Fiber optics 12812

Fiber optics produced by special methods from silica glass and quartz which replaced copper wire is very useful in telecommunications, long distance telephone lines and in examining internal parts of the body (endoscopy).

Equipment for photography is available with all current fiber-optic endoscopes.

Through a process known as total internal reflection, light rays beamed into the fiber can propagate within the core for great distances with remarkably little attenuation or reduction in intensity. In general, the methods of fiber production fall into three categories; (a) the extrusion method for synthetic fibers; (b) hot drawing of fibers from molten bulk material through an orifice; and (c) drawing of uncoated, coated and multiple fibers from assemblies of rods and tubes fed through a hollow cylindrical furnace. Three forms of fiber optics components have been proposed for the improvement of the image quality, field angle and photographic speed of various types of optical systems. These fiber optics elements, in the form of a field flattener, a conical condenser and distortion corrector, can be used separately or combined into a single unit called a " Focon". BOGAZICI UNIVERSITESI MAKINA MUHENDISLIGI DEPARTMANI MALZEME DERSI DONEM PROJESI YAZ OKULU 2000 OZET Gunumuzde bak? r tellerin yerini alan silikon cam? ndan ve kristalinden uretilen fiber optikler, telekomunikasyonda, uzun mesafeli telefon hatlar? nda ve insan vucudunun ic k? s? mlar? n? inceleyen endoskopilerde kullan? lmaktad? r. Fotograf ekipmanlar? nda da butun fiber-optik endoskoplara kullan? lmaktad? r. Tam ic yans? ma olarak bilinen islem yoluyla, fiberin icinde toplanan ? s? k ? s? nlar?, uzun mesafeler boyunca siddetinde kucuk bir azalma ve bozulmayla yol alabilmektedir. Genellikle, fiber uretimleri uc kategoridedir; Sentetik fiber uretiminde d? s? na c? karma methodu; Erimis dokme maddelerden ag? zlar? na dogru olusan fiberlerin s? cak cizimleriyle, kaplanm? s, kaplanmam? s veya kar? s? k fiberlerin cizimleriyle. Uc cesit olan fiber optik parcalar?; goruntu kalitesini, cesitli optik sistemlerdeki alan ac? s? ve fotografik h? zlar? gelistirmek icin dusunulmustur. Bu fiber optik elemanlar?; alan duzlestirici, konik yogunlast? r? c? ve sapma duzenleyici sekillerindedir ve ayr? veya “ Focon” ad? verilen unite icin birlesmis olarak kullan? labilirler. LIST OF FIGURES TABLE OF CONTENTS

 1. INTRODUCTION The technology of fiber drawing for

nonoptical applications is old and fairly standard. Very-small-diameter glass

and quartz fibers were made as early as by Faraday. In the early stages of the

production of glass fibers on an industrial scale, the main application of the

fibers was envisaged in the textile industry. More recently, they have been used

for insulation against sound, heat and electricity. Presently, very fine fibers

are being made of materials such as glass, quartz, nylon, polystyrene, polymethylcrylate. Of these, glasses, quartz and plastics are preferred for optical use because of their higher visible light transmission, longer thermal working range, better surface characteristics and mechanical strength. Furthermore, it has been shown that glass fibers can have greater tensile strength than can be expected from the bulk material. 2. HISTORY OF FIBER OPTICS

The conduction of light along transparent cylinders by multiple total internal reflections is a fairly old and well known phenomenon. It is entirely possible that grecian and other ancient glassblowers observed and used this phenomenon in

fabricating their decorative glassware. In fact, the basic techniques used by the old Venetian glassblowers for making ‘ millifiore’ form an important aspect of present-day fiber optics technology. However, the earliest recorded scientific demonstration of this phenomenon was given by John Tyndall in 1870.

In demostration Thyndall used an illuminated vessel of water and showed that,

when a stream of water was allowed to flow through a hole in the side of the vessel, light was conducted along the curved path of the stream. In 1951 when

A. C. S. van Heel in Holland and H. H. Hopkins and N. S. Kapany studied on the

transmission of images along an aligned bundle of flexible glass fibers. But it

was the year 1956 that Kapany first applied the term ‘ fiber optics’ to this

field and described its principle and various of possible applications. Kapany

defines fiber optics as the art of the guidance of light, in the ultraviolet,

visible and infrared regions of the spectrum, along transparent fibers through

predetermined paths. Between 1957 and 1960 Potter, Reynolds, Reiffel and Kapany

investigated the use of scintillating fibers for tracking high energy particles.

Potter also investigated the theory of skew ray propagation along fibers in some

detail. One of the biggest application area of fiber optics is in medicine.

Hirschowitz have been working on the developement of fiber optics gastroduodenal

endoscopes and Kapany have been researching fiber optics in gastrocopy, bronchoscopy, retroscopy and cyctoscopy. Kapany, Drougard and Ohzu have made

basic studies on image transfer characteristics of fiber assemblies. 3. WHAT IS

OPTICAL FIBRES? Optical fibres are glass or plastic waveguides for transmitting

visible or infrared signals. Since plastic fibres have high attenuation and are

used only in limited applications, they will not be considered here. Glass

fibres are frequently thinner than human hair and are generally used with LEDs

or semiconductor lasers that emit in the infrared region. For wavelengths near

0. 8 to 0. 9 m, gallium arsenide-aluminum gallium arsenide (GaAs-AlxGa1 – xAs)

sources are used, and, for those of 1. 3 and 1. 55 m, indium phosphide-gallium

indium arsenide phosphide (InP-GaxIn1 – xAsyP1 – y) sources are employed. As

noted earlier, optical fibres consist of a glass core region that is surrounded

by glass cladding. The core region has a larger refractive index than the cladding, so that the light is confined to that region as it propagates along the fibre. Fibre core diameters ranges between 1 and 100 m, while cladding diameters are between 100 and 300 m. Fibres with a larger core diameter are called multimode fibres, because more than one electromagnetic-field configuration can propagate through such a fibre. A single-mode fibre has a small core diameter, and the difference in refractive index between the core and cladding is smaller than for the multimode fibre. Only one electromagnetic-field configuration propagates through a single-mode fibre. Such fibres have the lowest losses and are the most widely used, because they permit longer transmission distances. They have a constant refractive index in the core with a diameter between 1 and 10 m. The index in the cladding layer decreases by roughly 0. 1 to 0. 3 percent. This type of fibre is called a step-index fibre. The multimode fibres may be step-index fibres with diameters between 40 and 100 m.

The refractive index step between the core and cladding is approximately 0. 8 to

3 percent. In a graded-index fibre, the core refractive index varies as a

function of radial distance. In such a fibre, a ray in the centre of the core

travels more slowly than one near the edge, because the speed of propagation v

is related to refractive index n as v = c/n, where c is the speed of light. The

ray near the edge has a longer zigzag path than the ray in the centre. The

transit times of the rays are thus equalized. Both single-mode and multimode

fibres are made of silica glass. The refractive indexes of the silica are varied

with dopants such as germanium dioxide (GeO_2), phosphoric oxide (P_2O_5), and

boric oxide (B_2O_3). Vapour-phase growth reactions are used to obtain the " preform"

rod, which is then drawn into optical fibres. For example, a GeO_2-SiO_2 film may

be deposited inside a silica tube. In this case, the GeO_2 increases the core

refractive index. In another method, preforms for low-loss, single-mode fibres are made by first depositing a low-index borosilicate layer on the inner surface

of the silica tube and then depositing a silica layer or inserting a pure fused

silica rod before collapsing the preform. The preform is then drawn into the

optical fibre and covered with a polymer coating. There are a number of factors

that contribute to attenuation in an optical fibre. Rayleigh scattering is

caused by microscopic variations in the refractive index of a fibre and is

proportional to 4. Absorption by hydroxyl (OH) ions increases the absorption and

gives the minim in loss at 1. 3 and 1. 55 m. At longer wavelengths; absorption by

the atomic vibrations in the silicon-oxygen atoms rapidly increases the loss.

Single-mode fibres commercially available for communications systems have losses

as low as 0. 2 decibel per kilometre. The low fibre loss permits increased

repeater spacing and lower system cost. High-bit-rate digital systems without

repeaters have been demonstrated for fibre lengths of more than 100 kilometres.

Fibre splicing techniques have been developed so that repairs can be made in the

field with losses of only 0. 1 to 0. 3 decibel. A variety of optical connectors

are used, providing both ease of use and low loss of only a few tenths of a

decibel. Fibres are combined into many different kinds of cables, which can be

laid both in the ground and under the sea. 3. 1 WHAT IS SILICA? Of the various

glass families of commercial interest, most are based on silica, or silicon

dioxide (SiO_2), a mineral that is found in great abundance in

nature–particularly in quartz and beach sands. Glass made exclusively of silica

is known as silica glass, or vitreous silica. (It is also called fused quartz if

derived from the melting of quartz crystals.) Silica glass is used where high

service temperature, very high thermal shock resistance, high chemical

durability, very low electrical conductivity, and good ultraviolet transparency

are desired. However, for most glass products, such as containers, windows, and

lightbulbs, the primary criteria are low cost and good durability, and the glasses that best meet these criteria are based on the soda-lime-silica system.

After silica, the many “ soda-lime” glasses have as their primary

constituents soda, or sodium oxide (Na_2O; usually derived from sodium carbonate,

or soda ash), and lime, or calcium oxide (CaO; commonly derived from roasted

limestone). To this basic formula other ingredients may be added in order to

obtain varying properties. For instance, by adding sodium fluoride or calcium

fluoride, a translucent but not transparent product known as opal glass can be

obtained. Another silica-based variation is borosilicate glass, which is used

where high thermal shock resistance and high chemical durability are desired–as

in chemical glassware and automobile headlamps. “ Crystal” tableware

was made of glass containing high amounts of lead oxide (PbO), which imparted to

the product a high refractive index (hence the brilliance), a high elastic

modulus (hence the sonority, or “ ring”), and a long working range of temperatures. Lead oxide is also a major component in glass solders or in sealing glasses with low firing temperatures. 3. 2 WHAT IS QUARTZ? Quartz has attracted attention from the earliest times; water – clear crystals were known to the ancient Greeks as krystallos – hence the name crystal, or more commonly rock crystal, applied to this variety. The name quartz is an old German word of uncertain origin first used by Georgius Agricola in 1530. Quartz has great economic importance. Many varieties are gemstones, including amethyst, citrine, smoky quartz, and rose quartz. Sandstone, composed mainly of quartz, is an important building stone. Large amounts of quartz sand (also known as silica sand) are used in the manufacture of glass and ceramics and for foundry molds in metal casting. Crushed quartz is used as an abrasive in sandpaper, silica sand is employed in sandblasting, and sandstone is still used whole to make whetstones, millstones, and grindstones. Silica glass (also called fused quartz) is used in optics to transmit ultraviolet light. Tubing and various vessels of fused quartz have important laboratory applications, and quartz fibres are employed in extremely sensitive weighing devices. Quartz is the second most abundant mineral in the Earth’s crust after feldspar. It occurs in nearly all-acid igneous, metamorphic, and sedimentary rocks. It is an essential mineral in such silica-rich felsic rocks as granites, granodiorites, and rhyolites. It is highly resistant to weathering and tends to concentrate in sandstones and other detrital rocks. Secondary quartz serves as a cement in sedimentary rocks of this kind, forming overgrowths on detrital grains. Microcrystalline varieties of silica known as chert, flint, agate, and jasper consist of a fine network of quartz. Metamorphism of quartz-bearing igneous and sedimentary rocks typically increases the amount of quartz and its grain size. Quartz exists in two forms: (1) alpha-, or low, quartz, which is stable up to 573? C (1, 063? F), and (2) beta-, or high, quartz, stable above 573? C. The two are closely related, with only small movements of their constituent atoms during the alpha-beta transition. The structure of beta-quartz is hexagonal, with either a left- or right-handed symmetry group equally populated in crystals. The structure of alpha-quartz is trigonal, again with either a right- or left-handed symmetry group. At the transition temperature the tetrahedral framework of beta-quartz twists, resulting in the symmetry of alpha-quartz; atoms move from special space group positions to more general positions. At temperatures above 867? C (1, 593? F), beta-quartz changes into tridymite, but the transformation is very slow because bond breaking takes place to form a more open structure. At very high pressures alpha-quartz transforms into coesite and at still higher pressures, stishovite. Such phases have been observed in impact craters. Quartz is piezoelectric: a crystal develops positive and negative charges on alternate prism edges when it is subjected to pressure or tension. The charges are proportional to the change in pressure. Because of its piezoelectric property, a quartz plate can be used as a pressure gauge, as in depth-sounding apparatus.

Just as compression and tension produce opposite charges, the converse effect is

that alternating opposite charges will cause alternating expansion and

contraction. A section cut from a quartz crystal with definite orientation and

dimensions have a natural frequency of this expansion and contraction (ie.

vibration) that is very high measured in millions of vibrations per second.

Properly cut plates of quartz are used for frequency control in radios,

televisions, and other electronic communications equipment and for

crystal-controlled clocks and watches. 3. 3 WHAT IS ENDOSCOPIC PHOTOGRAPHY? With

the use of modern light -weight single lens reflex cameras employing either

automatic exposure control or through-the-lens metering, good half or whole

frame 35mm colour photographs can be taken. Distal cameras (intragastric

cameras), producing 5mm or 6mm colour pictures and electronic distal flash, are

also available in some fibre-endoscopes. Endoscopic photography is the available equipment and the best method of obtaining the best possible colour photographs.

It is possible to obtain high-quality colour transparencies of bowel lesions.

These are generally employed for patient records, teaching and research. They

are not usually employed for diagnosis since visual inspection and biopsy will

already have been performed. An exception is in so called gastro-camera

diagnosis where miniature photographs are taken from within the stomach as an

aid to the detection of early gastric cancer. Endoscopic cine-photography is

useful for recording motility, endoscopic techniques, and unusual lesions. It

can be also be used to make teaching films. Close circuit colour television

endoscopy is already in routine use in some centres of Japan, the United States

and Europe and will undoubtedly find a wider use, especially for teaching and

training. This equipment is naturally very costly but cheaper equipment can be

anticipated. 4. ENDOSCOPIC PHOTOGRAPHY ELEMENTS 4. 1 FIELD FLATTENER In lens design, it is desirable that the image coincide with the Gaussian image plane so

that the whole field may be in focus simultaneously. In this case, the Petzval

sum of the optical system must be zero or, at most, be a small residual to

compensate for the secondary effects of higher-order astigmatism and oblique

spherical aberration. When the third-order astigmatism coefficient is zero, it

is well-known that the sagittal and tangential image surfaces coincide with the

Petzval surface. The curved fields of such an astigmatic lens system can be

flattened by using a bundle of fibers. The shape and curvature of the entrance

end of the bundle is determined by the image surface of the lens system that

precedes it. The other end of the fiber bundle may be flat if the system is to

be used for direct observation or photography, as shown in Fig. 4. 1. However,

when an image is field flattened in this manner, there is an interaction between

the lens distortion coefficient and a distortion term introduced on field flattening. Distortion term shows the exit pupil of a lens system through which

a principal ray passes at an inclination U' and intersects the Petzval surface

at the point P and the Gaussian image plane at the point Q. Since the principal

ray does not intersect the Gaussian plane when a field flattener is used but is

intercepted by a fiber at the Petzval surface, the effective image size is

changed by an amount OQ' = ? h. And ? h = hG – h where hG is the

Gausiian image height and h is the intersection height of the principal ray at

the Gaussian image plane. There are several methods available for the production

of a field flattener. In one of these methods, the fibers are ground and

polished along the curve desired according to the Fresnel element, and then the

entrance ends of the fibers are displaced to lie on the curved image surface.

Obviously, this method suffers from technological limitations and is acceptable

only when low-resolutison field flatteners are required. A second method

consisting of lapping the field flattener in against a metallic master. In the third, most promising method, a Fresnel surface is produced at the curved surface of the fiber assembly with a master, employing an epoxy of the type used for making diffraction grating replicas. 4. 2 CONICAL CONDENSER A conical fiber bundle is placed at the focal end of a lens system to increase the photographic speed of the system by utilizing the flux-condensing property of a cone. However, the condensing ratio of a glass-coated glass cone is determined by the ratio f- ratio and the field angle of the preceding image forming system, as well as the refractive indices of the fiber core and coating materials. If we make some simplifying assumptions of a meridional ray propagation in a cone with axial length many times greater than its diameter. For cones located off-axis at the image plane and with bend sides, there are obvious deviations. Figure 4. 2 shows an image transmitted by a conical fiber bundle having a 2, 5 : 1 ratio. 4. 3

DISTORTION CORRECTOR It is possible to fabricate fiber bundles with the capability of correcting for pin-cushion and barrel distortion. It is also possible to evolve techniques for fabricating fiber bundles to compensate for the distortion term introduced in large-angle line scan systems and S-shaped distortion of the type introduced in electron-optical systems. Figure 4. 3 shows images transmitted through two fiber plates, demonstrating the correction capability for pin-cushion and barrel distortion. Such fused fiber assemblies are fabricated by subjecting to well defined thermal and pressure gradients. As another intersting example of the application of a combination of field flattener and distortion corrector, we shall cite the problem of a wide-angle spot scan systems in which a severe distortion term proportional to the field angle is introduced because of a change in spot size. In such a system, it is also desirable to use a curved image fieldto facilitate the mechanical synchronization of the two scanning functions of the data-acqusition and print-out systems. 4. 4 FOCON RESOLUTION Of importance in the determination of the overall performance of a lens-fiber optics combination is the angular

resolution (Rang) of an image-forming system of a aperture diameter, D, which,

according to classical theory, is given by the formula: Rang = D/1. 22? By

inserting the value of the focal ratio (F), it is possible to determine the

linear resolution (Rang), which is given by the following expression; Rlin =

1/1. 22F? On the other hand, the linear displacement between two points

which can be resolved by static fiber optics is between 2d + 3t and d + 2t,

where d is the fiber diameter and t (? 0. 5 ?) is the spacing between

them. The resolution is then given by the reciprocal of this quantity. Waveguide

effects and evanescent wave coupling between the fibers can be avoided if the

fiber diameter is greater than or equal to ?? when the fiber numerical

aperture is close to unity. Such a fiber will propagate approximately 20 modes

of wavelength, ?. Thus the optimum static resolution that can be obtained

with fibers is approximately 1/ ?? + 2t. Consequently, for ? =

0. 5 ?, a maximum static resolution of 220 to 350 lines / mm can be expected

with high resolution fiber optics. Of course, dynamic scanning can be used to

improve the resolution. Thus the highest linear resolution obtainable with a

fiber bundle is considered to be equivalent to that of a diffraction-limited f/4

lens. Figure 4. 4 shows a curve of the resolution of fiber conical condenser used

in conjunction with diffraction-limited lenses of a given f-number. Each curve

corresponds to a conical condenser of ? = a2/a1 (no2 – n'2)1/2, where

a1/a2 is the cone ratio, and no and n' are the refractive indices of the fiber

core and coating, respectively. 5. ENDOSCOPIC PHOTOGRAPHY TECHNIQUES 5. 1 COLOUR

PHOTOGRAPHY WITH FIBRE-OPTIC ENDOSCOPES This technique is the one of employed in

great majority of endoscopic examinations. Photographs are taken through the

endoscope by a camera placed on the eyepiece. This means that whatever the

operator sees will be recorded photographically. The disadvantages of this method are that the fibre-matrix is also photographed. In addition, any imperfections in the operator's view, such as poor focus or bad picture composition, will be reflected in the photograph. To this extent the problems are similar to those of conventional photography, but otherwise there are few similarities. When employing a proximal camera for endoscopic photography the following points should be remembered. 1. A single lens reflex (SLR) camera must be employed. 2. Through the lens exposure metering (TTL metering) must be employed, unless there is automatic exposure control of the light source output.

3. A medium focal length lens, eg 70-105 mm or ' telephoto' lens, may be required with some endoscopes and must be focussed at infinity. 4. The camera lens must be focussed at infinity. 5. Photography must be carried out at aperture if a camera lens is employed. 6. It may not with some endoscopes be necessary to use a camera lens. 7. It is not usually possible to vary the

ligthing. 8. High speed film is usually necessary and must be of the correct type. 5. 2 CINE ENDOSCOPY Although cine endoscopy is employed routinely by some authorities to record lesions, motility , etc, it is usually reserved for occasional use in teaching because of the cost equipping with suitable cameras and films. Suitable cine cameras include: Super-8 Kodak M-30 with power-operated zoom lens (from f/1. 9) and Beaulieu R-16 B medical camera (16 mm). The Beaulieu R-16 B Euratom camera is undergoing evaluation at present. It houses an automatic light control system in place of the lens turret consisting of a graded neutral density filter wheel coupled to the exposure meter. This wheel is adjusted by a small servo motor so that the light reaching the film remains constant. This novel form of light control provides and alternative to the iris diaphragm which, as we have already seen, is not possible with endoscopy photography. At the present, however, this camera is nut fully tested. Probably the best currently available system is the standard 16 mm Beaulieu R-16 B medical camera, employing a suitable adaptor supplied by the manufacturer for their endoscopes. 5. 3 CLOSED CIRCUIT COLOUR TELEVISION ENDOSCOPY In a number of Japanese centers and in some centers in the USA and Europe, closed circuit colour television endoscopy is employed for demonstration and teaching. The results, as might be expected, are variable, but it is possible, by employing the best available equipment to produce excellent television images with good colour reproduction. Television technology is highly developed, nevertheless it will be useful to discuss the items that make up an effective system for endoscopy and to point out the weak links. A succesful system for use in gastro-intestinal endoscopy would consist of: a colour television camera; a flexible optical coupling between the television camera and the endoscope; a light control system; colour television monitor(s); a fibre-optic endoscope, and a suitable light source. 5. 4 GASTRO-CAMERA EXAMINATION Gastro-camera examination

of the stomach is an investigation in which a flexible tube is passed into the

stomach and multiple colour photographs taken employing a miniature camera and

flash lamp mounted distally on the tube. This method was developed by the

Japanese in 1950 in an attempt to diagnose gastric cancer, a disease that

accounts for more deaths in Japan than any other form of cancer. Diagnosis is

based on a complete photographic survey of the stomach, followed by careful

inspection of the transparencies. Suspicious areas are noted and the patient

called back for full fibre-endoscopy and biopsy, or alternatively surgical

biopsy. The term gastro-camera is understood to include ‘ blind’ gastro

–cameras which do not have visual control and ‘ visually controlled’

instruments with image blundles. With the ‘ blind’ gastro-cameras the tip of

the instrument is positioned by observing the light from it through the

abdominal wall. Clearly this must take place in darkened room. 6. CONCLUSION

Fibre-optic endoscopy has established itself as an important diagnostic tool in

the investigation and management of disease of the gastric-intestinal tract.

Considerable advances have been made in the design and construction of fibre-optic

endoscopes and their support systems, over the past ten years. It is unlikely

that development will take place at the same pace over the next decade. We are

now entering a phase of consolidation during which objective evaluation of each

area of endoscopy will take place as the techniques become more widely used.

Advances will be made in producing serviceable instruments and local servicing

facilities are likely to be increased and streamlinid. Fibre bundle technology

will probably not strive to produce smaller fibres since the limit has already

been nearly reached. Design will probably concentrate on reliability, and

cheaper meth-pds of production. Endoscope support systems, such as light

sources, will probably improve with the development of more powerful, cooler and reliable lamps. The great advantage of flexibility provides the key to the use of optical communication within as well as outside medicine. As a result of this technology medical fibre-optics are likely to receive the benefit of cheaper more dispensible fibre-bundles. These are, at present, the most expensive items in a Fibre endoscope. Bibliography

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