Investigation of possibility of creation of radiation resistance sensors for physical information based on fiber materials

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Abstract. The results of physical and material science and technological development of new materials of radiation photonics - nano- and microstructure of radiation-sensitive and radiation-resistant optical glass and fibers based on quartz are presented in the report. The possibility of their application in neutron diagnostics devices of nuclear power objects are considered. Component and construction options for the radiation-sensitive fiber and glass materials (with isotopes ^{10}B, ^{6}Li, Gd, ions of Nd^{3+}, Ce^{3+} etc.), in which radiation resistance is achieved through the organization of areas of "drain" and annihilation of radiation-induced defects are considered.

The scintillation detection device based on crystalline and organic materials have a high thermal neutron detection efficiency, but their field of application is limited by low temperatures (150-200 ^{0}C) and the ionizing streams (up to 10^7 n/cm^{2}s). Diagnostic panel and portable devices are created on the basis of multi-component silicate fibers (Nucsafe inc.). The further expansion of possibilities of application of fiber optic materials for the radiation instrumentation (including the reactor's instrumentation) can be achieved on the following principles:

- shift from silicate to multi-component optical fibers based on quartz to provide thermal resistance up to 1000 ^{0}C;
- multi-component silica glass with the implementation of the principle of radioluminescent detection of ionizing radiation due to the introduction in the glass matrix neutron-sensitive isotopes (^{3}Li,^{3}He,^{10}B, etc.) and the scintillating ions (Ce^{3+}, Nd^{3+}, $Pr^{3+}$and others);
- shift from homogeneous to heterogeneous materials, with a given phase and the structural organization of the luminescent radiation content to increase the radiation resistance of the material.

2D- and 3D-structuring of the functional detection of volume used as a basis for designing high-film-glass-fiber-optic radiation luminescent materials. The technological basis is the low-temperature processes of thermal destruction synthesis of nano- and micro-sized functional coatings, combined with layering processes and processes of chemical vapor synthesis [1,2]. As a result material is amorphous-nanocrystalline (crystallite size of 20-40 nm) and multilayer (interlayer distance ~ 10-30 nm) structure.

Determining for the rate of annihilation processes are defect diffusion coefficient (D), its environmental resistance movement and the distance to the annihilation region (L) (1):

$$1/\tau_{анн} \approx D/L^2 \quad (1)$$

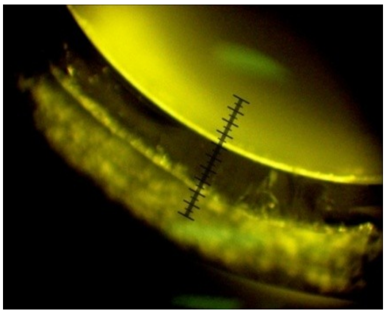
If the organization of a structure is the complex-phase than the coefficient D is an additive quantity and includes diffusion into the bulk crystalline and amorphous homogeneous environment (D_1 и D_2), motion along the grain boundaries (when nanocrystalline organization) (D_3) and migration of interlayer "surface" (when layering) (D_4), at that $D_1 < D_2 << D_3 < D_4$. Organization of amorphous and nano-crystalline structure (3D-structuring) of the material ensures the implementation of the abnormally high diffusion coefficients. Multilayer (2D-structuring) allows you to monitor and technologically "organize" the distance to a possible plane annihilation radiation-induced defect (L).

Uranium-oxide coats (radiators) of ionization chambers fission became the basis for the development of principles of 2D- and 3D-structuring. Nanolayers U_3O_8 (depth 20-40 nm) with the enrichment isotope ^{235}U 90% were obtained by low-temperature synthesis of oxide coatings from solutions of uranium carboxylates [3]. Plane organization of (2D-structuring with the inter-planar distance of 20-40 nm) material remained under cyclic repeating the synthesis process to ensure receipt of the radiator depth 2 mkm. Radiographic research has shown amorphous-nanocrystalline (3D) structure of the radiator. On the basis of the technological process we have been made and accepted to complete the uranium-oxide electrodes for the 4th unit of Beloyarsk NPP.

Methodology 2D- and 3D-structuring of the functional volume of material to provide icnreasing of its radiation strength and operational "durability" has been applied to the radiation-fluorescent optical fibers based on quartz. The combining technology with chemical vapor deposition process of structuring at the facility stretching and low-temperature chemical and structural modification of the surface is a technological basis for production of functional fiber optic materials. Radiation-fluorescent fiber-optic materials are the following types of isolated:

- radiation-luminescent quartz layers with a depth of 100 ÷ 300 microns, doped with REE: ^6Li, ^{10}B or Gd;
- ultra-thin film coating converts the neutron Gd_2O_3, U_3O_8, ThO_2, on the quartz layer doped with REE ions.

Figure 1a shows the photograph of the micro-layer on the inner surface of the quartz tube doped ^{10}B and Ce^{3+}. After consolidation in the extractor rod made of silica fibers, which are then, depending on the desired parameters for dimensions and sensitivity of the material in hexagonal structured elements inside the quartz tube and reuse overtighten in multi-core heterogeneous optical fiber (figure 1b). Figure 1b shows a photograph obtained for multi-core heterogeneous optical fibers based on silica glass doped with ^6Li and Ce^{3+}.


a)


b)

Figure 1. Micro-sized (~ 70 microns)SiO_2- layer, based on silica glass doped ^{10}B and Ce^{3+}(a) and photograph of multi-core heterogeneous optical fibers $Li(6)Ce^{3+}SiO_2$ (b)

A special way to build a hybrid radiation resistant sensor is needed to solving problems of neutron monitoring in areas with ultra-rigid temperature, vibration, and radiation conditions (mode of design and beyond design basis accident in a nuclear installation). At the moment the sensors of reactor physical quantities are based on the principle of removal and transmission of the electrical signal. Efficiency and accuracy of the signal is broken at the time of emergency situations.

The capabilities of radioluminescent and optical converters are connected in the hybrid sensor. For example, in a hybrid chamber the fission informative signal is optical radiation produced by ionization of the chamber working gas under the action of fission fragments of neutron-sensitive cores. The output photon signal made through fiber-optic light guide. Main advantages of it:

- direct conversion of the energy of nuclear reactions in the optical signal;
- informative signal transmission through optical fibers;
- interfacing with fiber optic communication lines (FOCL).

Application of functional materials (glass fibers) on the radiation instrumentation always involves a compromise between their performance and operational characteristics. Extreme conditions require to shift from a homogeneous volume of silicate glass to quartz multi-component 2D- and 3D-nano-structured materials. Appropriate chemical processes 2D- and 3D-structuring based on methods MCVD, low-temperature processes, chemical and structural modification of the surface and high-temperature consolidation.

Principles of 2D- and 3D-structuring of the functional scope used for uranium-oxide radiators of ionization fission chamber, multi-component multi-core quartz radiation-fluorescent optical fibers. A variant of the hybrid sensor neutron fields enabling the transition to an electro-independent autonomous diagnostic systems of physical quantities.

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References

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