Applied Optics Products for New Market

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In the 1980s, Fujikura started to apply its optical communication technology to other fields such as manufacturing and medical industries. We call those products for the new application " Applied Optics Products". Today, novel technologies including advanced photonics, semiconductor technology and electronics are incorporated into the applied optics products, and they have been deployed to new markets.

1. Overview

In the 1980s, Fujikura Ltd. released applied optics products such as specialty optical fibers, ultra thin endoscopes and optical fiber bundles. Those products were based on the technologies used for optical fibers, components and equipment in the field of optical communication. As an example of specialty optical fibers, an image fiber composed of multiple cores transmits an image, and as another example, a large core fiber whose core is very thick carries high optical energy to a remote point. Today, these products are used in a variety of fields such as an electric power plant, manufacturing facilities of semiconductor and electronics, and medical facilities.

Recently, Fujikura has added new products in its product line which are active devices or devices integrated with technology such as electronics. A fiber laser is an active optical fiber doped with a rare earth element and emits coherent light in an excited state. As an example of new products, a CMOS image sensor will be used for the medical field as a thin image transmission line.

This paper reviews our applied optics products which have been deployed in the industries and also describes newly developed technology for the applied optics.

2. Applied optics products for industry

Fujikura provides two categories of applied optics products for industrial use. One is a group of products based on specialty fibers, and the other is a group of illumination products made of resin.

The former product group includes industrial endoscopes, assemblies of large core optical fibers and optical fiber bundles, and they are our major products. The industrial endoscopes have been applied to monitoring and inspection of thermal and nuclear power plants. The large core fiber assemblies have been used in sensing systems for an oil well and a chemical plant. The optical fiber bundles have been incorporated into an exposure apparatus for manufacturing semiconductors or LCDs. The optical fiber bundles are also used to carry UV light for curing resin in the electronics industry. As the above-mentioned products are made of silica glass, they indicate good intrinsic durability for heat, irradiation and chemical attack, and also show distinguished transmission property derived from nature of silica glass.

The other category of product is the illumination product. It is used to decorate and illuminate a car interior, an amusement machine, and a portable electronic device.

2.1 Endoscopes for industrial use

Fujikura's industrial endoscopes are called "fiberscope", because the image fiber is made of silica glass fiber as an image transmission medium. The fiberscope is composed of an image fiber, an objective lens attached at distal end, and another imaging lens for coupling to a camera system. A light guide fiber is also bundled for illumination along the image fiber. Our fiberscope can transmit an image of an object in narrow space and in harsh environments like high temperature, high pressure, and high irradiation dosage, under which it is very difficult to capture the direct image of the object.

2.1.1 Fiberscope for coal gasification furnace

A coal gasification furnace [1)] is one of the candidates for an ideal furnace which realizes highly efficient combustion of fossil fuel and environment-friendly operation with reduction of CO_2, NOx , soot, and dust.

1 Applied optics products division

Abbreviations, Acronyms, and Terms.

Coal gasification furnace—A system to produce combustible gas as fuel for a generator from coal under high temperature and high pressure. Application of hydrogen generated by the furnace is also investigated for auto mobile and fuel battery.

IGCC—Integrated coal Gasification Combined Cycle. A power generation system combined with a coal gasification furnace and GTCC (Gas Turbine Combined Cycle). This system can work with high efficiency.

IGFC—Integrated coal Gasification Fuel cell combined Cycle. It is a power generation system combined with IGCC and High-temperature fuel cell (MCFC, etc.) This system shows higher thermal efficiency than IGCC.

Guide wire—A wire in an endoscope to guide a catheter securely to a diseased area through a vein or a lumen of organ.

CMOS—Complementary Metal Oxide Semiconductor; CMOS devices are widely used as a memory and a logic IC such as microprocessor, etc.

CMOS image sensor—imaging device made of CMOS. A CMOS image sensor is believed to be cheaper than a CCD (Charge Coupled Device) image sensor because CMOS devices are manufactured by common process for mass produced LSIs.

Catheter—A medical device in a form of tube. A catheter is inserted into the human body to eject body fluid, inject medicine, remove a calculus, and place an instrument like a stent. Many kinds of catheters are used for different purposes dependent on the figures of organ.

Feeding tube—A catheter to feed liquid food to a patient who has difficulty in swallowing.

Today, efficient electric generation systems like Integrated coal Gasification Combined Cycle (IGCC) and Integrated coal Gasification Fuel Cell combined cycle (IGFC) are almost on the practical stage.

Because the IGCC and IGFC are complex processes, it is necessary to monitor and analyze the inside of the coal gasification furnace for a stable operation. The fiberscope is the best method for this purpose because it can transmit an image of the inside of the furnace in water vapor under high pressure and high temperature. The combustion temperature is also measured simultaneously by near infrared spectroscopy through the fiberscope.

2.1.2 *Radiation resistant fiberscope*

A pure silica core fiberscope shows good optical and mechanical properties against irradiation such as X-ray or gamma ray. Fig.1 shows a radiation resistant fiberscope which is encapsulated with a robust sheath to withstand high temperature and high pressure.

The radiation resistant fiberscope is used to inspect and monitor operation of facilities annexed to a nuclear reactor.

Fig. 2 shows a test result of the radiation resistance fiberscope for gamma ray irradiation [2]. Fig. 2-1 is a color chart as an original image. Fig 2-2 is the initial transmitted image through the fiberscope with 3000 pixels before gamma ray irradiation. Fig. 2-3 shows the transmitted image after gamma ray irradiation with dose rate of 1kGy/h and irradiation time of 2h. Even after the irradiation of 2kGy dose, no change of image quality is observed in terms of contrast, color tone, brightness, and so on. Typical specifications and a transmitted image of a radiation resistant fiberscope are shown in Table 1 and Fig.3, respectively.

The newly developed method for maintenance and dismantlement of the nuclear reactor utilizes an advanced radiation resistant fiberscope which combines the features of the image fiber and the large core fiber [3].

2.2 *Illumination device for ornament*

Fujikura released light guides and illumination devices made of transparent resin such as polymethylmethacrylate (PMMA), polycarbonate (PC), etc., and we named them Illumi Rod and Illumi Panel. In the Illumi-products, dots, dents and hollows with a unique shape are mechanically formed to make light of emitting sources scatter efficiently to intended directions with controlled light intensity. The Illumi-products are flexibly designed to satisfy the customer's request. For decoration or ornament by light, Illumi-products have reduced the number of light emitting devices like LEDs, because the efficiency of scattering is so high.

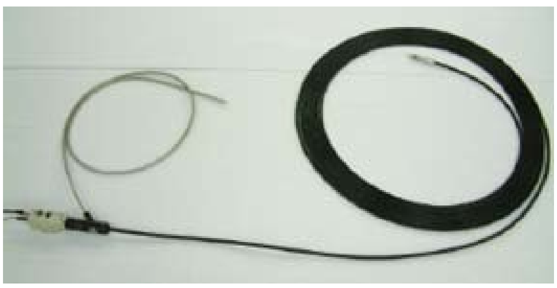

Fig. 1. Radiation resistant fiberscope.

Fig. 2-1. Original image (Color chart).

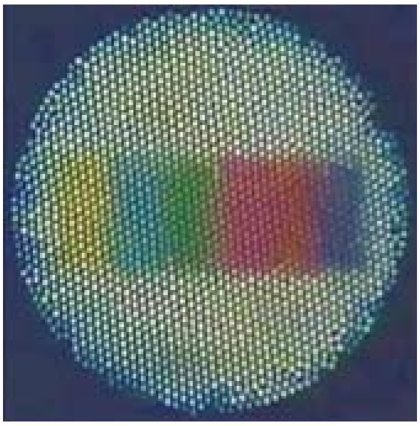

Fig. 2-2. Transmitted image before irradiation.

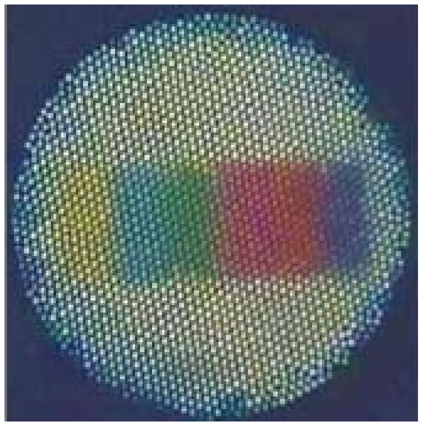

Fig. 2-3. Transmitted image after irradiation of 2kGy.

Table 1. Typical specifications of a radiation resistant fiberscope.

Items	Specifications
Number of pixels	10,000
Angle of view	40°
Direction of view	Forward view
Working distance	20 ~ 100 mm
Length of fiberscope	18.3 m
Diameter of objective including housing	ϕ15 mm
Light guide (LG) for illumination	Equipped with light guide fiber
	Branch length of LG : 2 m
Minimum bending radius	R 300 mm

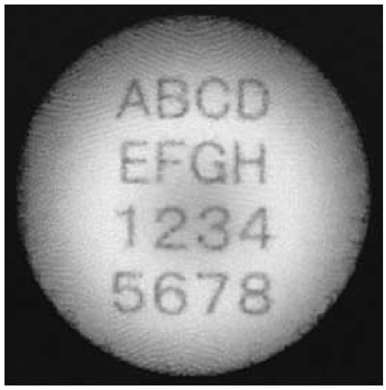

Fig. 3-1. Transmitted image of test chart through a radiation resistant fiberscope.

Illumi-products are used for decoration of car interior, ornament of a mobile phone and a tablet device, and an amusement machine such as Japanese game devices called “pinball” or “pachisuro” which is a kind of slot machine.

2.2.1 Light branching device for an amusement machine

As mentioned above, a device for illumination, decoration, and ornament requires reducing the number of used light sources like LEDs for cost reduction and energy saving as it keeps performance of lighting. Figures 4 and 5 show a typical Illumi-product. In the device, light from an LED is branched by total reflection and uniformly irradiates a wide area. Total reflection has realized efficient illumination of light without optical coating on the surface of the device. Fig.4 shows a device which radiates light widely and uniformly to one direction with a light intensity variation of +/−9 % on the average and also with the total efficiency of 52 %. The device is 10 mm in thickness, but it performs the same illumination as a conventional lighting system which uses more LED sources. [4)]

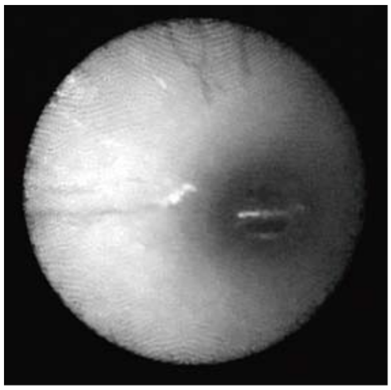

Fig. 3-2. Transmitted image of inner surface of a metal pipe.

3. Medical field

Fujikura has also developed applied optics products for medical use, such as an endoscope using an ultra-thin image fiber suitable for medical diagnosis, a laser drilling chip using a large core fiber for dental surgery, a fiber assembly for Photo Dynamic Therapy (PDT) and Photo Dynamic Diagnosis (PDD), and the peripheral equipment for those products. Today, Fujikura is

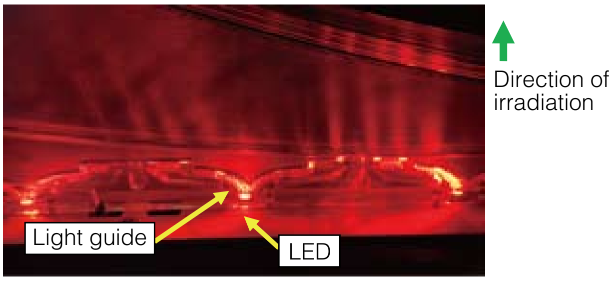

Fig. 4. Light branching device for an amusement machine.

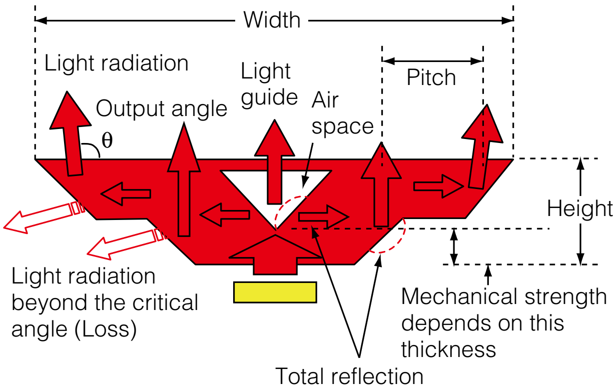

Fig. 5. Typical structure of light branching device.

developing another promising medical product, CMOS image sensor. A CMOS image sensor which is integrated with electronics is featured by high flexibility and potentially inexpensive.

This section introduces an ultra-thin fiberscope for angioscopy which is a special endoscope for blood vessels, and also describes a CMOS image.

3.1 Angioscope system

A novel endoscope with a diameter less than 1mm is composed of an ultra-thin silica-based image fiber. The endoscope can observe a narrow space in the human body, such as a blood vessel, an eye ball, a biliary duct, a pancreas duct, and a urinary duct, and so on. Significance of angioscopy is growing with increase of stent surgery for ischemic heart disease. Change of people's life style is on the background of the disease such as cardiac infarction and angina pectoris.

Although other observation methods for the disease such as intravascular ultrasound (IVUS) and optical coherence tomography (OCT) are used in recent days, only coronary endoscopy (CES) can observe the color and the shape of the affected part, identify the property of the diseased part, and suggest an informative way to cure. As a result, endoscopy is often used as a reference method for the diagnosis. [5)6)7)]

Angioscopy is classified into an occlusion type or a non-occlusion one. Occlusion means observation of a blood vessel after stopping a blood flow by inflating a balloon in the blood vessel and then flushing it with saline solution to completely push out blood. Although the occlusion method has a merit of getting a clear image, it has a risk to damage the blood vessel and to induce severe ischemic heart disease during the operation.

On the other hand, non-occlusion has a low risk to damage the blood vessel or to induce a heart trouble. However, because the non-occlusion method provides only an image of a limited area near the end of the flushing catheter, the method does not obtain an image of the whole affected area which is necessary for the diagnosis.

The conventional angioscopy has another problem due to a large diameter of the angioscope. In stent surgery, an angioscope is inserted to the heart through the vein of leg, but in the follow-up inspection after the operation, the angioscope is inserted from the upper arm where the vein is small for the conventional scope to pass through. Fujikura has developed a novel non-occlusion angioscopy system consisting of a fiberscope (Smart-i) which provides a wide view in spite of a thinner diameter than the conventional one. The new imaging system "i-Light" offers sequential shots of image of the affected area by moving the scope in a short time. As a result, a risk of ischemic in the stent surgery has been significantly reduced. The new system i-Light will be manufactured by FiberTech Co., Ltd. who is a subsidiary of Fujikura Ltd., and will be released by iHeart Medical Co., Ltd..

3.1.1 Angioscope system (Smart-i)

**Smart-i* is a trade name of iHeart Medical Co., Ltd.
As is explained in the previous section, the novel angioscope system has made it possible to insert the scope to the coronary thrombosis through a thin blood vessel of the upper arm in cardiac surgery. The system gives a clear image of the blood vessel by increasing a flush flow. The new angioscope is furnished with a tube in which a guide wire can move smoothly, and the wire helps a doctor to easily obtain sequential shots of clear images of the blood vessel. The new fiberscope also provides easy insertion of the fiberscope, easy rotation of the distal end to find a targeted portion of the vessel flexibly. A combination of a polyimide tube and a stainless steel tube called "hypotube" of a thin wall is used as a sheath of the scope to realize the smooth insertion and rotation.

Fig.6 shows an image observed by the new angioscope. The picture clearly shows an inner wall of blood vessel and a stent placed on it. Table 2 and Fig.7 show the specifications and an appearance of the system, respectively.

3.1.2 Imaging system(i-Light)

* *i-Light* is a trade name of iHeart Medical Co., Ltd.
Fujikura has developed an imaging system i-Light (IL-

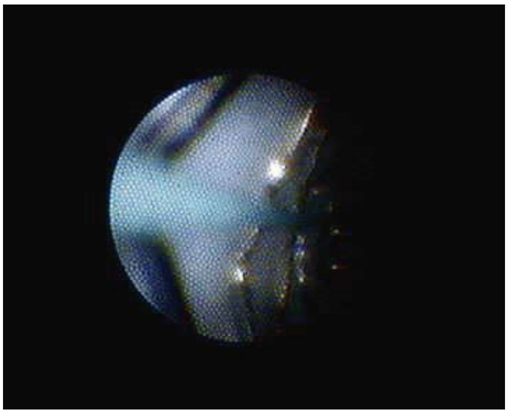

Fig. 6. Observed image of coronary of pig. The blood vessel wall is white, and a part of a stent appears metallic color.

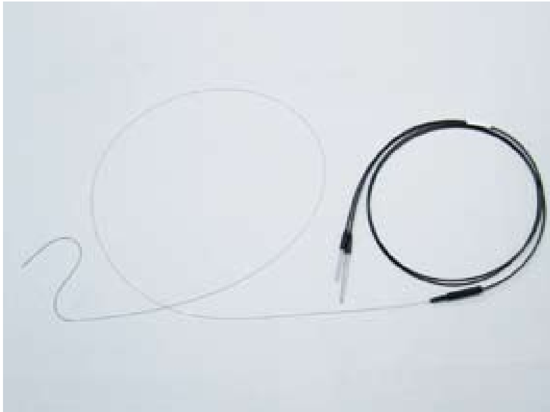

Fig. 7. Smart-i (S10).

Table 2. Specifications of Smart-i (S10).

Items		Specifications
Number of pixels		3,000
Angle of view		60° (in air)
Structure of distal end		Slider structure *Applicable to 0.010″guide wire
Diameter of fiberscope	Slider	1.0 mm × 0.7 mm
	Flexible portion	ϕ0.45 mm (Polyimide (PI) tube portion)
	Semi flexible portion	φ0.50 mm (Hypotube)
Maximum insertion length		1,550 mm
Applicable catheter diameter		ϕ1.33mm (4Fr) ~ ϕ1.67mm (5Fr)
Plugs	For image guide	Fiber Tech specification
	For light guide	Fiber Tech specification

Fig. 8. i-Light (IL-10).

10) for the new angioscopy. The imaging system is composed of a camera with a lens system and a light source for illumination, and an operator views pictures on an external monitor or a laptop computer. The system stores the pictures at a frame rate of 15 frames per second, and the data is also transferred to a PC or a USB memory. The imaging system is equipped with a battery and it works well even in case of power outrage or in a place without electricity. Table 3 shows specifications of this system.

3.2 CMOS image sensor module

Diagnosis and treatment by an endoscope are prevalent today because they are less invasive to the human body. An inexpensive disposable endoscope is desired because it decreases the healthcare expense and prevents risk of infection.

Actual setting of endoscope needs to check often the position of a catheter such as a feeding tube, and radiographic equipment like an X-ray device is usually required. The radiography forces a patient to go to hospital, and the patient is exposed to the X-ray radiation. As the catheters are changed frequently in an ICU, the dosage of X-ray for a patient increases.

To solve the above mentioned problem, Fujikura has developed a miniature CMOS image sensor module by which a doctor or an operator can identify the position of the catheter by direct view (Direct visualization [8]) of the picture instead of X-ray image. As shown in Fig.9, the newly developed miniature CMOS image sensor is small in size and inexpensive because we have integrated several domains of Fujikura's technology such as micro assembly of optics, semiconductor process, flexible printed circuits and thin cable assembly. The size of distal head of the CMOS image sensor is 1.2 mm in diameter and 5mm in length, and we believe that the values are the smallest in the world. The maximum transmission length is 3.5m and the angle of view is as wide as 120 degrees in air. The module has been designed to meet the medical requirements such as biocompatibility, electronics standards, and mechanical standards.

Fig.10 shows an image derived by the miniature CMOS image sensor module incorporated in a catheter product. The picture is good enough to position the head end of catheter.

Table 3. Specifications of i-Light (IL-10).

Item			Specifications
Power supply			AC adapter (Input voltage : 90 V ~ 264 V) Internal battery
Imaging device			1/4 inch CCD Effective pixels : 659 (H) ×494 (V)
Light source			White color LED
Video output			Digital output (DVI-D) VGA : 640 (pixel) × 480(pixel)/30fps
Interface			USB interface (USB 2.0)
Functions	Continuous shoot	Frame rate	5fps or 15fps (selectable)
		Recording size	VGA : 640(pixel) × 480(pixel)
		Recording format	JPEG
		Shooting time	1 ~ 10sec (adjustable by 1sec pitch)
		Recording capacity (internal RAM)	450 shots 5fps/10sec : 9 times 15fps/10sec : 3 times
	Digital zoom		x1, x1.5, x2, x4

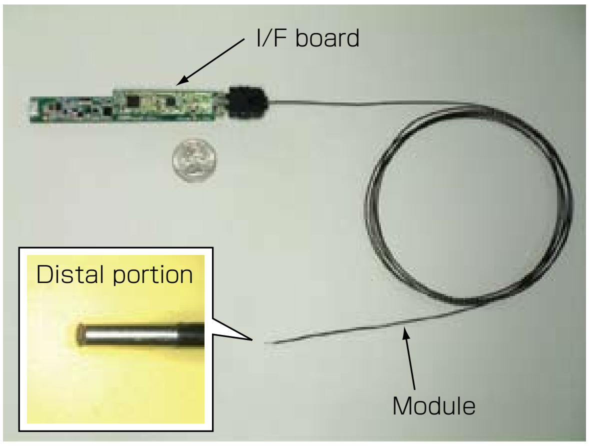

Fig. 9. Miniature CMOS image sensor module.

Fig. 10. An image of a mock duodenum observed by an endoscope system incorporated with the miniature CMOS image sensor module.

4. Conclusion

So far, Fujikura has been developing a variety of applied optics products. To meet customers' wide range of requests, we will continue to develop novel applied optics products and their applications by incorporating aggressively a variety of technology including not only our inherent technology but also others in electronics, mechanics, and so on.

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