EFFECT OF VOLUME CHARGE ON THE ELECTRON TRANSMISSION AND BACKSCATTERING COEFFICIENTS FOR IRRADIATION OF DIELECTRICS

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The effect of the electron current and energy densities on the change in the transmission and backscattering coefficients, owing to the accumulation of volume charge accompanying irradiation of dielectrics with fast electrons, was studied. The change in the energy of the bombarding electrons was accompanied by a corresponding change in the thickness of the target d so as to ensure that the condition d/R = const, where R is the total range of the electrons, holds. The electron energy was varied from 50 keV to 10 MeV; the results were compared for two extreme intervals: 50-300 keV and 1-10 MeV. The numerical calculations of the spatial distribution of the field of the volume charge and the relative change in the absorption and backscattering coefficients were performed for 50-300 keV electrons with a beam current density of 0.1-10 nA/cm^2 with irradiation of polymethyl methacrylate (PMMA) and polyethylene terephthalate (PETP) targets. The computational results were compared with the experimental data obtained with irradiation of PMMA with 75 and 100 keV electrons.

Let the flat dielectric target whose surfaces are coated with electrodes and grounded be irradiated with monoenergetic electrons, whose energy ranges from 50 keV up to 10 MeV. The maximum beam current density is limited by the value for which the intensity of the electric field of the volume charge $\mathscr{E}$ is relatively small ($e\mathscr{E}/B < 1$, where B is the stopping power of the medium), so that the field of the volume charge changes insignificantly the distribution of thermalized electrons and the absorbed energy. Then the distribution of thermalized electrons and the distribution of the absorbed energy not distorted by the field of the volume charge can be used to determine $\mathscr{E}(x, t)$, and the theory of the perturbation of transfer functionals can be employed to find the relative changes in the electron transmission and backscattering coefficients (δ_h and δ_η). In this case δ_h and δ_η are related with $\mathscr{E}(x, t)$ by the relation [1]

$$\delta_{h,\eta}(t)=\int_0^d F_{h,\eta}(x)\,\mathscr{E}(x, t)\,dx, \tag{1}$$

where $F_{h,\eta}$ is a function describing the sensitivity of the corresponding coefficient to the intensity of the field [1]. The dependence of the sensitivity function for the electron transmission coefficient on the coordinates of the target is approximated by a polynomial of degree zero, one, or two [1, 2]. The dependence of F_η on the electron energy E is of a power-law character, while the coordinate dependence is described by the Gaussian function

$$F_\eta=F_0E^{-(k-1)}\exp-(x/R-b)^2, \tag{2}$$

where F_0 and b are the parameters of the sensitivity function [1, 2]; k is the exponent in the energy dependence of the total electron range for the separated energy interval $R = R_0E^k$; R_0 is a parameter in the dependence R(E).

The spatial distribution of the intensity of the electron field in the short-circuited dielectric irradiated with electrons is found based on the phenomenological model of the formation of volume charge [3, 4]. The distributions of thermalized electrons $g_e(x/R)$ and the absorbed energy $D_e(x/R)$ over the depth of the absorber were employed for the starting data; they were determined by solving numerically the transfer equation with no electric field and calculated per incident electron [1, 5]. Their dimensions are $[R^{-1}]$ and $[m_ec^2\cdot R^{-1}]$. The model of the current of volume charge in [3] was employed for the conduction current. In this case the stationary spatial distribution of the intensity of the electric field of the volume charge can be written in the form

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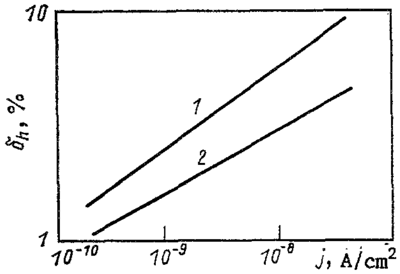

Fig. 1

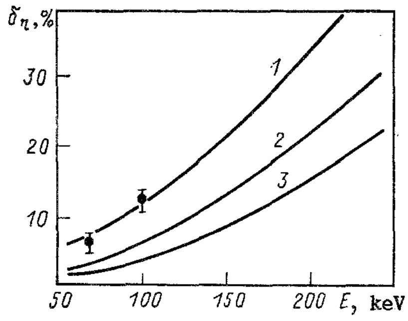

Fig. 2

Fig. 1. Dependence of the relative change in the electron transmission coefficient on the beam current density, calculated for the stationary state in PMMA (1) and PETP (2) targets with thickness d = 0.9R irradiated with 100 keV electrons.

Fig. 2. Dependence of the relative change in the backscattering coefficient on the electron energy for the stationary state with irradiation of the following samples: 1) PMMA, d = 7R; 2) PMMA, d = 1R; 3) PETP, d = 1R.

$$\mathscr{E}(x) = \pm \left\{ 2e/(\varepsilon\varepsilon_0) \int\limits_{x_0}^{x} \mu_n^{-1}(x') \left[\int\limits_{x_0}^{x'} g(x'')\, dx'' \right] dx' \right\}^{0,5}, \tag{3}$$

where x_0 is the coordinate of the plane in which the field is zero; $g(x)$ is the rate of injection of thermalized electrons [3]; μ_n is the effective mobility of the electrons, whose dependence on the dose rate has the form $\mu_n = \mu_0 \dot{D}^{\beta}$ [3]; and, μ_0 and β are parameters describing the effective mobility.

We shall use the expression (3) to study the effect of the beam current density j and the energy density (with d/R = const) of the electrons on the distribution $\mathscr{E}(x/R)$ taking into account the changes in $g_e(x/R)$ and $D_e(x/R)$. A change in the beam current density does not lead to a redistribution of the volume charge, and the position of the plane where the field equals zero remains constant. At each point of the target the intensity of the field is proportional to $j^{0,5(1-\beta)}$, and the exponent depends on the type and temperature of the dielectric. A change in the electron energy (d/R = const) is accompanied by an insignificant redistribution of the volume charge in connection with the nonproportional changes in g_e and D_e at different points of the target. As the electron energy is increased $g_e(x/R)$ changes insignificantly [5], but $D_e(x/R)$ grows proportionally. Then from the expression (3) we obtain

$$\mathscr{E}(x/R) = \mathscr{E}_0(x/R)\, j^{0,5(1-\beta)} E^{0,5[k+\beta(k-1)]}, \tag{4}$$

where $\mathscr{E}_0(x/R)$ is a parameter that does not depend on j and E. The intensity of the field and the density of the volume charge at different points in the target grow in a power-law fashion as the beam current density and the electron energy density increase with d/R = const; the value of the exponent for the energy interval 50-300 keV turns out to be higher than for the interval 1-10 MeV.

In the process of irradiating the dielectric, as the field of the volume charge increases the electron transmission coefficient decreases, while the backscattering coefficient increases up to a stationary value. Taking into account the dependence of the sensitivity function on the electron energy (2) and the dependence of the intensity of the field of the volume charge on the energy and current density of the beam (4) we obtain from the relation (1)

$$\delta_h = \mathrm{const}\, j^{0,5(1-\beta)} E^{0,5[3k+\beta(k-1)]}; \tag{5}$$

$$\delta_\eta = \mathrm{const}\, j^{0,5(1-\beta)} E^{0,5[k+\beta(k-1)]+1}. \tag{6}$$

The formulas (5) and (6) are approximate, but they permit judging the change in δ_h and δ_η for electron energies from 50 keV up to 100 MeV. In the energy interval 50-300 keV the values of δ_h and δ_η change more sharply than in the region 1-10 MeV, since the value of k is larger in the first case. The stationary values of the relative change in the electron transmission and backscattering coefficients grow in a power-law fashion as the current density and electron energy are increased (with d/R = const). This dependence is explained by the increase in the intensity of the electric field in the target, overlapping the decrease in the sensitivity function, as the electron energy is increased. Numerical calculations of δ_h and δ_η were performed based on the formulas (1) taking into account the known sensitivity functions $F_h(x)$ and $F_\eta(x)$ [1, 2] and the distribution of the intensity of the electric field of the volume charge $\mathcal{E}(x)$ for the case of irradiation of PMMA and PETP with electrons of medium energy. The computed curves of the change in the electron transmission and backscattering coefficients as a function of j and E for irradiation of samples of PMMA and PETP are presented in Figs. 1 and 2. Figure 1 also shows the measured [6] change in the backscattering coefficient of a short-circuited PMMA target 0.5 mm thick with sputtered aluminum electrodes and irradiated with 75 and 100 keV electrons with a current density of 1 nA/cm^2. The computed values agree well with the measured values.

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LITERATURE CITED

1. K. A. Dergobuzov, O. B. Evdokimov, and B. A. Kononov, Radiation Diagnostics of Electric Potentials [in Russian], Atomizdat, Moscow (1978).
2. V. A. Dyrkov, "Effect of fast electrons on the volume charge in dielectrics," Author's Abstract of Candidate's Dissertation, Physical-Mathematical Sciences, Tomsk Polytechnical Institute, Tomsk (1984).
3. O. B. Evdokimov, "Accumulation of volume charge in polymer dielectrics accompanying irradiation with fast neutrons," Review Information, Series on Radiation Resistance of Organic Materials, NIITEKhIM, Moscow (1979).
4. V. A. Dyrkov, "Effect of fast electrons on the volume charge in dielectrics," Izv. Vyssh. Uchebn. Zaved., Fiz., No. 11, 125 (1983).
5. O. B. Evdokimov and A. P. Yalovets, "Distribution of thermalized electrons and absorbed energy in dielectric mateials," Khim. Vys. Energ., 7, 271 (1973).
6. B. A. Kononov, Yu. I. Sapozhkov, L. F. Smekalin, A. P. Yalovets, and N. I. Yagushkin, "Reflection of medium-energy electrons from a dielectric target," Vopr. At. Nauki Tekhniki, Ser. Obshchaya Yad. Fiz., No. 3, 158-162 (1985).

APPARATUS FOR THE INVESTIGATION OF CRACKING OF MATERIALS IN THIN-WALLED ELEMENTS IN THE CORE OF A WATER-MODERATED, WATER-COOLED POWER REACTOR (VVÉR)

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Components for the core of a water-moderated, water-cooled power reactor (VVÉR) are fabricated from highly ductile materials which precludes the failure mechanism approach to assessment of fitness for work in a non-irradiated condition. A significant radiation hardening and embrittlement of these materials toward the end of the operating period means that an assessment of their cracking proves not only to be possible, but imperative.

For an investigation of the cracking of VVÉR core materials, a special flat specimen is used for axial tension tests (Fig. 1) [1]. Tests of specimens under static or cyclic loading were conducted on an existing remotely controlled apparatus consisting of a tensile-testing machine which was located in a chamber with a biological shield, control panels, and oil pumps, located in an operating room. The design of the machine permits the tests of the specimens both in air in the range 20-450°C and in corrosive media at 20-100°C (Fig. 2). The specimen is stressed by pumping oil into the cylinder. Oil pressure drives the piston coupled to the movable lower connecting rod. The upper connecting rod, rigidly fixed to the sleeve, force transducer, and fixed nut, freely hangs on the support tube. The sleeve and upper frame are water-cooled to provide a uniform temperature of the strain gauge force

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