Radiation Resistance Characteristics of Optical Fibers and Optical Fiber Devices for WDM Transmission Systems

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Radiation Resistance Characteristics of Optical Fibers and Optical Fiber Devices for WDM Transmission Systems

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Radiation resistance characteristics of dispersion shifted fibers, P-Al-codoped Erbium doped fibers, and fiber Bragg gratings were investigated through γ-ray irradiation. These results lead to the prediction that there will be no significant problems for long-year use under the actual submarine conditions.

1. Introduction

Drastic increment of transmission capacity has been demanded to satisfy the rapid growth of telecommunications and computer communications. Through a great deal of efforts to find out the suitable system, wavelength division multiplexing (WDM) system is coming up as the most practical and possible candidate[1]. This future system, which enables to transmit tremendous numbers of data in a single fiber by using plural wavelength-varied signals, will consist of novel components as follows.

WDM-Dispersion Shifted Fiber (WDM-DSF) : specially designed fiber[2] for WDM transmission systems to avoid signal distortion, crosstalk, and non-linear effects in long-haul transmission using a number of different-wavelength signals.

P-Al-codoped Erbium Doped Fiber (P-Al-EDF) : one component of the hybrid EDF[3] which has both high amplification efficiency and flat gain characteristics from 1543 nm to 1560 nm.

Fiber Bragg Grating (FBG) : fiber device which has periodical refractive index changes in the core region and thus enable only the signal whose wavelength meets the Bragg reflection condition to reflect backwards selectively[4].

Before practical use for any system, not only high performance but also high stability against possible environment is necessary to be guaranteed. In particular, above WDM components are needed to be examined in several additional conditions because they will be applied to undersea transmission systems for taking advantage of their characteristic high transmission density. Radiation resistance characteristic is one of important parameters as the ocean-bottom embedded radioactive sources may affect them for long-year use.

In this paper, we present results of γ-ray exposure tests for WDM-DSF, P-Al-EDF and FBG. These results lead to the prediction that there are no significant problem in the above components used under the actual submarine conditions.

2. Experimental

2.1 WDM-DSF

Refractive index profile of the DSF used in this study, which has large mode field diameters (MFDs) more than 9 μm, is illustrated in Fig. 1. A GeO_2-SiO_2 core is surrounded by a SiO_2 cladding. Fiber parameters of the DSF are listed in Table 1. The DSF was irradiated by γ-ray at dose rates of 1×10^2, 1×10^3 and 8×10^3 Gy/h for one hour. Transmission loss at 1.55 μm was monitored during and after irradia-

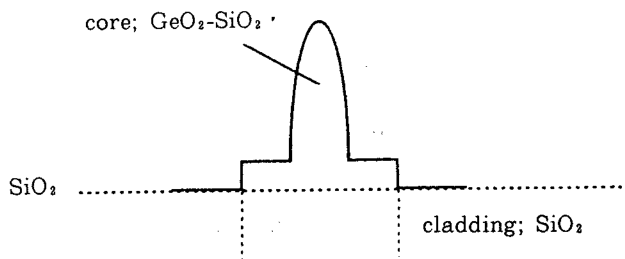

Fig. 1 Refractive index profile of new DSF.

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Table 1 Characteristics of new DSF

Cutoff wavelength	Mode Field Diameter @1.55 μm	Zero Dispersion Wavelength	Bending Loss @D30mm
[μm]	[μm]	[nm]	[dB/m]
1.68	9.4	1586	<0.01

tion. Long-term irradiation test at a dose rate of 2×10^{-2} Gy/h was also carried out. Transmission loss at 1.55 μm was monitored for successive fifty days using a 5000 m sample of the DSF.

2.2 P-Al-EDF

In order to investigate the effect of P and Al incorporated in the core of the EDF on γ-ray resistance, three kinds of EDFs were exposed to γ rays. Fiber parameters of the EDFs used in this experiment are listed in Table 2. Each EDF was irradiated by varying the irradiation dose rate and the irradiation time as in Table 2. Attenuation spectra and amplification characteristics were measured for four days after irradiation. Long-term irradiation test of Fiber 1 at dose rate of 2×10^{-2} Gy/h was also carried out. Transmission loss at 1.3 μm was monitored for successive six months using a 300 m sample of the EDF.

Table 2 Experimental conditions

Parameters of EDFs

Fiber	Al content (wt.%)	P content (wt.%)	Ge content (wt.%)	Er content (wt.%)
Fiber 1	1.2	4.4	20	0.1
Fiber 2	0.3	3.9	25	
Fiber 3	0	5.0	20	

Irradiation

Dose Rate(Gy/h)		0.15	1	10	10^2	10^2	10^3
Time(h)	Fiber 2	19	19	19	1	19	19
	Fiber 1,3	19		19	1		19

2.3 FBG

FBGs used here were fabricated by irradiating 248 nm UV-light of KrF excimer laser to the hydrogen-loaded Ge-doped single mode fiber through the phase mask. UV-light irradiation was controlled to obtain FBGs whose transmission loss was around 40 dB. FBGs were left for over two weeks to remove loaded hydrogen before γ-ray irradiation.

3. Results and Discussions

3.1 WDM-DSF

The results of loss monitoring for the DSF at dose rates of 1×10^2, 1×10^3 and 8×10^3 Gy/h are exhibited in Fig. 2. Transmission loss increased during the irradiation and it recovered to some extent after the irradiation. This tendency agrees with other kinds of fibers[5,6], therefore, it is considered that the loss induced by γ-ray irradiation consists of the component with a short decay time and the component with a long decay time.

It is known that the recovery curve of an induced loss, L(t), can be expressed using multiple exponential

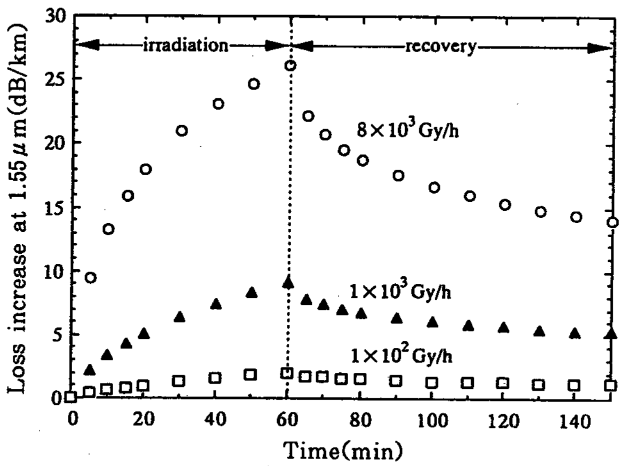


Fig. 2 Loss increase of new DSF during irradiation and its recovery after irradiation.

decay function as follows[7];

$$L(t) = \Sigma a_i \cdot \exp(-t/\tau_i) \quad (1)$$

Where t is time after the end of irradiation, τ_i is a decay time of i-th component of loss, and a_i is a constant. By fitting the plots during recovery in Fig. 2 to a curve Eq.(1), the induced losses can be decomposed into a transient loss with a short decay time and a permanent loss with an infinite decay time. The constant terms and the decay times of two components at each dose rate listed in Table 3. It is

Table 3 Constant (a) and decay time (τ) of transient and permanent loss component of both new DSF and conventional DSF at dose rates of 1×10^2, 1×10^3 and 8×10^3Gy/h

Dose Rate (Gy/h)	New DSF				Conventional DSF			
	Transient		Permanent		Transient		Permanent	
	a[dB/km]	τ[min]	a[dB/km]	τ[min]	a[dB/km]	τ[min]	a[dB/km]	τ[min]
8×10^3	10.9	23.1	14.2	infinite	11.1	31	16.0	infinite
1×10^3	3.5	23.2	5.4	infinite	3.8	21	6.7	infinite
1×10^2	0.8	24.3	1.2	infinite	0.5	19	1.0	infinite

found that both the transient loss and the permanent loss of the new DSF are almost equal to those of the conventional DSF.

In Fig. 3, permanent losses at each dose rate derived from the above decomposition are plotted as a function of a total dose. Moreover, the transmission loss growth during the irradiation at a dose rate of 2×10^{-2} Gy/h is also plotted in this figure. The permanent loss at high dose rates and the loss increase during exposure at a dose rate of 2×10^{-2} Gy/h show a good agreement. It indicates that accelerated tests at high dose rates can be useful for estimating a long-term loss increase in the environment with low dose rates by consisting the permanent loss components. From this result, loss increase at 0.125 Gy, which corresponds to the worst case of a total dose for 25 years in the undersea environment[8], can be estimated to be less than 0.02 dB/km.

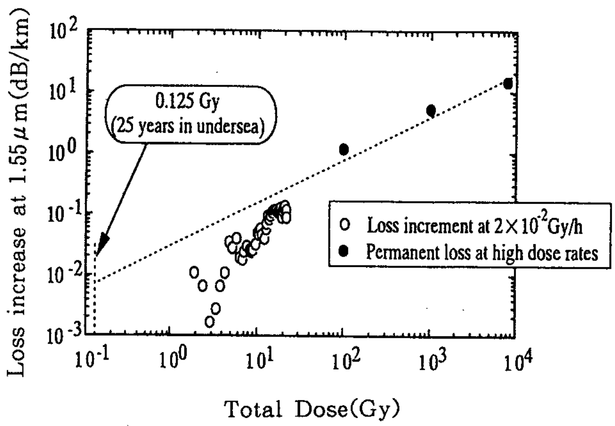


Fig. 3 Loss increase of new DSF during irradiation at 2×10^{-2} Gy/h and permanent loss at high dose rates.

3.2 P-Al-EDFs

Wavelength dependence of loss increase of the EDFs after irradiation are shown in Fig. 4. It is found that the loss increase of the P-Al-codoped EDFs (that is Fiber 1 and Fiber 2) is larger than that of the P-codoped EDF (that is Fiber 3). Among P-Al-codoped EDFs, the fiber of higher Al content shows higher loss increase. Further, it is clear that a tail of induced loss from a shorter wavelength region dominantly affect telecommunication windows for the P-Al-codoped EDF.

By contrast, as seen in previous reports[9], the P-codoped EDF shows loss-tail from longer wavelength region. These results clarifies that P is not significant for γ-ray resistance although the existence of Al

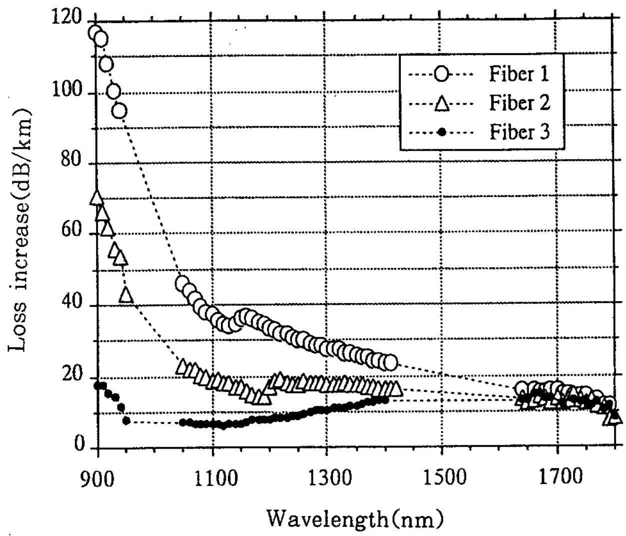


Fig. 4 Loss increase due to γ-ray irradiation (1×10^{2} Gy/h×1h).

in the core has a strong influence. Nevertheless, the loss increase of Fiber 1, which is the largest among the three EDFs, is only 30 dB/km at 1.3 μm and less than that of Al-codoped EDF[10] under the same total dose.

Figure 5 shows total dose dependence of the loss increase at 1.3 μm of the EDFs after irradiation. A similar tendency in loss increase can be seen among three EDFs, and further, this tendency is almost the same as that of Al-codoped EDF.

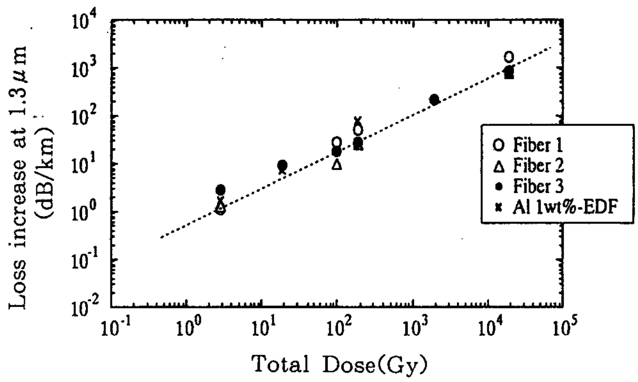


Fig. 5 Total dose dependence of loss increase of EDFs at high dose rates.

In Fig. 6, loss growth of Fiber 1 at 1.3 μm during irradiation at a dose rate of 2×10^{-2} Gy/h is plotted as a function of total dose. Loss increases of Fiber 1 at high dose rates are also plotted in this figure. Total dose dependence of loss increase at a dose rate of 2×10^{-2} Gy/h and that at high dose rates are almost the same.

From this result, the loss increase should be only

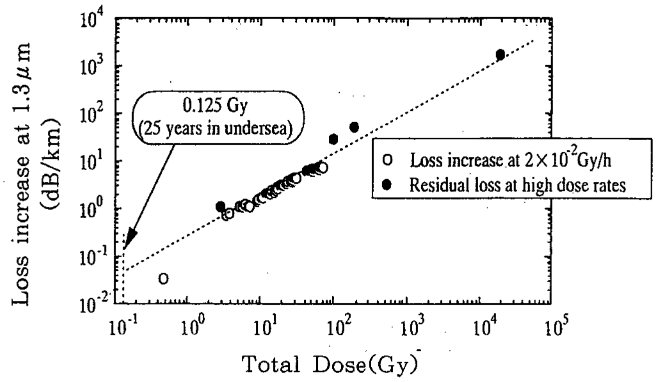


Fig. 6 Loss increase of Fiber 1 during irradiation at 2×10^{-2} Gy/h and residual loss at high dose rates.

less than 0.2 dB/km for years in the undersea environment[8].

In order to examine the effects of irradiation on amplification characteristics, wavelength dependence of the gain of Fiber 1 was measured before and after irradiation. Figure 7 shows gain spectra of Fiber 1 when pumped at 1.48 μm with a launched pump of 50 mW. Gain spectrum does not change with irradiation at an input signal power of -35 dBm. When the input signal power was -6dBm, gain degradation due to γ-ray irradiation was as small as 0.3 dB. Figure 8 shows gain spectra of Fiber 1 when pumped at 0.98 μm with a launched pump power of 50 mW. It is found that gain spectra show no change at all after irradiation, similar to gain spectra of 1.48 μm pumping. Furthermore, gain degradations in the case of 0.98 μm pumping are almost equal to those in the case of 1.48 μm pumping, although loss increase of 0.98 μm by γ-ray irradiation is larger than that of 1.48 μm. This is because the EDF length used for optimum amplification in the case of 0.98 μm pumping, is shorter than that in the case of 1.48 μm pumping. As the predicted total dose is much smaller[8] than that in this case, it is considered that degradation of amplification performance of P-Al-EDF due to γ-ray irradiation is negligible in the actual undersea envi-

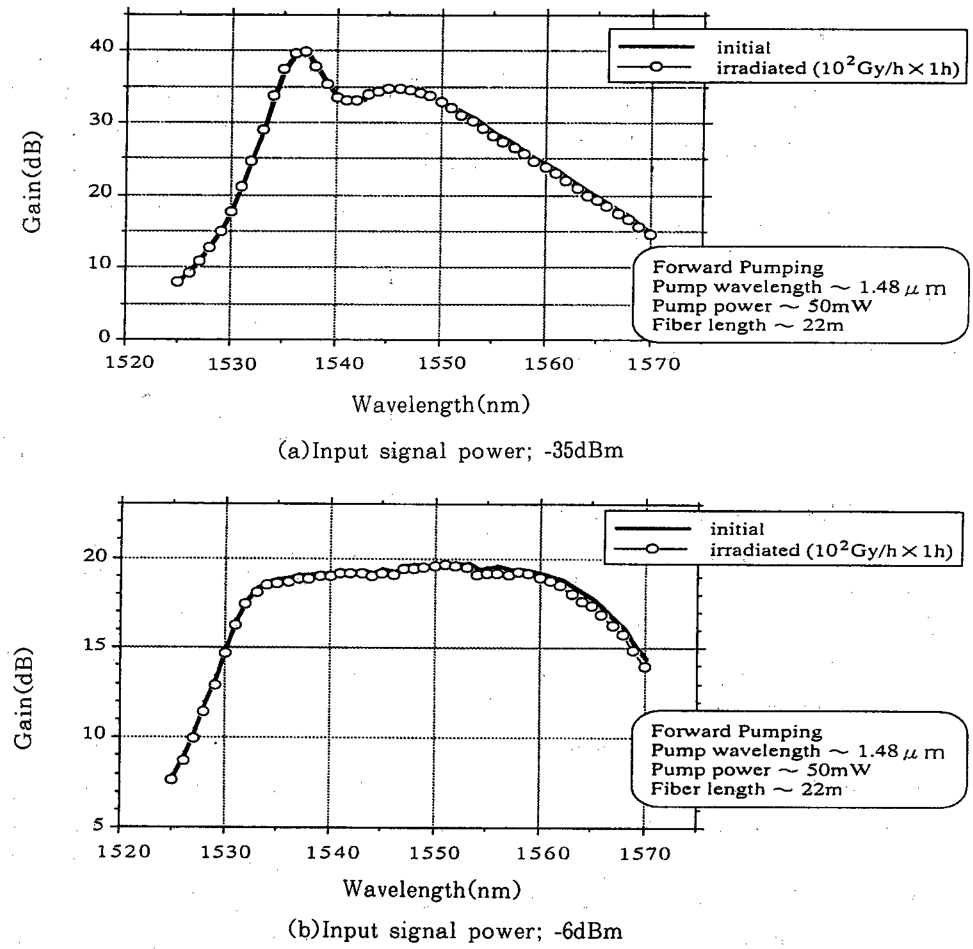
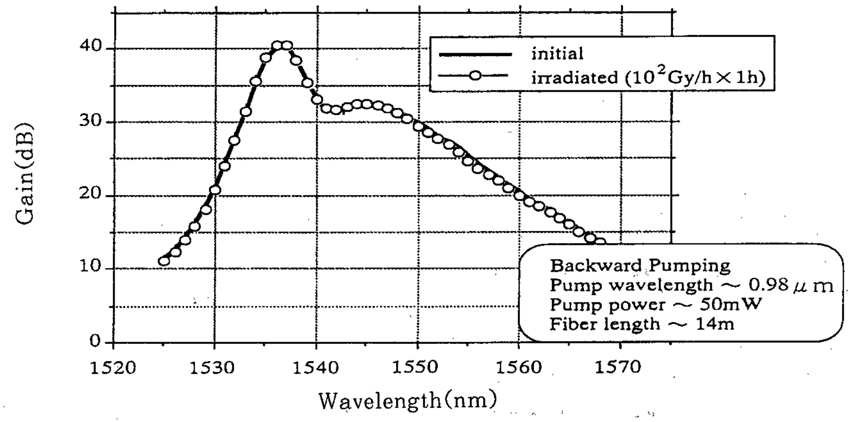
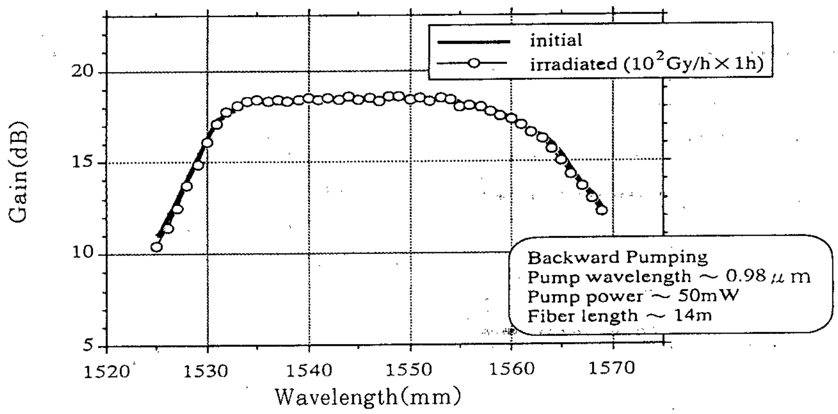


Fig. 7 Gain spectra of Fiber 1 before and after irradiation (1.48 μm pumping) ; Input signal power, (a) -35 dBm, (b) -6dBm.



(a)Input signal power; -35dBm



(b)Input signal power; -6dBm

Fig. 8 Gain spectra of Fiber 1 before and after irradiation (0.98 μm pumping); Input signal power, (a)-35 dBm, (b) -6 dBm.

ronment.

3.3 Fiber Bragg Grating

FBGs are fabricated by UV irradiation through a phase mask, as UV light induces photoreactions of Ge-related glass defects that causes x refractive index increase. Gamma rays possibly can also affect glass structures, because the loss increase phenomenon of optical fibers was observed being accompanied by the production of some kinds of glass defects under γ-ray radiation. This fact indicates that γ-ray may give rise to fatal damages to the FBGs.

Figure 9 shows transmission spectra of the FBG under sixty-minute γ-ray irradiation with a dose rate of 8×10^3 Gy/h and for twenty minutes after irradiation stopped. No remarkable changes and degradations are discernible both in shape and size through a series of transmission spectra. Figure 10 shows the detailed changes of Bragg refraction wavelengths and maximum transmission losses at that wavelength at dose rates of 8×10^3, 1×10^3 and 1×10^2 Gy/h. As their

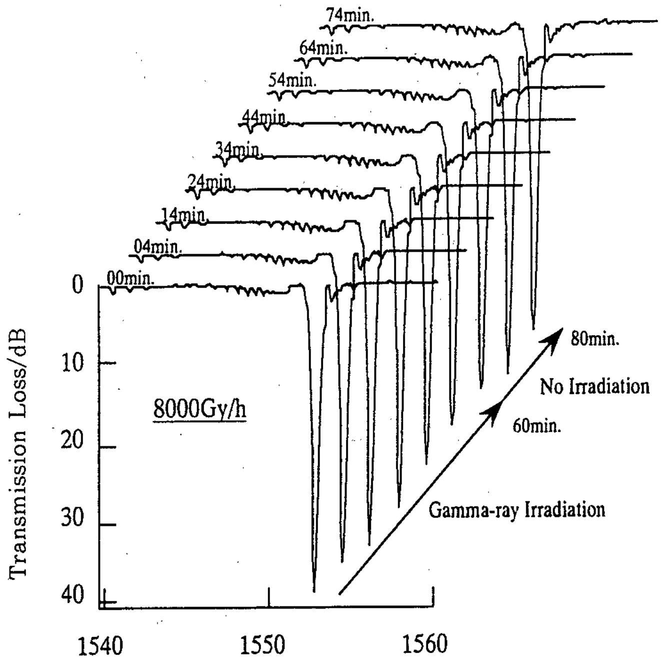


Fig. 9 Transmission spectrum changes of FBG under γ-ray irradiation.

changes, which occurred randomly throughout the measurements regardless of γ-ray irradiation, are negligibly small considering the measuring accuracy in the system, the FBG is inferred not to be damaged by γ-ray irradiation. To observe the FBG stability from another viewpoint, refractive index profiles of non-UV irradiated fiber and UV-irradiated (thus refractive-index-increased) fiber were measured before and after 1-hour γ-ray irradiation at a dose rate of 7×10^3Gy/h. As shown in Fig.11, no distinguishable changes are observed in both cases. From these results, it can be concluded that FBG is quite stable under γ-ray irradiation in the actual undersea environment[8].

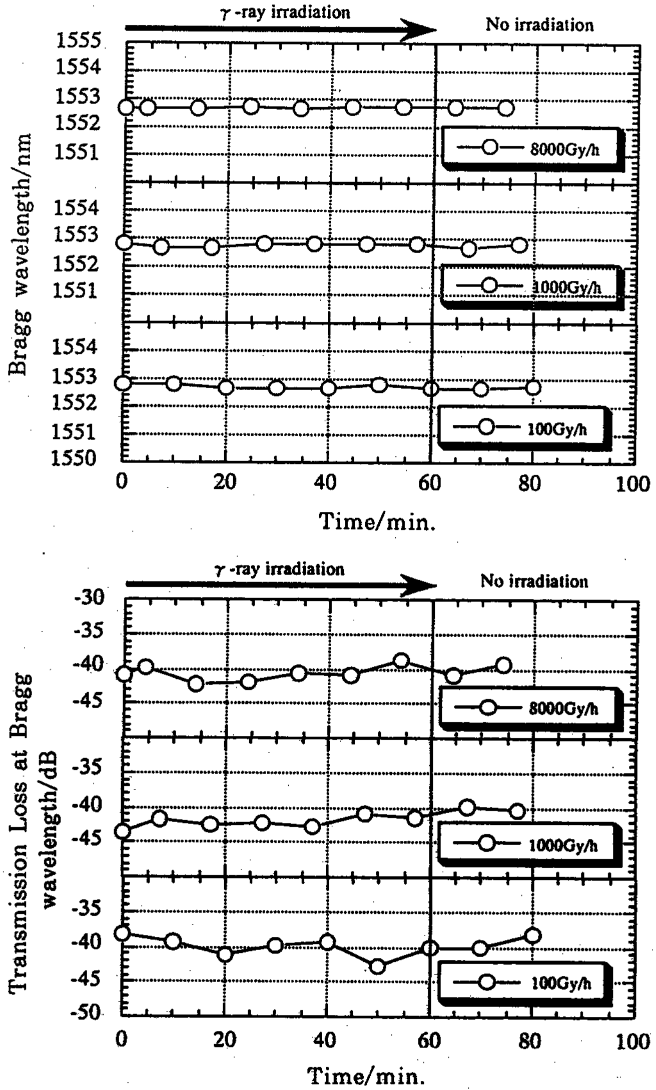


Fig. 10 FBG characteristics changes due to γ-ray irradiation; top, Bragg wavelength; bottom, transmission loss.

4. Conclusion

We have presented the results of γ-ray exposure test for WDM-DSF, P-Al-EDF and FBG. It has been predicted that there are no significant problem in the above components used under the actual submarine conditions.

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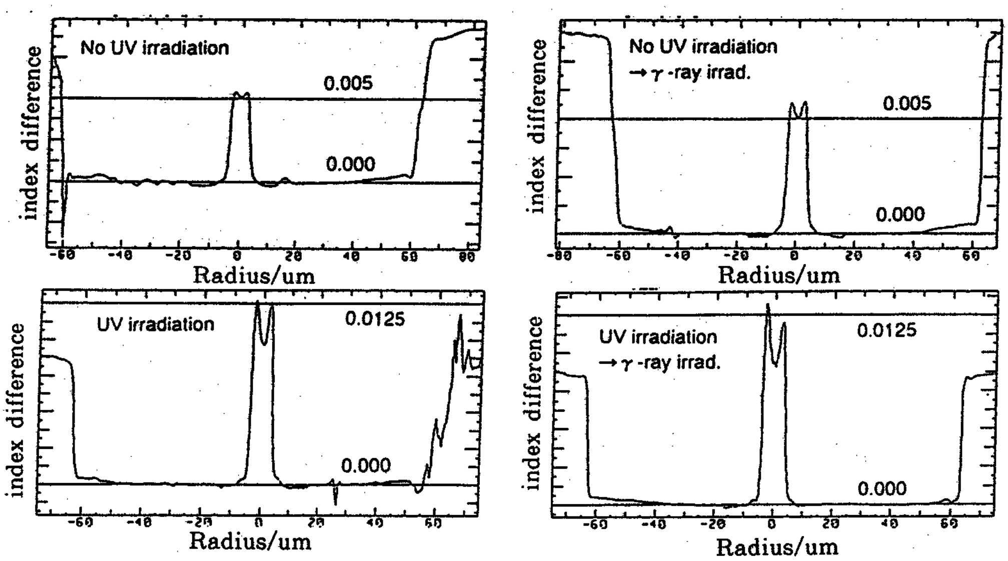

Fig. 11 Refractive index changes due to γ-ray irradiation; left, before γ-ray irradiation; right, after irradiation, top, without UV irradiation; bottom, with UV irradiation.

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