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# New model for assessing dose and dose rate sensitivity of Gamma ray radiation loss in polarization maintaining optical fibers

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## 1. Introduction

In the earth orbit, the device and the material of the satellite are influenced by the total dose accumulated by the long time Gamma ray irradiation [1]. It is common to choose the $^{60}Co$ as the irradiation source of the Gamma ray to investigate the degeneration evolution of the optical fiber material performance [2–5]. The optical fiber irradiation induced loss is related to the structure, component and the production technique. Thus, the degenerate regular of the optical fibers performance under the irradiation is different due to different types and manufactures [6,7]. Moreover, a “Capsule” type polarization maintaining optical fiber is a new type of polarization maintaining optical fiber [8]. The technology, dope and inner structure of the Chinese “Panda” type polarization maintaining optical fiber are different from that of the same kind of international optical fiber and the “Capsule” type polarization maintaining optical fiber. Irradiated by the Gamma ray, the enhancement of the irradiation induced loss at position of 1310 nm wavelength is caused by the increase concentration of the Si–OH [9–12]. In a silica fiber, the resonance wave of the Si–OH bond interfere with that of the Si–O bond each other, and then a series of absorption peaks appear in the transport frequency band of the optical fiber such as at the positions of 1.39, 1.24, and 0.95 μm wavelength, in which the 1390 nm wavelength is the most contribute one among them [10].

Considering the creation and annihilation of defects, solving the differential equation, using the simulation numerical results to obtain the parameters and draw the evaluation of the irradiation induced loss, lots of works have been done on describing the evolution of the irradiation induced loss of optical fiber by means of the phenomenological theory [13–19]. However, in previous papers, the parameters considered in these models are relatively simple. As we known, there is less report on the Gamma ray irradiation induced loss variation regular at 1310 nm wavelength for the “Capsule” type and “Panda” type polarization maintaining optical fiber. Different production technology and structure of the optical fiber result in different evolution of the irradiation induced loss, thus, the reported models are not feasible for investigating the evolution of the Gamma ray irradiation on the two kinds of optical fiber loss. In this work, the phenomenological theory model at are proposed to investigate the 1310 nm wavelength irradiation induced loss of the “Capsule” type and “Panda” type polarization maintaining optical fiber. The results are consistent with the irradiation induced loss measured in situ. The difference of the anti irradiation performance for both of the two types of polarization maintaining optical fibers studied and the reason for the difference are also discussed.

## 2. Samples and experiment

### *2.1. Samples*

The experimental samples include the “Capsule” type (made in Chinese Jiangsu Fasten Company Ltd.) and the “Panda” type (made

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in Chinese Yangtze Optical Fiber and Cable Company Ltd.) polarization maintaining optical fibers. Both of them are silica fiber with fiber center dope $GeO_2$ and coat is Poly methyl methacrylate (PMMA). Difference is that the stress region of the "Panda" type polarization maintaining optical fiber dope B and $GeO_2$, while the stress region of the "Capsule" type polarization maintaining optical fiber only dope B.

### 2.2. Irradiation induced loss testing device

The variation of the output optical power of the "Panda" type and "Capsule" type polarization maintaining optical fiber in situ measurement is displayed in Fig. 1 and the irradiation induced loss is also calculated. $^{60}Co$ is selected as the source of Gamma ray irradiation. For simple, constant irradiation environmental temperature and the optical fiber is fixed in order not to be disturbed by external force. The Gamma ray dose rate is set as 0.186 and 2.15202 rad/s, respectively.

## 3. Model assumptions

P.W. Levy proposed a simple phenomenological model of irradiation dynamics, to describe the variation of the number of optical material defects [15]. The number for a given type of defects is expressed as $N_i$ and $P_i$ represents precursor defects concentration. The defect can generate by irradiation and disappear by annealing. These two procedures under the irradiation proceed simultaneously and compete with each other. The creation and annealing competitive procedure of $i$ type defects which can be described by the following equation [15]:

$$\frac{dN_i}{dt} = F_i(P_{i0} + K_i t - N_i) - (R_i + U_i)N_i, \tag{1}$$

where $F_i$ presents the change coefficient from precursor defect to given type defect, $P_{i0}$ is the precursor defect concentration before irradiation, $K_i$ is the coefficient of the irradiation induced defect, $R_i$ is the annihilation coefficient of irradiation induced defect and $U_i$ is the regression coefficient of defect thermal.

Next, let us consider the Eq. (1). Since $F_i$ denotes the change coefficient that from precursor defect to given type of defect which has the same meaning with the coefficient of the irradiation induced defect $K_i$, so to eliminate $K_i$ and save $F_i$ for the reason that $F_i$ is the linear function of dose rate. Denote [18],

$$F_i = f_i\dot{D}, \tag{2}$$

where $f_i$ is a constant which is independent on the dose rate.

In the process of irradiation, the environmental temperature variation is negligible. The number of defects influenced by the irradiation factors larger than that of temperature, and irradiation in situ measurement data can also be seen as a major factor in the radiation, and $U_i$ is neglected here, and $R_i$ is assumed to be a constant which is independent of the dose rate.

T. Kakuta et al. have concluded that the Gamma ray irradiation result in the growth of optical fiber irradiation induced loss at 1310 nm wavelength due to the increase of the Si–OH defects concentration [9–12]. Si–OH defects are generated by Gamma ray irradiation silica which is a further reaction product of the degeneration reaction between the irradiation silica induced defect and PMMA. At room temperature, the Si–OH defect is a relatively stable thermodynamic saturation defects and the exposure led to maxima in accumulation of Si–OH defects. The optical fiber radiation induced loss at 1310 nm wavelength tends to a saturate value after irradiated by a certain dose of Gamma ray.

Based on these understanding, we replace $i$ with Si–OH and make the following assumptions:

(1) The Si–OH defect induces the absorption of the silica polarization maintaining optical fiber additional loss the at 1310 nm wavelength under the Gamma ray irradiation.

(2) The Si–OH defect generate in the process of the Gamma ray irradiating on the optical fiber [10–13]. However, the formation process of the Si–OH defect accompanied with decomposition process and the reaction is as following [20]

$$\equiv \mathrm{Si{-}OH} \rightarrow \equiv \mathrm{SiO}^- + \mathrm{H}^+ + e^-. \tag{3}$$

Thus, the Si–OH defect is thermodynamics saturation defect.

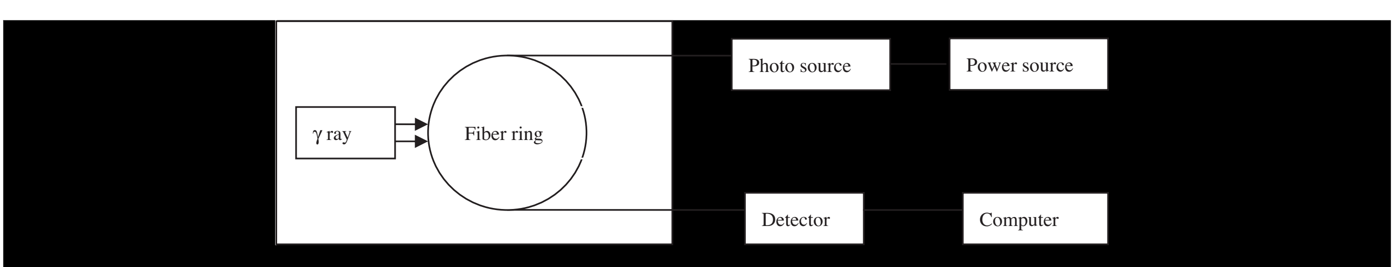
(3) We only study the silica polarization maintaining optical fiber loss induced by the Gamma ray irradiation, the loss value of optical fiber before irradiation is negligible. According to the experimental results, it is found that the Gamma ray irradiation induced optical fiber loss is three orders of magnitude larger than the original loss. The Si–OH defect concentration in silica polarization maintaining optical fiber before irradiation is set to be zero, while $n_{\mathrm{Si-OH}} = 0$.

(4) Let $f_{\mathrm{Si-OH}}\dot{D}$ represents change factor per unit time from precursor defect to Si–OH defect, $R_{\mathrm{Si-OH}}$ is irradiated Si–OH defects annihilation coefficient per unit time and it is a constant as for the same polarization maintaining optical fiber which is independent of irradiation dose rate. Correspondingly, a precursor defects saturation concentration is set as $P_{\mathrm{Si-OH}}$ and it is set as a constant at the beginning of irradiation. Set the same fiber with same fixed value for $f_{\mathrm{Si-OH}}\dot{D}$, $R_{\mathrm{Si-OH}}$ and $P_{\mathrm{Si-OH}}$ in the whole irradiation process.

(5) $n_{\mathrm{Si-OH}}$ denotes the Si–OH defect concentration of the "Capsule" type and "Panda" type polarization maintaining fiber, $\alpha$ is the radiation induced loss. $N_{\mathrm{Si-OH}}$ denotes the ratio coefficient of $n_{\mathrm{Si-OH}}$ and $\alpha$. We set the same $N_{\mathrm{Si-OH}}$ value because that the two kinds of polarization maintaining optical fiber centers with $GeO_2$ dope $SiO_2$.

### 3.1. Model and solution

Although there are some other defects generate in the process of the Gamma ray irradiating on the optical fiber, most of these defects induced optical absorption has no effect on the irradiation induced loss at 1310 nm wavelength, however, the Si–OH defect induced optical absorption has effect on the irradiation induced loss at 1310 nm wavelength [10–13], thus, we only consider the Si–OH defect in this work. Add "Si–OH" label, the Eq. (1) can be rewritten as

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