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Abstract

Full Text

PHYSICS

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ESTABLISHMENT OF CURRENT IN DIELECTRICS UNDER GAMMA IRRADIATION

Ionization produced in dielectrics by γ-irradiation causes an increase in electrical conductivity by an amount

$$\sigma_r = en\mu,$$

where σ_r is the radiation electrical conductivity; e is the elementary charge; n is the concentration of charge carriers; μ is the mobility.

As measurements in various materials have shown, the steady-state value of σ_r is directly proportional to the irradiation intensity γ. Such a regularity is evidently connected with the fact that the materials we investigated—quartz, polyethylene, sulfur, ceramics, etc.—possess traps in which captured electrons remain for a long time. In this case the ionization intensity—the number of ion pairs created by irradiation in 1 cm^3 in 1 sec—is equal to

$$g = b\gamma = \beta N(N - N_t),$$

where β is the recombination coefficient; N_t is the concentration of traps filled in the stationary state; N is the concentration of free electrons in the stationary state; b is a quantity proportional to the absorption coefficient of γ rays.

The concentration of free electrons is

$$N = \frac{b\gamma}{\beta(N + N_t)}.$$

If $N_t \gg N$, then

$$\sigma_r = \frac{e\mu b\gamma}{\beta N_t} = a\gamma,$$

in agreement with the measurement results.

Fig. 1. Dependence of the current I on time t under γ-irradiation of quartz. Irradiation intensities $Y_1 = 0.4$ r/sec and $Y_2 = 0.7$ r/sec, temperature $+79°$.

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In the materials we investigated, the stationary values of the current were established over a fairly long time after the start of irradiation, and, according to the character of the dependence of the current I on time t, all the materials could be divided into two groups, for which the curves $I = f(t)$ shown in Figs. 1 and 2 are typical.

For an approximate description of the process of current establishment, one may assume, omitting details, that generation of free electrons is produced only by γ-irradiation, while the loss of electrons occurs owing to recombination with positive ions and capture by traps. The corresponding scheme of energy transitions is given in Fig. 3.

According to this scheme,

$$\frac{dn}{dt} = g - \delta n(n + n_t) - \eta n(N_t - n_t); \tag{1}$$

$$\frac{dn_t}{dt} = \eta n(N_t - n_t), \tag{2}$$

where n is the concentration of free electrons; n_t is the concentration of electrons in traps; δ and η are transition coefficients.

At $t = 0$ the concentration is

$$n = n_t = 0, \tag{3}$$

and at $t \to \infty$

$$\frac{dn}{dt} = \frac{dn_t}{dt} = 0. \tag{4}$$

If the concentration n has an extremum at some value of t, then, as follows from (1),

$$\frac{d^2n}{dt^2} = \frac{dn_t}{dt}\, n(\eta - \delta). \tag{5}$$

Fig. 1. Dependence of the current I on time t under γ-irradiation of quartz. Irradiation intensities $Y_1 = 0.4$ r/sec and $Y_2 = 0.7$ r/sec, temperature $+79°$.

Fig. 2. Dependence of the current I on time t under γ-irradiation of sulfur. Irradiation intensity $Y = 0.3$ r/sec, temperature $+18^\circ$.

Figure 2: Fig. 2. Dependence of the current I on time t under γ-irradiation of sulfur. Irradiation intensity $Y = 0.3$ r/sec, temperature $+18^\circ$.

Fig. 3. Diagram of energy transitions.

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Fig. 3. Diagram of energy transitions.

Let $\eta > \delta$; then the extremum corresponds to a minimum, since $n > 0$ and $dn_t/dt > 0$ for any t. But then the concentration n must also have a maximum, since it changes continuously from $n = 0$ at $t = 0$ to $n = N = -N_t/2 + [(N_t/2)^2 + g/\delta]^{1/2} \simeq g/\delta N_t$ as $t \to \infty$. However, as is seen from (5), when $\eta > \delta$ a maximum is impossible. Thus, if $\eta > \delta$, then $n = f(t)$ has no extrema at all, and the concentration, increasing monotonically, tends to a limiting value, as occurs, for example, in quartz, for which the measurement results are given in Fig. 1.

Let $\eta < \delta$; then (5) corresponds to a maximum. From the considerations given above it follows that it can only be unique. Thus, if the curve $n = f(t)$ is similar to that shown in Fig. 2, then for this it is necessary that $\eta < \delta$. We shall show that this condition is also sufficient. From (2) and (3) it follows that

$$n_t = N_t(1 - y),$$

where

$$y = \exp\left(-\int_0^t \eta n \, dt\right).$$

Introducing $p = dy/dt = -\eta n y$, we find from (1) that

$$-\frac{p}{\eta y}\left(\frac{p}{y} - \frac{dp}{dy}\right) = g + \frac{\delta p}{\eta y}\left(N_t - N_t y - \frac{p}{\eta y}\right) + pN_t. \tag{6}$$

We seek the solution of (6) as $t \to \infty$ in the form of a series

$$p = \varphi(y) = \lambda y + cy^2 + \ldots \tag{7}$$

Since $y \to 0$ as $t \to \infty$, considering small values of y, one may restrict oneself in (7) to the first two terms of the series. Substituting (7) into (6), we find

$$c = \frac{\lambda N_t(\delta/\eta - 1)}{\lambda/\eta + \delta/\eta - 2\delta\lambda/\eta^2}, \tag{8}$$

where $\lambda = -\eta g/\delta N_t$.

It follows from (7) that, for small y, the electron concentration is

$$n = -\frac{p}{\eta y} = -\frac{\lambda}{\eta} - \frac{cy}{\eta} = N - \frac{cy}{\eta}$$

or $n - N = -cy/\eta$.

If $\eta < \delta$, then, as is seen from (8), $c < 0$, the stationary concentration $N < n$, and consequently $n = f(t)$ must have a maximum.

The capture coefficient $\eta = vs_t$, where v is the electron velocity and s_t is the capture cross section at the traps.

The recombination coefficient $\delta = vs_j$, where s_j is the recombination cross section at positively charged centers.

Thus, it may be considered that maxima in the process of establishment of the radiation current are observed in those materials in which the capture cross section of electron traps is smaller than the recombination cross section at positively charged centers.

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Note: Figure translations are in progress. See original paper for figures.