# NEWS FROM JAPAN

by

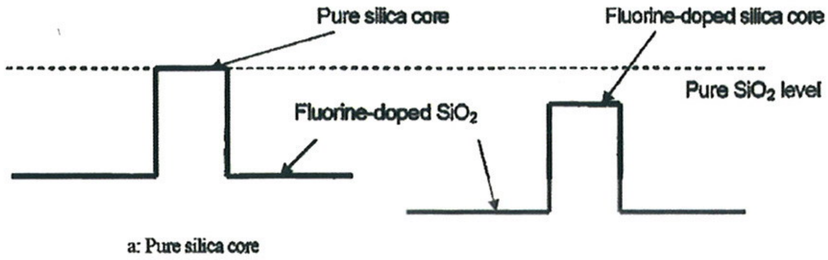
Y. Ohki

## Development of Radiation-Resistant, Single-Mode Optical Fibers for the CERN LHC

Optical fiber transmission systems are widely used in recent telecommunications, because optical fibers have a large bandwidth, low loss, are not influenced by electromagnetic induction, and their use can significantly reduce the size and weight of telecommunication cables. Moreover, the demand for data transmission is growing in various adverse environments such as hot and humid locations in chemical plants and those with high, dose-rate radiation like nuclear power plants or research facilities.

Especially, in high-energy physics research facilities, such as ion accelerator laboratories, the demand for optical fibers with a large transmission capacity and improved radiation-resistant characteristics is very high. In order to meet such demands, Fujikura Ltd., Tokyo, has been carrying out research and development of radiation-resistant optical fibers for more than 20 years. Fujikura has recently succeeded in developing new radiation-resistant optical fibers and has supplied them to the Large Hadron Collider (LHC) facility in the European Organization for Nuclear Research (CERN).

When silica-based optical fiber is exposed to radiation, various color centers are induced from precursor defects present in the fiber, thus increasing absorption and transmission loss. In optical fibers, dopants such as germanium are added to control the refractive index profile. It has been known that such dopants, the optical fiber manufacturing process itself, and remaining impurities are responsible for forming precursors to induce optical absorption in the ultraviolet to visible region.



a: Pure silica core

*Figure 1. Refractive index profiles of radiation-resistant, single-mode optical fibers.*

It also has been known that the radiation resistance is good when the OH content is high in the silica used for the optical fiber core. Therefore, Mr. Tsumanuma and other researchers in Fujikura determined to develop a fluorine-doped silica core, single-mode optical fiber optimized at a wavelength of 1.31 μm. They first developed a single-mode optical fiber with pure silica core and fluorine-doped silica cladding. The refractive index profile of this fiber is shown in Figure 1(a). Although the fiber shows relatively good resistance to radiation, it is not robust enough for locations with a very high radiation dose-rate such as the CERN-LHC. Therefore, they have developed a single-mode optical fiber, of which the core, in addition to its cladding, is fluorine-doped silica with a refractive index profile shown in Figure 1b. Various parameters and the characteristics of the fibers fabricated for trial purposes are shown in Table 1. All the fibers fabricated meet ITU-T G.652.B (ITU-T: Telecommunication Standardization Sector of the International Telecommunication Union). Therefore, it is possible to connect these fibers with standard single-mode optical fibers.

In order to examine the radiation resistance of the developed fibers, radiation-induced loss during irradiation of γ-rays

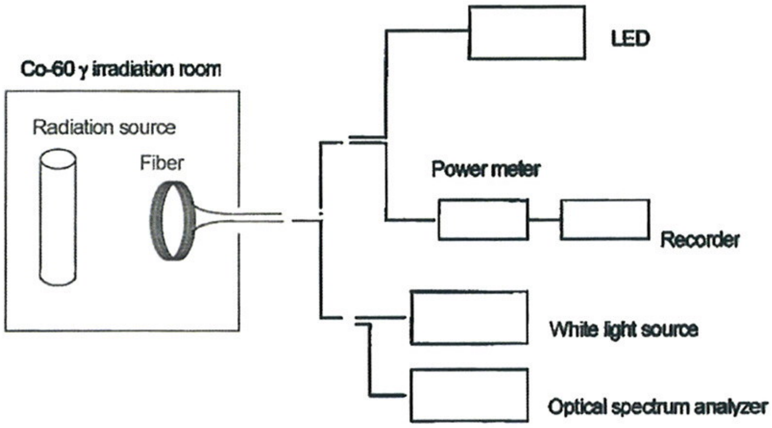


*Figure 2. Schematic of experimental system.*

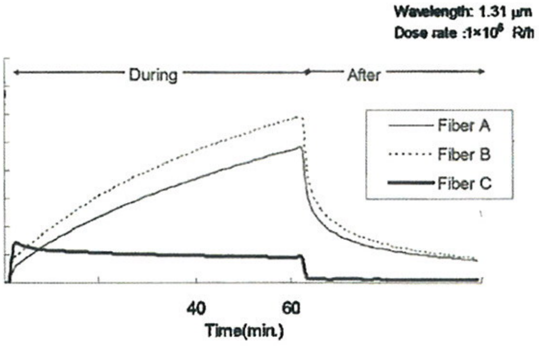


*Figure 3. Time response curves of radiation-induced loss.*

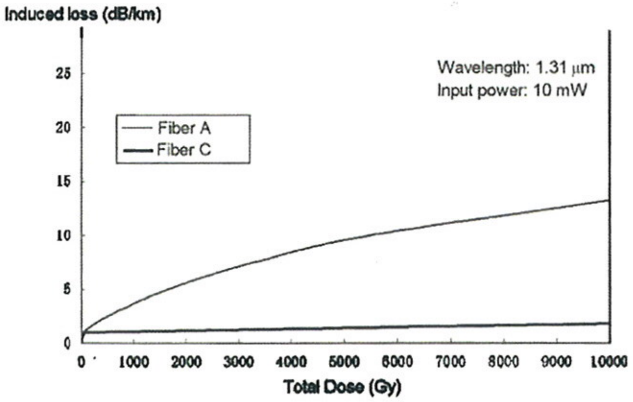


*Figure 4. Induced loss as a function of total dose.*

was measured in two ways using a light emitting device (LED) and a spectrum analyzer. Figure 2 shows a schematic of the measurement system. The length of the irradiated part in each fiber is 100 m. The increase in radiation-induced loss of the optical fiber was continuously measured at 1.31 µm during and after the γ-irradiation at three dose rates: 1 × $10^5$, 5 × $10^5$, and 1 × $10^6$ R/h. The loss recovery characteristics also were measured.

Figure 3 shows time-response curves of the radiation-induced loss at 1.31 µm during and after the irradiation with a dose rate of 1 × $10^6$ R/h and a total exposure time of 60 minutes. The induced loss increases with an increase in exposure time in Fiber A with a pure silica core and Fiber B with a core of 0.2 wt% fluorine-doped silica. But it does not increase in Fiber C, although a comparatively large loss is induced right after the start of irradiation. This is due to a kind of radiation hardening effect, in which fluorine annihilates the defects induced by γ-rays.

Figure 4 shows the total dose-dependence of the induced loss at 1.31 µm. observed in Fibers A and C. The induced loss keeps a small value in Fiber C, even after the irradiation of $10^4$ Gy, indicating excellent radiation resistance of this fiber. To conclude, the developed 1.3-µm optimized, single-mode optical fiber, shown in Figure 5, with a 0.8-wt% fluorine-doped silica core shows excellent radiation-resistant characteristics, and it satisfies the international standard ITU-T G.652.B.

Table 1. Characteristics of sample fibers

| Characteristics | Recommended value in ITU-T G.652.B | Fiber A | Fiber B | Fiber C |
|---|---|---|---|---|
| Fluorine content of core (wt%) | — | 0 | 0.2 | 0.8 |
| Loss (dB/km) at 1310 nm | ≤0.4 | 0.33 | 0.35 | 0.38 |
| Loss (dB/km) at 1550 nm | ≤0.35 | 0.18 | 0.21 | 0.25 |
| MFD (µm) at 1310 nm | 8.6-9.5 ± 0.7 | 8.6 | 8.6 | 8.7 |
| Cladding diameter (µm) | 125.0 ± 1.0 | 125.0 | 125.0 | 125.0 |
| Cutoff wavelength (µm) | ≤1.26 | 1.24 | 1.24 | 1.22 |
| Zero-dispersion wavelength [nm] | 1300-1324 | 1308 | 1308 | 1309 |

This article was completed with the cooperation of M. Kudoh and T. Tsumanuma of Fujikura Ltd.

*Figure 5. The developed radiation resistant optical fiber.*