The possibility of controlling the relaxation rate of color centers in the optical fibers

D S Dmitrieva¹, V M Pilipova¹, V I Dudkin¹, V V Davydov²,³ and V Yu Rud⁵

¹The Bonch-Bruevich Saint-Petersburg State University of Telecommunications, Saint Petersburg 193232, Russia
²Peter the Great Saint Petersburg Polytechnic University, Saint Petersburg 195251, Russia
³All Russian Research Institute of Phytopathology, Moscow Region 143050, Russia

Abstract. The necessity of method developing for losses compensation in the fiber optic communication lines after irradiation is substantiated. The reasons of appearance of radiation color centers in the optical fiber, which are the main sources of losses in irradiated fiber, are considered. The different methods of the governance of color centers relaxation rate after γ-radiation influence to the optical fiber are researched A method of the relaxation processes rate increasing of color centers is developed. It’s using allows to compensate the negative influence of γ-radiation on the fiber optic communication line of the during data transmission. The received experimental results are presented.

1. Introduction
In modern world of the high-rate big data exchange is impossible without using the fiber optic communication lines (FOCL). Like many of the communication systems, as a result of human activity of the FOCL are also subjected to the different negative influences [1-6]. The increased of the various radioactive elements using in the different areas of human activities, add to these influences a one more is γ-radiation [7-12]. The radiation influence on the optical fiber leads to change its properties (the fiber is getting dark). This increases the power loss in the optical signal during its transmission [7-9, 13-16]. The relaxation processes take a lot of time even at low dose of irradiation on the optical fiber [8, 9, 13-16]. The prolonged influence of γ-radiation and the high exposure doses of irradiation, for example, 1 kG/s, can lead to irreversible changes in the optical fiber. As the result, the information transfer by FOCL will be impossible. Moreover, most of the used devices for fiber optic diagnostic are not able to establish the fact of the γ-radiation influence in time testing of the FOCL [3, 8, 17]. This creates big problems.

Nowadays in FOCL design the preference is given to single-mode fibers with a core of pure or doped quartz. The most widely used are fibers with a core SiO₂ – GeO₂ [5, 13, 18]. Optical signals are transmitted at a wavelength λ=1550 nm. The standard losses (at λ=1550 nm) in the operating temperature range of the FOCL (from 213 to 338 K) are from 0.26 to 0.38 dB/km. During the irradiation influence, losses in FOCL extremely increase. These losses can be more then 400 dB/km. After then comes the partial destruction of the optical structure of the fiber (irreversible process). In such conditions the information will be lost. Further data transmission by the irradiated fiber is impossible until complete recovery of its properties, which can take a lot of time. We can’t completely eliminate the effect of the
\(\gamma\)-irradiation on FOCL. A lot of networks have a lot of distance and can lie in areas of technological disasters. [3, 5]. Therefore, solving the tasks of influence determine of the \(\gamma\)-irradiation to the optical fiber and the compensation a arising of the negative phenomena in its are extremely actual. The researches in fundamental and applied physics are directed at the solving them. One of the possible solutions to this problem, which is based on the governance the relaxation rate of color centers, is submitted in our work.

2. Radiation E’- centers and experimental setup for studying their relaxation velocity

The radiation E’- centers are microdefects, which are appeared in the optical fiber after the \(\gamma\)-radiation influence [19]. The E’- centers are appeared as the changes result in the structure of the optical fiber. In this article are considered the \(\gamma\)-radiation influences on the optical fibers with a core of pure quartz (SiO\(_2\)) and a SiO\(_2\)-GeO\(_2\) core (alloying 1.5 %). These fibers are used for transmission the information on the movable objects and in the trunk communication lines [8, 9, 13, 14].

The amount of these defects directly depends on the two effects in the optical fiber, which are appeared after irradiation. There are displacement and ionization effects [9, 13, 14, 18, 19, 20]. The displacement is the atoms shift under the \(\gamma\)-radiation influence. It can lead to the destruction of the optical fiber structure. This effect can become irreversible at high exposure doses of radiation [19, 20].

The ionization effect is based on the formation of electron-hole pairs during the \(\gamma\)-radiation influence. The electron knocks oxygen out of the OH compound and takes its place. As the result the amount of the ionizing atoms becomes higher, which lead to change of the electrical properties of the optical fiber. So, the influence of the ionization effect leads to the change of the refractive index \(n\) of the optical fiber. The changes, which are caused by this effect, have a high chance to recover because the free charge carriers have a high mobility. If the free charge carriers will not miss in the deep energetic levels of the optical material, they make unstable connections and will recover after ending the \(\gamma\)-radiation influence. These effects are reversible only up to a certain dose of irradiation in the optical fiber. Previous researches [8, 9, 13-16, 18-20] showed that losses (the number of E’- centers) increase with the increasing of the time of the radiation influence or increasing its exposure dose. If the formation rate of the new E’- centers will be higher than them relaxation rate, it will lead to the attenuation in the power of the optical signal. The relaxation is a process of the electron-hole pairs disappearing, which take part in the color centers formation. This process begins right after the electron-hole pairs formation, it’s rate depends on the value of exposure doses of irradiation and the duration of the \(\gamma\)-radiation influence.

After that the optical fiber will be destructed at the area of the \(\gamma\)-radiation influence. So, the opportunity to control the relaxation of radiation color centers during the \(\gamma\)-radiation influence on the optical fiber is the one of the opportunities to maintain the operability of optical communication lines.

The block diagram of the experimental setup for investigation the relaxation rate of the color centers is presented in fig. 1.

In the experimental setup the transmitting optical module was used as a continuous laser source 1. It’s power changes from 0 to 10 mW. To measure losses, the classical formula was used:

\[
\alpha_s = 10 \log(P_{out}/P_{in})/L
\]  

(1)

where \(P_{in}\) – the power input to the optical fiber, \(P_{out}\) – the power output from the optical fiber, \(L\) – the length of the optical fiber.

The design of the experimental setup was taken into account at the determinate of losses (figure 1). For connecting source, receiver and isolator together with the optical fiber are applied the detachable
connections, which have typical losses $\alpha_{pc} = 0.2$ dB. There are 6 such connections. The losses in the optical adder are 0.46 dB.

The losses on the optical polarizer are 0.32 dB. Total losses on the connections and adder are 1.98 dB. For registration of low power of the laser radiation at the high losses in the optical fiber the receiving optical module DFDMSH40-16M was used with the power meter. This module has highly sensitivity [21, 22] in the wavelength range of 980-1650 nm.

3. The results of the experimental researches of the velocity of E’-centers relaxation and discussion.
The investigations conducted by different scientists [8, 9, 23, 24] showed that the rate of the relaxation processes increases with the increasing of temperature. This method is used in the space systems (for example, recovering the properties of FOCL after the manipulator leaves the station in outer space).

The investigations conducted by us showed, that this method is ineffective for trunk communication lines. The E’-center formation rate increases at the constant exposure of the $\gamma$-radiation with the
increasing of temperature. The results of experimental investigations conducted by us (figure 2) showed, that, when T is rising, $\alpha_s$ increases with the same dose of the optical fiber.

![Figure 2](image.jpg)

**Figure 2.** Dependence of the radiation-induced losses $\alpha_s$ in single-mode fiber with irradiation dose $D_R$ at a wavelength $\lambda=1550$ nm. Charts 1, 2, and 3 correspond to core type of the optical fiber from pure quartz ($\text{SiO}_2$), which is under temperature T in K: 294.2, 313.4, 328.1. Chart 4 corresponds to the type of core of the $\text{SiO}_2$ – $\text{GeO}_2$ (alloying 1.5 %) at T=294.2 K.

The analysis of the experimental results (figure 2) shows that the process of the new color centers formation comes faster than the process of the exciting color centers destruction at the increasing T, so $\alpha_s$ also increase. Moreover, it is difficult to adjust the temperature of the optical fiber in the line on trunk FOCL at the long distances.

Therefore, we conducted the experimental investigations of the influence of the additional laser radiation to the changes of color centers relaxation rate in the FOCL which is exposed to $\gamma$-radiation influence. The results of the experimental investigations of the change of the losses $\alpha_s$ from time t are presented in figure 3.
Figure 3. Dependence of the change in loss $\alpha_s$ with time $t$ at a wavelength of $\lambda = 1550$ nm for a single-mode fiber with a SiO$_2$–GeO$_2$ core (alloying 1.5 %) at $T = 294.2$ K. Charts 1, 2, and 3 correspond to different laser radiation powers in mW: 0.1; 4.0; 40.0.

A single-mode fiber with a SiO$_2$–GeO$_2$ core (alloying 1.5 %) was pre-irradiated with a dose of 100 G. Operating wavelength is $\lambda = 1550$ nm. The additional laser radiation is $\lambda = 1310$ nm. The change of the rate of radiation-induced losses were studied during the $10^6$ s for the power of registered laser radiation, which is used for data transfer. In the first experiment were used the low powers of the pulsed laser radiation: 0.1, 4.0 and 40 mW.

The analysis of the experimental results shows, that the increasing of the additional radiation power accelerates the color centers relaxation process. After 1000 s with since the beginning the influence of the additional pulsed radiation the properties of the optical fiber become close to the initial ones (before irradiation).

At the figure 4 there are dependences of the change in loss $\alpha_s$ with time for the different powers of additional laser radiation and it form (meander pulses and constant level).
Figure 4. Dependence of the change in loss $\alpha_s$ with time $t$ at a wavelength of $\lambda = 1550$ nm for a single-mode fiber with a SiO$_2$–GeO$_2$ core (alloying 1.5 %) at $T = 294.2$ K. Charts 1, 2, and 3 correspond to different laser radiation powers in mW: 0, 200, 400. Chart 4 is the constant level of the laser radiation with the power 100 mW.

Analysis of the results shows, that the increase of the additional laser radiation power accelerates relaxation of color centers. The properties of the optical fiber recover less than 10 seconds. Moreover, the conducted results show, than the process of the optical fiber recovering is different after ionization effect (it depends on the form of the additional laser radiation). The pulsed laser radiation accelerates the relaxation process more than constant level. It allows to suggest that the phenomenon of the formation of radiation $E'$-centers is of a quantum nature. This question will be considered in more details in our next investigations.

4. Conclusion
The conducted experiments are confirmed the governance opportunity of the $E'$-centers relaxation rate by developed method with using the additional laser radiation.

The analysis of the experimental results (figures 2, 3 and 4) shows, that choosing a certain power of the additional laser radiation it is possible to have a balance of the number of new formed color centers and the number of centers, which were distracted by the influence of the relaxation processes. It allows to transmit through FOCL the optical signal, when it is situated under the $\gamma$-radiation influence.

The applicability limits of the developed by us for relaxation governance rate are established. The using of the additional laser radiation with 500 mW doesn’t introduce the significant distortions in the transmitted information through FOLC with the different concentrations of core doping.
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