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STRENGTHENING THE CAPABILITY OF THE SYRIAN SCIENTIFIC STUDIES AND RESEARCH CENTRE IN THE FIELD OF OPTICAL TECHNOLOGY

DP/SYR/86/011

SYRIAN ARAB REPUBLIC

Technical report: Assistance to the Scientific Studies and Research Centre *

Prepared for the Government of the Syrian Arab Republic
by the United Nations Industrial Development Organization,
acting as executing agency for the United Nations Development Programme

Based on the work of S.L. Galkin,
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Explanatory Notes

References to "Dollars" ($) indicates United States Dollars. The Following abbreviations, other than those commonly used are contained in the report:

- SAR - Syrian Arabian Republic
- SSRS - Scientific Studies and Research Centre
- HIAST - Higher Institute for Applied Sciences and Technology
- M/M - man-month

This report was prepared in accordance with the task set forth by UNIDC in Job Description for Consultant in Fiber Optics for Instrumentation Needs. The Duties of the consultant are:

1. Provide an assessment of the situation on the Syrian glass industry considering the future establishment of the small scale production of the optical fibers for instrumentation needs.
2. Advise on the appropriate base material for the fibers (multicomponent glasses, fused silica) and on the technology for fiber manufacturing (double crucible, quarz-polymer, rode-cylinder etc).
3. Identify the specifications for the machinery necessary for fiber-drawing , elaborate the workplane for the construction of the corresponding facilities indicate the possible bottlenecks in such a process.
4. Advise on the training programme for the local personnel, possible host organizations for fellowships and study tours.
5. Advise on the most useful industrial applications of domectically produced fiber (instrumentation, industrial sensors, local area networks) and on the infrastructural actions to be taken in order to organize the R and D, design and small scale manufacturing in this field.

6. Provide on-the-spot demonstration of several possible industrial applications of optical fibers.

In the final version of the report the intentions of SSRS in the field of Fiber Optics for Instrumentation Needs described in Brief Resume dated 2nd December 1989 have been taken into account.

CONTENTS

1. An assessment of the situation on the Syrian glass industry and in SSRC considering the future establishment of the production of the optical fiber

At present in SAR on the whole and in SSRC in particular there is an initial basis for establishing the production of optical fibers on a small scale and for organizing R+D (research and design) in the field of application of the opticalfiber system for instrumentation needs. This basis consists in the following:

a. In SAR the optical glass industry is sufficiently developed (KADAM factory and others).

b. In SSRC there are specialists and equipment that can perform optical and mechanical operations in the field of non-fiber optics (the manufacturing of lenses, plates, microobjectives etc). This equipment can be employed for making preforms for manufacturing fibers of "glass-polymer" type (see Appendix 1).

c. In SSRC there are specialists that can operate complex automatic equipment for the production of optical fibers: engeneering managers, computer/electronics engineers, mechanical engineers,chemical engineers and semi-skilled personnel. After a proper training they will be able to operate the equipment for quality control.

d. Taking into account items a., b., c., one can conclude that the purchase and installation of the initial equipment - the drawing tower - would allow SSRC to produce the fibers with the glass core and light-reflecting cladding. Such fibers are successfully used in the field of instrumentation and LAN (Local Area Network).

f. In SSRC there are specialists with the degree of PhD in the field of optical fiber systems. They can form the core of the group carrying out R + D in the field of optical fiber systems for instrumentation and communication needs.

2. The choice of the technique for manufacturing fiber light guides for instrumentation needs in SAR

The analysis of the state-of-the art in the field of different techniques for manufacturing fiber light guides (see Appendix 1) leads to a conclusion that MCVD (Modified Chemical Vapour Deposition) method is the most versatile and cost effective as compared to other methods such as VAD (Vapour Axial Deposition) OVD (Outside Vapour Deposition) and PCVD (Plasma Chemical Vapour Deposition).
The MCDV method permits to use the same equipment for producing multimode step-index fiber, graded index fiber and monomode fiber for communication systems, LAN and fiber optical sensors.

The equipment for manufacturing fibers by the MCDV method is produced by many companies in different countries (see Section 3). It is supplied and installed at the earliest possible dates (from four to six mounths). The companies carry out the training of personnel and put the equipment into operation. However as it will be seen from the following sections the cost of the complete equipment for manufacturing fiber cables on a small scale (3,000 km per year) is high enough. For this purpose it is necessary (see Section 3) to have the following initial equipment:

1)	2 MCDV glass working lathes 500,000 $ each	1,000,000 $
2)	two airtight boxes 15,000 $ each	30,000 $
3)	gas distribution system	200,000 $
4)	1 drawing tower	500,000 $
5)	clean room	15,000 $
6)	machinery and equipment for cable production and testing	800,000 $
		Total 2,545,000 $

Thus if one chooses to buy the complete MCDV equipment it should be understood that the cost of the equipment alone is high enough.

On the other hand, simpler methods - double crucible, and plastic cladding with glass or silica core (glass-plymer)- are suitable for producing miltimode fiber and fiber optical sensors (see Appendix 3). It should be emphasised that for the glass-polymer method the drawing tower design is practically the same as that of the MCDV method. The double crucible method requires a special drawing tower design.

The manufacturing of regular and irregular multifiber light guides for purposes and for instrumentation needs requires special techniques (see Appendix 2). Such equipment is also produced by a number of companies, its specification is given below. However simple multifiber light guides can be produced by means of the drawing which is used in MCDV, glass-polymer and rod-cylinder methods.

Taking into account these considerations and the goal of starting the small scale production of fiber light guides in SAR at the earliest possible date a working plan is proposed according to which the manufacturing of fibers and the development of R + D in the field of fiber optics for instrumentation needs is carried out step by step.
The intentions of SSRC to developthe production of fibres both for industrial measurement purposes and for communication purposes (see Brief Resume dated 2-nd December 1989) are taken into consideration.

It is very important that each stage of the proposed plan is complete and the project can contain one or more stages depending on financial conditions and specific goals.

The following technological stages are proposed:

1. At the first stage the drawing tower which is a part of the copmlete equipment (its specification is given in Section 3 of the present report) is purchased and put into operation. This tower is used to manufacture fibers of glass-polymer type.Cylindrical preforms made of Syrian multicomponent glass can be manufactured with the help of the equipment available in SSRC. These preforms can be small.

For example, a fiber which is about 200 m long and has the core 100 μm in diameter can be drawn out of the cylinder 100 mm long and 10 mm in diameter. Light-reflecting polymer cladding is put on fibres during the process of drawing on the tower in the same way as the protective coating is applied in the MCDV method. Longer preforms permit to draw proportionally longer fibres. As a result the production of step-index multimode fibres for LAN and sensors are started. The rod-cylinder and rod-cylinder-cylinder methods (see Appendix 2) allow to draw fibres for irregular multifiber light guides. As a result at the first stage it is possible to manufacture step-index multimode fibres, simple multimode light guides and to begin R + D in the field of LAN and fiber optical sensors. Simple LAN, simple short-haul communication systems and simple sensors can go into preproduction. This stage takes 18-24 months.

2. The second stage involves the production of the graded index multimode fibers and monomode fibers, dhich can be manufactured from imported MCDV preforms on the drawing tower already available. At this stage fiber jacketing machines can be purchased. Then it will be possible to start the production of simple monofiber cables. This will also open the way to R + D in the field of more sophisticated LAN, medium-haul trunk lines and phase fiber optical sensors as well as to a small scale production of simple systems and sensors. This stage takes 9-12 months.

3. At the third stage the equipment for manufacturing preforms by MCDV method (two lathes and auxilary equipment) is purchased and put into operation.

The equipment for cable production and testing is also purchased and put into operation. As a result at this stage all the equipment corresponding to the specification given in Section 3 is available which makes it possible annually 3,000 km of the optical fiber cable. The third stage can take 18-24 months.

The production can be increased by installing additional equipment if it is considered necessary or if the market conditions are favourable.

4. At the fourth stage the equipment is imported and the production of high quality regular multifiber light guides (the specification is given in Section 3) for endoscopy begins. This stage takes 18-24 months and can be carried out either simultaneously with the second or third stages or instead of them.

3. Specifications

3.1. Fibre optic cable production equipment

This offer comprises equipment for a full Fibre-Optic Cable production line, with a capacity of 3000 km of cable/annum. It is equally suitable for the production of mono-mode and multimode (graded index) fibre. The typical specification window for such cables is 3-6 db/km attenuation at 0,85 wavelength (multimode) with bandwidth 100-500 MHz-km, and 1 db/km at 1.30 μ for mono-mode fibre.

The offer comprises equipment for MCVD preform manufacture with preform tube preparation and preform assessment equipment, Fibre pulling equipment, with primarily coating, strength proof testing, separate tensile test rig and fibre characterisation and testing equipment, coating extrusion equipment for single core cables and multi-bobbin cabling lay-up machinery for multi-core cables.

The calculation of equipment requirements for 3000 km/annum is based on the following productivity/yield assumptions, derived from major fibre industry manufacturers, using conservative estimates of current technological capabilities:-

Fibre cladding dia:	125 μ
Fibre core dia:	50 μ (graded index) 8-10 μ (mono-mode)
Preform tube size:	20 mm OD, 2 mm wall, 1 m length overall
Length of fibre drawn/preform:	approx 4-6 km
No. preforms/8 hr shift/machine:	approx 2-3
Fibre drawing speed:	0.5-1.0/sec (thermally cured silicone coatings)
Actual productivity:	2.5 km fibre pulled/hr (including preform loading and fibre start up and feeding, coating centering etc.). (unyielded).

These productivities must be multiplied by 0.9 (servicing and maintenance downtime, adjustment etc) and further by 0.6 to allow for an optimistic view of the overall yield of in-specification fibre from preform starts.

For 3000 km/annum of finished cable therefore, the requirement is (assuming 5 day working, 50 weeks/year)

	Pulling Towers	MCVD Equipments
1 shift (8hr/day) working	1	2
2 shift (16hr/day)	1	1

For multiple core cables, the above estimates must be multiplied by the number of cores/cable.

A) MCVD Preform Production Equipment

A1) Central Preform Production Services

However many MCVD Preform Equipments are employed, the following Central services will be required:-

Item	Qty	Description
A1-1a	1	MCVD Preform Tube Cleaning System
1b	1	set Spare Parts, valves, seals, pump, fuses, electronic controls etc.
A1-2	1	Preform Analyser System with optis, electronics, software and interface
A1-3a	1	Master Conroller System controlling all MCVD systems via Slave Controllers
3b	1	set Spare parts, fuses, indicators etc.
4b	1	set Spare Parts
5b	1	set Spare Parts
A1-6a	1	Water Monitoring Hygrometer, with 2 channel continuous monitoring for the output gas dryness of Item 4 and 5 above with accuracy 0.01 ppm H_2O.

6b	1	Spare Parts Kit.
A1-7a	1	Emergency Extract Air Scrubbers.
7b	1	Spare parts kits.
A1-8	1	Bulk Reagent Storage Enclosures.
A1-9a	1	Bubbler Auto Fill Systems, each feeding one or two MCVD Systems.
9b	1	sets Spare parts.
A1-10a	1	Effluent Scrubbers (one per 2 MCVD systems).
10b	1	sets Spare parts for Item 10a.
A1-11a	1	Central Nitrogen Drier.
11b	1	Set Spare Parts.

A2 MCVD Preform Production Systems

Item	Qty	Description
A2-1	2	MCVD Preform Systems each comprising the following items.
1a		Gas Control System.
1b		Additional Freon Doping gas channel.
1c		Additional Helium carrier gas channel.
1d		Additional Chlorine gas channel.
1e		Slave Control Computer.
1f		Computer/Gas Control Interface
1g		Computer/Lathe Interface
1h		Lathe Control Unit
1i		Mimic Panel
1j		Preform Lathe
1k		2 channel 'polishing' drier for O_2 + Ar/He
1l		Rotary Seal
1m		Rotary Seal Purging
1n		Temperature Control System with O_2 Control (including Pyrometer system)
1p		Set of standard Bubblers
1q		Set of spare parts including seals, bearings, valves and gas flow components, mass flow controllers, 4 spare sets bubbl[illegible] electronic and components etc.

B. Fibre Pulling Equipment

B1 Central Fibre Production Services

The following Central Services for Fibre Production will be required for any number of Pulling Towers.

Item	Qty	Description
B1-1	1	Fibre Tensile Testing unit for continuous tensile testing of fibre before extrusion coating, comprising: Pay off drum unit, with adjustable torque clutch and pneumatic drum clamping device, having exit guide rollers, guiding the fibre to the Primary Tractor belt pulling unit, through which the fibre is fed to the Adjustable Tension Unit, comprising large diameter rollers with adjustable tension weights, which exert continuous pre-set tension on the fibre as it is paid through the system, without exerting high bending stresses, to prove the tensile strength of the fibre. The fibre is taken up by Secondary Tractor, which is identical to the Primary Tractor, and whose running speed (between 1-100 m/min) is slaved to the Primary, giving constant fibre speed through the system. The fibre is then fed through a Dancer System, with entry and exit control rollers, which controls the speed of the Take-up Drum, so regulating final winding tension (between 0.2-2 Newtons). The Take6up Drum has a variable speed between 1-100 m/min (under Dancer control), with automatic pitching of the drum between 0.1-1.5 mm/revolution, with a maximum drum width of 500 mm. Multiple winding layers can be programmed to occur, reversing the drum pitching direction, and the unit has a pneumatic drum clamp.

The following fibre characterisation system has been selected as the most comprehensive available. Partial duplication of facilities maybe desirable, and can be configured to choice.

B1-2a 1 Universal Fibre Optic Analyser

Basic Analyser for measurements of Attenuation, Optical IDR, Fair Field Pattern,Numerical Aperture (NA) (Includes laser and pulser with thermoelectric coolers, launch NA control wheel, input fibre stage, rotary output fibre stage.

B2 Fibre Pulling Towers

Item	Qty	Description
B2-1	1	Preform Fibre Drawing Tower continuos drawing with diameter control and primary coating, and on-line proof testing (bending), comprising the following:

1a Preform Feed Unit complete incorporation the following equipment and specification.

Preform Length 1000 mm

Traverse length of carriage and preform chuck 1100mm

Spindle bore 50 mm diameter

Carriage/preform down feed speed ranges from 0.2mm to 20mm per minute with a tolerance of ± 0.5%.

Carriage/preform fast down and return speed at 2000mm per minute. Fixed speed.

Watercooled plate between base plate and top face of furnace.

Safety-micro switch bar full adjustable of 1100mm length.

Ballscrew drive unit phosphate coated with an overall tolerance of 0.05 mm per length of 300 mm.

All materials that are not coated are either stainless steel or aluminium.

Frame structure manufactured from welded box section and covered with sheet metal on 3 sides and a special door mounted to front face.

Electrical control box mounted to side of framework for controling the following preform functions:

Preform Down - Fast Preform Up
Stop - Inch down

X-Y Position Controls:-

Backwards

Left Right

Forwards

1b Scroll Chuck hand operate type

The chuck is mounted to the front face of the spendle for claming preforms upto 50 mm diameter. Clamping jaws manufactured from stainless steel.

1c Preform Rotation

The spindle is connected via a timing belt drive to a splined shaft running the full length of the carriage. The spindle will rotate at an infinitely variable speed from 1 rpm to 100 rpm in both forward and reverse directions. Rotation speeds are controlled to within ±1%.

1d X-Y Automatic Preform Positioner

The movements of the preform slide are ± 12.5 mm in both directions from the centre line of the spindle. Both slides have a clearance hole through the centre of 20 mm diam. Both x and y slides mounted on slides and are connected via a ballscrew and nut which preloaded on both sides. These are connected to 2 DC motors.

The signals for positioning the DC motors are from the Anritsu measuring device and are interfaced so as to ensure that the preform is completely centralised to the axes of the furnace.

The measuring system is set at zero for the x-y unit during set up. It will always return to the cetral position when no fibre is being drawn. Tolerance on the x-y positioner is within ±0.04mm.

1e <u>Middle Frame Section</u>

Welded box secti n framework. Front face mounted dovetail slide location running full length of the frame.
Dovetail slide and screw location manufactured from stainless steel.

1f <u>Base Frame</u>
Welded box section framework. Front face mounted dovetail slide location running full length of the frame. Dovetail slide and screww location manufactured from stainless steel.

1g <u>Base Plate Support</u>
Welded box section framework baseplate with mounts for antivibration (air damping).

1h <u>Wall Plate Support</u>
Special mount for holding structure to wall at top of tower.

1j <u>Furnace System</u>
One of th Furnace Systems resistance graphite or r.f./zirconia susceptor.

1k <u>Diameter measuring system</u>
Measuring range 50-1000 mm with standard range of accessories. Tolerance range within band width of $\pm 0.3 \mu$m.

Unit mounted on special mounting bracket with micro x-y positioner for adjustment centre line to fibre.

1l <u>Coating cup assembly</u>.
Mounted on micro x-y positioning slide. Special mounting bracket. Coating cup assembly consisting of coating cup, auto fill system, watercooled jacket. Coating material: standard type silicone. Complete with centering laser monitoring system to ensure concentricity of coating to fibre.

1m Curing Furnace

1n Tractor Assy

The tractor pulling speed is infinitely variable from 1 m to 100 m per minute. The tractor will automatically adjust its pulling speeds on receiving a signal from the diameter to the tractor to increase or decrease its rotational speed dependent on fibre diameter information.

1o Dance Roll Take-Up Tencion Controller

The Dance Roll control consists of 3 guide rolls mounted on a special balanced potentiometer. This automatically controls the drum take up speed and controls the fibre tension.

1p Automatic Bend Proof Tester

4 axis roller bend proof tester.

1q Take Up Drum Assembly

The take up drum system has a variable speed control for 1m to 100m per minute fibre pulling speed controlled from the dance roll control, with automatic pitching from 0.1mm to 1mm per rotation.

1r Auto Control Fibre Break System

Both audible sound or flashng light upon fibre breakage between Tractor and Take Up. Automatic switch off on take up drums. Tractor rolls keep running providing fibre is being monitored in the diameter measuring device.

1s Double Electrical Control Cabinet housing all control equipment. All display instrumets are digital.

C. Cabling Equipment

Two types of cabling equipment are offered, one for a simple extruded coating (PVC, Acrylic or Nylon) for low strength service, and for secondary coating (0.8-1.2 mm diam) of primary coated fibre, prior to multi-strand lay up, and a more complex multiple stranding cable lay-up machine for assembling upto 18 secondary coated fibres around a strength member, and followed by a final extruder, giving an outer sheath for weather service.

C1 Extrusion Equipment

A complete Extrusion Line, f r PVC, Nylon, polypropylene or polyester cladding of fibre , with up to 10 mm diam coatings.

Specification

Pulling speeds	1-150 metres	
Pitching fibres:	Min 1.0 mm) Max 10 mm)	infinitely variable
Drum Diameters:	Min 1.5 mm Max 500 mm	
Traverse length:	Min 100 mm Max 500 mm	

C2 Multiple Core Lay-up Equipment

This is a purpose designed Optical Fibre Cable Stranding Line, capable of stranding up to 18 cores (secondary coated optical fibres and/or filler cores) around a central strength member (steel or Kevlar) with appropriate long helix angles to minimise fibre bending and optical loss. The multi-part core is automatically helically tape wound, and finally re-wound at a prescribed tension onto a Take-Up Unit, prior to final extrusion coating in a second Extrusion Line similar to Item C1, but with heavier duty Pay-Off and Take-Up Units and larger diameter extrusion tooling.

The maximum line speed is 50 m/min, but with relatively short lengths of cable, say 1-2 km, being laid up, re-loading and re-threading will reduce the effective operating speed to the order of 20-30 m/min, or 3000 km/year on a single 8 hour shift basis.

E. Raw Materials

The quantities of quartz tubing and chemicals required for plant operation will depend upon the fibre specification and exact process used for preform manufacture, as well as plant efficiency. These Raw Materials are therefore offered at minimum unit prices as follows:-

Item	Qty	Description		
		Waveguide Preform Tubes (minimum order quantity 100 tubes of any one size) as follows:		
		O/D mm	Wall mm	Length mm
E1-1a	100	14±1.0	1.2± 0.3	1250
1b	100	16±1.0	1.2± 0.3	1250
1c	100	18±1.0	1.0± 0.3	1250
1d	100	18±1.0	1.4±0.3	1000
1e	100	20±1.0	1.4± 0.3	1000
1f	100	20±1.0	2.0± 0.3	1000
1g	100	22±1.0	1.6± 0.4	1000
1h	100	24±1.0	1.6± 0.4	1000
1i	100	26±1.0	1.6± 0.4	1000

Each pack of WG tubes contains a computer print-out giving the geometrical specification for those particular tubes. An example of this print-out, explaining the various figures, is enclosed herewith.

These tubes are used alone for graded index fibre, but for mono-mode fibre, the collapsed preform (grown in a WG grade tube) is usually clad in a second tube chosen to give the required core/cladding diameter ratio prior to fibre drawing.

Item	Qty	Description
E2-1a	15Kg	Optipur Silicon Tetrachloride 11726 ($SiCl_4$)
E2-2a	5Kg	Optipur Germanium Tetrachloride 11456 ($GeCl_4$)
2b		Pack charge
E2-3a	5Kg	Optipur Phosphorus Oxychloride 7269 ($POCl_3$)

3b		Pack Charge
E2-5a	56Kg	Freon (CCl_2F_2)
5b		Pack Charge

The chemicals listed above are of the quality normally used for low loss telecommunications fibre (mono-mode and graded index). The rates of useage will depend upon the exact fibre design and doping profile chosen. For growth of mono-mode fibre preforms, fluorine doping maybe required in the cladding layer, in which case a supply of Freon 12 (CCl_2F_2) will be required (5a).

3.2. Fibre Optic Cable Production Facility Factory Services

The services and factory layout described in the enclosed drawings relate the production facility only, offices, canteens and general services should supplied in accordance with the customer's factory regulations.

General Construction

Hte unit should be constructed to the following specification:

FLOOR

175 mm thick reinforced concrete floor slabs with power float finish and applied liquid surface hardener. The floor should be treated to prevent dust, preferably with easily cleaned floor tiles.

WALLS

Cavity brickwork with sealed facing.

ROOF

Corrugated asbestos cement roof sheeting (or equivalent) with fibre glass insulation.

INTERIOR PARTITIONING

Walls should be constructed using Melamine (or equivalent) faced wall boaros and false ceilings should be fitted where practical. Care should be taken to ensure that all materials used are dust free.

AIR

Individual rooms have specific clean air requirements, but in general the factory temperature should like within the range 18-23 ^{o}C. Humidity should lie within the range 60-75% Relative Humidity.

LIGHTING

General lighting levels should be of the order of 110 Ft candles and on wort surfaces should exceed 120 Ft candles. Care should be taken to meet the regulations for lighting and moving machinery in the customer's own country.

ELECTRICITY

The electricity supply should be fed into a secure sub station and sufficient fused supply boxes fitted to enable the isolation of each piece of equipment.

A 380-440 Volts AC 50 Hz three phase supply should be used with a maximum capability of 200 KVA. The supply should be free from spikes and discontinuities.

STABILITY	Voltage	± 5 %
	Frequency	± 5 %

Failure to meet this specification will result in computer proplems and reduced yields are likely.

WATER

Water should be supplied at a pressure of 7 bar and flow of 200 litres/min to the factory. The water should have the following specification:

pH 7-8.5

Dissolved solids 400 ppm
Hardness 250 ppm
(Electrical conductivity 400 micromho - if r.f.heated drawing furnaces are used).

FACTORY EXTRACT SYSTEM

Whilst emergency scrubber systems are used to extract the gas control cabinets and the bulk reagent stores, a factory extaction system should be installed to extract the air from above each lathe, from the waveguide cleaner and the effluent scrubber. The following table enables the customer to estimate the required size of the system.

	Flow per unit
Waveguide tube cleaner	10 cu m/hr
Lathe	1250 cu m/hr
Effluent Scrubber	50 cu m/hr

The ducting should be constructed using galvanised steel and be of round cross section. The construction should be in accordance with the standard ventilation practice.

AIR QUALITY

All the rooms should meet the general specification defined above. The following additional cleanliness specifications should be noted:-

Tube Preparation Room	Class 1000 clean air.
Preform Production Room	Class 1000 clean air. N.B. The high extract flow through each lathe hood should be allowed for in calculation of the air

	input rate, providing adequate filtering is given , the extracted air may be fed back to other parts of the factory to conserve heat loss.
Test Laboratory	Class 100 to improve the reproducibility of the optical test equipment.
Master Control Room	Class 1000
Pulling Room	Class 100, although this only needs to be achived in the immediate vicinity of the tower.
Coating Room	Dry filtered air adequate
Stores	Dry filtered air adequate

NOTE: Class 100 specification requires less than 100 particles of 0.5 microns and no particles of 5 microns per cubic foot of air sampled.

Class 1000 specification requires less than 1000 particles of 0.5 microns per cubic foot of air sampled.

STAFF REQUIREMENT

As in the previous section only staff directly associated with the production unit are included. Additional staff such as factory management, clerical and non direct labour are not included.

Qty	Title	Job Description
1.	Supervisory Staff	- Management grade personnel.
1	ENGENEERING MANAGER	To supervise engeneering personnel involved with development and computer systems.
1	PRODUCTION MANAGER	To supervise production and maintenance personnel.

2. <u>Engineering Staff</u> - qualified to first or second degree level.

1	DEVELOPMENT ENGINEER	To update process recipes to give modified fibre specifications, continuously develop new products.
1	QUALITY CONTROL ENGINEER	Supervising quality control measurements and maintaining standards.
1	PRODUCTION ENGINEER	To maintain all aspects of process quality and supervise handling of hazardous chemicals. Responsible for programming master control system.

3. <u>Production Staff</u> - skilled and semi-skilled.

1	PREFORM LATHE OPERA)-TORS Semi-skilled	To operate the preform production systems, two per operator.Load waveguide tubes, refill bubblers and maintain process.
1	PULLING TOWER OPERATOR Semi-skilled	To load preforms into tower, initialise process and refill coating cups. One operator to run one tower.
1	EXTRUSION EQUIPMENT OPERATOR Semi-skilled	To operate primary extruder, secondary extruder and rewind equipment.
1	QUALITY CONTROL Skilled	To operate preform evaluation system fibre evaluation, mechanical proof testing equipment, data handling and fibre grading.

4. <u>Maintenance Staff</u> - Degree level and skilled.

1	COMPUTER/ELECTRONIC ENGINEER Degree level education	To maintain computers and electronic systems.

1	ELECTRICAL ENGINEERS skilled	To maintain electrical motors and general electrical systems.
1	MECHANICAL ENGINEERS skilled	For general repair and construction work.

3.3. Equipment for regular multifibre lightwave production. Specification.

Item	Qty	Description
A	1	Equipment for medicine fibres.
A1	1	Drawing tower for medicine fibres.
		Technology-rod-cylinder, preform length - 1500 mm max, fibre diameter - 50-300 μm
A2	1	Local dust-proof-system
B	1	Equipment for medicine lightguides pulling
B1	1	Drawing tower for medicine lightguides
		Preform length - 1500 mm max, length of lightguides - 0,5 - 3 m, ligthguide diameter 0,2-4 mm.
B2	1	Local dust-proof system
C		Etcher

3.4. Investment in machinery and equipment (world average)

1). Preform production

2	MCVD glass working lathes 500,000 $ each	1,000,000 $
2	airlight boxes 15,000 $ each	30,000 $
1	gas distrubition system	200,000 $
	TOTAL	1,230,000 $

2). Fiber drawing

1	drawing tower (included computer control)	500,000 $
1	tubular sleeve,clean rooms	15,000 $
	TOTAL	515,000 $

3) Cable production

1	stranding machine	390,000 $
1	fiber jacketing machine	28,000 $
1	bend test machine	28,000 $
1	tensile strength machine	110,000 $
	TOTAL	556,000 $

4) Equipment for medicine fibres pulling

1	drawing tower	450,000 $
1	local dust-proof system	100,000 $
	total	550,000 $

5) Equipment for medicine multifibres lightguide pulling

1	drawing tower	500,000 $
1	local dust-proof system	100,000 $
1	etcher	150,000 $
	TOTAL	750,000 $

3.5. Potential suppliers of equipment and technology

Raw materials

Pure gases andchrmicals	Airco Industrial Gases Apache Chemicals Eagle - Picher Ind. Omiya Chem. Shin-etsu Chem. Shin-etssu Chem. Stauffer Chemical Synthatron Ventron Wacker-Chemitronic Dynamit Nobel
Coating materials	DeSoto DuPont Toshiba Ceramics
Plastics for cabling	BASF Hoechst
Filling materials (jelly)	BP Chemicals Dussek Campbel

Semiproducts

Quartz tubes	FOI General Electrics Heraeus -Amersil Heraeus Thermal Americal Fused Quartz
Alumina mandrels	Speceram
Preforms	ISKRA Lightwave Technologies NOKIA Pilkington Fibre Optic Technologies Technointorg

Primary-coated fibres	all fibres manufactures

Machinery

Lathes and deposition systems	Canrad Hanovia Ferro Technique Heathway Machinery KDK Fiberoptics Iskra Litton Engineering Labs. NOKIA Norrsken SpecTran Wale Apparatus
Gas distribution and mass flow control	Tylan
Drawing tower and furnaces	Artcor Astro Industries Dentol Associates ISKRA Heathway Machinery Lepel NOKIA
Coating and jacketing machines	Formsprag - Webster Killion Extruders NOKIA Reel-O-Matic Systems RMT Srl
Stranding machines	AFA Industries Maillefer NOKIA Rosendahl Frisch
Clean rooms	Flow Laboratories NOKIA Seier Helmuth

Fiber thickness monitors	Beta Instrument
Splicing machines	Fujikura Furukawa Siemens/Siecor Sieverts Sumitomo Technointorg

<u>Test equipment</u>

Optical benches and mounts	Newport
Micropositioners	Klinger Scientific NPO "Scientific Instrumetion" Bolgaria
Attenuation meters	Ando Electric ISKRA
Time domain reflectometers	Ando Electric ISKRA
Bandwidth testers	Fotec Hamamatsu Hewlett-Packard ISKRA Oi Electric Photodyne Photon Kinetics Quante Siemens/Siecor Tau-Tron Tektronix York Technology
Fiber diameter measurement	Anritsu Electric Beta Instr. Photon Kinetics Vickers Instruments York Technology

Technology

Hard-clad silica fibers	American Fiber Optics Cabloptic CLTO Corning FOI GEC Optical Fibres Lightwave Technologies NKF Kabel BV Northern Telecom Phalo/OSD Philips SEL STL SpecTran Valtec Western Electric York Techn.
Compound glass fibres	BICC Nippon Sheet Glass Showa Electric Ware & Cable SpecTran
Plastic-clad silica fibers	EOTec Pilkington
Plastic/plastic fibers	Mitsubishi-Rayon NTT-Ibaraki Electrical Comm.Lab. Pilkington
Medicine fibers and multi-fibers lightguides	Hethway Optec Karl Zeiss
Cable technology	Belden Berkenhoff & Drebes BICC Cabloptic Ericsson FOI Fujikura

Furukawa
ISKRA
NKF
NOKIA
Nortern Telecom
Optec Daiichi Denko
Philips
Pilkington
SEL
Seemens/Siecor
Sumitomo
Valtec
Western Electric
WKM

4. Training of local personnel

It is necessary to consider the personnel training problem in the following aspects:

Training of personnel which will work in the field of the and optical cable production.

In spite of the equipment for the fiber and optical cable production should be imported the personnel training problem will be sold as soon as the company-provider carries out now training in each field: the preforms production fiber drawing and optical cable production. The firms enumerated in the section 3 may be visited for the first-hand observation with the equipment and technology.

The following firms could be chosen: NOKIA (Finland), ISKRA (Yugoslavia), York Technology (U. K).

If the equipment would be bought after the competition among the firms the study tour lasts about a week in each company.

Training in the R and D field.

When the most usefull industrial applications of optical fiber s systems (LAN, medium-houl lines, fiber optics sensors, meaturing systems) are chosen it is necessary to train Syrian specialists in the institutions where R and D are highly developed and carried out simultaneously in all these fields. Certain advantages have the Universities and Institutes where the studies and reseach laboratories connected with industry exit. In addition these laboratories are available as soon as the training of high qualification specialists is one of the their tasks. Among them the following institutes could be consider:

Technical University of Helsinki, Finland

Southhampton University, U.K.

Leningrad Electrotechnical Institute of Communications.

There are the fiber and cable production, R and D, optical fiber systems production in several companies (for example Philips, ISKRA, NOKIA) but their laboratories are less available for training in comparison with institutes and universities ones. Subjects of training should be:

- studies of research and design methods;
- studies of industrial optical fiber systems and sensors;
- studies of component characteristies of modern optical fiber systems (laser diodes, LED, optical detectors, directional couplers etc.).
- studies of measuring methods of components and systems, and equipment for these measuring;
- studies of fiber splicing technology,

The first group should consist of high professional level specialists, one of them (should have a doctor's degree) will head R and D in the field of optical fiber systems, the second one (should also have a doctor's degree) in the field of optical fiber sensors, the third one (an engineer) should be responsible for the measuring systems and the last one (a technologist) should be responsible for the development of the prototypes, splicing etc.

It takes into account that there are specialists who has a doctor's degree in field of fiber optics in SSRC. The period of the first traing lasts not less then 3 month. In future training will benecessary in the most developed fields.

There is one more opportunity of R and D training of specialists in the field of optical fiber systems. The large group of studets from the SAR is studing now in Leningrad Electrotechnical Institute of Communications. In responce to the wish of the Syrian partners the group of $5-I_0$ students may be training in the field of optical fiber systems and sensors. This training is carried out in Department of Optical Communication Systems for specialists of the USSR and Bulgaria.

5. The opportunity of Establishment of studies and Research Laboratory in HIAST

The situation in SSRC and HIAST shows that the studies and research laboratories could be established now in HIAST.
It is assumed that in this laboratory the last-year students with grounding in applied sciences and technology will study as well as engineers working in the field of telecommunication, electronic data processing and etc.

The laboratory will service Syria and the whole region . Courses "Optical Fiber Systems and their components " and "Optical Fiber Sensors" should be lectured during the one term. Lectureers may be invited and after training discribed in the previous section the SSRC specialists would be lectureers.

The laboratory ought to include the following laboratory works:

I. Measuring of attenuation and Pulse Dispersion in Fiber Optical Cables.

2. Measuring of characteristics of optical sources (LD and LED) .

3. Measuring of Photodetectors (p-i-n and APD) characteristics.

4. Digital optical fiber system of communication.

5. Amplitude optical fiber sensors.

6. Phase Optical Fiber sensor.

The following equipment and components are necessary for the laboratory:

Oscilloscopes	6
Current sources for semiconducting devices	6
Pulse Generator	2
Voltmeter	3
Optical Power Meter	I
Laser Diodes at 0,85 m	3
LED at 0,85 m	2
p-i-n Detector	3
APD (avalanche photodetector	I
Step-index optical fiber	2 x 500 m I x 3 m
x-y micropositioners	8
Optical transmitter unit (0,85 m , 8 MBit/s)	I
Optical receiver unit (o,85 m, 8 MBit/s)	I
Step-index fiber cable with connectors	I00 m

The laboratory work could be carried out with help of Fiber Optical Demonstration Kit, which SSRC has already. Working and characteristics meaturing of Optical Gyro are reseached in the laboratory work N 6. Multimode Fiber Optical Gyro could be bought for this purpose.

The total value of the equipment for the studies and reseach laboratory not exceed 80 000 $ (without Fiber Optical Demonstration Kit).

6. The most useful industrial applications of domestically produced fibers

The study of the possibilities of establishing the small scale production of fiber light guides in SAR and the examination of the main applications of fiber optical systems and instruments as, well as today's situation in SSCR allow to determine the most useful applications of domestically produced fibers and the actions to be taken to organize R+D and the small-scale production inthis field. The following factors are taken into account:

- "glass or silica-polymer" with step-index profile and high numerical aperture is likely to be the first type of fibres to be produced;

2 sold-state components of optical fiber systems (the sources and detectors of optical radiation) should be imported;

- electronic building blocks of simple optical fiber systems have the same degree of complexity as those used in other fields of technology, so conventional methods of R+D and production can be implemented. Specialists of this kind are available is SSRS;

- design principles of optical fiber systems (not taking into consideration the systems with ultimate parameters) and simple sensors, the sircuirs of their building blocks are well known and can be found on literature; the components of these systems are available on the world market. On this basis the following plan can be proposed.

In the fiels of optical fiber communication systems

R+D should begin simultaneously with the establishment of the production of the simplest step-indexx "glass-polymer" fibres. R+D should be carried out for those applications where high NA step-index fibres and cheap simple optical radiation sources, such as light emitting diodes(LED's) are used. These applications include (Appendix 3) short haul telecommunication system for:

- power plants and laboratories
- process control in chemical or explosive environment
- medical inspection
- highway and railroad control
- data exchange along high voltage power grids in fiber attached to or incorporated in power lines
- on-board data transmission
- data exchange between computers
- LAN

In the applications mentioned above the advantages of optical fiber systems such as electrical isolation and immunity to electromagnetic interference play a major role. R+D are begun by using short lengths of imported fibers. To begin the manufacturing of Syrian fibers is necessary to produce propotypes of one or two the systems and to deside which of the above listed systems would be most attractive to customers. The design work and manufacturing of several prototypes for customers should begin simultaneously with the manufacturing of fibres. Such components as connectors can cause difficulties, do at the first stage of production they can be imported. It is preferable to have connectors connected to short lengths of fiber. Therefore the equipment for splicing should be available. When fiber production increases R+D and small-scale production of medium-haul systems begin. Solid-state optoelectronic components (LD and LED) should be imported.

In the field of fiber optical sensors R+D should be at first implemented for amplitude fiber optical sensors. This is connected with the following:

- the design of such sensors is simple enough;
- in such sensors high NA step-index fibres ("glass or silica-polymer") are used;
- in such sensors cheap and reliable optical sources, namely LED's are used.

The advantages of these sensors suchas electrical isolation, immunity to electromagnetic interference, immunity to explosive, corrosive and other stressing environments render them indispensable when measuring parameters in the field of high voltage equipment, powerfuk radioelectronics, oil industry, chemical industry, automatic production. It is recomended to begin R+D with amplitude sensors which are relatively easy to manufacture and which will find application immediately:

- sensors of temperature
- fire-alarm sensors
- sensors of overheating (limiting temperature)
- sensors of displacement
- sensors of vibration
- sensors of approaching object

After small batches of sensors ean be manufactured by customers'orders. When the production of monomode fibres is well developed it would be possible to start producing phase sensors: fiber optical gyro, acoustic magnetic sensors.

In the field of flexible regular multifiber waveguides the main applications are connected with medical and technical endoscopes. The manufacturing of such endoscopes entirely depends on the availability of the necessary equipment (see Section 3 and Appendix 2).

As it is noted in Appendix 2, the manufacturing of irregular multifiber waveguides (which transmit light but do not transmit images) is less difficult, they can be composed of individual fibres. In industry they find application for lighting cavities, introducing light into spaces filled with explosive or inflammable gases and liquids. In medicine the treatment of mouth, gullet and stomack with laser radiation is also of interest. The main difficulties here are connected with gaining experience in manufacturing such waveguides.

7. On-the-spot demonstration of several industrial applications of optical fibers

During the mission of the consultant in SSRS on-the-spot demonstration of several industrial application of optical fiber was carried out. It was done with the help with Fibre Optical Demonstration kit delivered to SSRC from the leningrad Electrotechnical Institute of Communications (LEIS). Together with the representative LEIS Dr. Strigaliov the following applications of optical fibers were demonstrated:

- the analog optical fiber link with direct modulation;
- optical fiber sensor of electrical alternating voltage;
- optical fiber screen-type sensor of mechanical oscillations;
- optical fiber sensor of vibrations.

A speech and an alternating voltage oscillator singale were transmited along the link. The output sighals of sensors were regestreted the oscilliscope, the principle of operation of sensors was demonstrated on the TV-screen.

8. The feasible SIS programme

The special Industrial Services (SIS) programme could approach the begining of the optical fiber systems and fibers small-scale production. It will be a programme relating to preparation of project related to fibers and optical fiber systems small-seale production in respect of demonstration, choise and test of technology and components. The necessitity and urgenty of this programme are in the following :

- application of optical fiber devices and systems in undustry gives new opportunities connected with their advantages decribed in Appendix 3 and Section 6 of the report;
- at the present these devices practically are not used and produced in the SAR and surrounding region
- as was shown at the Section 1 in the SAR in the whole and in SSRS in particular there is an initial basis

for extablishing the small-scale production of fibers, optical fiber systems and devices. Absence of technology is the main impediment in this case.

Since the small-scole production could begin only within the framework of the large-scole project, the imported components may be used for RLD and development of systems and sensors prototypes. However the choise and test technology of working with optical fiber components and test of the components may preceed this process. This problem would be sold in consequece SIS programme.

- As a result of the solution this specific problem the SIS programme will be the important preparing satge for the project, related to fiber and fiber optical device production.

Proposal SIS programme has to be fulfiled in 6 months.

For choice of optical fiber treatment technology, when they are connected with other components, for demonstration and testing purposes the following equipment shoul be bought:

1. Optical fiber splising machine with tool-kit to prepare fibers for splicing with price 14000$.
2. Set of necessary components: Light emmibing diodes, laser diodes, electronic units of optical recievers and transmitters (λ =0,85μ , 8 MBit/s), section of fibers and optical cables connector, directional couplers with an amount prise 15000$.
3. The optical power mutter is costs 1000$

The total prise of the demonstrating and testing equipment and components is 30000$.

To be SIS programme fulfiled the missions of 2 consultents for a month is necessary.

The consultant in the field of the optical fiber systems should advice on the following problems:

1. The fiber splicing technology and it's practical realization
2. Technology of coupling fibers and connectors.
3. The production technology of directional couplers

and it's realixation in practice.

4. The measuring methods of a splicing fiber quality and demonstrating this methods

The consultent in the field of the optical fiber systems and sensors should advice on the following problems:

1. The choiee of constraction principle and components of the different optical fiber communication systems, which could be applied in the SAR (short-distance, medium-distance, distribution systems).

2. The production of digital communication systems, (λ =0.85 μm, 8 MBit/s) used the bought components ennumirated above.

3. The choice of contraction principle and components of different optical fiber sensors (amplitude sensors and phase sensors)

4. The production of simple amplitude sensor-sensor of vibration used ennumirated components.

In the begining of the programme three SSRS specialists take part in a study-tour abroad:
One of them - to the laboratory which carries out R & D in the field optical fiber communication systems
The second one - to the laboratory which carries out R&D in the field of optical fiber sensors
The third one - to the technological laboratory which works in the field of fiber splicing, assembly of connectors, directional couplers production.

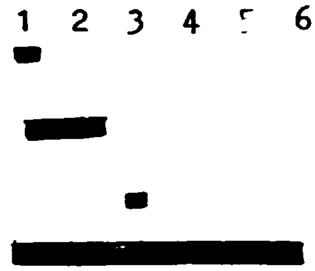
These study-tours are organized for the first-hand observation. When the study-tours finished and the demonstrating and testing equipment and components are delivered, SSRS specialist themself and with consultant's help wile study the splicing technology, the choice of components, the principle of construcation and production of optical fiber communication systems and sensors.

SIS PROGRAMME SCHEDULE

Activity

1. SSRS specialists study-tour
2. Equipment and components delivery
3. Consultant missions
4. SSRS activity in the mastering and choice technologies

Months



The problem of demonstration, choice and testing of the optical fiber system and sensor production technology will be sold by SIS programme. In addition optical fiber system and sensor prototypes will be developed.

Recommendations

1. To develope in SAR on the whole and in SSRS in particular the small scale production of optical fibres, cables and devices step by step.
2. At the first stage the drawing which is a part of the complete equipment is purchased and put into operation. This tower is used to manufacture fibers of glass-polymer type. Cylindrical preforms made of Syrian multicomponent or silica glass can be manufactured with the help of the equipment available in SSRS.
3. At the first stage to begin R&D in the field of short-distance fiber optical communication systems and fiber optical amplitude sensors.
4. At the first stage simple short-haul communication systems simple sensors and simple multifiber lightguides go into preproduction.
5. The second stage involves the production of the graded index multimode fibers and monomode fibers, which can be manufactured from imported MCDV preforms on the drawing tower already available. At this stage fiber jacketing machines can be purchased.
6. The second stage will open the way to R+D in the field of more sophisticated LAN, medium-haul trunk lines and phase fiber optical sensors as well as to a small scale production of simple systems and sensors.
7. At the third stage the equipment for manufacturing preforms by MCDV method (two lathes and auxilary equipment) is purchased and put into operation. The equipment for cable production and testing is also purchased and put into operation. As a result it is possible to produce annually 3000 km of the optical fiber cable.
8. The production can be increased by installing additinal equipment if it is considered necessary or if the market conditions are favourable.

9. At the fourth stage the equipment is imported and the production of high quality regular multifiber light guides for endoscopy begins. This stage can be carried out either simmultaneously with the second ot third stages or instead of them.

10. Each stage of the proposed plan is complete and the project can contain one or more stages depending on financial conditions and specific goals.

11. To establich the studes laboratory in HIAST for training students and specialists in the field of fiber optical systems and devices.

12. To fulfil short-term SIS programme relating to the preparation of project in respect of choice and testing of fiber optical system and devices production technology.

Appendix 1

A Comparison of Major Processes used for production of optical fiber for transmission systems and fiber optical sensors.

Two paths can be followed to produce optical fiber

- preform fabrication, then fiber drawing
- direct drawing from the double crucible.

At present first path is most widely accepted for the production of hegh-quality silica fibers and plastic clad fibers.

A 1.1. Preform fabrication

The processes may be divided into two main categories. Firstly are those involving deposition of oxide particles onto the outer surfasce of a mandrel by flame hydrolysis to form a boule of low density material, which is subsequenty sintered into a glassy rod. Such are VAD (Vapour Axial Deposition) developed in Japan by NTT, and OVD (Outside Vapour Deposition) developed by Corning Glass Works, both processes now in routine production.

The second category all utilise the formation and deposition of doped silica by direct oxidation inside the bore of a substrate tube. This tube is subsequently collapsed to form the rod preform. There are two main processes, MCVD (Modified Chemical Vapour Deposition) developed simultaneously by several groups but mainly attributed to Bell Laboratories, and PCVD (Plasma Chemical Vapour Deposition) developed to a commercial level only by Philips of Holland. A variant of MCVD called PMCVD (plasma augmented MCVD) has been developed at Bell although is not a fully productionised process.

VAD

This is now the principal production method used in Japan. It involves the growth of a partially consolidated 'soot' preform in the axial direction. Silicon and dopant halides are injected into an oxyhydrogen flame where they hydrolyse to form fine oxide particles, some of which impinge onto the

A 1-2

end of a rotating bait rod.

$$SiCl_4 + 2H_2O = SiO_2 + 4HCl$$

Silica deposition efficiencies in the order of 50 to 60% have been reported. The rod is withdrawn at a rate to maintain a constant burner to target distance, giving rise to a cylindrical boule of doped silica with a density of about 16% of that of fused silica.

The radial refractive index level is controlled by several factores. These include the radial distribution of dopants, principally GeO_2^2, in the flame, the flame stochiometry and the temperature profile across the end face, which is in the region of 600°C.
The nature of the oxide formation process inevitably leads to high ON levels in the boule. A subsequent dehydration process is therefore performed by heating the boule in an atmosphere of chlorine and helium at ca 1200°C. The chlorine reacts with water forming HCl which is purged out of the open network of oxide particles by the stream of helium.

$$2Cl_2 + H_2O = 4HCl + O_2$$

The level of drying agent can affect refractive index profile The boule is then consolidated, usually on line to the dehydration process, in a ring furnace at temperatures in the region of 1400° to 1600°C.

Considerable difficulty has been experienced in incorporating flourine by the VAD process but recently a successful technique has been developed where SF_6(sulphur hexafluoride) has been introduced into the consolidation atmosphere. The fluorine diffuses easily into the soot preform, and therefore can become incorporated into the core as well as cladding. However, some control of the fluorine doping profile has been achieved by the discovery that its incorporation level is inversely related to the soot density. Thus a low density clad-

ding/high density core structure will result in preferential fluorine take up in the cladding.
The resultant preform, approximately 25 mm in diameter, is then elongated and shaped to a uniform diameter on a lathe and sleeved by a silica tube prior to drawing into fibre. Extremely long continuous fibre lengths may be generated by this technique, with over 100 Km of continous single mode and multimode fibre having been demonstrated and preforms of over 500 Km potential have recently been produced. The spectral attenuation plot of such fibre exhibits extremely low hydroxyl attenuation due to the efficiency of the dehydration process thus offering a continuous operating window from 0.8 to 1.7 μ . The refractive index profile shows no axial dip, a feature of inside tube processes, but peaks at the core edge can be seen in a single mode profile. Multimode band widths of over 10 GHz/Km have been reported although 1.5 CHz/Km is more typical in prodution where average 1,3 μ losses of 0.5 dB/Km are obtained.

Typical Production core growth rates are reported to be in the order of 0.4 g/min although best laboratory results of up to 4.5 g/min have now been achieved, but with some loss penalty. Preform yields of 10-20 Km are obtained.

Control of the VAD process is Highly complex with many process parameters influencing both the resultant refractive indexx profile and geometry. The spatial arrangement of burners, their design. gas flow rates and ratios, extraction flow patterns all have major effects and mustm be rigorously controlled. During dehydration and consolidation, interaction between drying gases and dopants can cause modifications to the refractive index profile which have to be compensated for in the deposition stage. Total radial symmetry is not guaranteed in the growth process and the need to subsequently redraw and sleeve the preform add further possibilities for fibre geometry to deteriorate. Thus with single mode in particular, core concentricity may prove difficult to hold to the tolerances required for low splicing losses.

A 1 - 4

OVD

Although the amount of published data on the detailed technique involved in VAD is somewhat limited, OVD is even less well reported. However, the main principles are generally understood.

It differs from VAD primarily in that deposition is perfomed laterally onto a cylindrical mandrel rather than axially. Thus unlike VAD it is not theoretically a continuous process. The mandrel may 5-10 mm in diameter constucted of graphite or ceramic. It is clamped at one end and rotated, a hydrolysis torch being traversed back and forth along the mandrel, but stopping short of the free end. Prior to deposition, a layer of releasing agent is applied to the mandrel to assist in its subsequent withdrawal. As doped silica material is deposited, the torch is retracted to maintain a constant distance from the growth surface. Not only the core and optical cladding may be deposited, but the outer jacket material also, thus obviating the need for subsequent sleeving of the consolidated preform. After the boule is removed from the depositionlathe the mandrel is withdrawn and in the dehydration furnace the drying gases are passed down the central hole. On sintering, this hole collapses, but due to the relatively low temperature (1500°C) little evaporation of dopant occurs and no central index dip is generated. However a degeneration of the profile may be seen due to dopent diffusion.Ultimate low water levels have not yet been shown on OVD single mode fibre but losses at operating, wavelengths are still good. In production, multimode losses of 2.4 and 0.5 dB/Km at 0.85 and 1.5 μ respectively and bandwidths of 600-1000 MHz/Km are typical values.

Maximum fibre yields per preform are not as great as for VAD, 40 Km having so for been realised. Average production core growth rates are 0.7 g/min with average fibre yields of 13 Km per preform.

Control of concentricity and ellipticity by this process is good due to the circular symmetry of depostion. The many layers deposited allow fine gradation of refractive index profile, important for high bandwidth multimode. However the same factors as in VAD can seriously affect refractive index profile control. Likewise, dehydration can affect profile shapes and must be allowed for during deposition. Growth rates depend strongly on target diameter, which is constantly changing, so gradations in dopant levels to obtain a given profile shape have to be determined by a number of experimental iterations.

OVD, as VAD, is an outside process and so the fibre's optical, and mechanical properties will be more succeptible to contamination, from the preform environment, deposition torch, mandrel, etc, than are inside tube techniques.

MCVD

This is the most widely used technology for fabricaring preforms. Deposition of the optical core and cladding materials occurs by thermally initiated oxidation of halides inside the bore of a silica substrate tube, typically 20-25 mm in diameter with a 2-3 mm wall, ratated in a lathe with synchronised chucks. The halides in a stream of oxygen are passed through where, encountering a traversing hot zone of 1600-1800°C generated by an oxyhydrogen torch, they react and oxide particles are formed

$$SiCl_4 + O_2 \quad SiO_2 + 2Cl_2$$

The particles generated in the hot zone are transported downstream and some collect on the cooler tube wall, driven along a thermophoretic gradient, the remainder being carried away in the effluent stream.The hot zone, traversing in the same direction as the gases, sinters this soot to a clear glassy layer, typically 10-30μ thick, whilst continuing to react more material.

By multiple traverses of the hot zone, many layers deposited, each of a refractive index determined primarily by the concentrations of reactants in the vapour stream. Temperature also has an influence. Whereas $SiCl_4$ conversion is virtully total beyond 1750°C, that of $GeCl_4$ peaks at 1850°C and then diminishes as temperature is further increased. This is due to the reaction in this case being limited by the vapour phase equilibrium involving the partial pressures of both oxygen and chlorine.

Layer by layer, the desired refractive index profile is generated, and after deposition is completed, upto 1mm of glass may have been grown on the tube bore. The traversing torch then increases the tube temperature until at between 2000 and 2100°C its wall softens sufficiently for surface tension forces to cause rapid collapse to occur. After several traverses the bore is reduced and finally eliminated, leaving a preform typically of 12-17 mm in diameter whose core is derived from the deposited materials and the outer jacket from the initial tube. This preform may be further jacketed by tubes prior to fibre drawing. The extra tube material may be collapsed onto the preform as an additional operation on the lathe, orsimultaneously collapsed and drawn on the fibre pulling tower. Production fibre yield from a single preform rod is in the range of 3- to 15 Km, although sleeving can produce up to 40 Km yield.

The process is inherently clean, being fully enclosed in a tube and the absence of hydrogen compounds in the reaction zone leads to low hydroxyl levels in the deposited material. However, as it is sintered layer by layer, no subsequent dehydration of the type used in OVD and VAD can be employed. Thus it is necessary to exclude trace impurity levels of hydrogenated compounds from the reactant stream and to prevent moisture from rediffusing into the core material during collapse. The former is avoided by careful choice of materials and construction of the vapour delivery system, with particular emphasis on leak integrity of joints and preventing indiffusion of atmospheric moisture.

A 1-7

The latter may be inhibited by the use of adequately thick optical cladding layers to buffer the core from indiffusion of OH from the substrate tube, and by the presence of chlorine in the collapse atmosphere of the tube bore. A 20% concentration has been reported to produce a reduction in OH levels in multimode fibres of better than twofold and single mode of tenfold. The evaporation of dopant that occurs at the elevated collapse temperature leads to a central refractive index dip. This can affect bandwidth in multimode fibres but has no serious consequence in single mode. It may nevertheless be removed by a fluorine etching process performed by passing Freon 12 (CCl_2F_2) or sulphur hexaflouride (SF_6) down the tube during collapse.

Although SiO_2 formation is near 100% at normal MCVD temperatures, deposition efficiency is limited to the region of 50% due to the absence of any significant thermophoretic gradient across the centre of the tube. Normal production growth rates are in the region of 0.4 to 1.0 g/min; however, up to 2,3 g/min has been reported. To achieve this it was found necessary to considerably elongate the hot zone to maintain reaction efficiency, and the tube was force-cooled downstream by water in order to maximize the thermophoretic driving force.

At such high growth rates relatively thick lavers are formed due to the limitation on the hot zone traverse speed caused by the thermal conductivity and heat capacity of the tube. This implies a relatively coarse refractive index profile control, which is of no consequence to stepped index designs such as 1. 3μ single mode fibre, but could affect bandwidth in graded index multimode. A ripple superimposed on the profile caused by the layer structure, and seen particularly towards the core centre, can however be partially controlled by correct choice of relevant dopant and carrier gas levels.

The fact that deposition occurs over a finite length downstream of the hot zone leads to a taper of layer thickness at the inlet end of the tube, its length being equal to that of the deposition zone. This taper has an effect on yield of fibre from the preform. As an alternative approach, rampling of traverse rate over the taper zone can also be used to good effect, provided that correct ramp function is used.

Large scale production of MCVD fibre has been proceeding all over the world. Median losses are 2,8 dB/Km at 0,85μ and 0,5 at 1,3μ . Average bandwidths of 680 and 870 MHz/Km were recorded with a high frection over 1 GHz at both wavelengths. At this same factory single mode MCVD structures, over an initial 5000Km run, have median losses of 0,42 dB/Km at 1,31μ and 0.24 dB/Km at 1,55μ .

Higher growth rates combined with higher deposition efficiencies have been demostrated in a variant of the MCVD process Known as PMCVD, where in advance of the fusion torch an RF induction coil powered at 3,5 MHz surriunds the tube. A plasma is generated in the gas stream with a core temperature of 11,000K. A separation of 1 cm is maintained between the fireball and tube wall, the temperature of which a is maintained at 200°C by water cooling of the exterior. The enormous radial temperature gradient that this creates, causes a strong thermophoretic migration of particles onto the tube wall and growth efficiencies of 80% have been achieved combined with deposition rates of up 5 g/min. However, tube diameters of approximately 50 mm are required to contain the plasma without overheating the wall with consequent difficulty in controlling collapse. Champion results now approach these achieved by conventional MCVD.

Key factors affecting process control in MCVD/PMCVD are reactant flow rates and their ralative concentration levels, tube wall temperature profile and hot zone trabers rate. The fibre geometry will depend on the uniformity of the start tube, the degree of deformation it suffers during processing, and control of the taper of depostion thickness that occurs at the entry end of the tube.

A 1-9

Pıoven technology is available to control the critical process parameters and minimise tube distortion during preform fabrication. The uniformity of commercially available substrate and sleeve tubing has been shown to be sufficiently good to obtain average core to OD concentricity levels of 0.6 μ. Even when preforms were sleeved by further tubing, mean concentricity levels of 0.8 μ or better were realised. Single mode core diameter control was achieved to a standart deviation of 0.33 μ over 32 fibres without any special tube selection being perfomed.

PCVD

This inside tube process emplys low microwave discharge which causes non-thermally activated oxidation of halides heterogeneously at the tube surfaee, with no intermediate particulate formation. A microwave resonator operating at a frequency of 2.4 GHz, traverses the tube at a rate of 7-8 metres per minute in both directions. The tube is maintained at approximately 1200°C and an internal pressure of 10- 20 torr.

Hundreds of very thin (0.5 μm) layers are deposited giving close profile control and the ability to generate complex profile shapes. As with MCVD, the collapse process will give a central index dip, unless a pure silica core is employed or dip etching undertaken. Optical attenuation including hydroxyl absorption is now similar to that obtained by the MCVD route. Multimode mean losses in production of 0.65 dB/Km are reported with bandwidths of 1.5 to 2 GHz/Km.

The deposition efficienty of silica is 100%, and that of germanin is 85% contrasting with MCVD where the incorporation efficiency is 20% or so. Very high incorporation levels of fluorine are also possible without serious effect on deposition rate, so lending this process to the fabrication of fibre designs with very depressed index claddings. Values of up to 2% have achieved using C_2F_6 as a fluorine source. However, this process is also more efficient in incorporating hydroxyl contamination from the reactant gas stream. Extreme care is therefore required in eliminating all traces from the source compounds and vapour delivery system. An inverse relationship between C_2F_6 level and resultant hydroxyl concentration has recently been discovered which has enabled low water levels to be achieved in the depressed index cladding single modedesigns. However, in predominantly Germanium doped fibres levels still tend to be higher, with 16 dB/Km excess loss being typical in production .

Production growth rates of 0.5 g/min are achieved in conjunction with preform fibre potential of 8 Km, although 16 Km has been shown in development.

Process control is sensitive to reactant flow rate, as with other processes. Tube temperature must be stabilised to 10°C but variations in plasma power level and tube pressure are reported to have relatively small effects. Fibre geometry can be good, as no tube deformation will occur during deposition due to the low process temperature emplyed, although the effects of collapse are the same as with MCVD.

Factors Influency Choise of Process

In comparing the processes it will be obvious that all have strengths and weaknesses. In deciding which is most suited to his needs, a potential manufacturer should consider the following aspects:

Availablility of technology

Of those considered here, MCVD is the only process offering 'State of the Art' results that is not under proprietary control. Access to current technology by the other processes would require either large scale R & D, expensive licencing from the originators, or both.

A 1-11

Due to its very wide development and application by a large number of independent groups, and its basic physics and chemistry being well understood, the amount of data available on the MCVD process is considerable. This is not so with the other processes, where high level input will have originated primarily from a single source with a necessrily personailsed method of approach, and without the cross fertilisation of practical and theoretical considerations resulting from the worldwide use of MCVD.

Capital expenditure

The outside deposition process, especially VAD, involve complex multiple steps which require large quantities of costly equipment to execute and to control to the required levels. Although the PCVD process is simpler than these in concept, it nevertheless utilises a furnace, microwave generator and vacuum system in place of a simple gas torch. In addition, a second lathe system is required for collapsing preforms. In contrast, the MCVD process requires the minimum of hardware, of relatively simple design. A high degree of automation is therefore possible within a modest budget.

Yield levels

VAD currently offers a fibre yield potential per preform an order of magnitude greater than any of the alternative processes. This is not necessarily such an overwhelming advantage as it may seem, Firstly because it is the overall production rate which is of greater importance, and here there is no appreciable difference between the various techniques. Secondly, with ultra-low loss aplicing now routine, it is not essential to fabricate continuous lengths to maximum repeater spasings; and for landline systems, installed lengths may in may case be of 1 to 2Km. In addition, producing a "500Km preform" involves the investment a very large quantily of materials and production capacity on a single unit, which may be wasted by being aborted at a late stage, or subsequently yielding fibre that is found to be below specification. Despite giving less spectacular fibre unit lengths than VAD, MCVD offers a high conversion rate preform starts into high grade fibre due to its inherent simplicity. In addition, unit lengths achi eved by current production methods are highly competitive with OVD and PCVD, and fabrication rates are comparable with both these and VAD. There is also the possibility of scaling up at a later date to a plasma-augmented process for much higher deposition rates, without major alterations to existing equipment.

Materials costs

In high N.A. multimode fibre manufacture, the considerable cost of germanium tetrachloride would tend to favour the efficient PCVD process on economic grounds. However single mode and low NA graded index multimode fibre designs utilise sufficiently small quantities for it not to be a significant cost factor. Of all the processes discussed, only OVD routinely does not require silica tubes. This obviously offers a saving, but it should however be balanced against the cost of additional process time and the raw materials necessary to grow the jacket material.

Refractive index profile control

The fibre profile grading offered by VAD, OVD and PCVD, although theoretically an advantage over MCVD in bandwith control of multimode fibre, does not influence choice for stepped index single mode designs where high growth rates may be employed without detriment to profile control.

A 1-13

A review of the VAD, OVD, PCVD and MCDV processes indicates equivalent optical results are possible by all techniques, but MCVD is favoured because of the high level of technology universally available in that discipline, and its inherent simplicity with consequently low capital cost and high yield.

The potential benefits of some other processes in such areas as refractive index profile control and materials cost savings are not very relevant to the case of single mode fibre, and are insufficiently great on multimode to affect the overall technical and economic balance in favour of MCVD. It therefore remains the prime choice for the commercial fabrication of high quality fibre for telecommunication systems.

Plastic-clad fibers (glass-polymer) are designed to form silica or glass core has uniform refractive index profile. The cladding is a relatively low-loss polymer with a lower refractive index. This index differece can be chosen large so that high NA fibers result.

Starting material is a silica or glass rod of desired purity which determines the lower limiting loss value. Natural quartz is a popular choice. Phosphorus or boron may be added to lower the rod's melting temperature.

A chemical etch and a fire polish remove impurity centers at the future core/cladding interface. Then the fiber is drawn as described in next section. It is usual to use two layers of cladding: a soft first coating and a high-modulus second one. Hardeners mixed with the liquid coating speed up the curing process and fabrication of fiber. Exact composition of cladding materials is proprietary, but the following systems have been used

silicone resins
perfluoronated ethylene propylene
polymethacrylate
polyalkene

A 1.2 Fiber drawing

The fiber drawing tower cosists of a mechanism feeding the preform rod into the high temperature furnace and a capstan drawing the fiber.
The preform is suspended vertically by a chuck which is advanced into the furnace at a preset speed calculated to give the target drawing speed range at the desired fibre diameter.

The furnace must be cpable of sustained high temperature and regulated by a feed back loop from a pyrometer focussed on the element.Particulates in the furnace atmosphere should be kept to an absolute minimum to prevent degradation of the fibre surface. This may be actioned by using a high purity graphite resistance element surrounded by a blanket of argon gas. Oxidation is prevented by careful control of the gas flow patterns around top and bottom orifices. Particles shed by insulating materials can be excluded from the fibre environment by configuring the element as an unbroken cyliner within which the preform and fiber are shieldod from external influences.

An alternative furnace type, involving induction heating of a cylindrical zirconia susceptor operating in ambient air, overcomes the need for a protective atmosphere. However although not oxidising at high temperature, the element can still shed particles which will weaken fibre. It also needs to be kept continuously above its phase transition temperature of approximately 1400°C or it will disintegrate, thus rendering the furnace fatally susceptible to power failures.

As well measuring fibre diameter, the laser monitor beneath the furnace also detects the XY coordinates of the fibre, and a feedback loop to a positioner onto which the preform chuck is attached keeps the fibre line in a constant position with respect to the furnace. The zone between furnace and first coating applicator, where bare fibre is exposed to atmosphere, is also maintained at Class 100 conditions by a filter from which air is blown over the fibre zone.

One or two coating systems may be employed in tandem. By using an optical forward scattering technique it is possible to measure coating concentricity on-line. By mounting the assembly on an XY positioner itis possible to continously control this parameter.

A coating diameter monitor similar to the fibre diameter monitor may be employed. Although feedback to control coating diameter has not yet been established, use of flexible coating dies that can be constricted and/or variations in coating application pressure could make this possible.

Fibre drawing tension is monitored by passing the now robust package over a roller connected to a load cell. The tension level is comprised of the load required to draw down the preform to fibre and the viscous drag of the coating material. Draw-down tension, furnace temperature and pulling rate are all closely interconnected. Drawing tension is a direct way of gauging the true temperature at the preform tip, so its monitoring is important in obtaining the correct optical and strength properties of the resultant fibre. However, to obtain an accurate reading the component due to coating drag must be maintained to a knowm level. This implies close control of parameters such as coating viscosity (and therefore temperature and composition) and coating level (in open cups) or pressure (in pressurised applicators).

Drawing speed is controlled by a capstan rather than the winding drum, slight variations in relative speed being taken up by an accumulator. The purpose of this is to allow winding at controlled tension, independent of winding speed or drum diameter variations. Excessive winding tensions can result in artifically high microbending losses.

In some instances the fibre mey be passed from the accumulator directly into a secondary coating extruder where a coating of thermoplastic such as Nylon or Kynar may be applied to obtain a package up to 1mm in diameter. Such a package can then be stranded and cabled by conventional means. It is more usual however, for this (if applied at all) to be performed off line and after initial evaluation of the optical properties.

Also on-line can be performed a proof test of the fibre strength, where it is briefly subjected to a tensile load calculated to exceed, by a safe margin, the stresses likely to be encountered in cabling, installation and service. This can also be made to account for static fatigue effects. Due to problems in restariting a run if the fibre breaks during proof testing, this stage is commonly performed separately. Nevertheless as fibre strengths steadily improve, the likelihood of an on-line proof test break should diminish sufficiently to anable it to be performed with relatively low risk of an interrupted draw. Proof test levels of 0.5% for landline and 1% for submarine cable systems are quite typical, although the precise level required will depend on the cable design employed.

This construction of drawing tower is used for different preforms: MCVD, VAD, OVD and for pulling,"glass-polymer" fibers.

A 1-3. Drawing from the glass melt.

Most glasses are melted at temperatures between 1200 and 1450°C. At these high temperature, special care must be taken to avoid contamination of the glass either by the crucible itself or the refractories.

Two types of crucibles can be used : platinum crucibles (with a pure Pt grade containing impurities in the ppm range) and silica crucibles. With platinum, two problems are encountered, the corrosion of platinum by the glass which may cause unacceptably high loss inthough these problems can be overcome, silica crucibles have been preferred in most of the recent works on low loss glass fabrication. Partial dissolution of silica also occurs ; it does not introduce many impurities but rather silica rich striae in the glass. These striae can be maintained at an acceptable level by choosing glasses with low melting temperatures.

An alternative method which completely prevents contamination consists in heating directly the glass by R.F. induction while at the same time cooling the crucible with an air or water stream. For sufficient R.F. power to be coupled in the glass, a graphite susceptor is first introduced in the field to preheat the glass at a temperature of 1000°C.

To prevent other sources of contamination, special furnaces are built with only very pure oxides such as silica and recrystallyzed alumina surrounding the glass and protecting it from the other refractories and the ambient atmosphere.

The absorption losses of a glass are determined by a second set of parameters, the valency states of those impurities such as Fe and Cu which are multivalent. For instance, Fe^{3+} and Cu^{+} have absorption bands outside the spectral domain concerned by optical fibers while Fe^{2+} and Cu^{2+} have absorption bands respectively centered around 1.1 and 0.8 μ . By changing the redox conditions of the furnace atmosphere and adding a redox buffering agent such as As_2O_3 in the glass, it is possible to modify the distribution of the impurities between their different valency, states and so doing to lower their corresponding absorptions. This possibility has been studied in details for the sodium borosilicate glass system.

A careful control of the furnace atmosphere during melting also permits to lower the hydroxyl content in the glass. It was found that OH content is proportional to the square root of the water partial pressure in the furnace. Dry gases are thus sent through the furnace ; they are even often bubbled through the glass to fasten the drying and homogenize the glass. By this method, the absorption of the OH radicals at the 0.95 μ peak has been reduced to 15 dB/km in borosilicates and 6.5 dB/km in a soda-lime silicate glass which was prepared by wet mixing.

Several methods can be used to remove the glass from the crucible. The most common one is to draw a rod from the glass surface. The rods must be stored in a clean environnent until use for fiber pulling to avoid surface contamination.

To convert the core and cladding glasses to step index or graded index optical fibers, a specially designed crucible is used . This crucible can be in platinum since fiber pulling temperatures are lower than melting temperatures and the aforementionned platinum corrosion and leaching of impurities are not encounterd at these lower temperatures (800 - 1100°C). The glass rods are fed in the core and cladding crucibles (respectively the center and outside crucibles) and a fiber is pulled through the holes at the bottom. To obtain graded index fibers, interdiffusion between the core and cladding glasses is let to occur by increasing the time t the two glasses are in contact at high temperatures. The best fit to the desired parabolic index profile is obtained.

Typical attenuation results for multicomponent graded index glass fibers are following. The attenuation minimum around 0.85μ lies in the range 5-7 dB/km. An even lower attenuation of 4.23 dB/km has been for a soda-lime silica step index fiber. The techniques of glass melting and fiber pulling have been improved to a point where the impurity level in the fiber is practically the same as that of the starting materials.

A 1-4 Cable production

The first stage is the jacketing of the fiber in such way, that the fiber is sufficiently protected to be incorporated into cables. Despite the primary coating, which is applied immediately after the drawing process and consiste of one or two layers of cilicone or UV curable acrylate, the optical fiber is too fragile and vulnerable to damage by externally-induced stress or hostile environments. For the packaging two ways have been developed: the tight fit jacketing and the loose-tube jacketing.

Jacketing machines for both loose-tube and tight jacketing are essentially extrusion machines. The fiber(s) is (are) fed through a cross-head which is supplied with soft plastic (e.g. nylon at 192°C) by an extrusion screw conveyer. A light vacuum keeps the meniscus of the molten plastic sufficiently small. A vertical or horizontal length gives opportunity for the jacket to cool before the jacketed fiber(s) is wound on a spool. For loose tubing, the jacketing machine has to provide the jelly for filling also.

The second stage is cable stranding. Though there are special cable stranding machines for fibers available, the techni ques and equipment do not differ from ordinary machinery used in conventional cabling of metallic wires quite some time. Smaller cabling companies have successfully adapted conventional basket cabling machinery for the cabling of optical fibers. Special attention has to be paid to apply a uniform tension of the fibers to be stranded. Most of the larger cabling companies rely upon self-designed stranding machines and extrusion heads which they sometimes offer on the market. For instance, Siemens has developed a strading machine, based on the "SZ-stranding principle" where the spools containing the fibers are not arranged in a rotating basket, but where the fibers are loosely laid on light-weight 1-m diameter aluminium plates. With this machine very uniform tension is applied to the fibers, and,in principle, a nearly continuous cabling process is possible. The big advantage is the reduction of rotating mass.

Appendix 2

Technology of flexible regular multifiber waveguide production

As was noted in the report, regular multifiber optical waveguides are widely used in medical and technical endoscopes. Existing methods of guide production may be devided into three groups:

The first group is made up of singlestage methods based on the compact screw winding of the fiber. During the drawing the fiber is wound onto the reel coil by coil. In this case the distance between coils while winding is equal to the diameter of the fiber and the direction of winding in the each following layer is opposite to the previous one. When a sufficient number of layers are wound, fibers are glued in the narrow zone and then they are cut up in a direction perpendicular to the optical axis and after that the ends are grinded and polished. The ready optical guide is protected from mechanical demage by a polymer skin.

It is necessary to note that in this case we get an unstraightened regular optical guide.

The multistage winding methods belong to the second group. The doublestage work process may be taken as an example of get - ting a straightened fiber. At the first stage of this technological process the layer is obtained - a horizontal ring preform by simultaneously drawing the fiber and winding it onto a reel. Obtained wide ring preform is then devided into several preforms of required width, compacting at the same time the coils to avoid gaps between them. Then the coils of fiber are glued in the narrow zone, after that obtained ring tapes are installed into a matrix. Tapes are glued. Then the preform of the guide is cut up perpendicularly to the optical axis of the fiber in the glued zone.

In the methods described here is an essential problem connected with compact regular installation of the fiber.

The fiber diameter for optical guides with resolution capability 30-50 l/mm is 10-15 μ .

A 2-2

The grade of a regularity for the installation of separate fibers is dependent on the whole technological system and can be strongly affected by errors in the fiber drawing process and the installation of the fiber into the guide.

The main demand of the technology at this stage of the fiber production is the production of fibers with constant cross-section and correct geometrical form. At the stage of the regular installation is indentified arrangement of fibers on the both ends.

For the realization of the first demand the parameters of the technological processes, as temperature, fiber tension, the velocity with which the glass is fed into the furnace and the velocity of drawing must be constant.

As already noted the dencity and the regularity with which the fiber is installed depends on the realization of the whole technological sistem which must be carried out with an exceptional precision.

The main drawbacks with winding technology are the following:

1) The extreemly low productivity resolting from the labour-intensive character of the regular fiber process installation.

2) By this method it's very difficult to receive high quality waveguides with resolution capability more then 30 lines/mm because of the single fiber impalpability.

The method based on the etching of soluble layers from the stiff preform is free of these disadvantages. This method is unique in that the glass optical fibers are drawn whith two skins and the external skin is soluble in certain mediums.

Obtained fiber guides are gathered in packets of the necessary cross-section and redrawn to received a stiff guide with requiered resolution capability. The stiff guide preform is cut to the necessary length its ends are protected from the action of solution by hermetic, then this preform is placed into solution. After removal of the soluble skin a guide become flexible. The difficulties of this technology are:

1) A choice of glasses for a core, a skin and a soluble skin.

2) Elaboration of the fiber installation methods for the production of quides with a high resolution capability.

3) Elaboration of an etching process for external fiber skin.

4) To protect from distruction the transition zone between a flexible part and the stiff ends.

The singlefiber guides are produced by rode-cylinder-cylinder method. The diameter is laying from 150 to 500 μm (in winding technology is 10-15 μm) and it's more easy to work with them.

Singlefiber guides are gathered in packet to redrew them in a stiff guide preform.

It is necessary to note that difficulties connected with the fiber installation in the winding technology are absent here because of that singlefiber guides have an essentially bigger diameter and they are automatially installed in parallel way when the packet is formed.

The drawing temperature of the packet is established due to the lightisolated skin which has the highest toughness at this temperature.

Gaps between fibers are filled up with more easy fusible glass of the soluble skin to provide the density of ends in obtained multifiber guides.

Multifiber guides are chosen according to the field of vision purity (presence of broken fibers and distance between them) and geometrical characteristics, then the ends are protected by organic resins from etchant.

The process of the external fiber skin etching from the stiff preform is possible due to difference between chemical glass stability of external and lightinsulated skin. The external skin of fibers is removed by etchant but at the same time the working (operation) characteristics of fiber (mechanical tension, lighttransmission) must be constant. This condition is realized if a glass chosen for lightinsulated skin has the sufficien ly high chemical stability.

Boron glass used for the external skin in the flexible guides production interacts well with nitric, sulphuric, hydrochloric, acetic acids.

However the dissoluble in water salts as Br and Ca sulphates are generated when we use the sulphuric acid as an etchant and it makes the removing of interaction products from the space between fibers more difficult. The nitric acid reacts whith many organic compounds what limits its application to protect fiber ends. Hydro-chloric and acetic acids are more suitable for etching because the glass used for the external fiber skin is soluted without a sediment. However for etching of the external skin in industry production the hydro-chloric acid was chosen because its application provides in some cases the best field of vision purity.

Well soluble in water chlorides and the boric acid are generated from the interaction of the hydro-chloric acid with the glass of the external skin. The field of vision purity of obtained guides depend on the concentration, temperature and duration of the solvent action on the guide stiff preform. The choice of the etching condition is determined only by cross-section and the resolution capability of a guide and not depends on the length of etching stiff preform.

During the etching the following defects may arised:

1) Breaking of fiber into the border.

2) Breaking of fibers into the field in the ring or the half-ring form.

3) Breaking of fibers in the centre.

Defects of the first type arise when the border fibers are staying in the solvent for a long time and the lightin-solted skin is distroyed.

Defects of the second type arise when the products of the reaction are badly taken away from the space between fibers, they accumulate and break single and groups of fibers.

When the temperature increase the products of reaction are taken away more quickly and the defects dissapear.

The application of these methods for the production of guides with large cross-section is limited by the low velocity of the etching in the central zone due to the many gaps between fibers. It causes the discreasing of the mechanical tension of the border fibers. When the etching of the soluble layers is finished, the guide is washed with hot water and placed into the aceton. In this case the application of the aceton as one

of the chemical reagents solds the following technological problem - the drying of fibers and simultaneous solutiry the protective skins on the stiff ends. Aceton, as known, is one of the best solvents of many organical resins. The solution of the protective skin without mechanical actions on the stiff part of a guide is the positive point of the technology because the transition zone of the guide is not protected and the mechanical action to take away the protective skin would distroy fibers in the transition zone. Then the guide transition zone (between stiff and flexible parts) is glued to increase the mechanical tensile strength.
Bushes are glued on the transition and stiff zones and a guide is covered with the protective latex skin.

The final stage of the technology is a mechanical treatment of the guide ends. While the guide ends are sintered during the process of redrawing of stiff preforms, the difficulties connected with a glue (as in winding technology) are fallen away.

The production of irregular multifiber waveguides

Irregular multifiber guides are used for the transmission of light (illumination and optical radiation of internal areas in medcine) but not for the transmission of image.

In the irregular guides fibers are installed by an accident law in contrast to the regular ones. Due to this fact the difficult stage of the regular installation is absent in this technology. Irregular guides may be obtained from the fiber sections of the same length accidently gathered into a guide. Ends of the fibers are glued, then they are cut up in a direction perpendicular to the fiber axis and after that the ends are grinded and polished. To obtain the high quality irregular fibers the compact installation of fibers near the ends is necessary. For this the following technological method is used. One of the guide ends is fixed on the vibrating installation. After that the lower end of the fiber is formed under the action of vibration a plentifully wetted with liquid (for example, water). The campact installation is provided due to the surface tension and the fiber's weight. The obtained end is fixed in a clamp, a guide is turned over 180°C and the second end is formed by the same method.

Then the glueing, grinding and polishing operations are followed.

Appendixx 3

The main applications of optical fiber systems and devices

3.1. Communication systems
Long-distance lines

Long-distance lines serve traffic between continents (Terrestrial, submarine), islands, and cities. The distance to be bridged ranges from tens of km up to thousands of km. From the standpoint of system reliability and cost for maintenance and installation the main aim is to eliminate repeaters. At least, the number of repeaters necessary should be reduced to avoid their operation in so-called "manholes". The second aim is high-speed transmission in order to fully exploit the capacity of an installed fiber. These two requirements have led to strong effort in the development of high-performance single-mode in the wavelength regions around 1.3 μm and 1.55 μm characterized by lon dispersion and low attenuation.

There is a strong trend to use SM-fibers in long-distance systems. Whereas SM-fiber production has now rather matured, there remains work to be done in the field of splicing technology and connectors to yield routinely the encouraging results of laboratory work, where fusion splice losses of 0.03 to 0.1 dB and connector losses $<$ 0.5 dB have been reported. Elastomeric splicing technology is developed as a possible alternative to the fusion splice. Coupling of the laser output power into the SM-fiber gives also room for improvement (now 3 to 6 dB loss).

A further trend points toward improved receivers.PIFET detectors are being rapidly developed to increase their sensitivity and to reduce their noise contribution.

A3-2

Up to now simple on/off-keying in conjunction with direct detection is used in optical communications systems. Coherent detection schemes (heterodyne or homodyne detection) promise an improvement in sensitivity of 10 to 14 dB, already proven in experiments. The answer to the question whether the high technological effort with sophisticated transmitters/receivers will justify some more km repeater span is still pending. First field application of coherent systems will probably be in submarine links. More widespread use will depend on the development of low-loss polarization-preserving fibers or, even better, on the elimination of the need for such special fibers.

Medium-distance lines

Interoffice links: These systems connect two telephone central switching offices with a traffic ranging from tens of telephone channels (4 kHz = 64 kbit s each) to many thousands. A lot of such links are required in a telephone network. For low-capacity operation, the trend is to reduce components and fiber cost in order to compete with copper systems.

CATV trunking: Common antenna TV or cable TV is the distribution of TV signals to subscriber homes by cable instead of by free-space radiation. The central distribution points called "hubs" receive TV signals from TV stations directly or via the headend (radio-link terminal). Trunking between headend and hub or between hub and hub by fibers has the advantage to obviate the need for a repeater, which is to be found every km in coaxial systems.

Entrance links: Satellite ground stations and radio-link terminals are often located in relatively uncongested areas some km away from city centers. These are stations where large volumes of traffic converge. Optical fiber links can relieve the RF spectrum congestion which would arise if the connections to the city are via radio links. Analog transmission of the frequency-modulated 70 MHz intermediate frequency signal is possible but is limited to a few km due to the high signal-to-noise ratio required.

Feeder transmission line: It connects the central office to remote switching units in the subscriber loop.

The lengths typical for the mentioned applications cover the range from 4 to 30 km. distances which are, at moderate data rates of typical 34 Mbit/s, bridgeable with multimode systems without the use of repeaters. Systems worldwide installed operating at 0.85 μm well as 1.3 μm are proving economy and reliability. Due to the low dispersion and attenuation at 1.3 μm the trend is to use LEDs, which do not cause modal noise, are cheaper and easier to operate,and have practically unlimited lifetime. Whereas up to now LEDs have been used only at moderate data rates, recently developed 1.3 μm edge-emitter types have been employed to demonstrate 560 Mbit/s transmission over a 5 km long GI-fiber.

Short-distance systems

In this class we find intrabuilding or intraplatform links over some hundred meters for data transmission at low to moderate rates ($<$ 10 Mbut/s). The main task of these links is the undicturbed transmission in severe environment, which will be managed best by optical fibers. Various applications for control and surveillance in industrial and military systems benefit mainly from electrical isolation and the freedom of electromagnetic interference of optical fibers:

Power plants
Nuclear plants and laboratories
Process control in chemical or explosive environment

Medical inspection

Highway and railroad control

Data exchange along high-voltage power grids in fibers attached to or incorporated in power lines

On-board data transmission

The key point for more widespread use of fiberoptics in such applications is economy. Cheap active and passive components, using plastic materials to as large an extent as possible, will set the trend in this area. Because of use of plastic and high NA step-index fibers visible and near-infrared wavelengths are and will continue to be preferred.

Distribution systems

The distribution of a multiservice to a large number of users or subscribers (multi-user-multiservice) is a scenario of the future communications network. (It is an extension of the distribution of a single service such as the public telephone service). The services to be distributed, and the physical structures (networks), where they are now distributed, are

Telephone in the subscriber loop
data in the local area network (LAN-)
video in the cable TV (CATV) network

From the technical point of view optical fibers, with their inherent broad bandwidth, can realize such distributing systems with increased flexibility and capability The economics of using fibers for these applications, however, have to be carefully checked in each application.

A 3.2 Optical fiber sensors

Optical fiber sensor development has matured to the point where the impact of this new technology is now evident. Fiber sensors offer a number of advantages: increased sensitivity over existing techniques, geometric versatility in that fiber sensors can be configured in arbitrary shapes, a common technology base from which devices to sense various physical perturbations (acoustic, magnetic, temperature, rotation, etc.) can be constructed, dielectric construction so that it can be used in high voltage, electrically noisy, high temperature, corrosive, or other stressing environments, and inherent compatibility with optical fiber telemetry technology. Progress in demonstrating these advantages has been substantial in the past few years with over 100 different sensor types being developed. This lage number of individual devices is usually categorized into amplitude or phase (interferomentric) sensors. In the former case the physical perturbation interacts with the fiber or some device attached to the fiber to directly modulate the intensity of the light in the fiber. The advantages of intensity sensors are the simplicity of construction and the compatibility with multimode fiber technology. In some cases, sensitivity is traded off in order to realize these advantages. In view of the fact that extreme sensitivity is not required for most applications and that these devices are competitive with existing devices, a large market appears to exist for this class of sensor.

Amplitude sensors have been used for sensing magnetic, acoustic, acceleration, temperature, liquid levels, displacement, torque, and strain and offer cheap, easy to fabricate sensors suitable for harsh environmen tal deployment.

The phase (or interferometric) sensor, whether for magnetic, acoustic, rotation, etc., sensing, offerd orders of magnitude increased sensitivity over existing technologies. In the case of the acoustic sensor constructed utilizing optical fiber interferometers, these predictions have been verifield to the limit of state of the art in acoustic measurements. Additionally, other advantages have been accrued because these fiber acoustic sensors can be configured as extended elements permitting amplitude shading for sidelobe reduction, noise cancellation, and/or in fiber signal processing. In the case of the magnetic sensor, it appears that fiber sensors operating at room temperature offer detection sensitivities comparable to or exceeding cryogenic. technology, which normally operate between 4 and 10 K. Phase sensors therefore satisfy a market where geometric versatility and high sensitivity. Interferometric sensors appear to benefit most from fiber coatings technology. By changing the coating on the fiber, the sensing element can be changed from acoustic to magnetic or other sensor type. As an example, metal coatings are used to make current or magnetic sensor elements and to desensitize elements to acoustic fields. Compliant polymer coatings are generally used to enhance element sensitivity to acoustic fields and to damp out temperature effects. Placing the sensor element fiber on a suitable mandrel can be used to further increase sensitivity by as much as 15 dB. Having a common detection technology and changing only the coating on the fiber permits cost effective implementation of these sensors. Multisensors can easily be configured using a common detection scheme and various coated fiber sensor elements. This feature should find widespread application in specialized areas as oil field exploration, weapons guidance and targeting, and industrial processing control.

Passive fiber optic ring interferometers (Fiber optic gyro) have shown promise for use as inertial rotation sensors. The theoretically predicted sensitivities, based upon photon noise, are very high, but to date state of the art experimental gyroscopes have not met these theoretical predictions. However, rapid progress has been made recently in fiber optic gyroscope development, and sensitivities approaching the deg/h range have been demonstrated. Such sensitivities are already sufficient to make the fiber optic gyroscope attractive for several low performance applications.

Appendix 4: Addresses of companies

AFA Industries
20 Jewell St.
Garfield, NJ 07026, USA

Airco Industrial Gases
575 Mountain Ave.
Murray Hill, NJ 07974, USA

American Fiber Optics Corp.(AMFOX)
1196 East Willow St.
Signal Hill, CA 90806, USA

Ando Electric Co. Ltd.
Overseas Sales Div.
Kamata 19-7
4- chome Ota-ku
Tokyo 144, Japan

Anritsu Electric Co.Ltd.
10-27 Minamiazabu
5-chome
Minato-ku
Tokyo 106, Japan

Apache Chemicals Inc.
P.O. Box 126
Seward, IL 61077, USA

Artcor
3001 Red Hill
2-109, Cosa Mesa, CA 92626, USA

Astro Industries Inc.
606 Olive St.
Santa Barbara, CA 91101, USA

A 4-2

BASF AG
P.O. Box 212
D-6800 Mannheim 1, Germany

Belden Corp.
Fiber Optics Group
2000 S Batavia Ave
Geneva, IL 60134, USA

Berkenhoff & Drebes GmbH
P.O. Box 1140
D-6334 Asslar, FR Germany

Beta Instrument Co. Ltd.
Halifax House
Halifax Rd
Cressex Industrial Estate
High Wycombe, Bucks HP12 35W, UK

BICC Telecommunication Cables Ltd
P.O. Box 1
Prescot
Merseyside, L34 5SZ, UK

BP Chemicals Ltd
76 Buckingham Palace Rd
London, SW1W OSU, UK

Cabloptic SA
Rue de la Fabrique
CH-2016 Cortaillod, Switzerland

Canrad Hanovia Inc.
100 Chestnut St
Newark, NJ 07105, USA

CLTO (Comp. Lyonnaise Transm. Optiques)
35 rue Jean Jaures Bezons
F-95871, France

A 4-3

Corning Glass Works
Telecommunication Products Dept.
Baron Steuban Place
Corning, NY 14831, USA

DeSoto
1700 S. Mt. Prospect Rd
Des Plaines, IL 60018, USA

Denton Vacuum Inc.
2 Pin Oak Lane
Cherry Hill, NJ 08003, USA

DuPont
E.I. DuPont de Nemours & Comp.
Wilmington, Delaware 19898, USA

Dussek Campbel Ltd.
Thamse Rd
DA1 403 Crayford - Kent, UK

Eagle-Picher Industries Inc.
(Electro-Optic Materials Dep.)
P.O.Box 737
Quapaw, OK 74363, USA

EOTec Corp.
200 Frontage Rd
West Haven, CT 06516, USA

Ericsson Radio Systems AB
P.O.Boxx 1001
S-43126 Molndal, Sweden

Ferro Technique Ltd
695 Montee de Liesse
Montreal
Quebes H4T 1P9, Canada

A 4-4

Flow Laboratories GmbH
Mühlgrabenstra e 10
D-5309 Meckenheim, FR Germany

Fibres Optiques Industries (FOI)
11, Rue du Clos d'en Haut
F-78702 Conflans, Franse

Fotec
560 Harrison Ave
Boston, MA 02118, USA

Formsprag-Webster (Dana Corp)
11 Gore Rd
Webster, MA 01542, USA

Fujikura Ltd.
1-5-1 Kiba, Koto-ku
Tokyo 135, Japan

Furukawa Electric. Co. Ltd
6-1 Marunouchi 2-chome
Chiyodaku, Tokyo 100, Japan

GEC Optical Fibres
Church Rd
London E10 7JH, England

General Electric Co.
Semiconductor Prod.Dept.
W Genesee St
Auburn, NY 13021, USA

Hamamatsu Corp.
420 South Ave
Middlesex, NJ 08846, USA

A 4-5

Heathway Machinery Co. Ltd
Uxbridge Rd
Hillingdon, Middlesex, UK

Heraeus-Amersil Inc.
650 Jernees Mill Rd
Sayreville, NJ 08872, USA

Hereeus W C GmbH
Heraeusstra e 12-14
D-6450 Hanau, FR Germany

Hewlett-Packard
Optoelectronics Div.
640 Page Mill Rd
Palo Alto, CA 94304, USA

Hitachi Ltd
Fiberoptics Project Div.
5-1, Marunouchi 1- chome
Chiyoda-ku, Tokyo 100, Japan

Hoechst
P.O. Boxx 3540
D-6200 Wiesbaden 1, FR Germany

ISKRA,
61210, Lyubljana,
Yugoslavia

KDK Fiberoptics Inc.
19 Midstate Dr
Auburn, MA 01501, USA

Killion Extruders Inc.
56 Depot St
Verona, NJ 07044, USA

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Klinger Scientific Corp.
110-20 Jamaica Ave
Rchmond Hill, NJ11418, USA

Lepel Corp.
59-21 Queens Midtown Expwy
Maspeth, NY 11378, USA

Lightwave Technologies Inc.
6737 Valjean Ave
Van Nuys, CA 91406, USA

Litton Engineering Laboratories
P.O. Box 950
Grass Valley, CA 95945, USA

Maillefer SA
CH-1024 Ecublens, Switzerland

Mitsubishi Rayon Co.
2-3-19 Kyobashi
Chuo-ku, Tokyo 104, Japan

Newport Corp.
18235 Mt. Baldy Cir
Fountain Valley, CA 92708, USA

Nippon Sheet Glass Co.
4-8, Dosho-machi
Higashi-ku, Osaka 541, Japan

NKF Kabel BV
Telecommunications Div
Noordkade 64
P.O. Box 85
NL-2740 AB Waddinxveen, Netherlands

A 4-7

NOKIA,
00170, Helsinki, Finland

Norrsken Corp.
P.O.Box 970
Cheshire, CT 06410, USA

Northern Telecom Canada Ltd.
P.O. Box 13070
Kanata, Ont. K2K 1X3, Canada

NTT - Ibaraki Electrical Comm.Lab.
Tokai - Ibaraki 319-11
Japan

Oi-Electric Co.
3-16 Kikuna 7-chome
Kohoku-ku
Yokohama 222, Japan

Omiya Chemical Corporation
4-3, Nihonbashi hon-cho
Chuo-ku, Tokyo 103, Japan

Optec Daiichi Denko Co. Ltd
2-9, 1-chome, Haichiman-cho
Higashikurume - City
Tokyo, Japan

Phalo/Optical Systems Div.
900 Holt Ave
East Industrial Park
Manchester, NH 03103, USA

A 4-8

Philips Industries
Eindhoven
Netherlands

Photodyne Inc.
948 Tourmaline Drive
Newbury Park, CA 91320, USA

Photon Kinetics Inc.
P.O.Box 1481
Beaverton, OR 97075, USA

Pilkington Fibre Optic Technologies
Glascoed Rd
St. Asaph
Clwyd LL17 OLL, Wales

Quante Lasertechnik GmbH
Norkshäuschen 25
D-5600 Wuppertal 1, FR Germany

Reel-O-Matic Systems Inc.
P.O. Box 69
418 Hellam St
Wrightsville, PA 17368, USA

RMI Srl
Via Poliziano 52
I- 10153 Torino, Italy

Rosendahl Maschinen GmbH
Südstadtzentrum 2, P.O. Box 55
A-2346 Maria Enzersdorf, Austria

Seier Helmuth GmbH
Mühlgrabenstra e 10
D-5309 Meckenheim, FR Germany

A 4-9

Standart Electro Lorenz AG(SEL)
Hellmut-Hirth-Stra e 42
D-7000 Stuttgart 40
FR Germany

Shin-etsu Chemical Co. Ltd.
2-6-1, Ohte-machi
Chiyoda-ku, Tokyo 100,Japan

Showa Electric Wire & Cable Co.
Toranomon 1-chome
Minato-ku, Tokyo, Japan

Siemens AG
Hofmannstra e 51
P.O.Box 7000745
D-8000 München, FR germany

Sievert Kabelverk
S-17287 Sundbyberg, Sweden

Speceram SA
Le Col-des-Roches
CH-2412, Switzerland

SpecTran Corp.
Hall Rd
P.O. Box 650
Sturbridge, MA 01566, USA

Stauffer Chemical Co.
Nyala Form Rd
Westport, CT 06880, USA

Sumitomo Electric Industries Ltd
1 Taya-cho, Totsuka-ku
Yokohama 244, Japan

A 4-10

Synthatron Corp.
50 Intervale Rd
Parsippany, NJ 07054, USA

Tau-Tron Inc.
27 Industrial Ave
Chelmsford, MA 01824, USA

"Technointorg",
Ovchinikovskaja 18/1
113324, Moscow, USSR

Tektronix Inc.
P.O. Box 1700
Beaverton, OR 97075, USA

Thermal American Fused Quartz Co.
Route 202
Montville, NJ 07045, USA

Toshiba Ceramics Co. Ltd.
Shinjuku nomura Bldg.
1-26-2, Nishi shinjuku
Shinjuku-ku, Tokyo 160, Japan

Tylan Corp.
23301 S Wilmington Ave
Carson, CA 90745, USA

Valtec
99 Hartwell St
W Boylston, MA 01583, USA

Ventron GmbH
Zeppelinstra e 7
D-75000 Karlsruhe 1, FR Germany

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Vickers Instruments Inc.
300 Commercial St
P.O. Box 99
Malden, MA 02148, USA

Wacker-Chemitronic GmbH
P.O. Box 1140
D-8263 Burghausen, FR Germany

Wale Apparatus Co.
400 Front St
P.O.Box D
Hellertown, PA 18055, USA

Western Electric Co.
Atlanta Works
2000 Northeast Expressway
Norcross, GA 30071, USA

Wiener Kabel- u. Metallwerke GmbH (WKM)
Siemensstra e 88
A-1210 Wien, Austria

York Technology Inc.
1101 State Rd
Bldg q Q
Princeton, NJ 08540, USA

Dynamit Nobel AG
D-5210 Troisdorf
FR Germany

Frisch Kabel- und
Verseilmaschinenbau GmbH
Kaiserwertherstra e 79
D-4030 Ratingen, FR Germany

Standart Telecommunications
Laboratories Ltd.(STL)
London Road
Harlow Essex CM17 9NA, UK