retains control over production and profits.

Table 12. Principal strategies to acquire technology

Strategies	Contribution of developing countries	Ownership	Profit	Risk for developing countries
Independent development	Very high	Domestic	If any, domestic	Very high
Buying patent licenses	High	Domestic	If any, domestic	High
Buying technology packages	Medium	Domestic	If any, domestic	Moderate to high
Joint-venture	Medium	Domestic/ foreign	Domestic/ foreign	Moderate
Importation of a complete production plant	Low	Foreign	Mainly foreign	Low

Recommended strategies and their implications

The following strategies are recommended for developing countries wishing to enter the field of fibre production. Joint ventures are recommended for those developing countries that are on the threshold of industrialization. For those that are less developed, importation of complete production plants is recommended.

Joint-venture strategy

This approach requires the existence locally of relevant know-how. It could be provided by glass-making, chemical, cable or semiconductor industries. Also, a foreign company granting fibre technology is needed. Economically, this approach seems viable. A problem to be solved by bargaining is to make the enterprise profitable and attractive for the investor in fibre technology. For example, this could be achieved by temporary tax privileges, real-estate grants or creation of domestic markets in combination with a telecommunications policy to "buy domestic". "Local technological development" has just evolved as a means of corporate competition between multinational corporations, a fact which could aid in making the scheme work.

Socio-cultural benefits for the developing country would lie in a strengthening of its telecommunications industry, of paramount importance for the development of the information society of the future. The general level of technical skills and knowledge would be improved, assisting in implanting an affinity for science and technology. Although only a small number of people might be involved, it is a step toward industrialization. Glass fibres are a high-technology, high-quality product. Familiarity with high-quality products will raise awareness among workers as to what high quality is and how to achieve it. If, as required in this scheme, some technology sectors are already in existence, setting up a fibre/cable production would not, in itself, create a dual-economy situation. Finally, a successful joint-venture will strengthen the pride and the confidence of the people in their own achievements.

Variations on the joint-venture strategy

(1) Prepare for joint-venture fibre production. A developing country may wish to enter fibre production because it is seen as a step toward developing a telecommunications industry, but know-how is lacking in one of the relevant technological areas. A long-term strategy is outlined below, which is also highly recommended for the joint-venture approach as a parallel-track effort. This strategy consists of the following steps, measures, and policies:

- Purchase foreign fibre-optic cables. Train telecommunications personnel to become acquainted with problems involved in laying cable, splicing, operation, maintenance and repair on a test installation, if necessary with foreign assistance.

- Simultaneously set-up a small research facility (about 20 to 30 people) that is run and supported by a non-profit organization (or the government).

- Buy a technology license and have the R + D facility implement a small-scale trial production, if necessary with help from foreign personnel. Try out every step of fibre and cable production, starting with jacketing and then cabling of the purchased fibre. Proceed to preform-making and fibre drawing.

- Develop the chemical industry, which also can serve the semiconductor industry.

- Promote interaction, contact, and mobility between the R + D group and the telecommunications personnel operating the trial installation in order to raise the level of training and the awareness of problems.

- Protect the infant fibre/cable industry by adequate economic policy measures.

- Develop a domestic demand for fibres and cables.

This approach is a time-consuming one, requiring about five years. The inherent strength of this strategy is that a production system is created that is similar 39/ to those existing in advanced industrialized countries.

(2) Expand the existing cable factory. The joint-venture can favourably be grouped around a conventional cable factory already operating in a developing country. The discussion of the joint-venture approach and variation (1) is analogous to this variation. Many cable companies in industrialized countries have chosen this approach. In search for new products they have either developed or bought fibre technology. The discussion of this approach is restricted to the technology-transfer alternative.

Concerning profitability, some of the machinery already available (stranding machines, extruders, etc.) could be used in a modified form. Chances are high that local, qualified personnel are available with knowledge of some cable-manufacturing technology. Workers should be trained step by step for the new technology. A cost disadvantage would arise if the chemical industry of the developing country is unable to supply the necessary quantities of pure chemicals.

If the cable factory is partially owned by a multinational enterprise, it could well be possible that branches in other countries are already in possession of fibre know-how and that they might be willing to share this knowledge.

Existence of a domestic and/or regional market for optical-fibre cables would be helpful. The resident cable company would have experience in dealing with such a market. Restrictive policies to shut out foreign competition, if so desired, might not be necessary.

As a first step in entering the optical-fibre business, cables could be made from imported fibres. Technology transfer would take place in the form of a high-technology semiproduct, i.e. the fibre. The main advantages are: existing cabling know-how; use of existing machinery, at least in a modified form; existing business relations with suppliers of raw materials for cables; and very relaxed requirements concerning clean-room conditions as compared to fibre production. Risk would be comparatively low, even if fibre import is discontinued or when unexpected technical problems arose, since manufacture of conventional cable could continue. A certain flexibility in producing either cable type could be maintained.

The disadvantages of this approach lie in the dependence on punctual delivery of fibres and their availability in the required quality, and in the fact that shipping costs are incurred. If the social gains of a developing country, touched upon above, can be shown to outweigh the organizational and commercial problems, this variant is definitely recommended.

Importation of a complete production plant

This strategy involves importing a complete factory, including machinery and qualified personnel. The responsibility of setting up the production would rest mainly with the foreign company acting as an entrepreneur. Obviously, this is the easiest but not the most profitable way for a developing country to enter the fibre market.

To invite a company to transfer an existing facility or to construct a new production facility in a developing country, tax and/or profit transfer privileges might be conceded. The share of the value added remaining in the developing country would be small and the positive influence on the country's economy limited. The domestic market would probably be served from such a plant, but it would not be very important whether it exists. Finished products would be exported to a high degree anyway. A cost disadvantage would exist for such a company due to the necessity of importing all raw materials. Whenever the necessity for repair or maintenance arose, foreign specialists would have to be flown in from abroad.

There are some positive commercial aspects of this approach. There are few requirements concerning the state of development of the developing country, other than a continuous supply of electric energy and access to the factory by road, rail, ship or aeroplane. The factory could be set up in the shortest possible time and production could begin quickly. Capital investment on the part of the developing country would be small.

The following socio-cultural implications are foreseen. In developing telecommunications, importing a fibre plant provides an opportunity to leap-frog several technologies and enter into the fibre-optics age directly. Prior to a positive decision, a careful case study would have to prove the suitability of fibre-optics for the developing country under discussion. Any communications medium in a developing country (and elsewhere) must fulfill some basic requirements.

- . easy maintenance
- . high reliability
- . adaptability to local conditions
- . economy.

Very long repeater spacing and the possibility to meet future expansions and development are two important points in favour of optical fibres. Compared to many other branches of industry, fibre optics is a "clean" business with little ecological interference. Some negative aspects are involved. A dual-economy situation would be created or aggravated by this strategy. Only a few workers, mainly unskilled, would get a job in the factory. Also, control of decision would rest with the foreign company.

Altogether, this approach to acquire fibre technology is conditionally recommended for less developed countries. The other strategies enumerated are discouraged.

Independent development

This is a very costly strategy in view of the fact that about 1,000 man-years have been invested in the development of each of today's production processes. Even industrialized countries would be in a difficult position to invest considerable money and a large number of researchers in their work. Such a development, started today, would also bear fruit too late to catch a considerable market share.

Buying patent licenses or technology packages

These patterns of technology transfer, though practiced in the past in other branches of industry, do not seem suited for optical fibres and cables. Capital investment would be high as would be the risk. Once the patents or the plant is handed over to the owner in the developing country, all technical problems arising would be his problems. Even an experienced management and work force in industrialized countries fight hard to keep quality and yield high.

Which technology?

Two facts make it impossible to recommend a single technology for high-quality silica-fibre production. First, the international patent situation is unclear. In the courts of several industrialized countries, above all the United States of America (because it has the largest market by far), vigorous battles are waged for and against the acceptance of claims of patent infringement. Corning Glass Works has a strong patent position in several industrialized countries, but their position does not remain unchallenged. Basic patents of glass-fibre production will expire around the end of this decade. In developing countries, the patent situation might be more relaxed since major companies involved in developing technology have not taken the trouble to file patents in every country.

Second, "the race towards economic manufacturing of high-quality fibre-optics is just beginning ... A dominant process, if ever, is not likely to emerge in this decade...." 40/ Hence, in searching for a suitable technology, developing countries should not only look for production efficiency, but also for availability and accessibility of this technology. Also, the process to be chosen should have proven flexibility.

Plastic-clad silica (PCS) fibres

The production of the sometimes advocated plastic-clad silica (PCS) fibres should be avoided, if production for telecommunications is aimed at. They offer no real cost advantage in production, and can always be plagued by problems arising from water at the silica/plastic interface. If markets for fibres with lower quality (and lower selling price) can positively be defined, all-glass step-index (SI) fibres made by the double-crucible method are the first choice.

Marketing

A well-defined home market is extremely helpful for starting fibre/cable production. Without it, or without exact as possible predictions of its volume, optical-fibre production in a developing country might be doomed to premature abortion. Markets in other developing countries (regional markets) and in industrialized countries must inevitably be found to keep up production. Penetration of international markets will probably require co-operation with established fibre producers. Since co-operation on technology is a pre-requisite for successful optical-fibre production, this latter requirement is already met.

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PRESENT AND FUTURE TRENDS IN OPTICAL-FIBRE PRODUCTION *

J. E. Midwinter **

With respect to the present trends in the field of optical fibre production, it appears that the following processes, with a volume circa 50 to 500 thousand fibre km/annum, are now the most widely used processes. In the United States of America, Western Electric is thought to predominantly use the modified chemical vapour deposition (MCVD) process and Corning Glass is believed to predominantly use the outside vapour deposition (OVD) process. A number of other manufacturers use the MCVD process. In Japan, the MCVD process has been used widely, but following an intensive R+D programme involving Nippon Telephone and Telegraph (NTT), Fujikura, Furukawa and Sumitomo, it is believed that the vapour-phase axial deposition (VAD) process is now being widely used, although this author knows of no firm production figures. Within Europe, there is an OVD plant operational in the United Kingdom, with another reputedly under construction in another country as well as numerous MCVD plants. It is assumed that Philips uses the plasma-activated chemical vapour deposition (PCVD) process for their own fibre. There is also a large-scale development of the silica rod-in-tube process in France, aimed at local network application.

Since all processes use essentially identical starting materials and their cost is a small part of the finished product, there remains room for considerable cost reduction. Hence, during the remainder of the present decade up to 1990, it seems certain that the price of fibre will continue to fall as the volume installed increases and the processes become steadily more refined. As this happens, factors such as deposition and pulling rates, starting material costs (including silica tubing where used), yield of fibre to the required specification and the need for screening individual fibres will become key issues in deciding which process will be best equipped to meet the market. Strategic considerations may also have an impact, for example the supply of suitable tubing or a material such as germanium tetrachloride. The nature of wage structures in the Western industrialized countries has led to a great deal of development effort being expended on achieving higher productivity (fibre/km) per industrial man-hour as a major part of the cost reduction process, since wages make a substantial contribution to the cost of the finished product. In an economy with lower wage rates, this balance will obviously change and may allow them to undercut the price of fibre manufactured in Europe, North America or Japan.

A second trend that is already apparent will be an increasing switch from graded-index fibre to single-mode fibre. Already, the price of single-mode fibre has fallen close to or below that for good graded-index fibre, whilst offering much superior performance. However, its use in a system is probably still higher because of the additional cost of connectors, splicing and sources (single-mode pigtail lasers). Once again, volume production will reduce these component costs so that the cost/performance advantage of single-mode fibre will further increase.

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* This article is based upon a chapter of a larger study prepared by Professor J. E. Midwinter for UNIDO and is devoted to the present and future trends in the field of optical-fibre production. It also contains some ideas on the choice of technological processes to start domestic production.

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The largest potential future market in the West is for wideband TV distribution over fibre, optical CATV or pay TV systems. However, in general, the system specification for such an application is still so incomplete that it is not clear what type of fibre, if any, will be used. The only large-scale programme announced is that for France, for which the fibre is expected to be made domestically. There is great controversy within Europe about the programme and no consensus that it represents the correct route to follow.

The type of fibre used for under-sea systems this decade will undoubtedly remain single-mode silica fibre. The major change that can be anticiapted is the extension of repeater spacings, perhaps to 250 km. This would make many routes repeaterless, a development that seems likely to greatly and favourably affect their economics and perhaps generate more traffic. In the longer term, there is speculation that trans-oceanic repeaterless submarine systems might be possible, operating at wavelengths of 3 to 10 microns in non-oxide glass fibres (i.e. halides, chalcogenides, etc.). Whilst there is some theoretical evidence that suggests that losses as low as 0.001 dB/km might be achievable, it remains a matter for speculation as to what will be achieved. Values of about 10 dB/km have been achieved in the laboratory and the remaining problems appear formidable. Furthermore, the market is limited and very specialized; such systems would need completely new transmitters and receivers for the longer wavelength operation.

At present, the largest single market for fibre is North America, probably followed by Europe and Japan, in that order. In terms of magnitude, these markets are estimated to be 1 million and 100 thousand fibre km/annum for North America and Europe/Japan, respectively. Whilst these are large markets, it is questionable as to what extent they are open. The North American market appears to be largely closed to imported fibre, with several large contracts reputedly awarded to North American suppliers as opposed to overseas suppliers, not for reasons of cost but of national security. However, some Japanese companies are known to have sold fibre, cable and systems to Canada and the United States of America and it has been recently reported that one Japanese manufacturer, Sumitomo, is building a fibre-manufacturing plant in the United States of America. In Europe, the telecommunications administrations have traditionally required European-based manufacture for most key components and systems, and that does not appear to be changing significantly, although there have been some moves towards liberalization, notably in the United Kingdom. Likewise in Japan, NTT has traditionally bought only from within Japan, although, as a result of external trade pressure, they have indicated a willingness to purchase from overseas sources. The extent to which these markets will be truly open is a matter for speculation.

The above markets arise from the conversion of the existing networks from analogue to digital operation, coupled with the growth of traffic on major routes. In less industrialized countries, the markets are more likely to arise as a result of the expansion and improvement of old and overloaded networks. Many countries in South America and Asia provide good examples. Here, the major problem facing the would-be importer is that such countries can easily set up their own home-based manufacture, typically using the MCVD process or a minor variant. Whilst they may not achieve the levels of precision control and productivity demanded in Europe, North America and Japan, their system demands are often less stringent and their cost structures so different that little impediment arises. Furthermore, such countries are frequently short of foreign currency. Thus it seems certain that countries such as Brazil, China or India will rely almost exclusively on home-based manufacture, although they may well be interested in foreign investment in terms of both production plants and technology.

At the same time, it appears that the large open export markets for fibre do not generally exist, although there are many markets for small numbers of fibre cables for special purposes outside the mainstream telecommunications market. The nature of the manufacturing process is such that it is ideally suited to any country having a minimal industrial infrastructure that wishes to modernize its own network, provided that it does not set out to produce immediately the most sophisticated product.

While assessing the feasibility of domestic production of fibres, it is advisable to take into consideration the following:

- Home telecommunications markets should be carefully analyzed to establish the bit rate and length of systems that are best suited.

- The simplest fibre design should be identified that will meet these requirements.

- The volume requirement in fibre km per annum (f.km/a) should be estimated.

- For low volume (up to 50,000 f.km/a), the MCVD process or a variant is almost certainly the cheapest and easiest to establish and operate.

- For very high volumes (several 100,000 f.km/a), it is generally claimed that a process such as the OVD or VAD is the most economic, although the detailed case for such claims is very much dependent upon the relative cost of capital and wages. If such a process is sought, then licensing it is likely to be the best route.

- If a very high performance fibre is required (0.2-0.3 dB/km single mode for example), then a sophisticated version of the MCVD apparatus is likely to be best. It may be cheaper to license the key technology rather than to develop it, since the number of parameters to be individually monitored and controlled is large and the process optimization is likely to consume a great deal of time and skill.

* * * *

PUBLICATIONS

The following list of books was compiled from entries contained in New Technical Books, a monthly publication by the Research Libraries, The New York Public Library at Fifth Avenue and Forty-second Street, New York, N.Y. 10018, United States of America. Subscriptions are $15.00 per year, single numbers are $2.00. New Technical Books is a selective list of noteworthy English language books compiled from the many new titles submitted for the monthly exhibits of new technical books in the Science and Technology Research Center, The Research Libraries, The New York Public Library. Both the Library of Congress catalog card number and the International Standard Book Number (ISBN) are provided. The descriptive material (contents and notes) are prepared by members of the Center's staff.

Fibre optics

Chorafas, Dimitris N. Telephony: today and tomorrow, Englewood Cliffs, NJ: Prentice-Hall, 1984. 292 p. $19.95, paper # 83-3271. ISBN 0-13-902700-9.
Contents, abridged: The voice system. The new technologies. Modern communications networks. Glossary. Index.
Note: This book brings together everything pertaining to policy decisions, general perspective, and the component parts of modern systems in telephony. The author covers telcos, voice systems, PBX's, optical fibers, satellite systems, and local and long-haul networks. Of interest to those in the communications field. For special libraries.

Society of Photo-Optical Instrumentation Engineers. Proceedings. Vol. 355: Fiber optics: short-haul and long-haul measurements and applications. Edited by Robert L. Gallawa, Bellingham, Washington: Society of Photo-Optical Instrumentation Engineers, 1982. 170 p. $49, paper. 82-61900. ISBN 0-89252390-5.
Contents: A fiber optics potpourri. Fibre optics terminal devices. Fiber optics test and measurement. Fiber optics: short haul applications. Indexes.
Note: Covers many timely fiber optics topics with special attention given the matters of test and measurement, subjects not frequently discussed. For optical engineering collections.

Society of Photo-Optical Instrumentation Engineers. Proceedings. Vol. 374: Fibre optics '83. Edited by L.R. Baker. Bellingham, Washington: Society of Photo-Optical Instrumentation Engineers, 1983. 208 p. $47, paper. 83-050506. ISBN 0-89252-409-X.
Contents: Fibres and cables. Optoelectronic devices and connectors. Design of communication systems. Applications and testing of communication systems. Morning session. Afternoon session. Index.
Note: The papers included in these proceedings cover the main subject areas of interest to potential users of fibre optics, namely, communication systems, and industrial and military applications. The conference was organized to help encourage the smooth transfer of new developments from the laboratory into profitable industrial applications. There are thirty-two authoritative, well documented papers included in this volume. Illustrated with plates, diagrams, graphs, tables, and charts. For academic and special libraries.

Society of Photo-Optical Instrumentation Engineers. Proceedings. Vol. 417: Fiber optics multiplexing and modulation. Edited by Edward J. Miskovic. Bellingham, Washington: Society of Photo-Optical Instrumentation Engineers, 1983. 77 p. $49, paper. 83-50335. ISBN 0-89252-452-9.
Contents: Systems. Components/technology. Index.
Note: This conference deals with wavelength division multiplexing concepts on both systems and component levels. Editor is affiliated with ITT Defense Communications Division. For special libraries.

New ceramics

(The second issue of Advances in Materials Technology: MONITOR was devoted to new ceramics. Copies of this issue are still available from the UNIDO secretariat.)

Army Materials Technology Conference (6th: 1979: Orcas Island, Washington). Ceramics for high-performance applications-III: Reliability. Edited by Edward M. Lenoe, R. Nathan Katz and John J. Burke. NY: Plenum, 1983. 825 p. $89.50. (Army Materials Technology Conference Series; Vol. 6) 82-13243. ISBN 0-306-40736-1.
Contents: Heat engine applications. Quality of materials and component processing. Design concepts for ceramics. Emerging techniques for reliability prediction. Test, evaluation, and development of specimens. Critical issues workshop. Index.
Note: A collection of 1979 conference papers which highlighted issues relevant to the reliability of ceramics in advanced systems. Emphasized developments on ceramic gas turbine technology. Some discussion issues are listed. Includes an excellent index. For materials science collections.

McColm, I.J. Ceramic science for materials technologists. Glasgow: Leonard Hill, 1983. 357 p. $85 (Distributed by Chapman and Hall) 82-22205. ISBN 0-412-00351-1.
Contents: Traditional ceramics. Special light ceramics for modern applications. Glass. Glass-ceramics. Refractory oxide ceramics. Special ceramics--refractory hard metals.
Note: Topics in ceramics for students in materials science and materials technology course are treated. Knowledge of other topics common to materials courses, e.g., dislocation theory, phase diagrams and sintering is assumed. The approach the author uses is to develop the various types of ceramics and to use them to investigate the structures and properties found.

Steel

(Issue No. 1 of Advances in Materials Technology: MONITOR was devoted to the subject of steel and dealt in particular with high strength, low alloy (HSLA) steels. Copies of this issue are still available from the UNIDO secretariat.)

International Conference on Recent Developments in Specialty Steels and Hard Materials (1982: Pretoria, South Africa). Specialty steels & hard materials. Edited by N.R. Comins and J.B. Clark. Elmsford, New York, Pergamon, 1983. 466 p. $100. 83-2410. ISBN 0-08-029358-1.
Contents, abridged: Invited papers. Specialty steels: copper-boron low alloy high strength steels; copper-containing steels for severe service rails; metallury of a 12% chromium steel. Hard materials: microstructural basis of strength and toughness in hardmetals. The adhesion of hard and wear resistant coatings; non-oxide ceramics--a new class of engineering materials; diamond polishing--diamond's affinity for scaife materials in the polishing process of diamond.
Note: Papers presented at the proceedings of the conference (Materials Development '82) held 8-12 November, 1982 are included in this volume. Some major topics covered in this selection of papers include an examination of physical and mechanical properties of recently developed iron-based alloys. For researchers in the field. The editors are with the Council of Scientific and Industrial Research, Pretoria, South Africa. For research libraries.

Materiais science

Annual review of materials science. Vol. 13. Edited by Robert A. Huggins. Palo Alto, California: Annual Reviews, 1983. 454 p. $64. 75-172108. ISBN 0-8243-1713-0.
Contents: Experimental and theoretical methods. Preparation processing, and structural changes. Properties and phenomena. Special materials. Indexes.
Note: The 1983 volume contains 18 articles by experts in the field. An interesting feature is a prefatory chapter written by David Turnbill of Harvard which comments on the emanation and development of materials science as a discipline. Includes a list of related articles in other Annual Reviews, a subject index to the current volume, an index of authors contributing to volumes 9-13, and a list of the chapter titles of volumes 9-13 arranged by general subject. The editor is of Stanford University. For science and engineering collections in university, public, and special libraries.

Materials research centres. Edited by Eric Mitchell and Elizabeth Lines. Harlow, Essex, UK: Longman, 1983. 654 p. $160.00. ISBN 0-582-90013-1.
Contents, abridged: Algeria, Canada, Federal Republic of Germany, Israel, Monaco, Romania, Zambia. Titles of establishments index. Subject index.
Note: A world directory of organizations and programs in materials science (its sub-title) is a new international directory covering over 1,000 research units from 57 countries (as the work is arranged alphabetically). For each country, establishments and organizations are arranged alphabetically in the language of that country. Use of non-Roman languages is entered in English translation (e.g. Japan). For all science and technology collections in industrial, academic, and larger public libraries.

The following books are available from the Plenum Publishing Corporation, 233 Spring Street, New York, N.Y. 10013, United States of America or from their London Office, 88/90 Middlesex Street, London E1 7EZ, England.

New ceramics

Emergent process methods for high-technology ceramics. Edited by Robert F. Davis, Hayne Palmour III, and Richard Porter, North Carolina State University. New York, Plenum, 1984. 876 pp./ill. $95.00 ($114.00 outside USA and Canada). ISBN 0-306-41677-8.
Contents: Stressing the technology and underlying science of several novel emergent process methods for high-technology ceramics, practicing scientists and engineers discuss advances in colloidal processing, novel powder-forming and power-processing methods, polymer processing ceramics, chemical vapour deposition, iron beam deposition, laser and ion beam modification of surfaces, hot isostatic pressing, dynamic compaction, shock synthesis, and very high pressure processing. Volume 17 in the series Materials Science Research.

Deformation of ceramics materials II. Edited by Richard E. Tressler, The Pennsylvania State University, and Richard C. Brandt, University of Washington. New York, Plenum Publishing Corporation, 1984. 764 pp./ill. $19.00 ($114.00 outside USA and Canada). ISBN 0-306-41719-7.
Contents: Deformation of covalent crystals. Deformation of oxide crystals. Deformation of silicate minerals. Creep of polycrystalline ceramics. Creep crack growth and failure in ceramics. Near surface phenomena. Index.

This volume presents current results of research on the deformation behaviour of inorganic, nonmetallic materials. A number of the papers discuss dislocation dynamics and deformation of single crystals, including binary oxides, ternary oxides, silicates, nonstoichiometric oxides, covalent materials, and halides; and the effects of point defects and twinning. Articles addressing deformation of polycrystalline ceramics consider oxides, nonoxides, polyphase materials, and superplastic deformation. There are also several papers dealing with cavity nucleation and creep crack growth, topics currently receiving much research attention. Taken together, these contributions offer valuable information applicable to the utilization of ceramic materials in important new technologies. Volume 18 in the series Materials Science Research.

Materials science

Innovations in materials processing. Edited by Gordon Bruggeman, Army Materials and Mechanics Research Center, Watertown, Mass., and Volker Weiss, Syracuse University. New York, Plenum Press, 1984. 494 pp. $79.50 ($95.40 outside USA and Canada). ISBN 0-306-41839-8.

Contents: Confronting issues of productibility, productivity, reliability, and affordability, this timely volume reviews recent innovations in the processing of metals, ceramics, plastics, and composites. Described are key developments in process modeling and control, processing from the liquid state, processing of particulates, machining technology, and surface treatments. Volume 30 of the Sagamore Army Materials Research Conference Proceedings.

MEETINGS

Fibre optics

The first International Conference and Exhibition on Fibre Optics for the Developing Countries will be held in Ljubljana, Yugoslavia, from 14 to 18 October 1985. The conference and exhibition will be organized with the assistance of the Cankarjev dom Cultural and Congress Centre, the Slovenian PTT and the Yugoslavian electronics industry. Papers are being solicited in the following areas: systems design considerations, installation experiences, cost trade-offs, planning for fibre-optics installations, training requirements, conectors/splices techniques, sources and detectors, review papers, state-of-the-art papers, tutorial papers, organizing a fibre optics industry, fibre optic cable designs, fibre-optics sensors and instrumentation systems. The papers should focus on applications and be oriented to the needs of developing countries. The programme will consist of a two-day technical and business educational programme of tutorial and short courses from 14 to 15 October and a conference and exhibition from 16 to 18 October, 1985. Titles of papers and a 200-word abstract should be sent to the Technical Programme Chairman: Iztok Klemencic, Head, Optical Communications Laboratory, R + D Department, ISKRA Center for Electrooptics, 7 Stegne, POB 59, 61210 Ljubljana-Sentvid, Yugoslavia, telephone: (061) 575-505, telex: 31687 kskceo yu. For exhibiting and registration, contact: Dr. Paul Polishuk, President, IGI Consulting, Inc., 214 Harvard Avenue, Suite 200, Boston, Massachusetts 02134, United States of America. Telephone: (617) 738-8088, Telex: 499-6088 fiber.

The 8th Optical Fiber Communication Conference will be held by the Optical Society of America in San Diego, California from 11 to 13 February 1985. The purpose of the conference is to provide a forum for invited and contributed papers on optical-fibre communication and related topics ranging from basic research to hardware manufacture and systems development and applications. The conference will be divided into three principal areas: fibres and cables, components--active and passive, and systems and new fibre applications. Representative examples of topics to be considered are: fibres and cables, including propagation characteristics, fibre and cable materials, and radiation effects. To obtain further information, contact the Meetings Department, Optical Society of America, 1816 Jefferson Place, N.W., Washington, D.C. 20036, USA.

The Optical Fibre Sensors Conference will be held in San Diego, California from 13 to 15 February 1985. Topics for invited papers for the Conference include optical-fibre gyroscope systems, optical sensing techniques, optical components with particular reference to sensors, and application of optical-fibre sensors. For further information, contact the Meetings Department, Optical Society of America, 1816 Jefferson Place, N.W., Washington, D.C. 20036.

A Symposium on Optical Fiber Measurements was held in Boulder, Colorado from 2 to 3 October 1984. The symposium provided a forum for reporting the results of current research and an opportunity for discussion that could lead to further progress. Papers were solicited on experimental or analytical aspects of the characterization of optical fibres and fibre-optic systems (including attenuation, bandwidth/distortion, dispersion, index profile, cutoff wavelength).

New ceramics

The Fourth International Symposium on the Fracture Mechanics of Ceramics will be held in Blacksburg, Virginia, United States of America, from 19 to 21 June 1985.

The 13th Conference on the Science of Ceramics will be held in Orleans, France from 9 to 11 September 1985.

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Readers' comments

We should appreciate it if readers could take the time to tell us in this space what they think of the third issue of Advances in Materials Technology: Monitor. Comments on the usefulness of the information and the way it has been organized will help us in preparing future issues of the Monitor. We thank you for your co-operation and look forward to hearing from you.