## OCCASION

This publication has been made available to the public on the occasion of the 50th anniversary of the United Nations Industrial Development Organisation.

## DISCLAIMER



## FAIR USE POLICY



## CONTACT

Please contact publications@unido.org for further information concerning UNIDO publications.

For more information about UNIDO, please visit us at www.unido.org

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
Vienna International Centre, P.O. Box 300, 1400 Vienna, Austria
Tel: (+43-1) 26026-0 · www.unido.org · unido@unido.org

Distr.
LIMITED

IPCT.44(SPEC.)
29 October 1987

ENGLISH

UNITED NATIONS
INDUSTRIAL DEVELOPMENT ORGANIZATION

# MATERIALS DEVELOPED THROUGH SPACE-RELATED TECHNOLOGIES*

prepared by

Mir Akbar Ali**
UNIDO Consultant



* The views expressed in this paper are those of the author and do not necessarily reflect the views of the secretariat of UNIDO. Mention of firm names and commercial products does not imply an endorsement by UNIDO. This document has been reproduced without formal editing.

** Glass and Ceramics International Inc., Lomita, CA 90717, USA.

V.87-91294

## SUMMARY

This report identifies and describes new materials and related technologies which emerged as a result of space programs and has the potential for efficiently utilized in the developing countries.

The report describes the status of in-space production of selected materials such as single crystal silicon and the potential for space industrialization and the significance of involvement of developing countries in such programs.

The report also describes the details of selected high-tech materials that were primarily developed for space applications, however, their secondary appplications in industry are equally important. Such materials include carbon graphite fiber technology, high-tech or fine ceramic materials, materials for integrated optics and industrial sensors along with their best application parameters.

The report goes into the subject of the potential for transfer of such material related technologies to the developing countries and the various mechanism for transfer.

# CONTENTS

# 1.0 INTRODUCTION

In the lives of nations materials have always been of great interest and industrial progress has more often been hinged on the acquisition and ownership of these materials. For any developing country there is a direct link between their raw material resources and industrial infrastructure on one hand and effective industrial development on the other. For this reason, both, materials technology and available raw materials play a key role in the industrial development and economics progress of developing countries.

There are many developing countries which remain underdeveloped despite their possession of vast raw materials and human resource. Due to the fact that the developing countries cover a much larger portion of this planet's land area they own a major portion of natural resources. Either by choice or by circumstances many of the developing countries have been the materials supplier to the developed countries. Justifiably, they are not content to remain material suppliers. As such, the field of materials technology forces attention on cooperation between the developed and less developing countries. Many of the developing countries have an immediate need for proven technologies which they can acquire from the developing countries. Among the many proven technologies there is a wide selection and availability of the "spin-offs" of the space-related materials processes and technologies developed by the industrialized and developed countries. Within the U.N. systems, this has been documented at the Unispace-82 Conference (1).

The successful orbiting of the Russian Sputnik in '57 followed by equally formidable achievements in the U.S., under the direction of National Aeronautics and Space Administration (NASA) gave new incentives to the industrialized countries to marshall their scientific and engineering resources for developing materials for space technology. The field of materials engineering and technology was one of the chief beneficiaries of this change in national priorities of the industrially advanced countries. As a general observation materials technology is in a highly developed state among the industrialized nations and transfer of this proven technology to the developing countries would save the latter considerable time and expense.

These materials related "spin-offs" of space technologies offers the potential to spur industrial, economic and social development for the developing countries. These technology may not be a total solution for a country's industrial development problems and neither can there be any generalized prescription for the use of space-related technologies for all countries. However, this approach of space-related technology transfer as seen in several U.S. technical assistance programs, has been a more effective alternative for achieving a given goal and has brought about a qualitative change by doing thing not possible through more conventional means (2, 3a).

Although the primary responsibility for the industrial development of developing countries rests upon these countries themselves, however, the transfer of space-related technologies to the developing countries is a unique situation and provides an opportunity for UNIDO to play the "catalytic role". 'UNIDO can be one part of the three-way partnership' with the developing and developed countries who can offer the spin off's of developed through space-related technologies.

Space science and technology cannot be considered in isolation but must be seen as an integral part of the totality of science and technology, which in turn forms part of the industrial and technological progress for the entire human race. Space technology derived from engineering effort, is in turn dependent upon that world pool of scientist, technologist and engineers from the developed and developing countries who contributed to are part of the development of space technologies.

The sharing of this space-related technologies can be a vital link in the assurance of future peace, happiness and safety of all societies specially those in the various stages of development and reconstruction. The present and future welfare of human society on this planet cannot be established unless a sound and healthy balance of technical economic and social standards are achieved. Science and technology, if and when, properly applied, can achieve this objective. Scientists whose aims and objectives are instinctively to safeguard the welfare and happiness of future generations attach a far more greater weight and importance to the application of space technology to daily human life than a mere heroic deed of the space conquest or the mastery of the Moon, Mars or other planets.

The following sections of this report addresses the materials processes and technologies developed through space-related technologies.

It needs to be pointed out that there are two categories of materials that are being developed for space processing programs. One is exclusively for in-space (on-board) processing with the space industrialization as the final objective. Such programs includes production of silicon ribbon for integrated circuits (IC) and space processing of chaleogenide glasses.

The second category relates to new and improved materials and proccesses which were used in the design and fabrication of space flight equipment and facilities and incl ies fine ceramics (structural ceramics) and various composites. Since the developing countries are at different levels/stages of space programs, as such, this report will address the development of both categories of materials.

Finally, for the transfer of space-related technologies to the developing countries it needs to be emphasized that the United States through NASA has taken a very possitive position. The foreign licensing program of NASA serves to promote and utilize foreign patent rights vested in the Administration. The objective of this program is to extend the patent coverage of NASA owned inventions to various foerign countries to advance the international relationships of the United States limited. The section on transfer of space-related technologies to developing countries addresses this subject detail.

## 2.0 MATERIALS PROCESSING IN SPACE

The processing of materials is influenced by the Earth's environmental characteristics such as the atmosphere in which the processing occurs and gravity. The former can introduce adverse contamination influences which be minimized by using artificial atmospheres such as inert gasses. Nothing practical can be done on earth about gravitational effects which includes phase separation, density segregation, uneven cooling characteristics and container contamination for glass ceramic and metallic materials. On the other hand materials can be processed in space under conditions of virtual wieghtlessness with the potential advantages of solar energy and a vacuum sink of unlimited volume.

The forces that have an effect on the composition or shape of a solidified glass, metal and to a lesser extent for ceramics are volume changes, surface tension and gravity induced segregation and convection.

Various countries, depending on the status of their space technology programs, conducted experimental materials processing studies. Such studies were both ground-based (on earth under simulated near zero "G" conditions, using acoustic and or electromagnetic levitators) and also on board space flights.

Further, efforts were also made to exploit the potentials of space industrialization which include feasibility studies for the commercial manufacture of electronic materials. The following sections will describe the details of the experimental and commercial manufacturing.

2.1 MATERIALS PROCESSING IN SPACE -- EXPERIMENTAL STUDIES

Based on their space technology capabilities various countries had conducted both ground based and on-board materials processing studies.

The United States materials processing studies were managed and administered by National Aurenautics & Space Administration (NASA). Ground-based experimental studies were also conducted by selected industrialized and developing countries. In the U.S., such studies were performed in Apollo, Spacelab and Space Shuttle Missions; Salyout and Syrena in the U.S.S.R.; TEXUS in W. Grermany; The European Space Program to name a few.

The purpose of ground-base studies was to conduct materials-related experiments on earth in a near zero "G" environment and to establish the potential improvements or a specific characteristic which could not be achieved otherwise.

NASA has long had an interest in materials, particularly those of value for the industry, aeronautics and space flights. NASA had carried out extensive studies on materials in its down laboratories and sponsored research in academic and industrial laboratories.

For example, glass melts are highly reactive materials. They react with virtually any container even with platinum (4). This includes chalcogenide glasses for transmitting in the infrared region and laser glasses. In this context, NASA had sponsored gound based studies in an acoustic levitator to process chalcogenide and laser host glasses (5, 6 ).

Among the advantages claimed for growing semiconductor electronic materials in space are improved homogeneity, greater purity, reduction of physical defects and the ability to grow large diameter crystals. Experiments on skylab by Wiedemeier (7), Witt and Gatos (8) have been cited for evidence that crystals grown in a low "G" environment are superior to those grown under the influence of earth's gravity.

Likewise, the Russians had also conducted a variety of space-related materials processing studies. This includes the directional crystallization of germanium under the influence of space environment (9); Space processing of CdHgTe, CdMgSe and PbSeTe (10) and the structural studies on the Te-Se solid solutions on-board SALYUT-6 (10).

Such and similar space related materials processing studies were conducted by other countries independently or in collaboration with the U.S. or Russian space programs (11). Further, there were several U.S. - Russian joint studies under the Apollo-Soyuz program (12, 13).

Materials related studies were also conducted in the Skylab orbiting space station. The Skylab materials science and techr logy studies were mainly with metallic materials. The materials studied include the amiliar steel, aluminum, copper, nickel, and silver and the less familiar gallium, germanium, indium and tellurium. The objective of these studies was to evaluate the space environment for single crystal growth, immiscible alloy compositions, microsegregation in germanium, whisker reinforced composites and so on (14).

The Space Shuttle program is also being utilized for the development of low-cost transportation to and from the earth orbit. The system itself is composed of The Orbiter having the Space-lab to do research and develop techniques on a variety of subjects including materials related technologies. The Space Lab is an international program developed by European Space Research Organization (ESRO), (15). The Space lab provides an extension of the ground based studies with the added qualities which only the space flight can provide such as long term gravity-free environment. Ten members of the European space community consisting of West Germany, France, United Kingdom, Belgium Spain, the Netherlands, Denmark, Switzerland and Austria have pooled their resources and combined with the U.S., to conduct scientific and technological application and studies which includes materials development and processing. For example, germanium selenide (GeSe) was grown abroad skylab and was about the size and shape used in the electronic devices. The study indicated that this type of production is feasible and provided data on the conditions under which products of this kind can be manufactured in space.

As can be seen all these ground-based and on-board test flights are a stepping stone for eventual industrialization of space. The next section describes the details of space industrialization.

## 2.2 SPACE INDUSTRIALIZATION STUDIES

The potentials of industrializing outer space is one of the most exciting concepts of the space program. The word itself - industrialization - denotes a new vista of thinking. One must use terms such as production of goods and services, manufacturing equipment, labor force, return on investment, products, markets and risks.

Among suggested space industries are unique materials for earth and earth resources surveys. Besides allowing the manufacture of better products, space processing facilities will also enhance our technical knowledge of materials behavior. The actual properties of many of our materials are far below their theoritical limit; and space-based materials research promises to help us come much closer to these fundamental limits than efforts here on earth. Space processing allows investigators to eliminate the gravity-induced effects on materials, allowing better fundamental studies on solidification, phase transformation, the kinetics of vaporization and condensation and the dynamics of froths and diffusion in fluids in a temperature gradient.

The new and cheaper products manufactured in space will be those that benefit from lack of gravity. With the exception of weightlessness all other characteristics of the space environment such as high vaccuum and radiation can be achieved on earth.

One major benefit of such low-gravity processing would be that materials to be processed could be 'levitated' - suspended in space without touching the container. Since there would be no need for containers in space factories, there would be no danger of impurity contamination from the container - a major problem in earth - manufactured highly reactive and high melting materials. For example, as indicated earlier, crucible contamination is probably the most serious limitation in producing high purity glasses for lasers, laser system optics and has seriously hindered the abil.ty to grow pure crystals for semiconductors.

A second major advantage of low-gravity processing is the elimination of container's surface irregularities which contact the melted material. These irregularities provides sites for undesireable crystal growth in the solidifying liquid which spoils the perfection of the solid.

Furthermore, in weighless space, molecular forces like conesion and adhesion will replace gravity as the strongest environmental forces and become significant factors that control processes and there could drastic changes in the casting and drawing processes such as those encountered in crystal growth and fiber and ribbon drawing.

In this context NASA conducted an extensive techno-economic feasibility study for manufacturing single crystal silicon and silicon ribbon in space (16, 17).

The first task was to evaluate the most common earth-based crystal growing processes in relation to processing in space. Figure 1 presents the details of the earth-based crystal growing processes which includes:

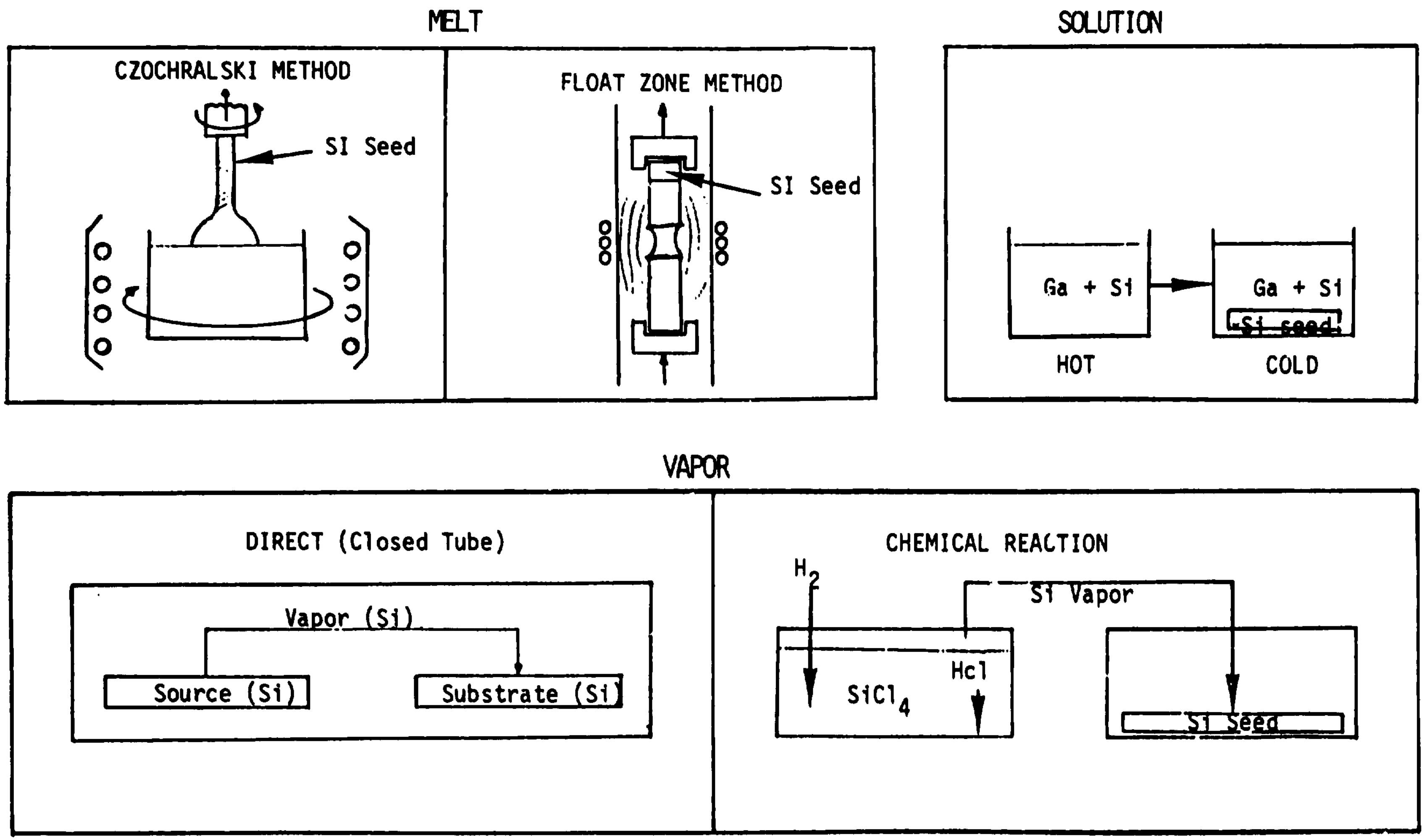
a. Melt growth

b. Solution growth

c. Vapor phase growth

Each of the three processes has their own particular advantages for use in space. As such, each method was evaluated on the basis of its adaptability to the production of single crystal silicon

FIGURE: 1 SINGLE CRYSTAL SILICON GROWTH METHODS

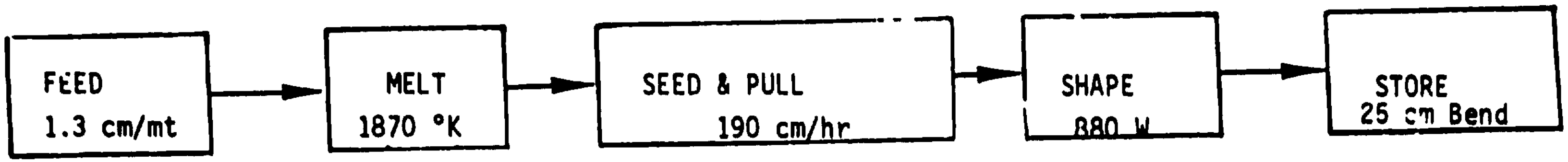


ribbon in space. The technical criteria for selection was that the process must be continuous, the shape of the end product be ribbon, and, in order to be economically attractive, the process must be capable of a high crystal growth rate. (17)

The selected process had the combination of the best features of melt growth and zone refining crystal growing process together with some unique space techniques. The process was called Ribbon from Melt Growth in Space or simply RMGS process. Figure 2 (next page) provides a block diagram and conceptual sketch of the RMGS process (17). In this model process the growth of single crystal ribbon was made from a levitated, spherical melt heated by a solar colllector. There are two major advantages to this process -- direct conversion of the polycrystalline silicon into the desired single crystal planar form and the elimination of contamination by the contact of molten silicon with its sorroundings.

The single crystal silicon currently grown on earth is not in the desired planar form but is in the form of large cylinderical boules. The boules are sliced into wafers and mechanical and chemical polishing is required for removing the damaged surfaces. These loses amounts to 50% of the starting material. However, in space manufacturing operation direct conversion of polycrystalline silicon into ribbon form is optimum because it eliminates processing loss. Further, microgravity makes possible

## RIBBON FROM MELT GROWTH IN SPACE (RMGS) PROCESS



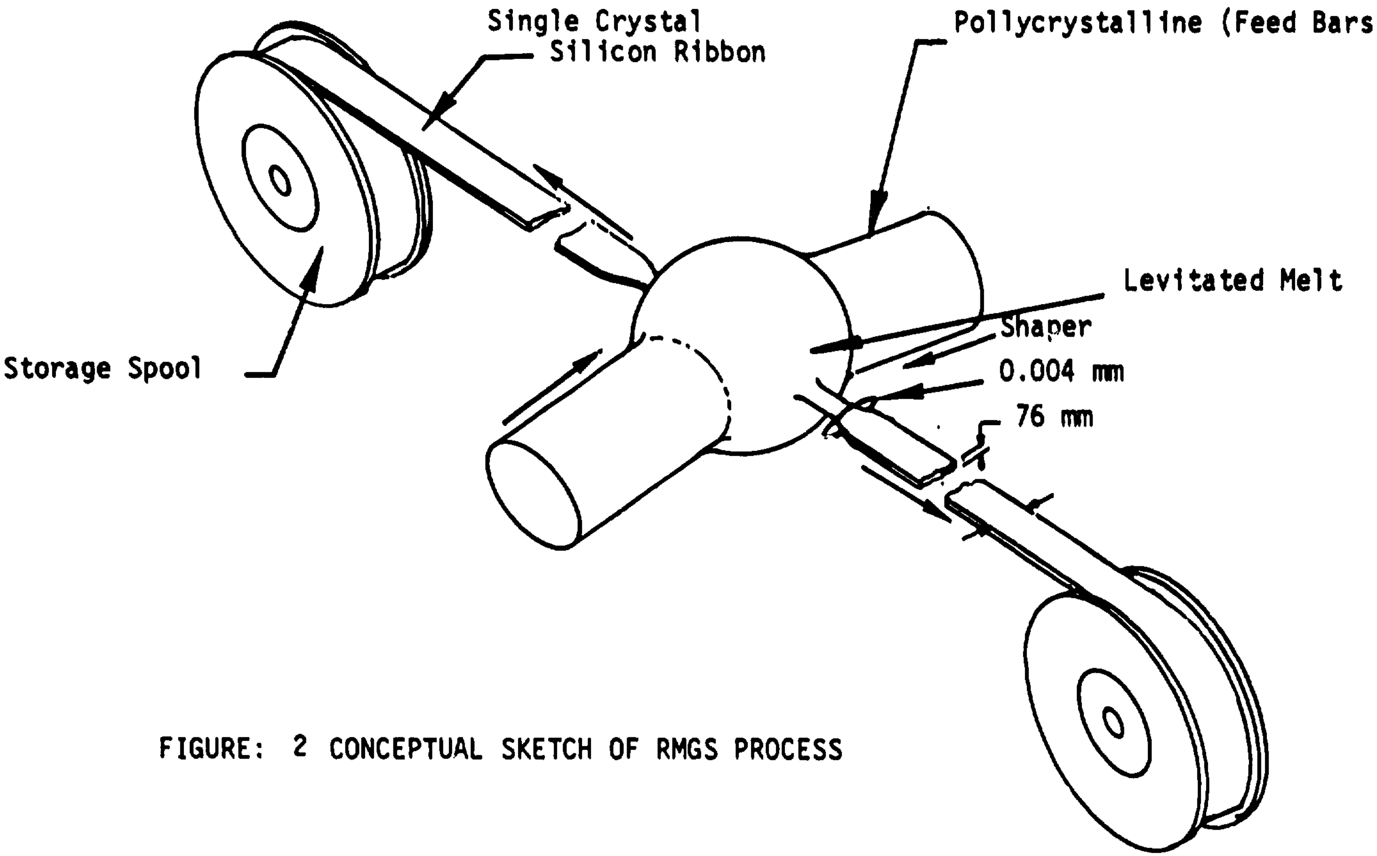




FIGURE: 2 CONCEPTUAL SKETCH OF RMGS PROCESS the levitation of the melt as illustrated in Figure 3 (below). Leviation of the melt eliminates both the material loss and the transportation costs for the lost (waste) material.

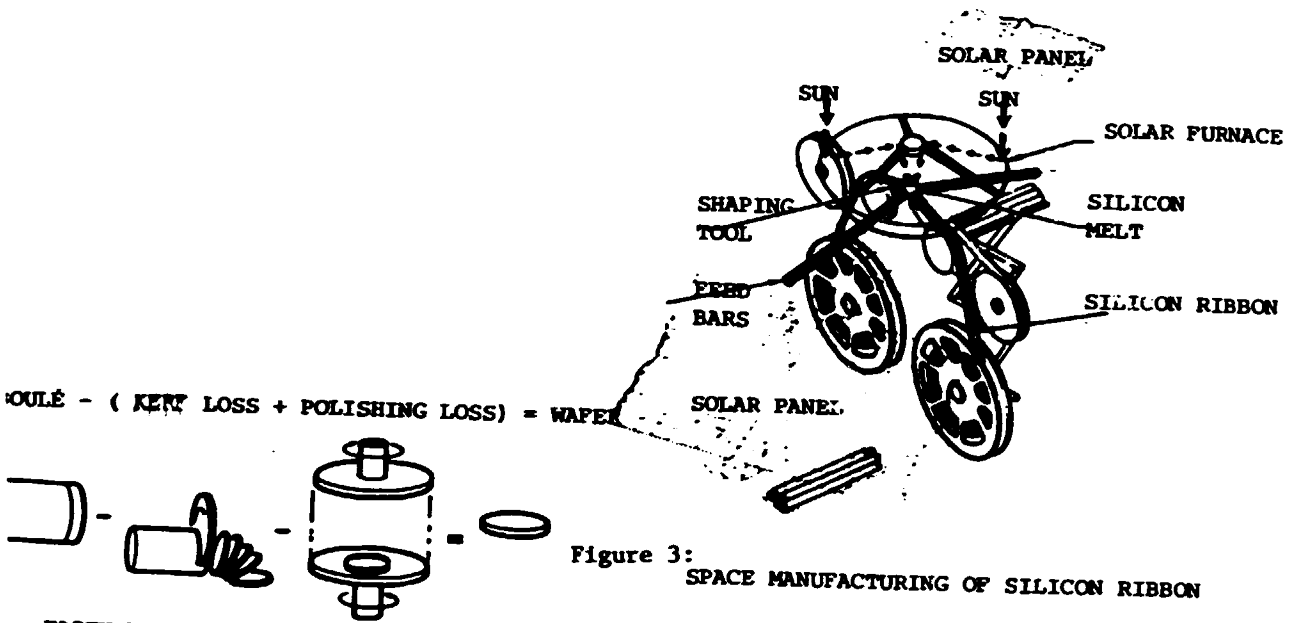


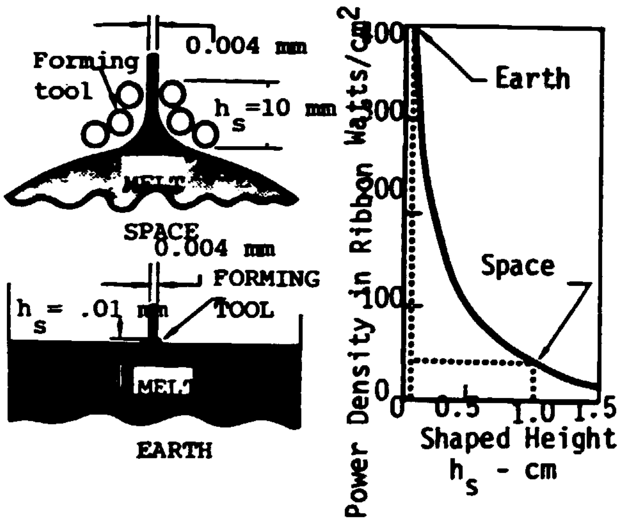

Figure 3:
SPACE MANUFACTURING OF SILICON RIBBON

EARTH MANUFACTURING OF SILICON WAFER

Further, silicon ribbon suitable for IC's have been mechanically shaped using high purity quartz (18), however, for space processing, die errosion and frequent die replacement would have resulted in higher production costs. The process uses alternating current which in the coils results in a radio frequency force field that forces the molten material into rectangular cross section. Radio frequency force field shaping has been largely unsuccessful on earth (19), but the microgravity of space should facilitate its application.

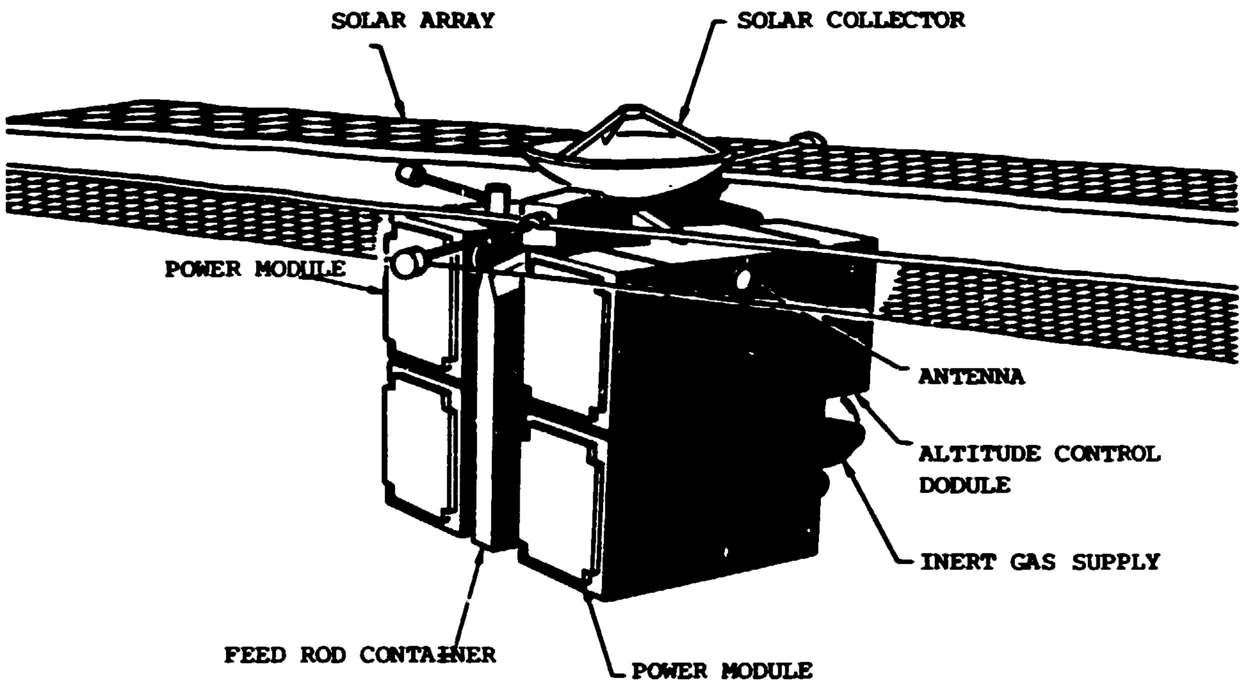
The advantage of microgravity is that surface tension becomes dominant force and shaping can be effected over a much longer meniscus height as shown in Figure 4 below. This longer meniscus height allows the use of multiple coils of larger cross section thus minimizing resistance losses. The decreased power density in the ribbon for the longer shaped height space allows a better balance to be achieved between shaping force and heating of the molten silicon.

Figure 4 ADVANTAGES OF FORMING IN MICROGRAVITY ENVIRONMENT




The postulated silicon ribbon process was incorporated into the space manufacturing plant design as shown in the following Figure 5(next page) (17). One groundrule was that the plant would be an automated free flying spacecraft to provide good operating economics. The production rate was based on a 7.6 cm ribbon width and a pull rate (190 cm/hr) already achieved on the ground using mechanical dies (17).

Figure 5 SPACE MANUFACTURING OF SILICON RIBBON PLANT




For determining the economic feasibility of space manufacture, cost comparisons were made with earth manufacturing. Property improvements, extrapolated from Skylab experimental results, were postulated for the space grown crystal and evaluated in terms of integrated circuit processing yield. The yield improvements for the two principal device technologies, bipolar and metal-oxide-semiconductor (MOS) are shown in Figure 6 (next page) for a 0.38 cm x 0.38 cm baseline large scale integrated (LSI) circuit or chip. The approach used was to calculate the LSI manufacturing cost using earth material cost yield (17).

Further, integrated circuit manufacturing consist of three major steps: diffusion, assembly and test. In diffusion the transistors and interconnections are formed by selectively

| | OVERALL YIELD | |
|---|---|---|
| | SPACE | EARTH |
| BIPOLAR | 13.5% | 6.3% |
| MOS | 29.2% | 16.8% |

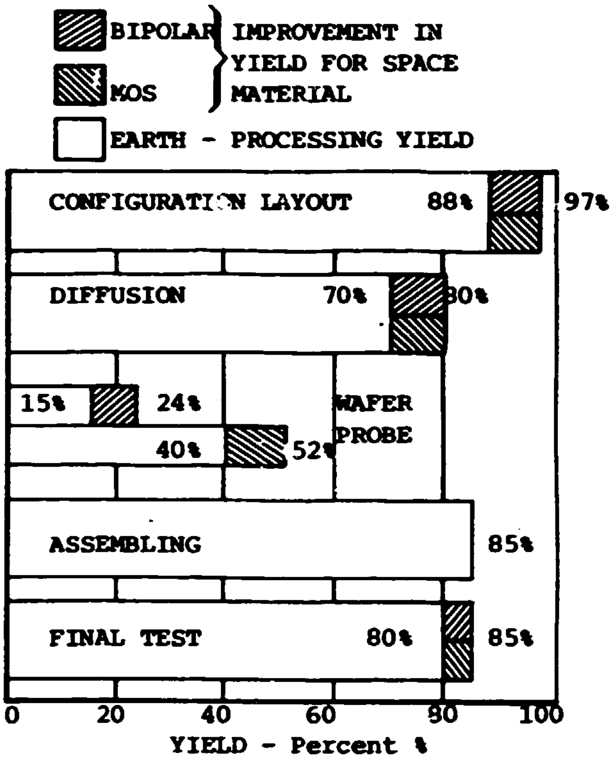



Figure 6 INTEGRATED CIRCUIT PROCESSING YIELD

doping the substrate in a multistep process. The circuits are probed and separated into individual chips. The good chips are then assembled into packages and the final step is to test the assembled integrated circuits.

The effects of the increased yields projected for space processed integrated circuit material costs are shown in Figure 7 (next page) (17).

The largest effect of space processing is the decrease in diffusion cost per killogram which is inversely proportional to the overall yield. There is also a small decrease in assembly and test cost due to the small improvement in final test yield.

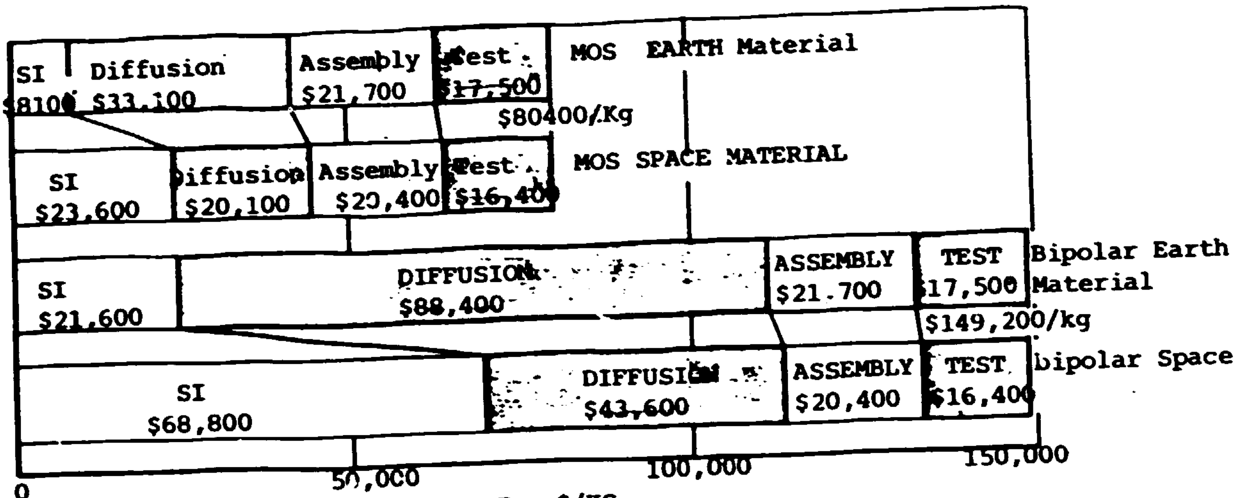



Figure 7:
EARTH & SPACE PROCESSING COST BREAKDOWN FOR INTEGRATED CIRCUIT (IC)

Finally, in order to determine the value and market for space produced silicon market analysis was also conducted to identify market characteristics and is illustrated in Figure 8 (16, 17) below.

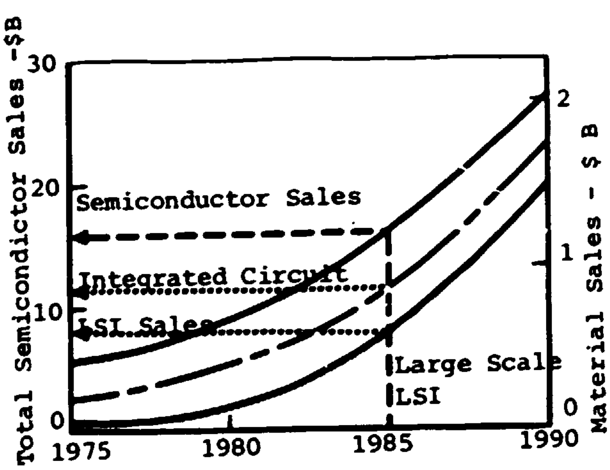



Figure 8 Projected World Semiconductor Market

The semiconductor market is composed of discrete devices and IC's and is currently around $20B and is growing at an annual rate of 11%. Single crystal silicon for use in IC's requires extremely high quality material in terms of purity and structure. The damaging effect of defects increases with circuit size and is greatest for large scale integrated circuits (LSI). These LSI would be a candidate for space processed silicon if the Skylab and shuttle studies could be realized in developing a manufacturing process in space with an eventual objective of industrializing space.

Space industrialization is the medium by which services, products and energy are returned from space to earth to provide industrial economic benefits to the entire world. In fact, the developing countries are now, and will continue to be prime beneficiaries from space industrialization. It is possible to construct credible scenarios which could bring the developing countries to the level of industrially developed countries in a relatively lesser time frame and cost (20). The worldwide interest in space industrialization is reflected by the number of countries and agencies that are actively participating by their involvement at the UNISPACE-82 Conference (21). The great power for what is considered "good" in the industrialized world (the word "good" relates to health, education, knowledge, creative growth, safety, etc.) afforded by space industrialization has been comprehended by a very few, but there is evidence that realization is spreading. It is hoped that this report and the associated studies by UNIDO will assist in the realization and help promote the utilization of space-related industrial materials spin-off for the developing countries.

# 3.0 MATERIALS DEVELOPED FOR SPACE APPLICATIONS

## 3.1 TECHNOLOGY OF CARBON/GRAPHITE FIBERS

The significance of fiberous materials and products became identified with structural developments in the aerospace industry. The urgency of structural requirements for the space-related industries led to the development of carbon/graphite fiber composites.

Carbon is an abundant element on earth and elemental carbon is sixth in the periodic table with an atomic weight of 12.011 and consisting of 98.9% $C_{12}$ and 1.1% fo $C_{13}$ .

The high strength and high modulus carbon fibers are about 7 to 8 microns in diameter and consists of small crystallites of "turbostratic" graphite, one of the allotropic forms of carbon. In a graphite single crystal the carbon atoms are arranged in hexagonal arrays as shown in Figure 9 (next page), and are stacked on top of each other in a regular ABAB sequence (22,23).

The atoms in the layer or basal planes are held together by very strong covalent bonds and there are weak Van der Waal forces between the layers (24). This means that the basic crystal units are highly anisotropic -- the in-plane Young's modulus parallel to the A-axis is 910 $GN^{-2}m$ and the Young's modulus parallel to C-axis (normal to the basal planes) is 30 GN $cm^{-2}$ . The spacing between the layers is 0.335 microns. The "turbostatic" graphite resembles graphite single crystal except that the layer planes

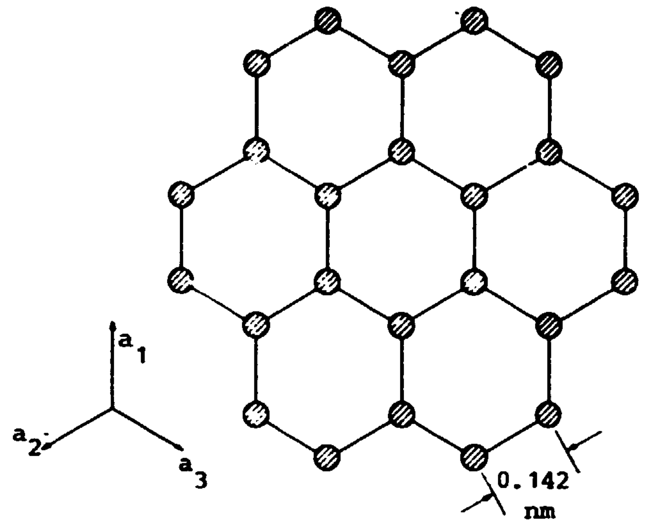



Figure 9: Arrangement of Carbon Atoms in the Layer Planes of Graphite

have no regular packing in the C-axis and the average spacing between the layer planes is about 0.34 nm.

The technique for obtaining high modulus and high strength is to have the layer planes of graphite to be alligned parallel to the axis of the fiber. Details are available in review articles by Johnson (25,26), Fourdeux, Perret and Ruland (27) and Reynolds (28,29).

In the U.S., the development of high strength carbon graphite whiskers was reported by NASA (30) and also by Steg (31), Schmidt and Hawkins (32), and Economy (33). Detail information is also available in several U.S. patents (34-74).

Basically, in the various process patents reviewed for the manufacture of carbon fibers, a variety of precursor (starting material) are used. The basic process in manufacturing graphite fibers is to utilize an organic base precursor with a high percentage of carbon atoms, and through heat and tension, drive off all volatile fractions leaving only the carbon atoms. The three most popular precursors are polyacrylonitrile (PAN), staple rayon fibers and pitch fibers. All the three precursors can be carbonized to various degrees with varying difficulty and properties.

A. Polyacrylonitrile (PAN): Base graphite fibers are made from a long chain linear polymer consisting of a carbon backbone with attached carbonitrile groups. The first step involved in producing a graphite fiber from this polymer is to cyclize the linear structure into a "ladder" type structure. The cyclization reaction is accomplished by holding the prestretched polymer under tension at temperature of 205-240 degrees Celcius for up to 24 hours in an oxidizing atmosphere.

After the completion of cyclization the resulting infusible fiber is heat treated in an inert atmosphere to temperatures ranging from 1400 degrees - 3000 degrees Celcius. The final processing temperature significantly influences the degree of graphitization that is achieved and the resultant properties of the fiber. Several U.S. patents describes their process in more precise detail (75).

On a commercial scale, the oxidation of PAN fibers to carbon fibers was revealed in the U.S. Patent (37) which also covered the copolymers of PAN, and two Japanese patents (76). Both of the Japanese patents are licensed to Tokai Electrode Company and the Nippon Carbon Company.

In the preparation of high strength high modulus fibers, Toray (70) oxidized the PAN precursor by contacting the fibers (for less than 1 second) intermitantly at a surface temperature range of 200 - 400 degrees Celcius. Brittish patents granted to Union Carbide described a process for the continuous graphitization of textile fibers by stretching at temperature around 2200 degrees Celsius (77).

Royal Aircraft Establishment (RAE), England, developed a process for the conversion of PAN fibers into high modulus carbon fibers. This required an initial oxidation of PAN fibers in air between 200 - 300 degrees Celcius followed by carbonization and then graphitization in an inert atmosphere up to 3000 degrees Celcius (78).

B. Staple__Rayon__Precursors: The use of cellulose fibers as precursors for carbon fibers was an important adva..cement for the C/G fiber technology. Such commercial fibers from union Carbide under the trade name of Thornel-50 and Thornel-75 are made by heat-treating rayon filaments in inert atmosphere in a series of steps to temperatures on the order of 2700 to 2800 degrees Celcius. At these elevated temperatures the filaments are subjected to tensile loads and are stretched or elongated in order to allign the graphite layer planes in a direction parallel to the axis of filaments (34,35,36,40,42,79).

It needs to be described that the carbon fibers made from rayon precursor are irregular in shape and the fiber size may range from 5-50 microns in diameter.

C. Pitch Precursors: The newest carbon fiber processing technique being utilized more aggressively involves the spinning and thermal decomposition of an intermediate liquid pseudo-crystalline phase of a coal tar pitch known as mesophase. The mesophase structure forms in a pitch after heating in a temperature range of 400 - 500 degrees Celcius for up to 40 hours. At this stage the pitch is in the form of a viscous liquid and the carbon molecules are kind of plate - like in shape.

After the conversion of the pitch to mesophase state it is spun through small orifice (bushing) into filament form. The spinning process forms fibers having a high degree of axial orientation. These ordered fibers are made infusible by thermosetting at a relatively low temperature.

The use of low cost commercial pitches without the costly stretching of fibers at elevated temperatures was first reported by Singer (69, 80). However, Otani and co-workers in Japan had filed a patent (45) the efforts of Singer led to the use of pitch as a precursor for high strength high modulus, graphite fibers.

### 3.1.1 PROPERTIES OF CARBON/GRAPHITE FIBERS:

Carbon/graphite fibers offer a combination of low weight, high strength, high modulus and stiffness properties quite superior to similar properties of conventional non-metallic and metallic aerospace related fiberous materials. Further, for the carbon/graphite fibers, their properties vary with the precursor material and this point is well illustrated in Tables I & II in the next two pages.

Even within a specific precursor material, the properties of the final product (graphite fiber) varies and depends on the processing parameters such as the carbonization and graphitization temperature. Table II (next page) illustrates this aspect of graphite fibers made from mesophase pitch.

As indicated earlier, the carbon/graphite fibers were developed for a variety of space-related application where the superior mechanical and strength properties of these fibers played a vital role in providing the unmet need. The next section describes the strength related properties of graphite fibers based on the precursor materials.

TABLE I COMPARATIVE PROPERTIES OF CARBON/GRAPHITE FIBERS

(BASED ON PRECURSOR MATERIALS)

| S NO. | PROPERTY | PRECURSOR MATERIAL | | |
|---|---|---|---|---|
| | | PAN | PITCH | RAYON |
| 1 | TENSILE STRENGTH ($10^3$ PSI) | 360-450 | 225 | 300-400 |
| 2 | TENSILE MODULUS. ($10^6$ PSI) | 30-50 | 55 | 60-80 |
| 3 | SHORT BEAM SHEAR ($10^3$ PSI) | | | |
| | untreated | 10-4 | 6 | 4 |
| | treated | 18-8 | 10 | 8 |
| 4 | SPECIFIC GRAVITY | 1-8 | 2 | 1.7 |
| 5 | ELONGATION, % | 1.2 - 0.6 | 1 | --- |
| 6 | FIBER DIAMETER, m | --- | 7.5 | 6.5 |

TABLE II PROPERTIES OF GRAPHITE FIBERS MADE FROM MESOPHASE PITCH

| | | AFTER CARBONIZATION (1500°-1700° C) | AFTER GRAPHITIZATION (2800° C) |
|---|---|---|---|
| 1. | SPACING OF CARBON CRYSTALLITES | 3.40 - 3.43 Å | 3.36 - 3.37 Å |
| 2. | DENSITY (GM/CC) | 2.1 - 2.2 | 2.1 - 2.2 |
| 3. | TENSILE STRENGTH | 140-160 ksi | 250-350 ksi |
| 4. | YOUNGS'S MODULUS | 25-35 msi | 75-120 msi |
| 5. | ELECTRICAL RESISTIVITY | $800\text{-}1200 \times 10^{-6}$ ohm-cm | $150\text{-}200 \times 10^{-6}$ ohm-cm |

3.1.2 TRENGTH PROPERTIES CARBON/GRAPHITE FIBERS:

Carbon/graphite fibers are the preferred material due to their low weight and high modulus strength properties. Further, their properties are also related to the precursor material and are described as follows:

PAN-BASE GRAPHITE FIBERS: Factors which governing the tensile strength of PAN-base fibers in relation to heat treatment temperature is that the strength gradually increases with temperature to a maximum at 1200 degrees Celcius, and, again gradually drops and level at 2800 degrees Celcius when the tensile strength is around 200 psi (81).

The referenced figure (81) clearly indicated that the tensile strength does not rise with the increase in heat treatment temperature. The tensile strength reaches a maximum strength of about 450 ksi for fibers processed around 1200-1400 degrees celcius. The tensile strength drops off significantly for fibers processes at higher heat treatment temperatures. According to Watt and Johnson (82,83) the tensile strength of fibers is controlled by the presence of discreet flaws both within and on the surface of the fibers. Barnet and Norr (84) published a summary of strength limiting factors for PAN-base carbon fibers. Many of the internal flaws can be classified into three categories: inorganic and organic inclusions, longitudinal voids due to dissolved gases and irregular voids (85). During heat treatment these defects change into imperfections and can be seen in the final product (86-88). Basal plane flaws are important because they affect the tensile strength of PAN-base carbon fibers (89).

Surface flaws introduced during the spinning of the polymeric fiber retain their shape even after carbonization (81). According to Tokarsky and Diefendorf (90) the tensile strength of graphite fibers is a function of not only internal and surface flaws but also of the radial and axial flaws.

All of these flaws can be removed by careful processing (91) resulting in a significant improvement in the tensile strength.

The elctrical properties of PAN-base carbon/graphite fibers were also studied and indicated major changes in the electronic structure of the fiber at the heat-treatment temperature of 1750 degrees Celcius (92,93). This has been attributed to the release of nitrogen. Merchand and Zanchetta had shown that the release of nitrogen affects the graphitization process (94).

PROPERTIES OF PITCH BASE AND RAYON BASE FIBERS:

The tensile strength of pitch base graphite fibers is directly related to their processing or heat-treatment temperature (95). The ultimate tensile strength increases relative to the processing temperature ranging from an average of 200 ksi for fibers heat treated at 1700 degrees celcius to 320 ksi for fibers processed at 3000 degrees Celcius. The ultimate tensile strength values of pitch base fibers are relatively low and the primary source of failure is due to porosity.

The electrical properties of pitch base graphite fibers were discussed in detail by Bright and Singer (96). The electrical resistivity of pitch base graphite fibers drops with increasing processing temperature (from 10 ohm-cm processed at 1700 degrees Celcius to 2x10 ohm-cm processed at 3000 degrees Celcius). As such, the pitch-base fibers are excellent conductors and their electrical conductivity is significantly better than PAN-base fibers.

The Rayon base fibers posses a high degree of crystallinity ranging from 25-50% and during processing the structure breaks down around 300 degrees Celcius and a re-orientation of structure occurs around 1000 degrees Celcius resulting in voids due to precursor and consequently lower density (1.3 gr/cc) (97,98). As such, the tensile properties of rayon-base fibers are dependent on several processing parameters (98).

Carbon/graphite fibers are basically strong fibers, however, their strength increases almost by an order of magnitude when they are used as fibers composites.

Composite materials offer a combination of strength and stiffness properties superior to non-reinforced fibers. Graphite fiber reinforcement are essentially graphitic due to the fact that the fibers primarily consist of carbon which is amorphous, and a lesser amount of graphite which has a hexagonal crystalline structure. The percentage of graphite in the fiber depends on the final processing temperature and increases with increase in the final temperature.

Further, the form of graphite fiber plays a significantly effect on the fabrication of a selected composite structure. The composite product form is determined both by the structural requirements of the end product and the manufacturing process. Table III (next page) provides the data on the mechanical properties of graphite fiber composites and compares with Aramid 49, 'S' glass and boron fiber composites. The table clearly indicates the overall superiority of graphite fibers composites except when compared with boron fiber composites which are very expensive.

### 3.1.3 APPLICATIONS OF CARBON/GRAPHITE FIBER COMPOSITES:

A very large and broad technology and information data base has evolved during the past quarter of the century for advanced graphite fiber composite materials. This data base has been established primarily by work sponsored by U.S. federal agencies and aerospace companies. As part of the program to develop confidence in graphite composites, information is available indicating the progress that has been made in this material for a variety of aerospace and industrial applications.

TABLE III MECHANICAL PROPERTIES OF COMPOSITES (60% FIBER VOLUME *

| REINFORCEMENTS | ULTIMATE TENSILE STRENGTH(ksi) | | ULTIMATE COMPRESSIVE STRENGTH (ksi) | | INITIAL TENSILE MODULUS (msi) | | ULTIMATE TENSILE STRAIN (%) | | COMPOSITE DENSITY ($lb/in^3$) |
|---|---|---|---|---|---|---|---|---|---|
| | 0° | 90° | 0° | 90° | 0° | 90° | 0° | 90° | |
| A-GRAPHITE FIBER | 220 | 7-12 | 220 | 40 | 18 | 1.5 | 1.2 | 0.5-0.9 | 0.056 |
| HT-GRAPHITE FIBER | 220 | 6-12 | 200 | 35 | 22 | 1.3 | 0.8 | 0.5-0.9 | 0.057 |
| HM-GRAPHITE FIBER | 130 | 5-10 | 130 | 30 | 27 | 1.3 | 0.5 | 0.3-0.8 | 0.058 |
| VHM-GRAPHITE FIBER | 200 | 2-3 | 97 | 27 | 45 | 0.9 | 0.5 | 0.2-0.3 | 0.058 |
| ARAMID 49 | 220 | 3-4 | 45 | 15 | 13 | 0.8 | 1.5 | 0.2-0.3 | 0.050 |
| S-GLASS | 260 | 5-9 | 100 | 23 | 6-8 | 2.0 | 3.0 | 0.3-0.4 | 0.072 |
| BORON FIBER | 230 | 9-13 | 400 | 30 | 30 | 3.0 | 0.7 | 0.3-0.4 | 0.075 |

* W.T. FREEMAN AND G.C. KUEBLER "MECHANICAL & PHYSICALLY PROPERTIES OF ADVANCED COMPOSITES", COMPOSITE MATERIALS, TESTING AND DESIGN ASTM-STP, Vol. 546, Page 205, 1974

In a program s' ~sored by NASA at Lockheed Corporation, advanced carbon/graphite .iber composites technology has been developed for vertical fins (ACVF) used in L1001 transport aircraft (99). The experiences of several commercial aircraft manufacturers continuous to show promise in application of the advance graphite fiber composites. Graphite fiber epoxy composites were studied at Douglas for NASA-Langley Research Center where in Thornel 300 graphite fiber composite were used in the vertical stabilizer of DC-10 jets (100).

Carbon/graphite composites have also been used in the design of space orbiter and space shuttle (101). Further, there were many noteworthy space-related advanced components involving the use of carbon/graphite composites and include space stable support system for the secondary mirror of an optical telescope (102), structural components in the design for X-ray observation of galactic and extra-galactic X-ray sources (103).

A potential application for the developing countries is the use of Carbon/graphite fiber composites for various parts and components of lightweight aircrafts. This includes wheels and brakes systems (104), landing gear spring blades and engine fan frames (105).

Advanced carbon/graphite fiber composites are also being used in the automotive industry. One of the most effective way to improve the miles per gallon performance of passenger cars is through a drastic reduction in weight of a car (106-111). Ford Motor

Company is working in this direction (106) and weight reduction for heavier trucks has also been reported (107,108).

Further, there are several industrial and commercial applications of carbon/graphite fibers which have been in operation in the industrialized countries. They cover a broad range and include bicycle frames (112,113), carbon fiber reinforced concrete (as a building material) (114), corrosion resistant valves (115), and medical prosthesis devices (116 and 117).

From a generalized interpretation the carbon/graphite fibers composite technology may be considered as part of the fiber reinforcement plastics industry, as such, could play an effective role in the industrialization of those developing countries which have a broad fiber composite technology base. In this contest, several potential products and design applications are suggested. In these applications the intrinsic qualities of the fibers are utilized just as they are provided by the manufacturers. This is in contrast to structural applications where R&D has defined more sophisticated requirements.

Bushman had updated the role of carbon/graphite fibers as a source for heating in non-metallic tooling (118). Among the tools that benefited from integral heating elements are bonding fixtures, tools for thermal forming of thermoplastic sheets and tools for the curing of thermosetting matrix prepeg into finished components.

Carbon/graphite fibers have found many applications in radiological equipment. Advantage was taken of these fibers transparency to X-rays making it possible to monitor patient's vital sign during some X-ray diagnosis (119). In another application carbon/graphite fibers were used to make light-weight and X-ray transparent tables used during patients' examination (120). In some X-ray diagnosis patients need to be moved and rotated which is an uncomfortable procedure during internal examination.

All these applications clearly indicate the significance of this space related technology in the industrial development. This is a growing industry, and aside from the key markets which have been identified there are many small segments which are difficult to locate because available data i both limited and restricted. However, for the sake of identification selected commercial carbon/graphite manufacturers have been identified.

### 3.1.4 COMMERCIAL MANUFACTURERS OF CARBON/GRAPHITE FIBERS:

There are several commercial manufacturers of graphite fibers who make the fibers based on the three precursor materials, viz, PAN, Rayon and Pitch. Tabel IV (next page) provides the names of selected manufactures, the trade name of the fiber, processing technique and selected properties of the fiber.

There are several manufacturers of carbon/graphite fibers and their identification is beyond the scope of this report. However,

TABLE IV    COMMERCIAL CARBON GRAPHITE FIBER MANUFACTURERS

| S. NO | MANUFACTURER/ COUNTRY | TRADE NAME | PROCESSING TECHNIQUE | DENSITY Gr/cc | Av. STRENGTH $10^3$ psi | Av. MODULUS $10^6$ psi |
|---|---|---|---|---|---|---|
| 1. | | MODMOR I | PAN | 1.85 | 340 | 59 |
| 2. | CELANESE INC. U.S.A. | CELION 70 | PAN | 1.96 | 300 | 88 |
| 3. | COURTLANDS ENGLAND | COURTLANDS HMS | PAN | 1.94 | 250-350 | 50-60 |
| 4. | GREAT LAKES U.S.A. | FORTAFIL 6T | PAN | 1.91 | 420±20 | 59 ± 3 |
| 5. | COURTLANDS ENGLAND | COURTLANDS HT | PAN | 1.86 | 325-375 | 35-40 |
| 6. | GREAT LAKES U.S.A. | FORTAFIL 5T | PAN | 1.80 | 400±20 | 48±3 |
| 7. | HERCULES U.S.A. | HERCULES TYPE A | PAN | 1.77 | 400 | 32-28 |
| 8. | UNION CARBIDE U.S.A. | THORNEL 300 | PAN | 1.70 | 325 | 34 |
| 9. | UNION CARBIDE U.S.A. | UCC TYPE R | PITCH | | 60-200 | 50 |
| 10. | UNION CARBIDE U.S.A. | THORNEL 75 | RAYON | 1.82 | 385±17 | 76 ± 3 |
| 11. | UNION CARBIDE U.S.A. | THORNEL 50 | RAYON | 1.67 | 320±20 | 57±3 |

brief description of the major manufacturers is as follows:

1. Union Carbide Corporation (UCC), United States:

   Since 1960 this company has been identified as a major manufacturer of carbon/graphite fibers made from rayon precursor, and from 1970 UCC has been the distributor of C/G fibers produced by Toray of Japan. In recent years UCC has been making pitch precursor-base C/G fibers. Their products are identified as "Thornel" - Thornel-50 means (fibers having $50 \times 10^6$ psi Modulus etc).

2. Hercules, Inc., U.S.A.:

   Like UCC, Hercules has been distributing C/G fibers and in recent times has been producing their own PAN precursor fibers. They are also the exclusive distributors of Courtaulds (England) C/G fibers here in the U.S. The C/G fibers made by Hercules are identified under the trade name of "Magnamite".

3. Celanese, Inc., U.S.A.:

   A relatively smaller company, Celanese, however has a unique product - ultra high modulus graphite fiber (70-75 x $10^6$ psi) identified as GY-70. Their PAN precursor products Celion 3000 and 6000 are the other products.

4. Great Lakes Carbon Corp. U.S.A.:

   One of the smaller manufacturers of C/G fibers, their products are sold under the trade name of Fortafil.

5. Courtaulds, England:

   One of the major C/G fiber manufacturer, this English company pioneered the PAN-based fibers developed for Royal

Aircraft Establishment (RAE) in the 60's. Currently their products are sold under the trade name of GRAFIL.

6. Toray, Japan:

A leading manufacturer of C/G fibers and a pioneer in the development of PAN-based fibers. They also supply substantial quantities of C/G fibers in the U.S., through UCC. Their fibers are sold as 1000, 3000 and 6000 filament yarn. Grade M-40 is a high modulus fiber.

## 3.2 SPACE-RELATED ADVANCED CERAMIC MATERIALS:

Space environment demanded a variety of unique characteristics which could only be satisfied by ceramics. This assesment concerns a number of new ceramic materials and products that have been developed over the past quarter of a century to fulfill the unmet need of space environment and for its unique application. At the same time, the spin-off of these materials and technologies are:

1. Technical ceramics or fine ceramics.
2. Materials for integrated optics.
3. Industrial sensor materials.

There are other materials and technologies, however, due to the scope of this report the selected technologies are considered as mature enough for transfer and significant enough for potential industrial progress of the developing countries.

### 3.2.1 HIGH TEMPERATURE CERAMICS-FINE CERAMICS:

The application of heat to ceramic raw materials is one of the earliest of materials technologies. Ancient man discovered that heated wet clay could be molded into a variety of shapes before baking or firing. By the time the ancient Greeks coined the term "Keromos", man had been shaping and firing common clay.

Now, the space age era is using this ancient material under sophisticated names for a variety of industrial application which includes automobile engines. There is little doubt that advanced ceramics/structural ceramics is a significant "emerging technology" worldwide, affecting such diverse areas as auto enginers, power generation, cutting tools, microelectronics and industrial sensors.

In the United States, these high temperature ceramic materials are known as advanced or technical ceramics. These hi-tech ceramics referred to in Japan as "Fine Ceramics" are made from extremely pure, composition-controlled, ultra-fine particles formed, sintered and treated under highly controlled conditions. Their properties give the ceramics superior performance characteristics. The great diversity of practical applications of these fine ceramics as identified by the Fine Ceramic Office, MITI, Japan, is presented in Figure 10 (121) (next page).

What are these so-called advanced ceramics, high-tech ceramics or fine ceramics and how do they differ from the traditional ceramics?

Unlike the traditional ceramic materials based primarily on silicates, advanced ceramics include nitrides, carbides, oxides, carbonates, etc. These materials posses specialized properties including high heat, wear, and corrosion resistance as well as specialized electrical and optical properties which allows these new ceramics to perform well in a number of high-value added applications. Figure 11 (next page following) provides an overview of these materials. The following are selected high temperature materials.

SAILON: The acronym "Sailon" was originally given to new ceramic

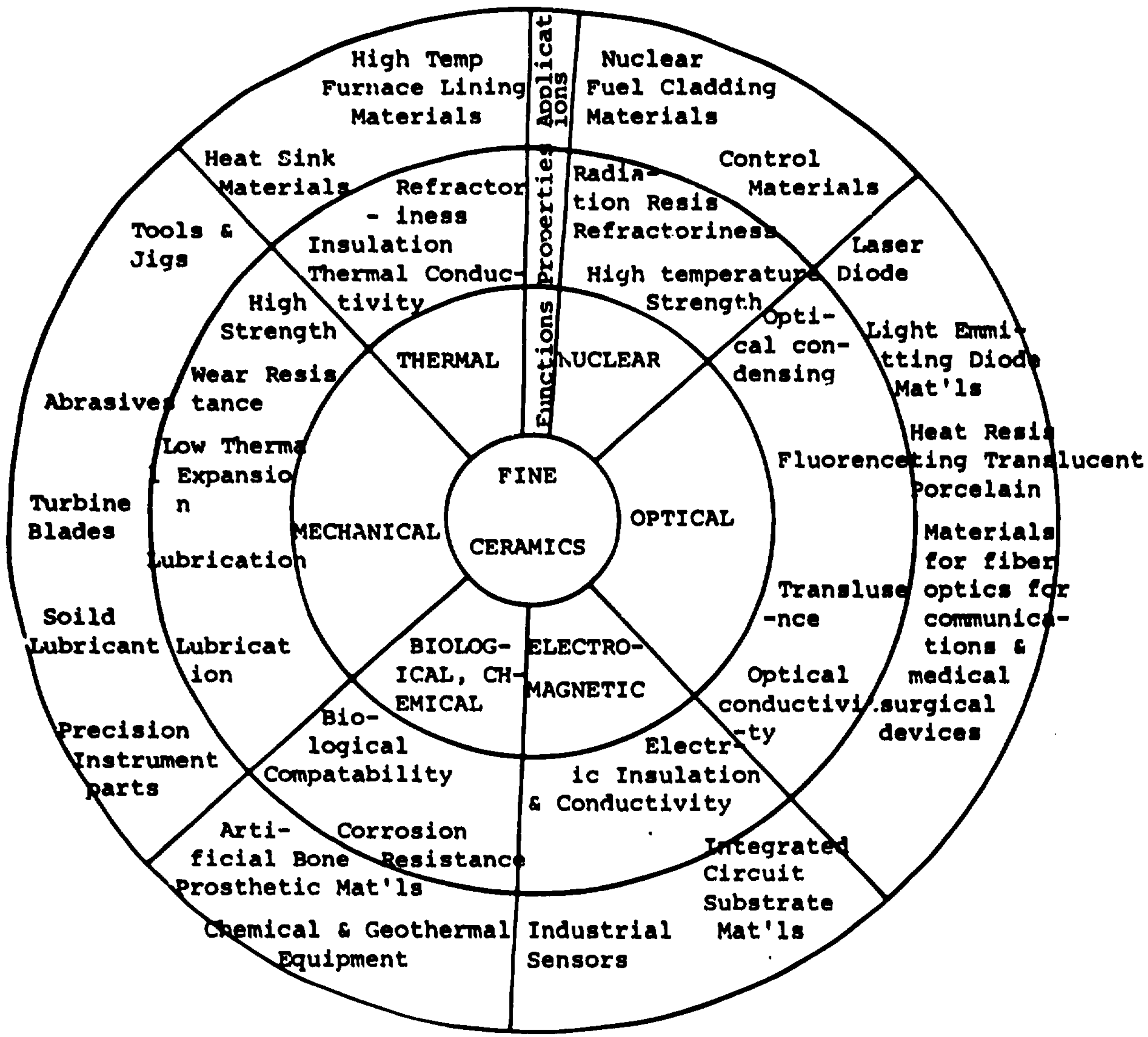



FIGURE 10: Examples of Functions & Applications of Fine Ceramics (Source: Fine Ceramics Office, Ministry of International Trade & Industry - MITI Tokyo, Japan)

FIGURE 11 CLASSIFICATION OF HIGH TECH CERAMICS BY FUNCTIONS**

| Function | Material | Application |
| --- | --- | --- |
| Electric functions | Insulation materials ($Al_2O_3$, BeO, MgO) | IC circuit substrate, package, wiring substrate, resistor substrate, electronics interconnection substrate |
| | Ferroelectrics materials ($BaTiO_3$, $SrTiO_3$) | Ceramic capacitor |
| | Piezoelectric materials (PZT) | Vibrator, oscillator, filter, etc.; Transducer, ultrasonic humidifier, piezoelectric spark generator, etc. |
| | Semiconductor materials ($BaTiO_3$, SiC, $ZnO-Bi_2O_3$, $V_2O_5$ and other transition metal oxides) | NTC thermistor: temperature sensor, temperature compensation, etc. |
| | | PTC thermistor: heater element, switch, temperature compensation, etc. |
| | | CTR thermistor: heat sensor element |
| | | Thick film thermistor: infrared sensor |
| | | Varistor: noise elimination, surge current absorber, lighting arrestor, etc. |
| | | Sintered CdS material: solar cell |
| | | SiC heater: electric furnace heater, miniature heater, etc. |
| | Ion conducting materials ($\beta$-$Al_2O_3$, $ZrO_2$) | Solid electrolyte for sodium battery |
| | | $ZrO_2$ ceramics: oxygen sensor, pH meter fuel cells |
| Magnetic functions | Soft ferrite | Magnetic recording head, temperature sensor, etc. |
| | Hard ferrite | Ferrite magnet, fractional horse power motors, etc. |
| Optical functions | Translucent alumina | High pressure sodium vapor lamp |
| | Translucent magnesium, mullite, etc. | For a lighting tube, special purpose lamp, infrared transmission window materials |
| | Translucent $Y_2O_3$-$ThO_2$ ceramics | Laser material |
| | PLZT ceramics | Light memory element, video display & storage system, light modulation element, light shutter, light valve |
| Chemical functions | Gas sensor (ZnO, $Fe_2O_3$, $SnO_2$) | Gas leakage alarm, automatic ventilation fan, hydrocarbon, fluorocarbon detectors, etc. |
| | Humidity sensor ($MgCr_2O_4$-$TiO_2$) | Cooking control element in microwave oven, etc. |
| | Catalyst carrier (cordierite) | Catalyst carrier for emission control |
| | Organic catalyst | Enzyme carrier, zeolites |
| | Electrodes (titanates, sulfides, borides) | Electrowinning aluminum, photochemical processes, chlorine production |
| Thermal functions ($ZrO_2$, $TiO_2$ ceramics) | | → Infrared radiator |
| Mechanical functions | Cutting tools ($Al_2O_3$, TiC, TiN, others) | Ceramic tool, sintered SBN; Cermet tool, artificial diamond; Nitride tool |
| | Wear resistant materials ($Al_2O_3$, $ZrO_2$) | Mechanical seal, ceramic liner, bearings, thread guide, pressure sensors |
| | Heat resistant materials (SiC, $Al_2O_3$, $Si_3N_4$, others) | Ceramic engine, turbine blade, heat exchangers, welding burner nozzle, high frequency combustion crucibles |
| Biological functions | Alumina ceramics implantation; Hydroxyapatite bioglass | → Artificial tooth root, bone, and joint |
| Nuclear functions | Nuclear fuels ($UO_2$, $UO_2$-$PuO_2$) | |
| | Cladding material (C, SiC, $B_4C$) | |
| | Shielding material (SiC, $Al_2O_3$, C, $B_4C$) | |

** George B. Kenney et al.,"High Tech Ceramics in Japan Current and Future Markets" Am. Cer Svc. Bill, 62 (5) 590 May 1983 compounds derived from silicon nitride and oxynitride by simultaneous replacement of silicon and nitrogen by aluminum and oxygen. Similar replacements are possible with other structures and other metals such as lithium, beryllium and magnesium . Sailons are made of one -, two- and three- dimensional arrangements of (Si, Al) (O,N) and (M,Si)(O,N) tetrahedra in the same way as the structural silicate tetrahedrons are in the (SO4). Aluminum plays a special role because the AlO4 tetrahedron with five negative charges is about the same size as SiO4 and can replace in the rings, chains and networks, provided valency compensation is made elsewhere in the structure. Jack reported the first of these new materials "Sailon" (122), and about the same time Oyama and Kamingato (123) and Tsuge (124) reported similar achievements in Japan.

Further, from the point of view of developing these technologies in the developing countries, Sailon type materials can also be prepared from naturally occuring minerals. Dense, sintered solids with compositions in the Si3N4-Al2O3-AlN systems were obtained by hot pressing a mixture of naturally occuring silica sand and aluminum powder in a nitrogen atmosphere. Hot pressing was carried out at a pressure of 200 kg/cm 2 and temperatures ranging from 1600 to 2000 degrees Celcius for one hour in a nitrogen atmosphere (125).

Hot pressing, as a fabrication process, has found increased use in ceramic processing industry with particular emphasis on the preparation of material with improved properties through composition, microstructure and density control. A general description of ranges in hot pressing fabrication is included here and there are no sharp distinctions in the pressure ranges employed as seen in Table V (next page).

In view of their potentials, the application of advanced ceramics to a variety of products is in increase and includes gas turbine engines, and cutting tools to name a few. Perhaps the most difficult engine component imaginable for ceramic applications is the turbine blades in terms of thermal and mechanical stress. Typical values of blade specific stress for small engines are of the order of 100,000 psi. Allowing a safety factor of 3 for ceramic turbine blades, the desired specific strength exceeds 300,000 psi. For this reason alone materials technology in the field of Si3N4 and SiC has been directed towards further improvements in the processing and fabrication of these materials (126,127). Specifically such trends have also been concisely identified by Kelly (128).

These high temperature ceramic materials because of their thermal and hardness properties have found near-term application in such vehicular parts such as turbocharger rotors, piston rings and pistons, cylinder liners and small stationary engine parts.
Further, due to their hardness, the largest single use of these

TABLE V RANGES IN HOT PRESSING FABRICATION

| PRESS RANGE & APPLICATION | MOLD MATERIALS | SIZE LIMITS FOR FABRICATED PARTS |
|---|---|---|
| 1. 1,000-5,000 psi UNIAXIAL | GRAPHITE | UPTO 2ft IN DIAMETER |
| 2. 5,000-20,000 psi UNIAXIAL | SPECIAL GRAPHITES | |
| 3. 10,000-50,000 psi ISOSTATIC | $Al_2O_3$, SiC, $TiB_2$, $ZrB_2$ | INCREASED LENGTHS UP TO 20 - inch |
| 4. 50,000-300,000 psi UNIAXIAL | HIGH STRENGTH STEEL AND CEMENTED TUNGSTEN CARBIDE | 1 inch - 3 inch DIAMETER |
| 5. 300,000 - 750,000 psi | CEMENTED TUNGSTEN CARBIDE | ¼" - ½" DIAMETER |

advanced ceramics is for metal cutting tools and wear parts. On Table VI (next page), provides a list of major U.S. firm engaged in advance ceramic products (129).

Along with the U.S., another industrialized country which have been in the forefront of developing and agressively competing with the U.S., is Japan. Japan is strongly committed to the rapid development and exploitation of high-tech ceramics. The origin of Japan's commitment is a combination of economic necessity and opportunity. Basic industries such as aluminum and refractories are being threatened by the developing countries and survival thus dictates a move away from commodity to value-added products. There is a need to develop substitutes for critica' and strategic metals and to develop energy-efficient materials. These is also the desire to vigorously develop areas where Japan already has a high technology foothold such as the electronic automotive industries (130,131).

3.2.2 MATERIAL FOR INTEGRATED OPTICS:

Integrated optic (IO) circuits are optically guided wave devices that perform a variety of processing functions on the light beams which they guide. The largest end use for IC's is in fiber optic communication systems which includes both the military and commercial communications.

IO devices can be manufactured using single crystal ceramic materials such as lithium niobate as substrate because of its

# TABLE VI HEAT ENGINE AND PARTS **

## ENGINE DESIGN AND DEVELOPMENT

FORD MOTOR CO.
GARRETT CORP.
CUMMINS ENGINE CO.
GENERAL MOTORS CORP.
WESTINGHOUSE ELECTRIC CORP.
GENERAL ELECTRIC CO.
INTERNATIONAL HARVESTER CO.
HAGUE INTERNATIONAL CO.
TERRATEK INC.
CATERPILLAR TRACTOR CO.
PRATT & WHITNEY CO.

## CERAMIC MATERIALS AND PARTS

CARBORUNDUM CO.
NORTON CO.
CORNING GLASS CO.
COORS PORCELAIN CO.
CERAMTECH, INC.
GTE SYLVANIA
GENERAL ELECTRIC CO.
KAMAN SCIENCES CORP.
DOW-CORNING CO.
UNITED TECHNOLOGIES CORP.
AIRESEARCH CASTING CO.
CERADYNE INC.
DUPONT
CELANESE

## CUTTING TOOLS

KENNAMETAL, INC.
CARBOLOY SYSTEMS DEPT.
GTE WALMET CO.
TELEDYNE FIRTH STERLING
COORS PORCELAIN CO.
TRW/WENDL-SONIS
TALIDE METAL CARBIDES CORP.
ADAMS CARBIDE CORP.
BABCOCK & WILCOX

## WEAR PARTS

CARBORUNDUM CO.
GENERAL ELECTRIC CO.
NORTON CO.
COORS PORCELAIN CO.
ESK CORP.
ART INC.

** A COMPETIVIVE ASSESSMENT OF THE U.S. ADVANCED CERAMICS INDUSTRY
NTIS ACCESS NO. PB84-162288, MARCH 1984

desirable electooptical properties. Another such material is the gallium arsenide. These IO devices offer the potential for significant performance and cost saving benefits, in particular, for fiber optic systems.

IO devices are fabricated by diffusing waveguides or substrates made of materials that have large electrooptic effects. The waveguides or channels have higher indices of refraction than the underlying substrate material and allows them to contain and transmit light. Due to the large electroptic effect the index of refraction of the substrate material changes as voltage is applied. This change in the refractive index of the substance along with the geometry of the waveguide that determines the functions of the device.

Most optical glass and high tech ceramic materials for use in integrated optics are evaluated for having such desirable characteristics large electro-optic effect and ease of fabrication. The need for a large electro-optic effect is due to the fact that it allows for a shorter interaction distance, as such, a compact device. The change in refractive index in a particular crystallographic direction is related to the applied stresses by the electro-optic coefficient in that direction. The desired material must have a high value for the electro-optic coefficient (r) to induce a substantial effect that is close to being equal in various crystallographic directions.

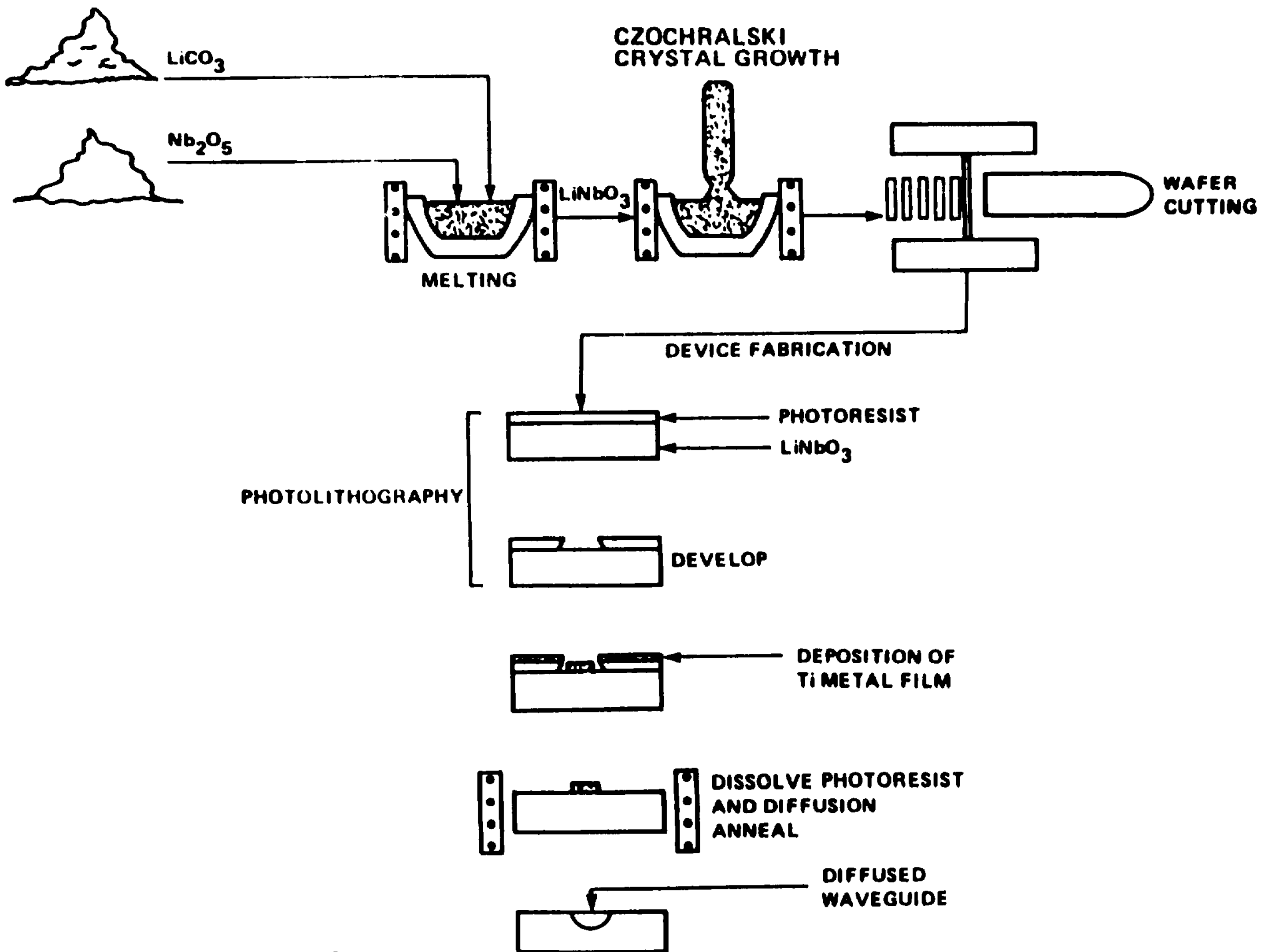
In this context, Ali et al had developed a family of high index glasses for use as IO couplers. Details on the materials and design development for the glass couplers are referenced (132-134).

Other preferred materials are from the family of single crystals-lithium niobate and lithium tantalate.

Lithium niobate is the preferred material due to the fact that it has relatively the same values of "r" in different crystallographic directions thus making it insensitive to the plane of polarization of the incoming light wave, and to the ease in fabrication. Other candidate materials include strontium barium niobate.

Lithium niobate is a relatively mature material. It is used in single crystal form and is grown from melt by the standard Czochralski method. Figure 12 (next page) describes the fabrication flow sheet for lithium niobate. The starting materials are:
lithium carbonate - a relatively cheap material and niobium pentaoxide, which is expensive. The two are mixed and melted in a crucible and a single crystal is pulled out from the molten melt. The final crystal is generally three inches in diameter and two feet in length. The crystal is cut into 1 millimeter wafers for producing waveguides.

FIGURE 12. FABRICATION FLOWSHEET FOR LITHIUM NIOBATE DIFFUSED STRIP WAVEGUIDE **




** Charles River & Associates; &
H. Kugelnik, Review of Integrated
Optics.,"
Fiber & Integrated OPtics., Vol. 1(3), 1978

The waveguides are made by having channels which are a few microns in diameter. Different kinds of devices - from couplers to switches and modulators are formed by changing the design of the channel patterns an electrode configurations. Figures 13,14 and 15 illustrates some basic IO devices and a schematic of a fiber optic system using lithium niobate waveguide devices (135-137).

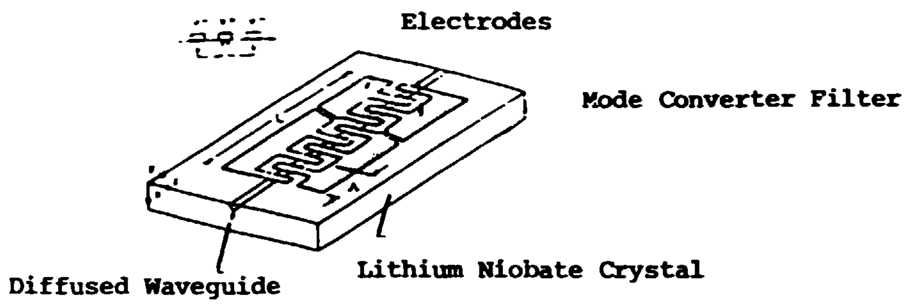
3.2.3 NDUSTRIAL SENSOR MATERIALS:

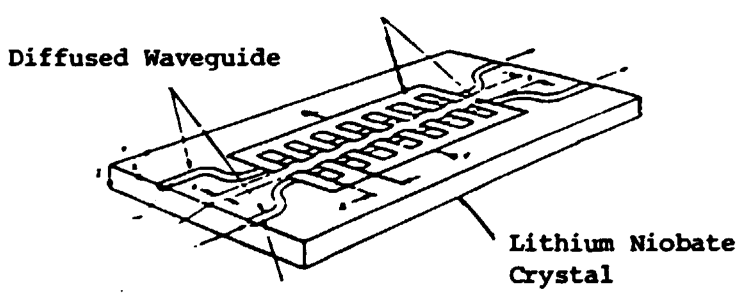
An important spin-off of space related technologies sensor materials and technologies could be effectively utilized in the developing countries. The sensors are useful in electrical and mechanical equipment and a whole grab bag of new industries and technologies offer hope and promise of new approaches to sensing. These includes solid state sensor, biosensors, fiber optic sensors, robot sensors and smart sensors (149).

What are these industrial sensors? Simply speaking a sensor is a small device that detects and or measures conductance, capacitance and resistance or self-generating effects into electrical signals. More precisely, it is a device which senses and quantifies a relative or absolute value of a physical or chemical phenomenon such as temperature, pressure, pH, flow rate or the intensity of radio, sound, light or air waves and converts into a useful signal (138-141).

FIGURE 13

SELECTED BASIC INTEGRATED OPTICS DEVICES

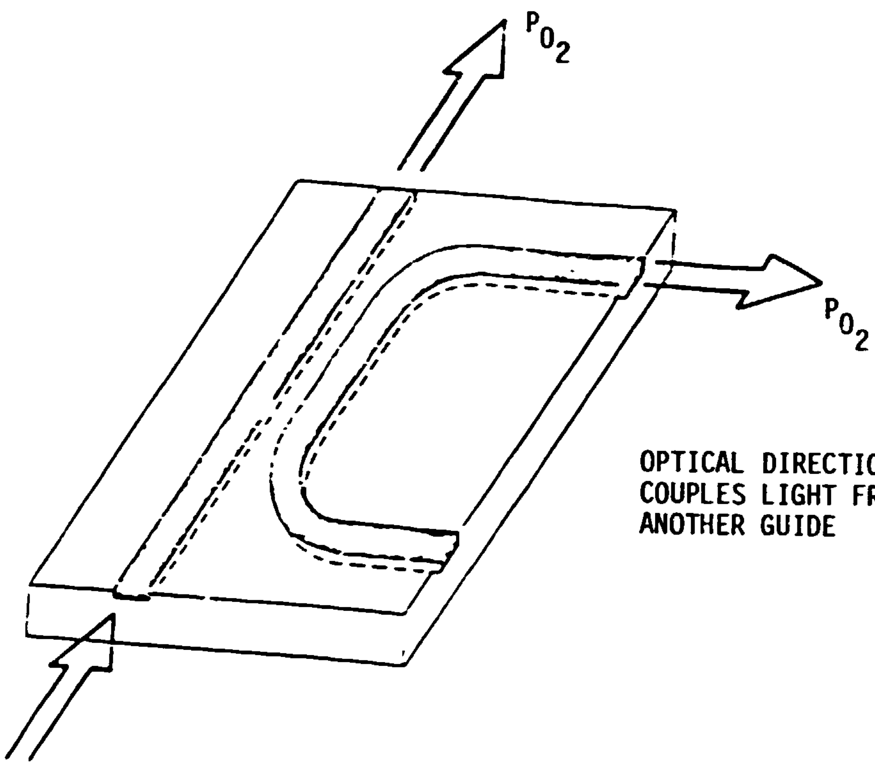


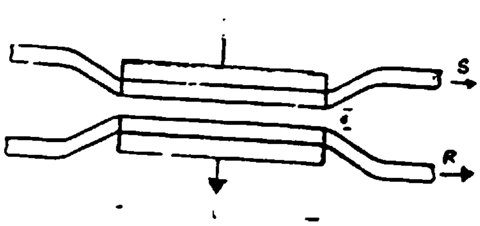

Polarization Independent Filter

SOURCE: H. Kugelnik, 'Review of Integrated Optics', Vol: 1 No. 3, 1978 & R.C. Alferness,'Guided-Wave Devices For Integrated OPtics', IEEE Journal of Quantum Electronics, Vol: QE-17(6), June 1981.

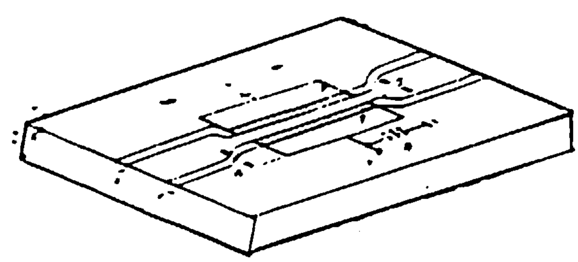
FIGURE 14 SOME BASIC INTEGRATED OPTICS DEVICES




OPTICAL DIRECTIONAL COUPLERS
COUPLES LIGHT FROM ONE GUIDE TO ANOTHER GUIDE



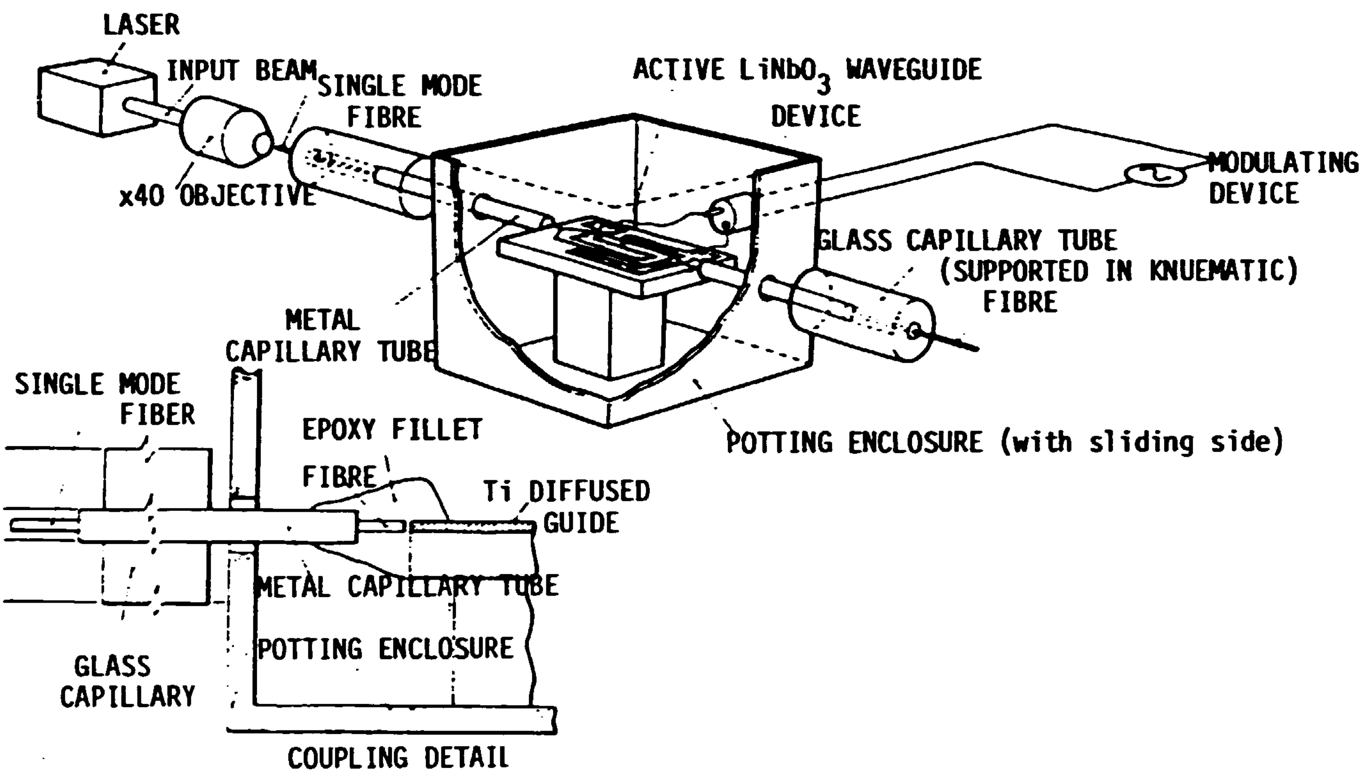

2. OPTICAL DIRECTIONAL COUPLER SWITCH SWITCHES LIGHT ON/OFF BETWEEN GUIDES.



3. HIGH-SPEED DIRECTIONAL COUPLER MODULATOR ALTERS PHASE, POLARIZATION FREQUENCY, OR AMPLITUDE

SOURCE: H. KUGELNIK, "REVIEW OF INTEGRATED OPTICS" FIBER AND INTEGRATED OPTICS, V.1(3) 1978
R.C. ALFERNESS, "GUIDED WAVE DEVICES FOR INTEGRATED OPTICS" IEEE JOURNAL OF QUANTUM ELECTRONICS V. QE-17(6) JUNE 1981

FIGURE 15 SCHEMATIC OF FIBER OPTICS SYSTEM UTILIZING LITHIUM NOIBATE WAVEGUIDE DEVICE




SOURCE: FIRST EUROPEAN CONFERENCE ON INTEGRATED OPTICS, Sept. 1981, pp. 11

Solid state sensing devices are made from a variety of materials including single crystals, semiconducting and polycrystalline materials. However, silicon, due to a number of its sensitive characteristics, is a useful sensing material. The material can be combined with other materials such as piezoelectric materials which makes it sensitive to acceleration, mechanical vibration and direct measure of electronic potentials.

One of the important application of silicon sensors utilizes the near perfect characteristics of silicon - its elasticity for sensing pressure(142). Other applications includes micro-electronic and for sensing magnetic field (143). Other similar magnetosensitive devices include a CMOS magnetic field sensor and a carrier-domain magneto-meter (144).

One barrier to full industrial automation has been a lack of instrumentation for use in industrial environment. Space related technologies had resolved the problem by the development of noninvasive and noninstrusive instruments. Another term used to describe these instruments is by the technique of nondestructive testing or NDT. For space applications an equipment is often allowed to retire often a given number of hours, miles or similar unit of measure even though the spacecraft or equipment may be perfectly good. This is achieved by NDT to find incipient failures.

In this context a device was developed using a small Yttrium iron garnet (YIG) sphere of about 30 mil diameter looped around with a single turn of wire. The device becomes a resonant element in an oscillator circuit. The frequency and amplitude of the oscillator provides the information relating to the condition of the resonator which is affected by cracks, flaws, etc. The idea was developed by Auld at Stanford University and perfected at Batelle Pacific Norwest Laboratories (145).

Solid state imaging devices are being used in robot sensors or robot vision wherein information is obtained without disturbing the environment (146), such as in charged-coupled device - CCD (147,148). Currently CCD's are of the size of postage stamps, have low voltage requirements and generate direct digital output and registers good image.

Robotic sensors are also being used in welding where a major application is in seam tracking and for robotic seam welding (150-152).

The greatest impact of the space related sensor technology for indi trial applications has been in the area of optical fiber sensor technology. Development of fiber optic sensors started around late seventies - 1977. Fiber optic sensors offer a number of advantages over existing techniques and includes geometric verstability, rotation and can be used in corrosive, high voltage, electrically noisy and other stressing environments such as arc welding (153-155). A review paper by Giallorenzi et al with 133 references presents the current state-of-the-art of optical fiber sensors (156). The paper further points out the various advantages and industrial applications of fiber optics sensors. In conclusion he highlighted the interferometric sensors which benefited most from fiber optics technology. By changing the cladding (coating) material of the fiber optics the sensing could be changed from an acoustic to a magnetic element. As an example he cited a metal coating on fiber for making magnetic sensor and polymeric coating to enhance the acoustic sensing (157).

Industrial Sensor (149) in their comprehensive report has given a great significance to fiber optic sensors and cites and variety of industrial applications. Due to the extra-ordinary growth in the field of optical communications, the potentials for converting optical signals to electronics are becoming obvious. As such, a variety of new technologies seems to offer new approaches to the sensing problem. A list of various appplications are cited for references (158-162).

## 4.0 TRANSFER OF SPACE RELATED TECHNOLOGIES TO DEVELOPING COUNTRIES:

The previous sections described the space-related materials, processes and technologies which has the potential for applications in the developing countries. This section describes the efforts made and outlines potential mechanisms for the transfer of space-related technologies to the developing countries.

The extent to which space technology has influenced and revolutionized our lives will be judged through the consideration of its non-space applications - an area controlled by the concepts of innovations and discoveries and probably by the guiding objectives of Space Technology.

In this context the constructive role of the U.S. National Aeronautics & Space Administration (NASA) has been very cooperative and several developing countries has benefited (163).

Further, in recent times NASA has published a compilation of its own significant patents and inventions for licensing in foreign countries (164). The objective of the program is to extend the patent coverage for valuable NASA-owned inventions to various foreign countries and to advance the international technical assistance programs and projects of the United States.

UNIDO, within the U.N. system, is playing a unique role in transfering space-related technologies to the developing countries. At the UNISPACE-82 Conference the author wrote an in-depth paper outlining selected space-related technologies to sensitize developing countries on the potentials and limitations of such advances (165).

It is a recognized fact that space-related technologies (or spin-offs) has brought benefits to many countries. While most developing countries use space technology they have not yet fully exploited its considerable potentials.

Further, it is also a recognized fact that space related technologies can be a powerful tool for accelerating national development. It provides a way to take a giant step over obsolete technologies and getting away from percolation and run down models of development for which developing countries do not have the time.

Space technology offers the potential to spur industrial and economic and social development of all countries. The necessary resources and technological potentials exist for eliminating the under development of the developing countries. Although there are several fields that are being pursued by the developing countries, but none relates to materials processing and technologies as identified in this report. As such, in the context of this report such fields of application are being addressed.

## 4.1 POTENTIAL FIELDS OF APPLICATIONS:

The variety and list of space-related materials processes and technologies are quite substantial. This report covers selected high tech processes and technologies that has the potential for successful transfer and adaptation in the developing countries. In this content it is important to note that the technological progress made by the developing countries in their field of space sicence and technology has been quite substantial and was documented at the UNISPACE-82 Conference (166).

Materials related processes and technologies identified in this report (Section 3.0) are a broad based technical field which has wide application for both internal applications and as a high-price export item as these technologies are also new for the developed countries.

It needs to be emphasized that it is neither necessary nor imperative that the developing countries always have to follow the lead of the developed countries in establishing new processes, technologies and industries. If a developing country has the technical base and infrastructure then they can start the industrial development venture.

This report had identified selected spin-offs of spacerelated materials processes and technologies which has both present and future industrial potential for the developing countries. Further, these technologies are new and find applications both for internal applications of the developing countries and also as a high-priced, high tech and low cost export material. The low manufacturing cost of the end product and material is due to the use of indegineous raw materials which are getting scarce for the developed countries. In this context high-tech ceramics is a very good example and its applications are covered in detail. Likewise, materials and technologies for the integrated optics and industrial sensors, in a proper industrial environment, has the potential for providing a quantum jump for the developing countries having the necessary industrial infrastructure.

## 4.2 ECONOMIC ESTIMATE:

The form or dimension in which economic benefits are expressed depends on the type of product and user. For some products and users it may be defined by one single term and for others by the trade-off between several terms or the combined benefits encountered by various users (for example, the material producer, the product manufacturer and the country). For the total effectiveness a further trade-off is necessary between the gains and negative factors, that is, investment and return. The cost of research and development is always a negative factor.

However, in the context of the spin-offs of space-related technologies there is no R&D cost. These are the proven technologies and needs transplantation in a manufacturing environment for an immediate return or investment.

In this context, again NASA had funded several mission oriented studies involving applications of aerospace technology in selected industries (167-169). All these studies indicated that there is no single method to develop economic cost estimates which can be relied upon. This is due to the fact that the investment required to develop and manufacture would depend on the local industrial base and infrastructure of the developing country. Clearly, the economic estimates should take into consideration:

A. The technical and industrial needs of the country,

B. Its priorities

C. The feasibility of meeting these needs and priorities through the use of space-related technologies,

D. The financial, resources, the industrial infrastructure and the technological capabilities of the country,

E. The availability of matching scientific and application-oriented as well as managerial and decision-making infrastructure and human resources required for effective utilization of data and of the information derived therefrom.

It is therefore obvious that there can be no fixed formula of universal validity. It is equally evident that costs and benefits of utilizing space related technologies in the developing countries would vary from country to country and situation to situation.

Thus, each choice of a space-related technology by a developing country has to be unique: a decision based upon the parameters of its particular context. This requires that each country carry out studies regarding costs and benefits.

## 4.3 TECHNICAL SKILL REQUIREMENTS:

Materials related processes and technologies identified in this report do not involve any new disciplines but are mainly a trans-disciplinary combination of well-established fields including physics, chemistry, mathematics, electronics and various engineering disciplines which includes mechanical, structural and chemical engineering. Many developing countries do have at least some infra-structure in these fields, and can therefore, with only marginal help, develop a core of people who understands and can in the first instance, make decisions regarding space-related technologies and applications relevant to their country.

Further, most developing countries do have small nuclei of technical experts which needs to be identified and expanded through suitably tailored national and international efforts on advance education and training: Where necessary, UNIDO and such U.N. agencies could help the developing countries to develop their expertise by arranging fellowships for training and visits to appropriate center.

In this context UNIDO should support the establishment of Materials Research Centers at regional level, linked whenever possible, to potential manufacturing centers or industrial complexes. These could be located in developing countries that have active space programs. Necessary fundings for such centers should be made available through UNIDO and or international financial institutions. These training centers, with UNIDO's assistance if necessary, should organize regular training courses of varying durations for different levels of trainees from the developing countries. In the long term, technicians training should be done nationally and these regional centers should become centers for excellence and high level training and exchange of knowledge through seminars etc. The faculty should be internation.ı and drawn from developed and developing countries. Besides t..e need for technologists and application specialists there may also be a need for developing a cadre of technical .nagers for the planning and speedy implementation of technological as well as application programs. E. lly important is that with the growing role of space-related technologies, developing countries also induct appropriate technologists and application-oriented specialist from various disciplines into the administration or governemnt decision making machinery. This will certainly unable countries to make better choices and to derive greater benefits from the spin-offs of space related technologies through more efficient and knowledgeable procedures of integrating the results and services from space applications into the decision making process.

As indicated at the UNISPACE-82 Conference, a few developing countries now have both the human resources and the industrial infra-strucutre to implement the spin-offs of space-related materials technologies for various industrial applications. This is a very important capability because this can be effectively utilized for the transfer of technology from one developing country to another. There is further scope here for joint effort among the developing countries - a pooling of human, industrial and financial resources by grouping of developing countries. The following table provides some selected economic factors that needs to be considered.

## TABLE VII

**FACTORS AFFECTING USE OF NEW MATERIALS PROCESSES & TECHNOLOGIES**

**- ECONOMIC FACTORS -**

| | | | | | |
|---|---|---|---|---|---|
| CONSTRAINT | HIGH MATERIAL COSTS<br><br>UNCERTAIN MATERIAL COST PREDICTIONS | HIGH FABRICATION COSTS<br><br>UNCERTAIN FABRICATION COST PREDICTION | SHORTAGE OF RESOURCES AND PRODUCTION FACILITIES AND LACK OF FIRM ORDERS CONTRIBUTE TO EXCESSIVE DEVELOPMENT TIME | SIZE AND AMOUNT OF MATERIAL REQUIRED TO EVALUATE FOR USE, AND TO BE ACTUALLY REPRESENTATIVE OF SIZE TO BE USED, CAN BE COSTLY FOR PRODUCER (i.e. REQUIREMENT FOR HEAVY ALUMINUM PLATE) | LACK OF FACILITES FOR MATERIAL PRODUCTION AND HARDWARE FABRICATION |
| POSSIBLE SOLUTION OR ACTION | MATERIAL PRODUCER SHOULD BE ENCOURAGED TO LOWER MATERIAL COSTS. NONAEROSPACE USES OF MATERIALS SHOULD BE SOUGHT TO BROADEN USAGE BASE.<br><br>A GOOD PREDICTIVE METHOD OR SOUND ESTIMATE ON FUTURE ANTICIPATED COST TRENDS WOULD HELP THE SYSTEM PLANNER IN HIS FORWARD PLANNING.<br><br>MATERIAL INFORMATION CENTERS HSOULD ESTABLISH A GOOD HISTORICAL BASE OF COSTS AND DISSEMINATE INFORMATION REGARDING IMPROVED ESTIMATING TECHNIQUES.<br><br>OVERCOME COST-VOLUME BOTTLENECK BY INCREASING USAGE VOLUME THROUGH CONTRACTUAL INCENTIVES. | IMPROVED AND NOVEL APPROACHES TO TOOLING AND MANUFACTURING METHODS BY DEVELOPMENT CONTRACTS OR INCENTIVE CLAUSES IN SYSTEMS CONTRACTS. | CREATION OF SOURCES, FACILITIES AND DEMAND IN ADVANCE OF PRODUCTION REQUIREMENTS SEEMS ONLY WAY TO ATTACK THIS CONSTRAINT. A JOINT INDUSTRY, USER, GOVERNMENT PLANNING ACTIVITY APPEARS NECESSARY.<br><br>JOINT PROGRAMS TO ESTABLISH CAPABILITY SUCH AS GIANT PRESS, SPECIAL EXTRUSION FACILITIES, AND EQUIPMENT POOLS, IN ADVANCE OF NEED ARE WARRANTED. | POTENTIAL USERS SHOULD AID PRODUCERS TO ESTABLISH USE PARAMATERS FOR NEW MATERIALS, SHPAES, OR FORMS. THE GOVERNMENT MAY FIND IT NECESSARY TO SUPPORT INITIAL PARAMETERS DETERMINATION WHERE LARGE QUANTITIES OR SIZES BEYOND PRODUCERS' RESOURCES ARE INVOLVED. | IF BENEFITS FROM USE OFFSET FACILITY COST THIS IS SELF-MOTIVATING.<br><br>COMMITEMENT OF FUND: FOR PILOT SIZE TRIALS.<br><br>CONTRACTUAL INCENTIVES OR RAPID RECOVERY THROUGH TAX ADJUSTMENT FOR SPECIAL FAC. FOR NEW MATERIAL.<br><br>ENCOURAGE THE DEV. OF UNIV. M/C SUCH AS DIGITALLY GUIDED TAPE LAYERS, LARGE PRESSES, BY GOVT. FUNDING OR FAST TAX WRITEOFFS. |

## 5.0 CONCLUSIONS

It is clear from previous sections that:

A. The spin-offs of space-related materials, processes and technologies have been commercialized in several industrialzed and developed countries.

B. These technologies have predictable prospects of development in the developing countries, both, for a variety of internal applications and also as an export-item to the developed countries.

Further, the previous sections has indicated that are two types of material-related space technologies that are currently available for transfer/adaptation by the developing countries - one relates to materials related technologies that are being developed for in-space processing and eventual industrialization of space. This is an area in which those developing countries who have already established a foot hold can keep pace with the developed countries.

Manufacturing of materials in space using terrestrial or extra-terrestrial raw materials is an important are in the developing countries also. Crystal growth, synthesis of materials and other manufacturing experiments may lead to a 'space industry' in these areas in the future. While such commercialization of these processes could lead to scientific insights, new materials and higher quality and lower cost of exisitng materials, the benefits of these would be available mainly to those who can make the necessary investments in such space technologies now.

The second category relates to specific material such as high-tech ceramics (or fine ceramic) and carbon/graphite composites and similar materials that were developed for space applications. However, these materials have found a wide variety of applications here on earth, as such, they are being manufactured and extensively utilized in such high performance applications as ceramic engines, rotor blades and cutting tools. The proven technologies are available and depending on the infrastructure, industrial needs and potentials of a country, can be transferred.

The transfer of such technologies needs a focal point - a go between those who have the knowhow and those who need them.

In this context UNIDO can play a vital role. Being an U.N. agency, it has and can be an industrial bridge for transfering materials - related space technologies to the developing countries. Later on, these experiences could be utilized for similar space related technologies.

Such roles should be both passive and active ranging from promotion of greater cooperation in space science and technology between developed and developing countries to the setting up UNIDO supported Materials Research Centers on a regional basis.

With this broad consensus, one must accomodate the basic concept that change is necessary not only for survival but also is the only means for growth and development. This is also true for the Industrial development of the developing countries.

The elaborate structure of present day society is not only in the highly industrialized countries, such as the U.S., but throughout the world rests ultimately on a material base and on the institutions that provide and utilize materials technology. Whether or not this condition is a good thing is irrelevant; it is a fact and result of an irreversible process and mankind must make the best of it. Every developing country can be considered to have a strategy for the materials field. It may be to develop rigid and comprehensive five-year plans or it may be to ignore the issues and let events take their nautral course or somewhere in between. Either way, consciously or by default, a strategy has to be chosen.

Space-related material technologies now span over a wide spectrum of industries. Likewise, there are a variety of applications. It is within this bewildering array of possibilities that a developing country must make choices about what applications and which technologies it wishes to pursue. Clearly, the choices must be determined by:

a. The needs of the country

b. The priorities

c. The feasibility of meeting these priorities through the use of materials developed through space-related technology.

d. The industrial infra-structure, financial resources and the technological capabilities of the country.

e. The availability of matching scientific, industrial, and application-oriented as well as managerial and decision making infrastructure and human resources required for effective utilization of data and of the information derived therefrom.

It is therefore obvious that there can be no fixed formula of universal validity. It is equally evident that costs and benefits of space applications also will vary from situation to situation and from country to country. Thus, each choice of a space-related technology by a developing country has to be unique: a decision based upon the parameters of its particular context. This requires that each country carry out studies regarding costs and benefits before deciding upon the adaption of a particular application. Such studies should take into account not only the economic aspects, but also technical and social effects that may result from the use of space technology.

Many of the developing countries may not themselves have all the expertise necessary for such inter-disciplinary studies. In such situations the role and input of UNIDO becomes obvious. In many cases, assistance may not be required for basic decisions regarding whether to get into a specific application; rather, it may be required for choices of systems, type of equipment and selection of the most suitable methodological approach to tac the problem. The latter is a particularly improtant element, because it has a significant bearing on the choices of the most appropriate system or instrumentation and thus also determines other parameters such as cost, organizational set-up, degree of self reliance, extent of indigineous participation possible, etc. Here again, UNIDO can provide assistance to the developing coutries. These are all policy issues.

The translation of policy issues into the framework of specific industrial policy requires, guidelines or recommendations for a program and is addressed in the following section.

## 6.0 RECOMMENDATIONS

A coherent and effective program of policy measures for the introduction of space-related technologies in developing countries requires an acceptance of the fact that space science and technology has provided many practical benefits and an increase in knowledge. The years ahead hold promise of even greater and possibly more revolutionary benefits in fields ranging from materials sciences, astronomy, space biology, satellite communications to large structures in space and new technogies for remote sensing, The recommendations that follows aim at realizing these potentials.

Also, it is often times argued that basic science in general and space science in particular are not important for developing countries who are pressed with practical problems. This may not be correct. Besides, the fundamentals argument is that an understanding of the universe we live in is important in its own right, and, it is often true that initiatives in space applications have most often been taken by people who were earlier motivated by their interest in space science.

1. As such, it is recommended that there should be an encouragement of space science and technology at the universities and institutions in the developing countries. Such programs would provide an important stimulus and strong support to the industrial development and practical applications of space technology in the developing countries.

2. It is also recommended that serious consideraion be given by UNIDO for the development of a fellowship program for the training of space technologist and application specialists from the developing countries. Scuh training facilities should be worked out at the industries, technical centers and similar operations dealing with the materials related spin off's of space technologies.

3. In the case of space science missions, launching experimental payloads and crews on spacecrafts, there should be more cooperation between the developed and developing countries. In the past a healthy tradition had been established and it is important such cooperation to continue and be further encouraged. Major space observations to be set up in the future should be located in the developing countries and be open for qualified scientists and experimenters from all countries.

Further, it is essential that the results of experimentation continue to be widely disseminated and readily available to scientisits working in these areas in the developing countries.

4. The spin-off's of materials related space technologies such as those identified in this report are high-tech materials. The developing countries, based on their own infrastructure and needs, should evaluate these and similar materials for transfer and or adoption.

5. UNIDO should initiate a model materials - related space technology transfer study for a developing country wherein all the essential elements of transfer should be addressed. Such a study would provide important and relevant data relating to the position of developing countries and their inherent advantages and disadvantages.

6. There is a need and desireability for setting up a division/section at UNIDO dealing with space-related technologies for the developing countries. Such a division/section should exclusively look into the industrial aspects of space-related technologies and the transfer of such technologies to the developing countries.

7. There is a need and desireability for expanding UNIDO's Industrial Information Service so as to accomodate an International Space Information Service. Such a service should be able to provide complete information on space-related technologies.

8. For the implementation of item 7 it is suggested that UNIDO's Industrial Information Section should look into the operational mechanics of the U.S. National Aeronautics and Space Administration's (NASA) Industrial Application Centers (NIAC).

9. It is also suggested that UNIDO's Technology Programme Section or similar section should have a Space Related Technology Team which would be a bridge, a go-between mechanism for the transfer of space related technologies from the developed to developing countries. The scope of such a team should include bt not limited to working with the member states, government and private industries and technical institutes for applying aerospace - related technologies for application in the industrial sector of developing countries.

## 7.0 ACKNOWLEDGEMENT

The multi-disciplinary nature of the various aspects of this report necessitated cooperations from agencies and input from a number of professional colleagues, as such, the author would like to acknowledge their input, suggestions and cooperations.

Literature search and related information for this report came through NASA - Industrial Application Center (NIAC), University of Southern California, Los Angeles, California. The computer - based literature search at NIAC was provided by Martin Zeller - his patience and constructive suggestions are sincerely acknowledged.

Several of my professional colleagues provided suggestions and assisted in the location and identification of pertinent articles, books and specific technical publications. As such, I would like to acknowledge the cooperation of Murray A. Schwartz, at the U.S. Bureau of Mines, Washington, D.C.; Dr. Seymour L. Blum, Vice President, Charles River & Associates, Boston, MA; Dr. Tappan Mukherjee at National Science Foundation - N.S.F., Washington, D.C.; Mark L. Kieffer, International Affairs Division, NASA, Washington, D.C.; Edward Hartouni and William W. McCracken, General Dynamics, Pomona, CA and Judy Briles at the Industrial & Economics Management Division, Denver Research Institute, Denver, CO.

Finally, I would like to thank UNIDO's Division of Industrial Studies--in particular the suggestions and encouragement of Dr. G.S. Gouri, and patience and lot of patience from Dr. K. Venkataraman, Senior Technical Advisor, UNIDO, is sincerely appreciated and gratefully acknowledged.

## REFERENCES

1. "SECOND UNITED NATIONS CONFERENCE ON THE EXPLORATION AND PEACEFUL USES OF OUTER SPACE" DRAFT REPORT OF THE CONFERENCE NO. A/CONF. 101/3, VIENNA, AUSTRIA, 9-21 AUGUST, 1982

2. A.K. CHAKRABARTI, et al., "THE EFFECT OF TECHNO-ECONOMIC & ORGANIZATIONAL FACTORS ON THE ADOPTION OF NASA INNOVATIONS BY COMMERCIAL FIRMS IN THE U.S.", NORTHWESTERN UNIVERSITY, EVANSTON, ILLINOIS, U.S.A. 1972

3. S. UCCETTA, "PILOT PROJECT IN TECHNOLOGY TRANSFER TO A DEVELOPING NATION", AMERICAN SOCIETY MECHANICAL ENGINEERS, WINTER ANNUAL MEET, NEW YORK, N.Y. DEC: 5-10 1976

3a. J.M. CARLSON, "TECHNOLOGY TRANSFER - THE NASA PERSEPCTIVE", IN: TECHNOLOGY TRANSFER: SUCCESSES AND FAILURES, PROCEED OF CONF. SEATTLE, WA, NOV. 28-30 1972 (A74-30116 13-34) SAN FRANCISCO PRESS, INC. SAN FRANCISCO, pages 148-155, 1974

4. M. AKBAR ALI, "SUBSTITUTION OF PLATINUM METAL CRUCIBLE USED IN THE GLASS INDUSTRY", U.S. DEPARTMENT OF INTE[illegible]EAU OF MINES CONTRACT NOS: J0123056 & J0113098" GLASS & CERAMICS INTERNATIONAL, LOMITA, CA AUGUST 1984

5. M. AKBAR ALI et al., "SPACE PROCESSING OF CHALCOGENIDE GLASSES", NASA CONTRACT NO. NAS8-30627, IIT RESEARCH INST., CHICAGO, IL FEB. 22, 1975 - FEB. 21, 1976

6. G.F. NEILSON et al., "OUTER SPACE FORMATION OF LASER HOST GLASS", JR. OF NON-CRYSTALLINE SOLIDS, VOL. 23, NO. 1, 43-58, JAN. 1977

7. H. WIEDEMEIER, "CRYSTAL GROWTH FROM THE VAPOR PHASE" ASTP FINAL REPORT, pp. VII-1 TO VII-40, ALSO, JR. ELECTRO CHEMICAL SOCIETY, 124: 1095-1102 (1977)

8. H.C. GATOS et al., "INTERFACE MAKING IN CRYSTALS", NASA TECHNICAL MEMO TMX-73360, NASA-MARSHALL SFC, PP. V-1 TO V-65, JAN. 1977

9. E.V. MARKOV et al., "INFLUENCE OF SPACE CONDITIONS ON DIRECTIONAL CRYSTALLIZATION OF GERMANIUM AND ITS PROPERTIES" PROC. 3RD EUROPEAN SYMP ON MATERIALS SCIENCE IN SPACE, GRENOBLE, APRIL 1979

10. A.S. OKHOTIN et al., "EXPERIMENT 'SYRENA' 1,2,3 - SPACE PROCESSING OF CdHgTe, CdHgSe & PbSeTe,", PROC. 3RD EUROPEAN SYMPOSIUM ON MATERIALS SCIENCE IN SPACE, GRENOBLE, APRIL 1979

11. MATERIAL SCIENCES IN SPACE, PROC OF THE THIRD EUROPEAN SYMPOSIUM, GRENOBLE, APRIL 1979

12. MATERIALS PROCESSING IN SPACE, REPORT OF THE COMMITTEE ON SCIENTIFIC AND TECHNOLOGICAL ASPECTS OF MATERIALS PROCESSING IN SPACE, PUBLISHED BY: NATIONAL ACADEMY OF SCIENCES WASHINGTON, D.C. 1978

13. SPACE PROCESSING OF MATE , POSITION REPORT AM. ASTRONAUT SOC., SAN DIEGO, CA 1977

14. SKYLAB EXPERIMENTS VOL 3 MATERIALS SCIENCE., NASA WASHINGTON D.C.

15. SPACCE SHUTTLE; NASA - LYNDON B. JOHNSON SPACE CENTER, HOUSTON, TX pp. 14-15, FEB. 1975

16. "FEASIBLITY STUDY OF COMMERCIAL SPACE MANUFACTURING" VOLUMES I, IIA-IIF AND VOL. III," NASA CONTRACT-NO NAS8-31353, MC DONNELL DOUGLAS ASTRONUATICS CO., 1975

17. "FEASIBILITY STUD OF COMMERCIAL SPACE MANUFACTURING" PHASE II - VOLUME I & II", NASA CONTRACT NO NAS8-31353, MC DONNELL DOUGLASS AERONAUTICS CO. 1977

18. SINGLE CRYSTAL RIBBON PILOT LINE, AFML-TR-69-162, TEXAS INSTRUMENTS, INC. DALLAS, TX OCT. 1969

19. F.A. PADOVANI et al., "GROWTH OF A SINGLE CRYSTAL RIBBON IN SPACE" TEXAS INSTRUMENTS, INC. REPORT #03-72-121, DALLAS, TX MAY 1973

20. "SHOULD WE INDUSTRIALIZE SPACE" MFS-23963, NASA TECH BRIEFS VOL. 5, NO. 1, SPRING 1980

21. UNISPACE-82 CONFERENCE, 2ND U.N. CONFERENCE ON THE EXPLO. & PEACEFUL USES OF OUTER SPACE, VIENNA, AUSTRIA, AUG. 1972

22. P.L. WALKER, CHAPTER ON "ULTRAFINE CARBON", ELECTROCHEM. SOCIETY SYMPOSIUM, PUBLISHED BY JOHN WILEY AND SONS, N.Y. PAGE 297, 1973

23. L.C. BLACKMAN, "MODERN ASPECTS OF GRAPHITE TECHNOLOGY", ACADEMIC PRESS, NEW YORK 1970

24. R.J. DIEFENDORF et al., "HIGH PERFORMANCE CARBON FIBERS" POLYMER ENGINEERING SCIENCE, 15 pp. 150-159, 1975

25. D.J. JOHNSON, "MICROSTRUCTURE OF VARIOUS CARBON FIBERS", PROC.: 1ST INTERNATIONAL CONFERENCE ON CARBON FIBERS, THEIR COMPOSITES & APPLICATIONS, PUBLISHED BY PLASTICS INSTITUTE, LONDON, ENGLAND, PAGES 52-56, 1971

26. D.J. JOHNSON, "RECENT ADVANCES IN STUDIES OF CARBON FIBER STURUCTURE," PHIL TRANS. R. SOC. LOND., A-294, PP. 443-449 1980

27. A. FOURDEAUX, R. PERRET AND W. RUHLAND, "GENERAL STRUCTURAL FEATURES OF CARBON FIBERS, " PROC. 1ST INTERNATIONAL CONFERENCE ON CARBON FIBERS, THEIR COMPOSITES AND APPLICATIONS, PLASTIC_INDSTITUTE , LONDON, pp. 57-67, 1971

28. W.N. REYNOLDS, "STRUCTURE AND PHYSICAL PROPERTIES OF CARBON FIBERS," CHEMISTRY_AND_PHYSICS_OF_CARBON_-_VOL._2, EDITED BY: P.L. WALKER et al., PUBLISHED_BY_MARCEL_DEKKER, MAIDENHEAD, BERKSHIRE, ENGLAND pp. 2-68, 1973

29. W.N. REYNOLDS et al., "SOME FACTORS AFFECTING THE STRENGTHS OF CcARBON FIBERS," PHIL_TRANSRAY_SOC._LONDON, a-294, pp. 451-461, 1980

30 C.G. HARMON, "NON GLASSY INORGANIC FIBERS AND COMPOSITES," NASA_SP-5055, AUG. 1966

31. L. STEG, "WHISKER AND SHORT FIBERS REINFORCEMENTS," SAE REPORT 660640, AERONAUTICS & SPACE MEETING, LOS ANGELES, 1966

32. D.L. SCHMIDT & H.T. HAWKINS, "FIBEROUS CARBON REINFORCEMENTS," SPE, RETEC. CONFERENCE, SEATTLE, WA 111, 1965

33. J. ECONOMY, "PRESENT STATUS & FUTUPE FOR HIGH STRENGTH FIBERS," SAMPE_JR., VOL. 12, pp. 5, NOV./DEC. 1976

34. U.S. PATENT NO. 3,107,152 - "FIBEROUS GRAPHITE , OCT.1963

35. U.S. PATENT NO. 3,107,180 - "PROCESS FOR DEPOSITION OF PYROLYTIC GRAPHITE," 1963

35. U.S. PATENT NO. 3,235,323 - "HEAT RESISTANCE BLACK FIBERS FROM RAYON", 1966

36. U.S. PATENT NO. 3,242,000 - "INPREGNATED ACRYLIC TEXTILE PRODUCTS", 1966

37. U.S. PATENT NO. 3,285,696 - "PREPARATION OF FLEXIBLE CARBON FIBERS", 1966

38. U.S. PATENT NO. 3,125,404 - "HEAT RESISTANT FIBEROUS PRODUCTS AND METHOD OF MAKING", 1964

39. U.S. PATENT NO. 3,179,605 - "MANUFACTURE OF CARBON CLOTH", 1965

40. U.S. PATENT NO. 3,304,148 - "CARBON CLOTH ANNEALING PROCESS", 1967

41. U.S. PATENT NO. 3,313,597 - "METHOD OF CONTINUOUS GRAPHITIZATION OF CARBON THREAD", 1967

42. U.S. PATENT NO. 3,333,926 - "CARBON CELLULOSIC TEXTILE MATERIALS", 1967

43. U.S. PATENT NO. 3,367,812 - "PROCESS FOR PRODUCING CARBONIZED ARTICLES", 1968

44. U.S. PATENT NO. 3,378,345 - "PROCESS FOR PRODUCING PYROLYTIC GRAPHITE WHISKERS", 1968

45. U.S. PATENT NO. 3,392, 2[illegible]6 - "PRODUCING CARBON STRUCUTURES" 1968

46. U.S. PATENT NO. 3,395,970 - METHOD OF CARBONIZING POLYACRYLONITRILE", 1968

47. U.S. PATENT NO. 3,399,252 - "METHOD & APPARATUS FOR MANUFACTURING HIGH STRENGTH HIGH MODULUS CCARBON FILAMENTS" 1968

48. U.S. PATENT NO. 3,412,062 - "PRODUCTION OF CARBON FIBERS" 1968

49. U.S. PATENT NO. 3,427,120 - "PRODUCING METHOD OF CARBON MATERIALS", 1969

50. U.S. PATENT NO. 3,443,899 - "PROCESS FOR MAKING GRAPHITE FIBERS", 1969

51. U.S. PATENT NO. 3,449,077 - "DIRECT PRODUCTION OF GRAPHITE FIBERS", 1969

52. U.S. PATENT NO. 3,454,362 - PRROCESS FOR PRODUCING FIBEROUS GRAPHITE", 1969

53. U.S. PATENTT NO. 3,461,082 - METHOD OF PRODUCING CARBONIZED LIGNIN FIBER", 1969

54. U.S. PATENT NO. 3,503,708 - "GRAPHITE YARN", 1970

55. U.S. PATENT NO. 3,529,934 - "PROCESS FOR PREPARING CARBON FIBERS", 1970

56. U.S. PATENT NO. 3,533,743 - "MANUFACTURE OF CONTINUOUS HIGH MODULUS CARBON FILAMENTS", 1970

57. U.S. PATENT NO. 3,552,923 - "PRODUCTION OF CARBON FIBERS" 1971

58. U.S. PATENT NO. 3,629,379 - "CARBON FILAMENTS FROM LOW PRICED PITCHES", 1971

59. U.S. PATENT NO. 3,635,675 - "PREPARATION OF GRAPHITE YARN" 1972

60. U.S. PATENT NO. 3,702,054 - "PRODUCTION OF GRAPHITE FIBERS" 1972

61. U.S. PATENT NO. 3,705,236 - "METHOD OF PRODUCING CARBON FIBERS", 1972

62. U.S. PATENT NO. 3,718,574 - "METHOD FOR HEAVYING POLYCYLIC SUBSTANCES", 1973

63. U.S. PATENT NO. 3,723,605 - "PRODUCTION OF CONTINUOUS LENGTH OF GRAPHITE FIBERS", 1973

64. U.S. PATENT NO. 3,787,541 - "GRAPHITIZATION OF MESOPHASE PITCH FIBERS", 1974

65. U.S. PATENT NO. 3,837,904 - "METHOD OF SIZING CARBON FIBERS", 1974

66. U.S. PATENT NO. 3,894,863 - "GRAPHITE COMPOSITE", 1975

67. U.S. PATENT NO. 3,931,392 -"ENHANCEMENT OF TENSILE STRENGTH OF CARBON FIBERS", 1976

68. U.S. PATENT NO. 3,997,654 - "METHOD OF PRODUCING CARBONACEOUS STRANDS", 1976

69. U.S. PATENT NO. 4,005,183 - "HIGH MODULUS HIGH STRENGTH CARBON FIBERS FOR MESOPHASE PITCH", 1977

70. U.S. PATENT NO. 4,065,549 - "HIGH TENSILE STRENGTH, HIGH YOUNG'S MODULUS CARBON FIBERS", 1977

71. U.S. PATENT NO. 4,070,446 - "PROCESS FOR PRODUCING OF CARBON FIBERS", 1978

72. U.S. PATENT NO. 4,079,122 - "PREPARATION FO CARBON FIBERS", 1978

73. U.S. PATENT NO. 4,154,807 - "PROCESS PRODUCTION OF CARBON FIBERS", 1979

74. U.S. PATENT NO. 4,186,179 - "PROCESS FOR OXIDIZED CARBON FIBERS", 1980

75. U.S. PATENT NOS. 2,789,915; 2,913,802; 3,027,222 AND 3,125,404.

76. JAPANESE PATENT NOS. SHOWA 37-4405 (1962) AND SHOWA 38-12375 (1963)

77. BRITTISH PATENT NOS. 1,032,542 AND 1,110,791

78. V.C. McLAUGHLIN et al., NTIS PUBLICATION NO. AD-A026-743 DEC. 1974, NTIS, SPRINGFIELD, VA 22161

79. U.S. PATENT NOS; 3,053,775; 3,116,975; 3,174,895; 3,179,605 3,305,315

80. L.S. SINGER et al., "HIGH MODULUS CARBON FIBERS FROM MESOPHASE PITCHES", 12TH BIENNIAL CONFERENCE ON CARBON, PAGE 329, AM. CARBON COMMITTE, PITTSBURGH, PA, JULY 1975

81. J.W. JOHNSON, "FACTORS AFFECTING THE TENSILE STRENGTH OF CARBON -- GRAPHITE FIBERS", APPL. POLYM. SYMPOSIUM NO. 9, PAGE 229, 1969

82. W. WATT AND W. JOHNSON, "THE EFFECT OF LENGTH CHANGES DURING THE OXIDATION OF POLYACRYLORNITIRLE FIBERS ON THE YOUNG'S MODULUS OF CARBON FIBERS", APPL. POLYMER SYMPOS. NO. 9, P. 215, 1969

83. G.A. COOPER AND R. MAYER, "THE STRENGTH OF CARBON FIBERS", JR. MATERIALS SC., 6, 60, 1971

84. F. BARNET AND M. NORR, "FACTORS LIMITIZING THE TENSILE STRENGTH OF PAN-BASED CARBON FIBERS" NOLTR-74-172, NOV. 1974

85. D.J. THORNE, "DISTRIBUTION OF INTERNAL FLAWS IN ACRYLIC FIBERS", J. APPL. POLYMER SC., 34, 103, 1970

86. R. MORETON, FIBER SCIENCE TECHNOLOGY, 1, 273, 1969

87. E. MURPHY AND B.F. JONES, "SURFACE FLAWS ON CARBON FIBERS" CARBON, 9, 91 1971

88. J. JOHNSON AND D. THORNE, "EFFECT OF INTERNAL POLYMER FLAWS ON STRENGTH OF CARBON FIBERS PREPARED FROM AN ACRYLIC PRECURSOR", CARBON, 7, 659, 1969

89. B.F. JONES AND R.G. DUNCAN, "THE EFFECT OF FIBER DIAMETER ON THE MECHANICAL PROPERTIES OF GRAPHITE FIBERS MANUFACTURED FROM POLYACRYLONITRILE AND RAYON", J. MATER SC., 6, P. 289 AND 1225, 1971

90. E.W. TOKARSKY ADN R.J. DIEFENDORF, "THE MODULUS AND STRENGTH OF CARBON FIBERS", 12TH BIENNIAL CONFERENCE ON CARBON, PITTSBURGH, PA 1975

91. W. WATT, "CARBON WORK AT THE ROYAL AIRCRAFT ESTABBLISHMENT" CARBON, 10,121, 1972

92. D. ROBSON et al., "AN ELECTRON SPIN RESONANCE STUDY OF CARBON FIBERS BASED ON POLYACRYLONITRILE", J. PHYSICS, d4, 1426, 1971

93. D. ROBSON et al., "SOME ELECTRONIC PROPERTIES OF POLYACRYLONITRILE BASED CARBON FIBERS", J. PHYSICS, D5, 169, 1972

94. A. MARCHAND AND J.V. ZANCHETTA, "PROPERTIES ELECTRONIQUES D'UN CARBONE DOPE A L'AROTE", CARBON 3, 483, 1966

95. R.K. AGRAVAL, "EVALUATION OF RELATIVE WETTABILITY OF CARBON FIBERS", CARBON, 15, 291, 1977

96. A.A. BRIGHT AND L.S. SINGER, "ELECTRONIC AND STRUCTURAL CHARACTERISITICS OF CARBON FIBERS FROM MESOPHASE PITCH", PAPER PRESENTED AT THE 13TH BIENNIAL CONFERENCE ON CARBON IRVINE, CA, PAGE 100-101, 19

97. H. HERMANS,: PHYSICS AND CHEMISTRY OF CELLULOSE FIBERS ELSIVIER PRESS, AMSTERDAM, 1949

98. R. BACON AND W. SCHALAMON,: "PHYSICAL PROPERTIES OF HIGH MODULUS GRAPHITE FIBERS MADE FROM RAYON PRECURSOR", APPL. POLYM SYMP., NO. 9, 285, 1969

99. LOCKHEED CORPORATION, REPORT NOS. LR28843 AND LR28873 BY NASA-LANGLEY RESEARCH CENTER CONTRACT NOS. NASI-14000; NASI-15069 JAN, 1979 AND NASA REPORTS 14,5381-1 AND 14-381-2, AUG. 1978

100. C.O. STEPHENS, "ADVANCED COMPOSITES VERTICAL STABILIZER FOR DC-10" REPORT ACEE-03-PR-8484, NASA CONTRACT NO. NASI-14869 JUNE 1978

101. ANON, "IT BOOSTS PAYLOAD OF NASA SPACE SHUTTLE", MODERN PLASTICS, VOL. 54, NO. 6, PAGE 58, JUNE 1977

102. D.D. SMITH et al., "SPACE SHUTTLE STABLE OPTICAL SUPPORT STRUCTURE", SAMPLE JR., PAGE 4, SEPT/OCT. 1974

103. J. PUNTE et al., "APPLICATIONS OF THERMALLY STABLE GRAPHITE COMPOSITES TO A SPACF TELESCOPE STRUCTURE", SAMPE - 22ND NATIONAL SYMPOSSIUM, VOL. 22, PAGE 718 SAN DIEGO, CA, APRIL 1977

104. C. STOTLER et al., "ADVANCED COMPOSITE FAN FRAMES FOR QUITE, CLEAN SHORT HAUL EXPERIMENTAL ENGINES", SAMPLE 23RD NATIONAL SYMPOSSIUM, VOL. 23, PAGE 1218, MAY, 1978

105. L.M. LACKMAN et al., "COMPOSITE APPLICATIONS TO AIRCRAFT STRUCUTRES", sae PAPER 790146, COBO HALL, DETROIT, MI, FEB. 1979, (U.S. R&D, PAGE 4673, AUG. 1979).

106. R. KAISER, "TECHNOLOGY ASSESSMENT OF AUTOMOTIVE USES OF ADVANCED COMPOSITE MATERIALS", SAMPE 24TH NATIONAL SYMPOSSIUM, VOL. 24, PAGE 904, SAN FRANCISCO, CA, MAY 1979

107. ROCKWELL INTERNATIONAL, "ADVANCED COMPOSITES IN AUTOMOTIVE COMPONENTS", SP 7926, 1979

108. B.A. SANDERS, "ENGINEERING PROPERTIES OF AUTOMOTIVE FIBER REINFORCED PLASTICS", SOC. MANUFACTURING ENGINEERS, EMR 78-04, 1978

109. R.E. BONNETT et al., "DESIGN AND FABRICATION OF AUTOMOTIVE COMPONENTS IN GRAPHITE FIBER - REINFORCED COMPOSITES", SAE PAPER 790031, COBO HALL, DETROIT, MI, FEB. 1979

110. D.R. SIDWELL, "GRAPHITE - REINFORCED PLASTIC PASSENGER CAR FRAME", SAE PAPER 790030, COBO HALL, DETROIT, MI, FEB. 1977

111. D.A. CEDAR, "FABRICATION AND ASSEMBLY OF GRAPHITE FIBER REINFORCED PLASTIC VEHIVLE", SAE PAPER 790029, COBO HALL. DETROIT, MI, FEB. 1979

112. E.M. TREWIN, "GRAPHITE FIBERS - THE EXPANDING SCOPE OF APPLICATIONS IN THE INDUSTRIAL MARKET", PROC OF THE 1976 INTERNATIONAL CONFERENCE ON COMPOSITE MATERIALS, AMERICAN INSTITUTE OF MINE, METAL AND PETROL ENGS, NEW YORK, NY, PAGE 1462-1473, 1978

113. R. KAISER, "TECHNOLOGY ASSESMENT OF ADVANCED COMPOSITE MATERIALS", FINAL REPORT TO NATIONAL SCIENCE FOUNDATION CONTRACT NO. ERS 77-19467, ARGOS ASSOCIATES, INC., WINCHESTER, MA APRIL 1978

114. K. OKYDA, "PITCH BASED CARBON FIBER REINFORCEMENTS", CONF. ADVANCED COMPOSITE TECH; PAGE 26, TECHNOLOGY CONFERENCE ASSOCIATES, EL SEGUNDO, CA 1978

115. P. LEOPOLD, "ADVANCED COMPOSITED GRAPHITE/PPS VALVE", SAMPE 23RD NATIONAL SYMPOSSIUM, VOL. 23, P. 651, CA, 1978 AND CHEMISTRY AND ENGINEERING NEWS, PAGE 21, DEC. 19, 1977

116. E. FITZER at al., "TORSIONAL STRENGTH OF CARBON FIBER REINFORCED COMPOSITES. AS INTERNAL BONE PLATES", 14TH BIENNIAL CONFERENCE ON CARBON, AMERICAN CARBON COMMITTEE PAGE 58M PENN STATE UNIVERSITY, JUNE 1979

117. U.S. PATENT NO. 4,070,514 - "METHOD OF FABRICATING GRAPHITE FOR USE AS A SKELETAL PROTHESIS", JAN. 1978

118. E.F. BUSHMAN, "CARBON FIBER - TOOLING", 33RD ANNUAL TECHNICAL CONFERENCE, SP1, RP/C INSTITUTE, SECTION 2F, WASHINGTON, D.C. 1978

119. M. MOLYNEUX, "CARBON FIBER REINFORCED PLASTIC PARTS IN RADIOLOGICAL EQUIPMENT", 33RD ANNUAL TECHNICAL CONFERENCE SPI, RP/C, INSTITUTE, SECTION 12e, WASHINGTON D.C. 1978

120. PROCEEDINGS, "WORLD OF COMPOSITES" FOCUS 1986" PUBLISHED BY TECHNOMIC PUBLISHING COMPANY, INC., P.O. BOX 3535, LANCASTER, PN 17604, U.S.A.

121. "EXAMPLES OF FUNCTIONS AND APPLICATIONS OF FINE CERAMICS" SOURCE: FINE CERAMICS OFFICE, MINISTRY OF INTERNATIONAL TRADE AND INDUSTRY - MITI, JAPAN

122. K.H. JACK AND W.I. WILSON, "CRYSTAL CHEMISTRY OF SAILONS" NATURE PHYS. SCI. (LONDON), 235, 28 1972

123. Y. OYAMA et al., JAPAN JR. APPL. PHYSICS, 10. 1637, 1971

124. A. TSUGE et al., YOGYO-KYOKAI-SHI, 82, 351, 1974

125. S. UMEBAYASHI, "DIRECT PREPARATION OF SAILON-TYPE MATERIALS FROM NATURALLY OCCURING MINERALS", IN NITROGEN CERAMICS, EDITED. F.L. RILEY, PROCEED: Y. NATO ADVANCED STUDY INSTITUTE, AUG. 1976, PUBLISHED BY NOORDHOFF INT'L PUBLISHING, NETHERLANDS, 1977

126. V.D. FRECHETTE et al., "CERAMIC ENGINEERING AND SCIENCE - EMERGING PRIORITIES; PLENUIM PRESS, NEW YORK, NY 1974

127. TRENDS AND OPPORTUNITIES IN MATERIALS RESEARCH. "MATERIALS RESEARCH ADVISORY COMMITTEE, NATIONAL SCIENCE FOUNDATION" 1984

128. A. KELLY, "TRANDS IN MATERIALS SCIENCE/PROCESSING VICE-CHANCELLOR'S OFFICE, UNIVERSITY OF SURREY, ENGLAND OCT. 1984

129. A COMPETITIVE ASSESSMENT OF THE U.S. ADVANCED CERAMICS INDUSTRY, PREPARED BY: INDUSTRY ANALYSIS DIV., OFFICE OF INDUSTRY ASSESSMENT, ASST. SECREATRY FOR TRADE DEVELOPMENT U.S. DEPARTMENT OF COMMERCE, NTIS ACCESSS NO: PB-84-162288 MARCH, 1984

130. HIGH TECHNOLOGY CERAMICS IN JAPAN, U.S. NATIONAL MATERIALS ADVISORY BOARD, NATIONAL RESEARCH COUNCIL, NMAB-418, NATIONAL ACADEMY PRESS, WASHINGTON, D.C. 1984

131. TECHNOLOGICAL AND ECONOMIC ASSESSMENT OF ADVANCED CERAMIC MATERIALS, VOL. 1 SUMMARY AND CONCLUSIONS, PREPARED BY: CHARLES RIVER AND ASSOCIATES, INC. AUGUST 1984.

132. M. AKBAR ALI et al., "HIGH INDEX GLASSES FOR INTEGRATED OPTICS", GLASS_TECH (ENGLAND); VOL. 26, NO. 4, PAGES 186-189, AUG. 1985

133. M. AKBAR ALI et al., "GLASS COUPLERS FOR INTEGRATED OPTICS", LASER_AND_APPLICATIONS, VOL: IV, NO. 9 PAGES 119-122 SEPT. 1985

134. M. AKBAR ALI et al., "GLASSES FOR INTEGRATED OPTICS (IN JAPANEESE) O_PLUS_E, VOL: 5 NO. 78, PAGES 68-73 MAY 1986

135. TECHNOLOGICAL AND ECONOMIC ASSESSMENT OF ADVANCED CERAMIC MATERIALS: VOL. 4 A CASE STUDY OF INTEGRATED OPTIC DEVICES CHARLES_RIVER_AND_ASSOCIATES, CRA REPORT NO. 684, BOSTON, MA, AUG. 1984

136. S.L. BLUM, "CERAMIC GAIN LEADING EDGE IN ELECTRONICS", CERAMIC_INDUSTRY, SEPT. 1985

137. DENNIS G. HALL, "INTEGRATED OPTICS - THE SHAPE OF THING TO COME", PHOTONICS_SPECTRA VOL. 20, NO. 8, PAGES 87-92 AUG. 1986

138. CARL HELMERS, "THE NEW WORLD OF MACHINE PERCEPTION ENGINEERING", SENSORS, PP. 2-8, JAN. 1984

139. R.S. MEDLOCK, "SENSORS FOR MECHANICAL PROPERTIES", JR. PHYSICS AND SCIENTIFIC INSTRUMENTATION (U.K.), VOL. 16 pp. 964-972 1983

140. T. SEIYAMA et al., "CERAMIC HUMIDITY SENSORS", SENSORS AND ACTUATORS, VOL. 4, PAGES 85-96, 1983

141. G. TSCHULENA et al., "KEY TECHNOLOGIES FOR SENSOR MANUFACTURE IN SENSOR '82 BATELLE INSTITUTE E.V., FRANKFURT, FED. REP. GERMANY

142. S. MIDDLEHOCK et al., "SILICON AND HYBRID MICRO-ELECTRONIC SENSORS", ELECTROCOMPONENT SCIENCE AND TECHNOLOGY, VOL. 10 PAGES 217-219, 1983

143. R.S. PAPOVIC et al., "AN INTEGRATED SILICON MAGNETIC FIELD SENSOR USING THE MAGNETODIODE PRINCIPLE", IEEE TRANSACTIONS ON ELECTRON DEVICES, VOL. ED-31, NO. 3 PAGES 286 - 291, MARCH 1984

144. ZENTRALE FORSCHUNG AND ENTWICKLUNG, LGZ LANDIS; AND CYR ZUG AG, SCHWEIZ, FED. REP. OF GERMANY

145. B.A. AULD et al., "EDDY CURRENT PROBE RESPONSE TO OPEN AND CLOSED SURFACE FLAWS", JR. NONDESTRUCTIVE EVALUATION

VO.. 2, NO. 1. PAGE 1-21, 1981

146. J. ALEKSANDER et al., "FAST, FLEXIBLE PARALLEL VISION FOR ROBOTS", IN DEVELOPMENT_IN_ROBOT_1983, EDITED BY B. ROOKS IFS/NORTH HOLLAND, PAGES 133-140 1983

147. M.M. BLOUKE et al., "800X800 CHARGED-COUPLED DEVICE (CCD) IMAGE SENSOR", OPTICAL_ENGINEERING; VOL. 22 PAGE 640FF, 1983

148. ASEA_ROBOTICS, INC. NEW BERLIN, WI, CCD TECHNOLOGY

149. __INDUSTRIAL_SENSORS A REPORT ON LEADING-EDGE TECHNOLOGY, ET NO. 13, PUBLISHED BY: TECHNICAL_INSIGHT_INC., FORT LEE, NEW JERSEY, 1984

150. J. KREMERS et al. "DEVELOPMENT OF A MACHINE VISION BASED ROBOTICS ARC WELDING SYSTEM", IN 13TH_ISIR/ROBOTS 7, PAGES 14-19.

151. AUTOMATIX, CILLERICA, MA

152. P. WILLERS, "SENSOR_REVIEW, JULY 1982

153. P.D.W. BAKER, "OPTICAL FIBERS IN THE INDUSTRIAL AND COMMERCIAL ENVIRONMENT", PROCEEDINGS OF THE PHOTON CONFERENCE, PARIS PAGES 7, MAY 16-19, 1983 "SENSING - THE OPTICAL FIBERS HIDDEN TALENTS", ELECTRICAL REVIEW, VOL. 211, PAGES 25, 26-29, JAN 1983

154. "CHEMICAL SENSORS USING OPTICAL FIBERS," CHEMICAL AND ENGINEERING NEWS, PAGES 22-23, SEPT. 24, 1984

155. GEORGE E. COOK, ""ROBOTICS ARC WELDING - RESEARCH IN SENSORY FEEDBACK CONTROL", IEEE TRANSACTION ON INDUSTRIAL ELECTRONICS, VOL. IE-30, NO. 3, PAGES 252-268, AUG. 1983

156. THOMAS G. GIALLORENZI et al., "OPTICAL FIBER SENSOR TECHNOLOGY", IEEE JR. OF QUANTUM ELECTRONICS, VOL. QE-18 NO. 4, PAGES 626-665, 1982

157. J.P. WILSON et al., "MAGNETOSTTRICTIVE FIBER OPTIC SENSOR SYSTEMS FOR DETECTING DC MAGNETIC FIELDS", OPTICS LETTERS VO. 8, NO. 6, PAGES 333-335 JUNE 1983

158. E.R. COX, "FIBER OPTIC COLOR SENSORS BASED ON FABRYPEROT INTERFEROMETRY", IEEE CONFERENCED ON OPTICAL FIBER SENSOR CONFERENCE PUBLICATION NO. 221, PAGES 122-126, 1983

159. B. CULSHAW, "OPTICAL SYSTEMS AND SENSORS FOR MEASUREMENT AND CONTROLS", JR. OF PHYSICS, VOL. 16, 1983

160. ROBERT W. FAYFIELD, "THE ROLE OF FIBER OPTICS IN PHOTO-ELECTRIC SENSING OPERATIONS", SENSORS, PAGES 22-28, AUG. 1984.

161. G.A. PAVLATH et al., "APPLICATIONS OF ALL-FIBER TECHNOLOGY TO SENSORS", IN PROC. OF SPIE - VOL: 412 PAGES 70-80, APRIL 1983

162. JOHN J. PETERSON, "FIBER OPTIC SENSORS FOR BIOMEDICAL APPLICATIONS", SCIENCE, PAGES 123-127, APRIL 1984

163. C.A. STONE et al., "TECHNOLOGY TRANSFER TO A DEVELOPING NATION. A REPORT OF THE AID-NASA PILOT PROJECT IN TECHNOLOGY TRANSFER TO THE REPUBLIC OF KOREA", IIT RESEARCH INSTITUTE, CHICAGO, IL 1973

164. SIGNIFICANT NASA INVENTIONS - AVAILABLE FOR LICENSING IN FOREIGN COUNTRIES: NASA 1984 SP-7038 (07), NASA, WASHINGTON D.C., U.S.A. 1984

165. MIR AKBAR ALI, "POTENTIAL APPLICATIONS OF SPACE-RELATED TECHNOLOGIES TO DEVELOPING COUNTRIES", UNIDO-BACKGROUND PAPER NO. A/CONF. 101/BP/IGO/13, JULY 26, 82, PRESENTED AT UNISPACE-'82, AUG. 1982

166. NATIONAL REPORTS, ABSTRACTS & BACKGROUND PAPERS - LIST OF DOCUMENTS AT UNISPACE-'82 CONFERENCE DOCUMENT NO. A/CONF.101/MISC.-1, AUG. 1982

167. MARTIN B. ROBBINS et al., "MISSION-ORIENTED R7D AND THE ADVANCEMENT OF TECHNOLOGY. THE IMPACT OF NASA CONTRIBUTIONS," DENVER RESEARCH INSTITUTE, DENVER, CO, VOL. I AND II NTIS NOS. N72-25953 AND N72-25954, MAY 1972

168. JAMES P. KOTTENSTETTE et al., "APPLICATIONS OF AEROSPACE TECHNOLOGY IN INDUSTRY: A TECHNOLOGY TRANSFER PROFILE", DENVER RESEARCH INSTITUTE, DENVER, CO., NTIS NO. N72-12515 JULY 1971.

169. JOHN SS GILMORE et al., "THE ENVIRONMENT AND THE ACTION IN TECHNOLOGY TRANSFER", REPORT OF A CONFERENCE DENVER RESEARCH INSTITUTE, DENVER, CO., NTIS NO. N70-26339, 1970