AD P000545

GAMMA IRRADIATION CHARACTERISTICS OF OPTICAL FIBERS

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SUMMARY

The characteristics of optical fibers during 60 Co γ irradiation, i.e. the effect of dopant, OH content, dose rate and temperature were investigated. Moreover, the model which presumes the effect of long term use from the result of short term irradiation was investigated. The range of environment and a type of fiber which could be used for a long time was decided.

From experimental results, it became clear that the fiber which could be used in radiation exposed area was only pure silica core fiber. Moreover, the increase of transmission loss of pure silica core fiber was able to be explained from the model of color center formation by irradiation and from the dose rate dependence. The increase of transmission loss of pure silica core fiber used for a long time was presumed quantitatively. So we could find the guide of optical fiber cable design for long time use in radiation exposed area.

In addition, the degradation of mechanical strength by irradiation was investigated.

INTRODUCTION

Optical fiber is rapidly being developed to operate in nuclear environments because of its low loss and high bandwidth. For this purpose, it is essential to know how radiation affects transmission properties and mechanical strength of fibers. Optical communication systems used in an atomic power plant will be required to withstand exposure to nuclear environments. Although radiation-induced loss in optical fiber has been studyed by some investigators[1),2)], more quantitative studies must be made on the growth and the recovery of radiation induced loss and the influence to mechanical strength. This report is concerned with the induced loss in various types of optical fibers during steady-state 60 Co gamma ray irradiation. We also describe the effects of ambient temperature, OH content in fiber and irradiation dose rate on the growth and recovery of radiation-induced loss, also propose a model by which the lifetime of fiber can be estimated from accelerated irradiation.

SAMPLES AND IRRADIATION CONDITIONS

The samples are Ge-P doped silica core GI type fiber, Ge-B doped silica core GI type fiber, P doped silica core SI type fiber, pure silica core silicone clad fiber and pure silica core B-F clad fiber. All optical fibers were jacketed with nylon. Irradiated fiber length was 100 to 500 m. A experimental apparatus for measuring the radiation-induced loss in optical fiber waveguides is shown in Fig. 1.

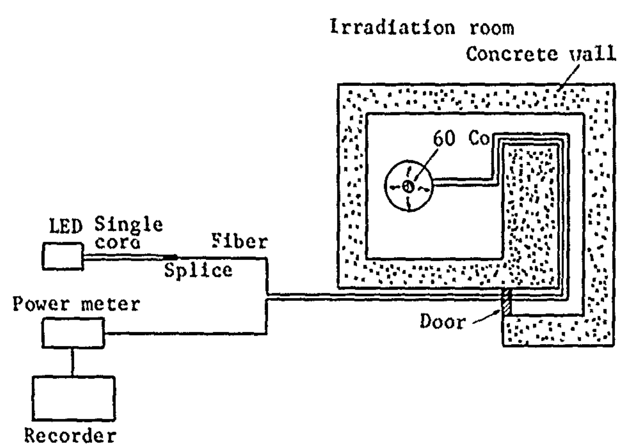

Fig. 1 The Experimental Apparatus

The apparatus consists of a light source and injection optics, the fiber, a constant temperature chamber, a source of radiation (60 Co) and a detector. The dose rate was determined by changing the distance between the radiation source and samples in the chamber. Samples and dose rate and total dose for each sample are listed in Table 1.

Table 1 Samples and Measurement Conditions

Fiber	Dose rate (R/H)	Total dose (R)	Wave-length (μm)	OH (ppm)	Remarks
Ge-P doped core GI type	30	5.0×10^3	0.84	-	
			1.26		
Ge-B doped core GI type	3	1.2×10^4	-	-	*1
P doped core SI type	30	5.0×10^3	0.84	-	
Pure silica core Silicon clad SI type	3	1.2×10^4	-	-	*1
	780	1.0×10^5	0.84	2	
Pure silica core B-F doped clad SI type	3	1.2×10^4	-	2	*1
	780	1.0×10^5	0.84	2	
	1.55×10^4	2.2×10^6	0.84	2	50°C, 80°C *2
	2.3×10^4	3.2×10^6	0.84	2	
	3.4×10^4	4.8×10^6	0.84	2	
	6.2×10^4	8.7×10^6	0.84	2	
	7.0×10^4	1.0×10^7	0.84	2	
Pure silica core B-F doped clad SI type	1.0×10^5	1.7×10^6	0.84	10	
	3.0×10^5	5.0×10^6	0.84	10	
	5.0×10^5	8.4×10^6	0.84	10	
	7.0×10^5	1.0×10^7	0.84	10	

*1: Intermittent irradiation for about 4,000 hours

*2: Irradiation at room temperature except 50°C and 80°C

RADIATION INDUCED LOSS IN FIBER

1. Ge-P doped silica core fiber

Fig. 2 shows radiation induced loss (at 0.84 and 1.26 μm) in the Ge-P doped silica core GI type fiber as a function of dose in situ steady state 60 Co irradiation.

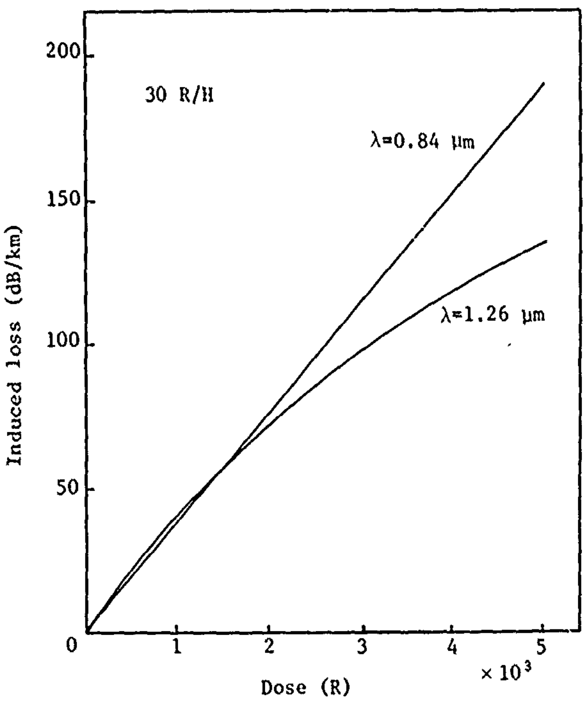

Fig. 2 Radiation-induced Loss (Ge-P Doped Core GI Type)

At 0.84 μm, the induced loss was great in spite of the low dose rate 30 R/H, and was proportional to the dose. The induced loss per unit dose was 0.03 to 0.04 dB/km/R. The induced loss at 1.26 μm grew in low dose range like at 0.84 μm, but was not proportional to dose in the high dose range.

Fig. 3 shows the recovery of the radiation induced loss in this fiber after irradiation. The additive loss remains 60 dB/km at 0.84 μm even after 7 weeks at room temperature.

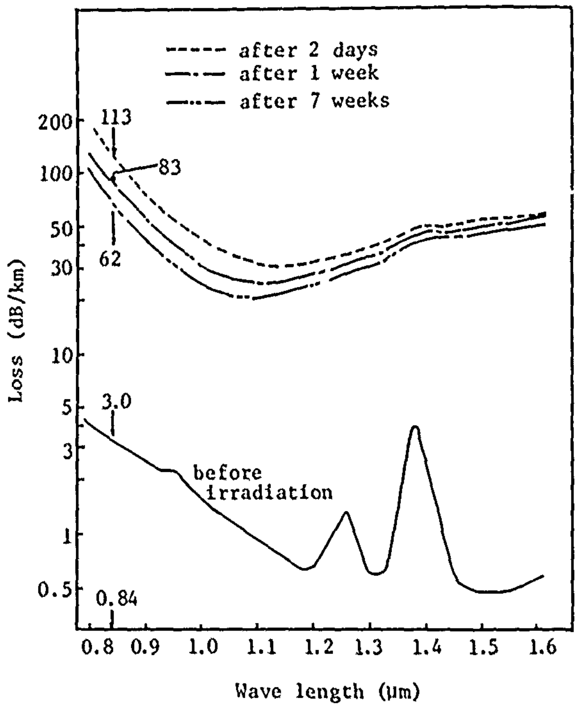

Fig. 3 Loss Spectra after Irradiation (Ge-P Doped Core GI Type)

2. Ge-B doped silica core fiber

Fig. 4 shows the loss spectra of the Ge-B doped silica core fiber to be irradiated for about 4,000 hours at 3 R/H. The radiation induced loss measured immediately after irradiation was 18 dB/km at 0.84 μm inspite of being as low as 3 R/H.

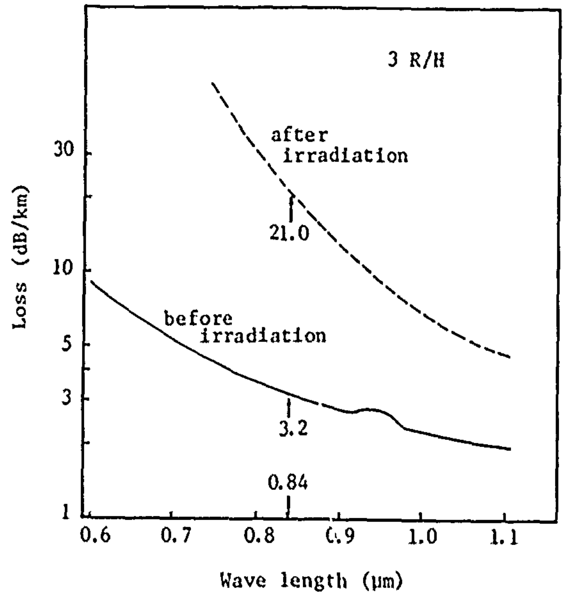

Fig. 4 Loss Spectra after Irradiation (Ge-B Doped Core GI Type)

3. P doped silica core fiber

Fig. 5 shows the radiation induced loss in the P doped silica SI type fiber.

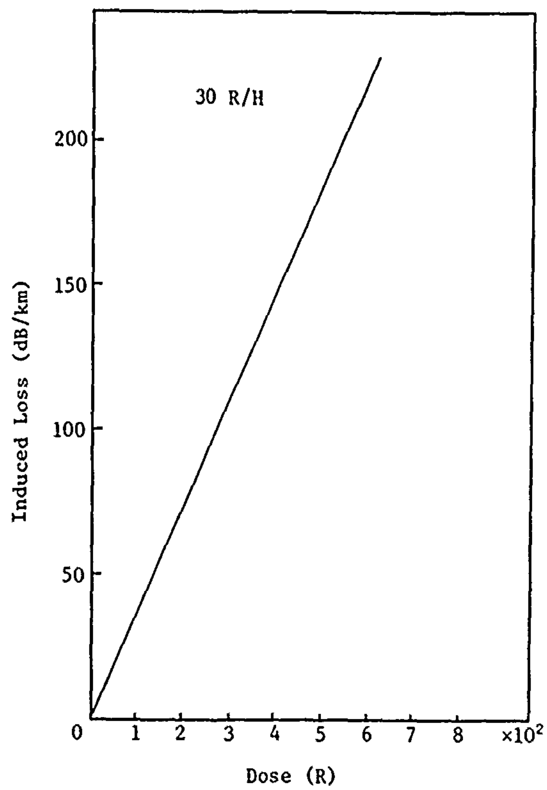

Fig. 5 Radiation-induced Loss (P Doped Core SI Type)

The induced loss is proportional to the dose and the induced loss per unit dose is 0.3 to 0.4 dB/km/R, which is about 10 times of that in Ge-P doped core fiber.

4. Pure silica core fiber

Ge, P or B increases the radiation sensitivity as described above, but the pure silica core fiber is considered to lower radiation sensitivity than a doped silica core fiber. Fig. 6 shows the radiation induced loss in pure silica core silicone clad fiber and pure silica core B-F doped silica clad fiber at 780 R/H dose rate. The induced loss is saturated at 3.5 dB/km in B-F doped silica clad fiber and at 4 dB/km in silicone clad fiber over dose of 7×10^3 R. The radiation-induced loss in B-F doped silica clad fiber after irradiation recovered to the level of before irradiation in about 3 weeks but in the case of silicone clad fiber, the additional loss is 0.7 dB/km in 7 weeks after irradiation. The degradation of the cladding silicon caused by irradiation attribute the additional loss. In the condition at dose rate of 3 R/H and radiation time of 4,000 H, the induced losses of both fibers were not detected.

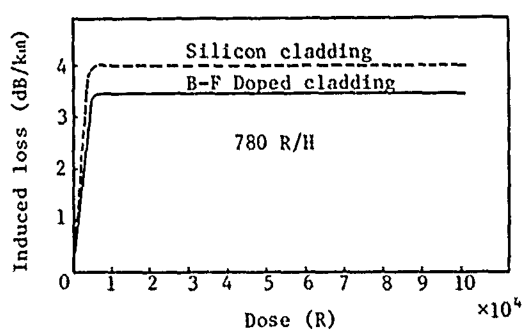

Fig. 6 Radiation-induced Loss (Pure Silica Core Fiber)

Fig. 7 shows the radiation induced loss at 0.84 μm in the pure silica core B-F doped silica clad fibers with different OH contents at 7×10^4 R/H dose rate. The effect of OH content on the radiation response of pure silica core fiber is clearly evident in Fig. 7. The fibers which have a much lower OH content, have greater radiation sensitivity.

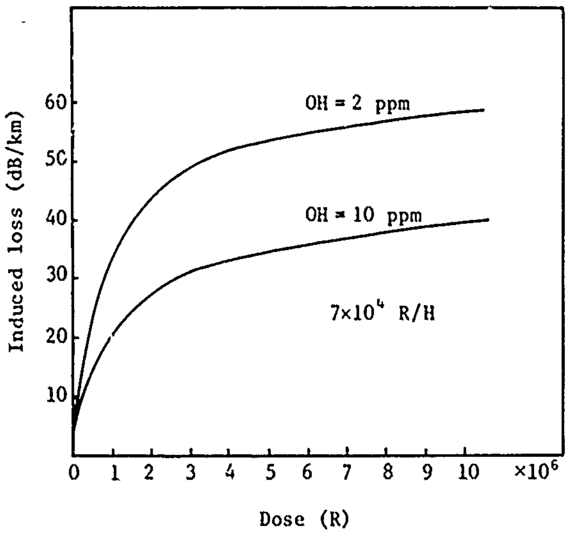

Fig. 7 Radiation-induced Loss (Pure Silica Core Fiber)

Fig. 8 shows the radiation induced loss in the pure silica core fiber with 2 ppm OH during irradiation at 6.2×10^4 R/H over the $0.6 \sim 1.1$ μm wavelength range. A loss spectrum can be obtained following the irradiation by sweeping the wavelength with the monochromater. The induced loss measured at 0.84 μm seems to be primarily due to the tail of an intence induced absorption in the UV and visible.

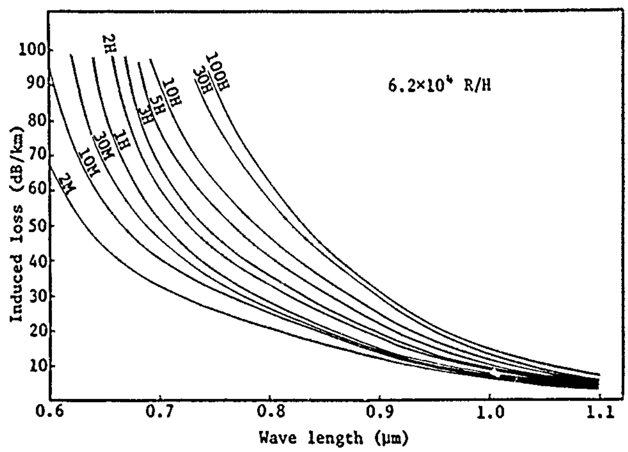

Fig. 8 Radiation-induced Loss Spectra during Irradiation

The growth and recovery of radiation induced loss depends upon the core glass composition and pure silica core fiber withstands exposure to radiation environments.

DOSE RATE DEPENDENCE OF RADIATION INDUCED LOSS

We quantitatively discuss the production of color centers in pure silica core fiber during steady state 60 Co irradiation, and estimate the lifetime of the fiber in the radiation environments.

1. Growth of radiation induced loss[3)]

Dotted line in Fig. 9 shows the radiation induced loss vs. time in pure silica core fiber at dose rates (1.55×10^4, 2.3×10^4, 3.4×10^4 and 6.2×10^4 R/H).

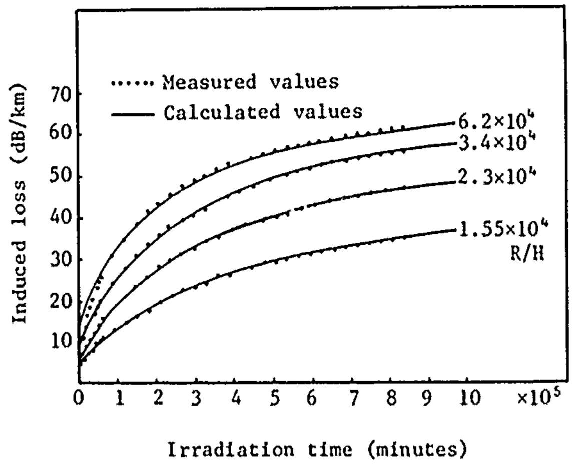

Fig. 9 Radiation-induced Loss of Pure Silica Fiber (OH 2 ppm)

The measured data in Fig. 9 (dotted lines) can be accurately fitted by the expression

$$\Delta\alpha = \alpha Lt + \sum_i \alpha i\{1 - \exp(-\lambda it)\} \quad ...... \quad (1)$$

Where, $\Delta\alpha$ is the induced loss and t the irradiation time. The fitting is accomplised by a computerized least-squares procedure. The constant (αL, αi, λi) from the fit were listed in Table 2.

Table 2 The Coefficient of Equation (1) (OH 2 ppm)

	1.55×10^4 (R/H)	2.3×10^4 (R/H)	3.4×10^4 (R/H)	6.2×10^4 (R/H)
λ_1	5.1×10^{-4}	5.4×10^{-4}	6.9×10^{-4}	8.6×10^{-4}
λ_2	8.0×10^{-3}	8.7×10^{-3}	9.5×10^{-3}	1.1×10^{-2}
λ_3	1.4×10^{-1}	2.0×10^{-1}	2.5×10^{-1}	4.3×10^{-1}
α_L	1.5×10^{-3}	1.8×10^{-3}	2.1×10^{-3}	1.8×10^{-3}
α_1	17.50	26.04	30.81	33.69
α_2	0.96	1.60	1.77	5.52
α_3	4.45	5.15	6.12	6.55

2. Analysis of experimental results

The results presented in the previous section can be qualitatively understood on the basis of a simple kinetic model for color-center formation. Assume first that an initial precursor consentration Poi exist in glass before irradiation, and that additional precursors are created at a constant rate of Ki during irradiation. Second, assume that during irradiation, carrier trapping at precursors proceeds at a rate proportional to the number of empty precursor sites, with rate constant Fi. Finally, assume that both thermal untrapping and carrier recombination remove charges from precursor traps at rates proportional to the concentration of trapped charges, the respective rate constants being Ui and Ri. This leads to the equation

$$\frac{dNi}{dt} = Fi(Poi + Kit - Ni) - (Ri + Ui)Ni \quad \ldots(2)$$

Where Ni is the concentration of filled trapping sites of the i-th type. The simplest solution of (2) are obtained by assuming that each of the i components are independent. The solution, for $Ni = 0$ at $t = 0$, is

$$Ni = \frac{Fi}{Fi+Ri+Ui}\left[\left(Poi - \frac{Ki}{Fi+Ri+Ui}\right)\{1 - \exp-(Fi + Ri + Ui)t\} + Kit\right] \quad \ldots\ldots\ldots\ldots (3)$$

If the observed absorption is assumed proportional to a linear combination of i-th different carrier trap concentration whose behavior is given by (3), growth curve expression of the from (1) are obtained immediately. Data obtained at different dose rates are consistent with the models discussed above. Assume that Fi, Ri and Ki are directly proportional to the dose rate ϕ, this leads to the expression for the λi coefficients

$$\lambda i = Ai\phi + Ui \quad \ldots\ldots\ldots\ldots (4)$$

$$\alpha L = B\phi \quad \ldots\ldots\ldots\ldots (5)$$

Also, since αi should be equivalent to the collision probability, it can be expressed as follows;

$$\alpha i = \alpha oi \exp(-Ci/\phi) \quad \ldots\ldots\ldots\ldots (6)$$

Where Ai, B, αoi and Ci are intrinsic constants of core materials. λi, αL and αi in Table 2 are shown in Fig. 10, 11 as function of dose rate ϕ. These relations in Fig. 10, 11 fit to the assumption (4),(5),(6).

From the above, the radiation induced loss during steady state 60 Co irradiation as function of dose rate and irradiation time can be expressed by the following;

$$\Delta\alpha = B\phi t + \sum_i \alpha oi\exp(-Ci/\phi)\{1 - \exp -(Ai\phi + Ui)t\} \quad \ldots\ldots\ldots\ldots (7)$$

The induced loss at low dose rate for long irradiation time can be quantitatively estimated from equation (7).

The solid lines in Fig. 9 are based on values obtained by calculating equation (7) with Ai, B, Ci of Fig. 10, 11.

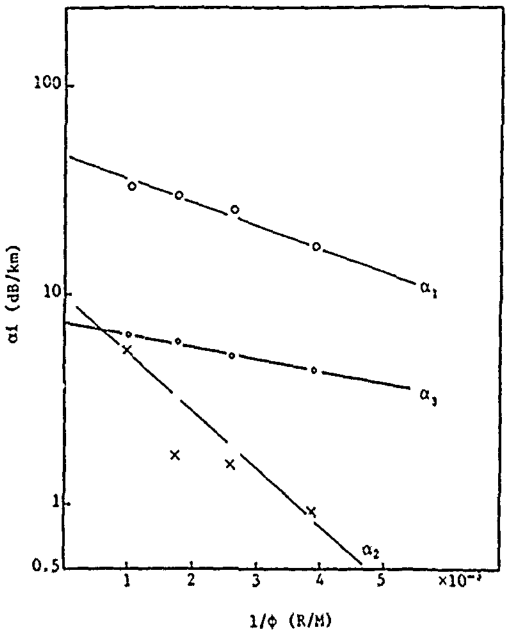

Fig. 10 Dose Rate Dependence of αi (OH 2 ppm)

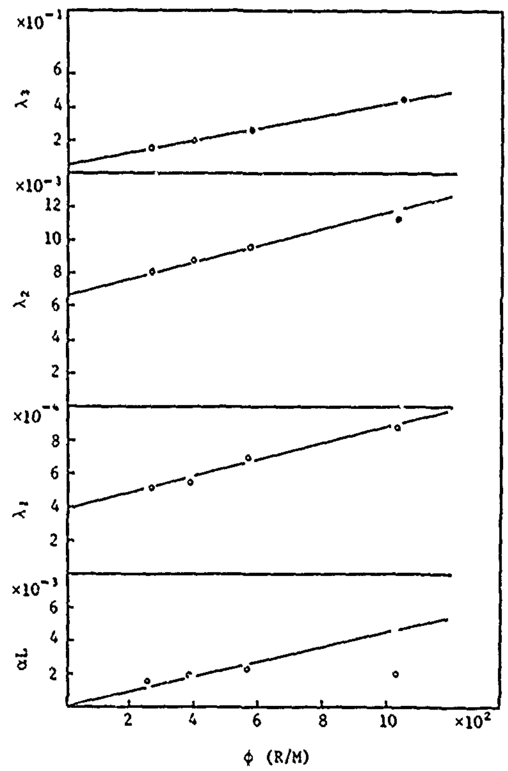

Fig. 11 Dose Rate Dependence of λi and αL (OH 2 ppm)

3. Effect of ambient temperature

The measured induced loss is influenced by experimental parameters such as temperature. In order to confirm the effect of ambient temperature during irradiation, the relation of the radiation induced loss vs. the irradiation time were measured at 50 ± 2° and 80 ± 2°C. The dotted lines in Fig. 12 show the radiation induced loss at them.

The constants of equation (1) obtained from the dotted curve are shown in Table 3, Fig. 13, 14, 15. As is shown, if two identical fibers are irradiated at the same total dose and the same dose rate at different temperatures, the induced loss at low temperature is greater than that at high temperature. The solid lines in Fig. 12 are calculated values, obtained in the same way as in Fig. 9.

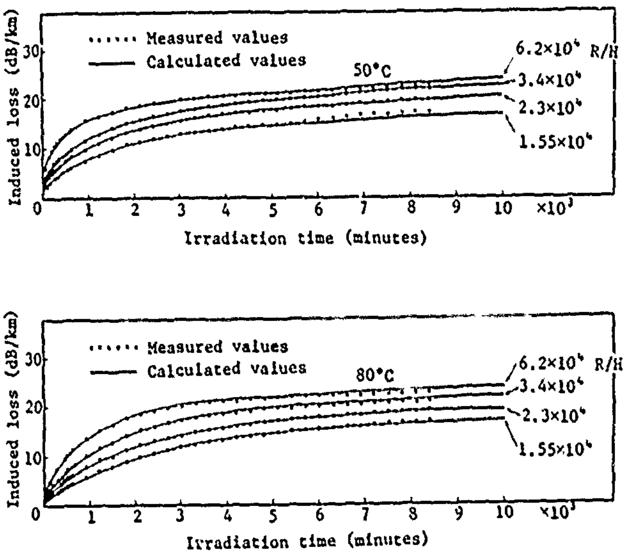

Fig. 12 Radiation-induced Loss of Pure Silica Core Fiber (OH 2 ppm, 50°C and 80°C)

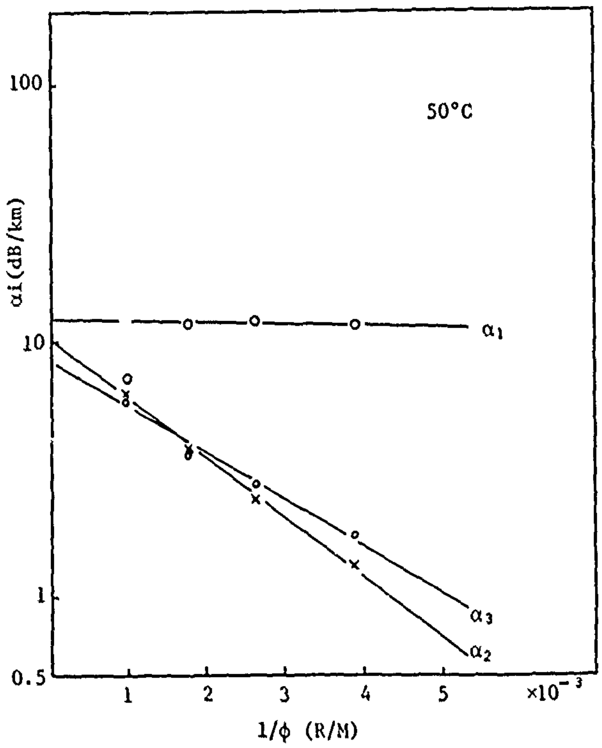

Fig. 13 Dose Rate Dependence of αi (50°C)

Table 3 The Coefficient of Equation (1) (Temperature Effect)

	50°C				80°C			
	1.55×10^4 (R/H)	2.3×10^4 (R/H)	3.4×10^4 (R/H)	6.2×10^4 (R/H)	1.55×10^4 (R/H)	2.3×10^4 (R/H)	3.4×10^4 (R/H)	6.2×10^4 (R/H)
λ_1	4.9×10^{-4}	5.1×10^{-4}	4.9×10^{-4}	6.0×10^{-4}	3.1×10^{-4}	3.2×10^{-4}	3.0×10^{-4}	4.3×10^{-4}
λ_2	2.8×10^{-3}	2.9×10^{-3}	2.9×10^{-3}	3.5×10^{-3}	1.0×10^{-3}	1.6×10^{-3}	1.7×10^{-3}	1.8×10^{-3}
λ_3	3.1×10^{-2}	3.2×10^{-2}	3.5×10^{-2}	3.9×10^{-2}	7.0×10^{-3}	7.3×10^{-3}	5.7×10^{-3}	7.0×10^{-3}
α_L	2.3×10^{-4}	3.2×10^{-4}	4.1×10^{-4}	4.5×10^{-4}	0.3×10^{-5}	0.7×10^{-5}	1.0×10^{-5}	1.7×10^{-5}
α_1	11.83	12.01	11.55	7.15	15.71	16.30	16.38	14.18
α_2	1.35	2.45	3.82	6.30	0.86	1.95	4.02	5.09
α_3	1.75	2.81	3.61	5.90	1.66	2.32	3.41	4.90

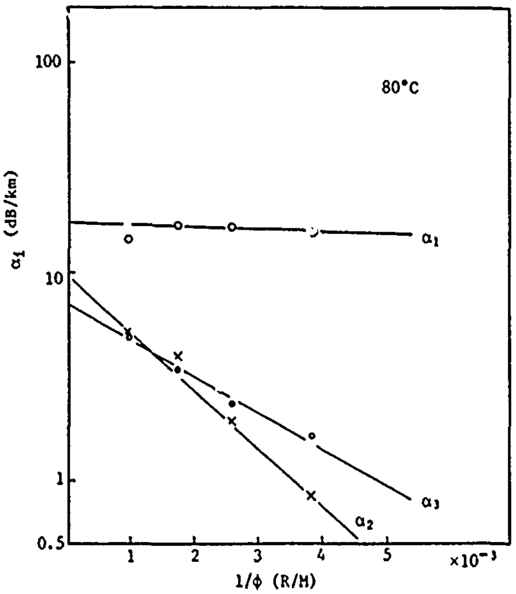

Fig. 14 Dose Rate Dependence of αi (80°C)

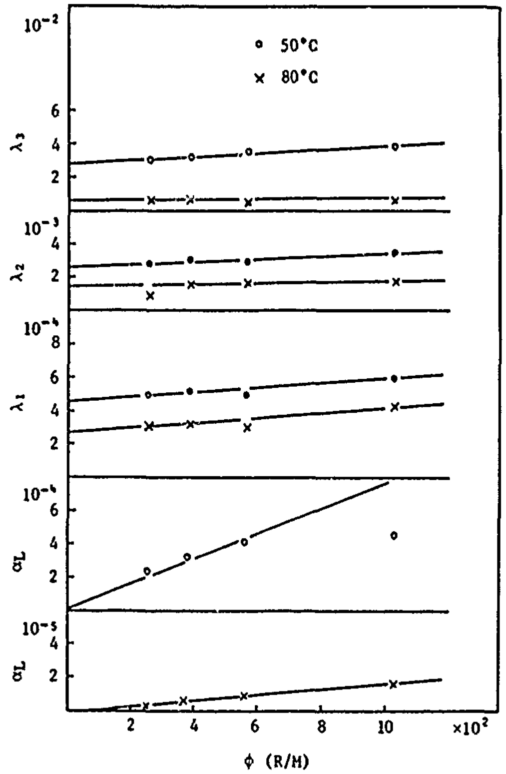

Fig. 15 Dose Rate Dependence of λi and αL (50°C, 80°C)

4. OH content

As shown in Fig. 7, the induced loss changes with OH content in fiber. It is important to discuss the effect of OH content on the parameters λi, αL and αi for forcasting the induced loss for a long time. Data obtained by irradiating the 10 ppm OH content fiber, at dose rate 1×10^4 R/H, 3×10^4 R/H, 5×10^4 R/H and 7×10^4 R/H, at 0.84 μm are shown in Fig. 16 with dotted line. Table 4 lists the parameter calcurated from the equation (1), and Fig. 17 and Fig. 18 show the dose rate dependence of above parameters. It seems that the OH content dominantly affects on αL.

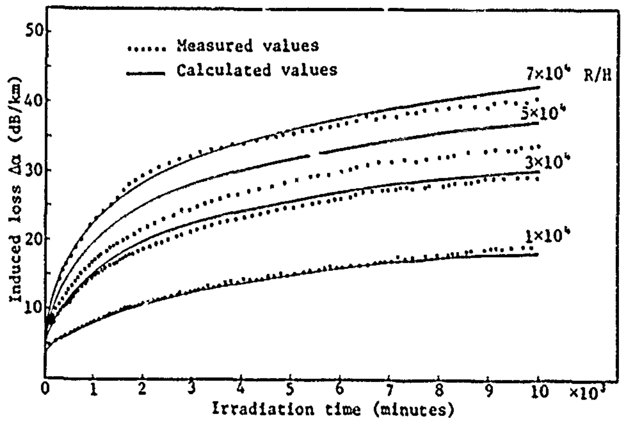

Fig. 16 Radiation-induced Loss of Pure Silica Core Fiber (OH 10 ppm)

Table 4 The Coefficient of Equation (1) (OH 10 ppm)

	1×10^4R/H	3×10^4R/H	5×10^4R/H	7×10^4R/H
λ_1	2.9×10^{-4}	3.3×10^{-4}	4.6×10^{-4}	3.0×10^{-4}
λ_2	2.0×10^{-3}	2.5×10^{-3}	3.2×10^{-3}	1.4×10^{-3}
λ_3	2.1×10^{-1}	7.1×10^{-1}	2.9×10^{-1}	3.3×10^{-1}
α_L	2.0×10^{-4}	5.0×10^{-4}	7.8×10^{-4}	1.1×10^{-3}
α_1	11.85	15.11	15.82	7.51
α_2	0.73	4.93	4.88	21.96
α_3	4.32	5.00	5.71	4.00

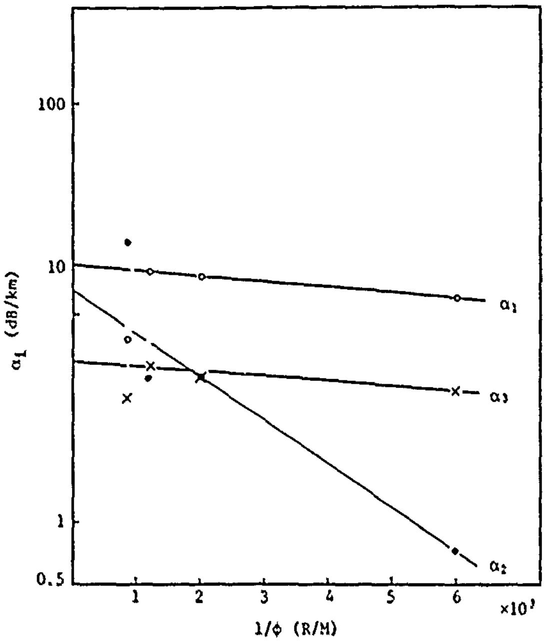

Fig. 17 Dose Rate Dependence of αi (OH 10 ppm)

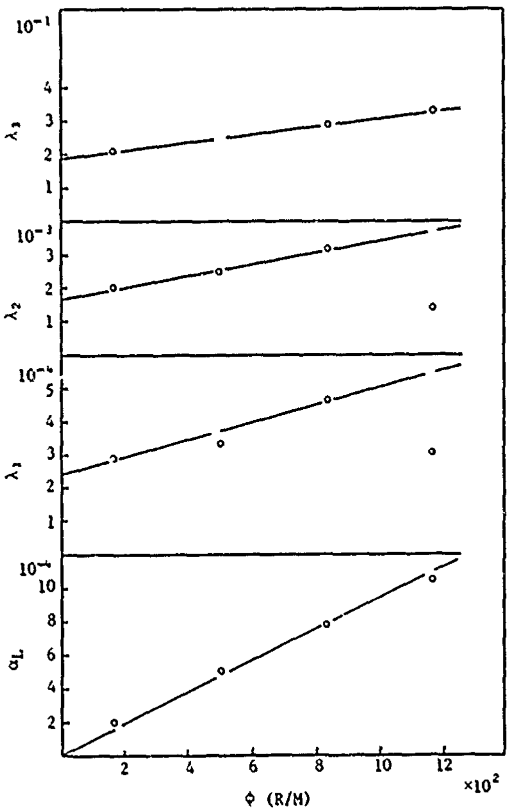

Fig. 18 Dose Rate Dependence of λi and αL (OH 10 ppm)

5. Estimate of induced loss

The radiation-induced loss can be estimated for a long time at a low dose rate. For example, the induced loss during irradiation at 20 R/H are shown in Fig. 19.

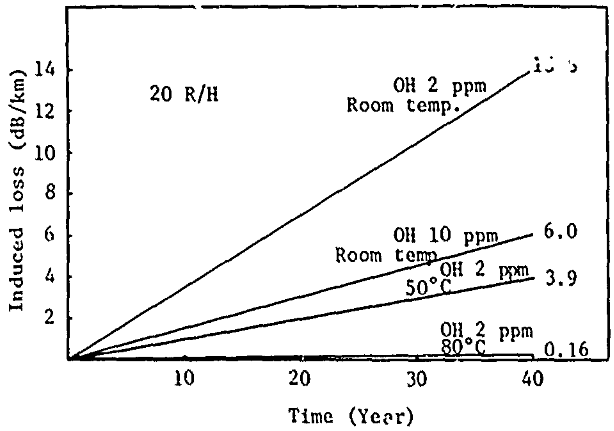

Fig. 19 Forecast of Radiation-induced Loss at Low Dose Rate

In the case of fiber containing 2 ppm OH, the radiation-induced loss at 50°C is only about one third of that at a room temperature, and the induced loss is almost negligible at 80°C. In the case of optical fiber containing 10 ppm OH, the radiation-induced loss is no greater than half of that of 2 ppm fiber.

We have thus been able to obtain a guide for installing optical fiber in radiation environment for a long time.

DECAY OF RADIATION-INDUCED LOSS

The radiation induced loss immediately begins to decrease once the γ-ray irradiation is terminated. Fig. 20 shows the decay curves of the induced losses in pure silica core fiber following the irradiation shown in Fig. 12 and 16.

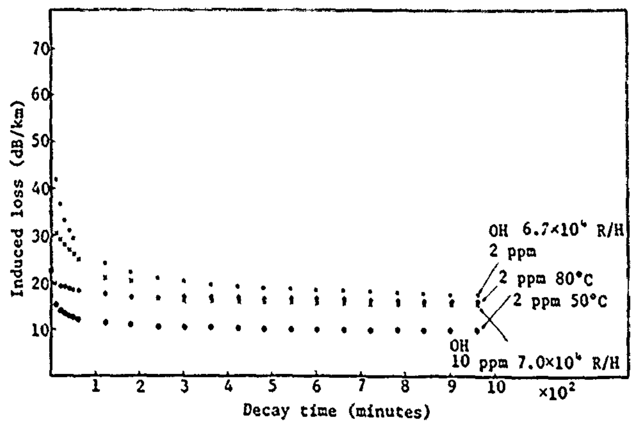

Fig. 20 Decay of the Induced Loss

All decay curves can be resolved into four decaying exponential components as given by the expression

$$\Delta\alpha d = \sum_{i}^{4} \alpha di \exp(-\lambda dit) \quad \text{.............} (8)$$

Where $\Delta\alpha d$ is the induced loss at the time t and t the time after irradiation. The fitting procedure is similar to that mentioned above. Values of constants (αdi, λdi) obtained from the fit are shown in Table 5.

The values of λdi remain almost constant on all fiber, without depending on the dose rate, and $\alpha di/\Sigma\alpha di$ also is not changed by the dose rate. The rate of a short lived component in induced loss is the majority. A long lived component is greater as the temperature rises and more OH is contained. From these results, equation (8) can be expressed in the following equation:

$$\Delta\alpha d/\Delta\alpha o = \sum_{i}^{4} Mi \exp(-\lambda dit) \quad \text{..........} (9)$$

Where, $\Delta\alpha o$ is the radiation-induced loss at the time when the irradiation is terminated, and Mi is the rate of i-th decaying exponential components. The relations of the standardized induced loss vs. decay time are shown in Fig. 21.

Table 5 The Coefficient of Equation (8)

OH 2ppm	1.55×10^4	2.3×10^4	3.4×10^4	6.2×10^4	Average
λd_1	1.0×10^{-4}	1.1×10^{-4}	1.4×10^{-4}	1.4×10^{-4}	1.23×10^{-4}
λd_2	10.9×10^{-3}	9.8×10^{-3}	7.3×10^{-3}	8.4×10^{-3}	9.1×10^{-3}
λd_3	6.5×10^{-2}	5.6×10^{-2}	3.9×10^{-2}	4.2×10^{-2}	5.04×10^{-2}
λd_4	0.61	0.44	0.22	0.24	0.378
M_1	0.47	0.40	0.37	0.34	0.395
M_2	0.25	0.23	0.21	0.19	0.22
M_3	0.22	0.24	0.24	0.26	0.24
M_4	0.06	0.13	0.19	0.22	0.15
OH 2ppm 50°C	1.55×10^4	2.3×10^4	3.4×10^4	6.2×10^4	Average
λd_1	1.0×10^{-4}	1.2×10^{-4}	1.1×10^{-4}	1.2×10^{-4}	1.13×10^{-4}
λd_2	1.6×10^{-2}	1.9×10^{-2}	1.8×10^{-2}	1.3×10^{-2}	1.65×10^{-2}
λd_3	7.2×10^{-2}	1.2×10^{-1}	1.5×10^{-1}	5.3×10^{-2}	9.88×10^{-2}
λd_4	6.2×10^{-1}	6.4×10^{-1}	4.4×10^{-1}	2.7×10^{-1}	4.93×10^{-1}
M_1	0.69	0.65	0.60	0.54	0.62
M_2	0.14	0.16	0.20	0.16	0.165
M_3	0.09	0.11	0.13	0.13	0.115
M_4	0.08	0.07	0.07	0.17	0.098

OH 10ppm	1.0×10^4	3.0×10^4	5.0×10^4	7.0×10^4	Average
λd_1	2.3×10^{-4}	2.1×10^{-4}	2.2×10^{-4}	2.1×10^{-4}	2.16×10^{-4}
λd_2	1.2×10^{-2}	1.2×10^{-2}	1.6×10^{-2}	1.2×10^{-2}	1.29×10^{-2}
λd_3	0.5×10^{-1}	0.4×10^{-1}	1.1×10^{-1}	1.0×10^{-1}	0.76×10^{-1}
λd_4	0.32	0.22	0.73	0.63	0.475
M_1	0.53	0.46	0.46	0.44	0.479
M_2	0.16	0.16	0.21	0.22	0.191
M_3	0.18	0.15	0.21	0.17	0.179
M_4	0.13	0.22	0.12	0.13	0.15
OH 2ppm 80°C	1.55×10^4	2.3×10^4	3.4×10^4	6.2×10^4	Average
λd_1	0.8×10^{-4}	0.8×10^{-4}	0.9×10^{-4}	0.9×10^{-4}	0.85×10^{-4}
λd_2	1.7×10^{-2}	1.8×10^{-2}	2.0×10^{-2}	1.7×10^{-2}	1.80×10^{-2}
λd_3	1.6×10^{-1}	0.9×10^{-1}	2.8×10^{-1}	1.9×10^{-1}	1.80×10^{-1}
λd_4	1.22	1.06	0.62	0.94	0.96
M_1	0.86	0.83	0.81	0.77	0.818
M_2	0.08	0.11	0.11	0.12	0.105
M_3	0.04	0.02	0.06	0.07	0.048
M_4	0.02	0.04	0.02	0.04	0.03

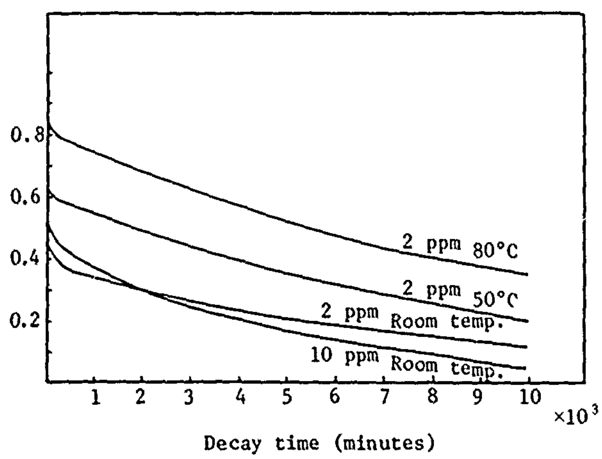

Fig. 21 Decay of the Induced Loss

MECHANICAL STRENGTH

It is important that we know mechanical properties of optical fiber in the radiation circumstance.

Fig. 22 is the Weibull diagrams of tensile strength of irradiated fiber and not irradiated fiber. In Fig. 22, optical fiber is 2 ppm OH content pure silica core fiber, radiation dose rate is 6.2×10^4 R/H and total dose is 8.7×10^6 R.

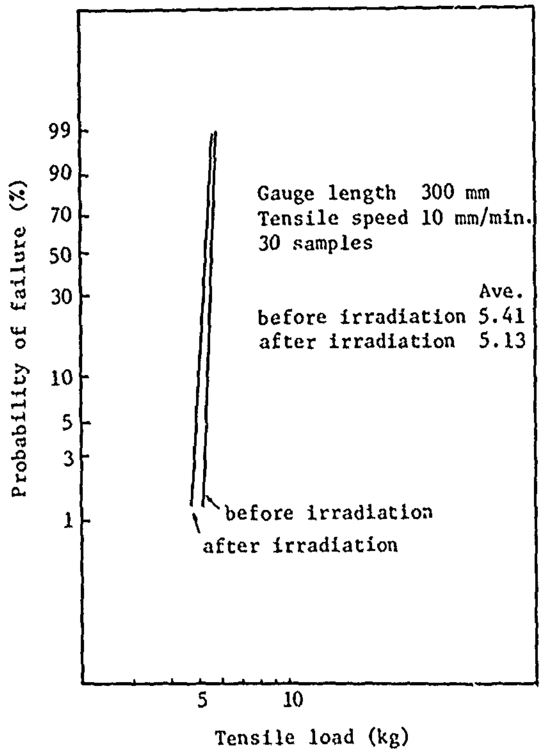

Fig. 22 Tensile Strength before and after Irradiation

Irradiated fiber display about 5% degradation compared with the not irradiated fiber. This degradation seems to be caused by the jacketing Nylon and the strength of the fiber itself may not be degraded.

SPLICED POINT

Investigation of irradiation effect on splicing loss and tensile strength of spliced point is as important as that to fiber strength. Splicing loss was measured as follows. Two optical fibers of 100 m length, one included 10 splicing points and other included no splicing point, were irradiated at the same time. Then induced losses at splicing points were estimated by comparing the induced losses of both fibers. Splicing loss per 10 points before and after 7.1×10^6 R irradiation is 0.201 dB and 0.204 dB, respectively (Table 6). Tensile strength is shown in Table 7.

Table 6 Splicing Loss before and after Irradiation

No.	Before irradiation (dB)	After irradiation (dB)
1	0.25	0.22
2	0.34	0.27
3	0.27	0.24
4	0.18	0.18
5	0.20	0.20
6	0.13	0.18
7	0.18	0.23
8	0.20	0.27
9	0.15	0.11
10	0.11	0.14
Ave.	0.201	0.204

Table 7 Mechanical Strength at Splicing Points before and after Irradiation

Before irradiation (kg)	After irradiation (kg)
3.3	3.1
2.3	3.5
2.8	2.3
2.1	3.4
2.1	2.8
1.9	3.1
2.0	3.1
2.8	3.2
2.3	2.9
2.6	2.8
Ave. 2.42	Ave. 3.02

Average tensile strength after irradiation is greater than before. This increase in tensile strength seems to be caused by the crosslinking of the epoxy resin that is used for reinforcement. From these results, we think that radiation did not affect to splicing point.

CONCLUSIONS

1. Fiber that can be used inradiative circumstances is limited to pure silica core fiber only.

2. Increase of transmission loss in the infrared wavelength region caused by irradiation is mainly caused by an absorption band that is formed in UV and visible range.

3. Radiation-induced loss of pure silica core fiber can be explained using a model of color center formation by γ irradiation and it can be quantitatively assumed from the dose rate dependence.

4. It seems that the rate constants of the radiation-induced loss is reduced as the temperature rises.

5. OH contained in the core influences a long lived component of radiation-induced loss.

6. As to the mechanical strength, irradiation does not cause substantial degradation of glass itself up to irradiation of 8.7×10^6 R.

7. No problem is foreseen on the influence to spliced parts from irradiation of up to about 7×10^6 R.

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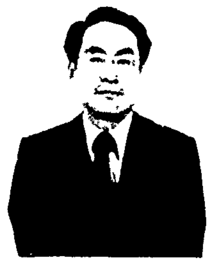

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