ELECTROPHYSICAL PROPERTIES OF ORGANIC MATERIALS IRRADIATED WITH ACCELERATED IONS

F.F. Komarov, A.V. Leontyev, S.N. Nechayev, Y.S. Leontyeva
(Belorussian State University, Minsk)

In this paper the results of investigation of high-dose ion irradiation influence on polymer material conductivity are presented. Analysing available literature data we can note the following principal moments. Firstly, under specific irradiation regimes it is possible to achieve the increasing of polymer material conductivity by a factor of 10^{12} to 10^{13} [1]. Secondly, dependence of conductivity σ upon basic irradiation parameters (ion types and its energies, ion beam density and substrate types) is presently not sufficiently studied up to now. These problems are treated in this paper.

1. EXPERIMENT

As the initial objects for investigations the films of wide-spread positive photoresist FP-383 (based on novolac resins and naphtohuinone diazide) and polyimide (PI), synthesized on the base of pyromellitic dyanhydride and 4,4 - diaminodiphenyl ether, have been chosen. Photoresist films (thickness of about 1,0 μ) were spun coated onto single crystal silicon, alumina and ceramic substrates. Before irradiation the samples were prebaked in a three-zone IR-oven for 15 to 30 minutes at T=120-140-160 °C. In analogous way the films of polyimide were formed. Prebaking was carried out at 100°C for 30-40 minutes and theat 210 °C for 20-30 minutes. The above mentioned films were irradiated with H^+_2, N^+_2 and Ar^+ ions at energies of 100 to 300 keV in a dose range of 10^{15} to 10^{18} cm^{-2}. The dependencies of surface resistance (ρ_s) on the dose of implanted ions at room temperature were measured by means of the four-probe method. Low temperature experiments were performed with a closed cycle helium refrigerator and the two-probe method for measurements was used.

2. Results and discussion

The results of surface resistivity measurements ρ_s for the films of FP-383 resist are presented in Fig. 1. In view of limitedness of suitable experimental procedures, ρ_s values for implantation doses less than 10^{16} cm^{-2} were not reliably measured. It may be only roughly evaluated that in the dose range of $10^{15} < D < 10^{16}$ cm^{-2} the value of ρ_s > 100 k$\Omega/\square$. In table 1 the dependence of ρ_s (I) is given. As can be seen from data of table 1 and Fig. 1, ρ_s values at the same irradiation dose are strongly distinguished in dependence from the ion beam current. The dependence ρ_s**(I)** gives evidence of essential influence of thermal processes on structural-phase transformations in irradiated organic layers. Also must be noted the stability of electrophysical properties of irradiated polymers: keeping in air atmosphere during a year practically does not lead to any change of ρ_s value.

Table 1

Dependence of ρ_s (kOhm/□) for the photoresist films irradiated (FP-383) with Ar^+ ions at energy 100 keV from ion current ($D=1\times10^{16}$ cm^{-2}).

Substrate	Beam current, μA						
	150	200	250	300	400	600	650
Alumina	100	42,0	17,8	10,8	4,7	3,2	1,6

The investigation results of influence of light ion irradiation on surface conductivity may be interpreted in the following manner. Under implantation of H^+_2, He^+, N^+_2 ions in the energy range of 100 to 300 keV, the ρ_s value approaches to 100 k$\Omega/\square$ only at doses of D > $2*10^{17}$ cm^2. Therefore, the implantation of these ions at the mentioned regimes is not effective. Irradiation with heavy ions (**As^+, Sb^+, In^+**) at the energy values of 100 to 300 keV permits to achieve the high surface conductivity, but in this case the morphology of the film surfaces gets worse. The cracks and traces of gas bubbles are observed.

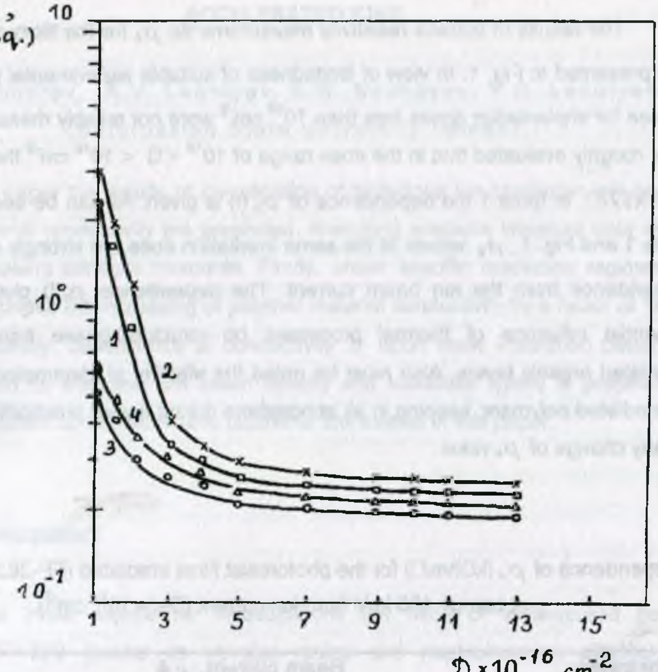

Fig. 1. Dependencies of ρ_s (kOhm/□) for photoresist (FP-383) films implanted with **Ar**$^+$ ions at energy of 100 keV versus irradiation dose: 1,2 - I = 300 μ**A**, 3,4 - I=600 μ**A.** The curves 1,3 correspond to irradiated samples; 2, 4 - correspond to ones after keeping during a year in air atmosphere conditions.

2.1. Low-temperature conductivity

It is well known that organic films exposed to ion irradiation are perspective materials for creation of cryogenic temperature sensors on its basis. Therefore, investigation of low-temperature conductivity in these systems is of special interest. The conductivity of irradiation polymers is usually considered as a succession of 1-D and 3-D jumps. Low-temperature conductivity σ(T) may be described on the base of the Mott's notion about conductivity of disordered systems. In polymer films exposed to ion bombardment two types of disorders may be revealed: positional and topological. For the latter, availability of free bonds is characteristic, forming additional localised defects. The information about availability of free bonds may be obtained from the ESR spectroscopy data. The ESR spectra for photoresist FP-383 films irradiated with **Ar^+** ions were characteristic of randomly oriented free radicals (the g-value decreases from g = 2,0030 for D = 5×10^{15} cm^{-2} to g = 2,0025 for D = 1×10^{17} cm^{-2}) «trapped» in an amorphous polymers matrix. In table 2 the dose dependence of relative intensity of the ESR signal line is presented. It can be seen that the value $I_{relative}$($I_{rel.}$) increases with the irradiation dose increase, reaches maximum at D = $3*10^{16}$ cm^{-2} and then begins to decrease. Therefore it may be considered as the evidence of the existence of essential quantity of free bonds in implanted samples, and Mott's theory can be used for the explanation of low-temperature dependencies σ(T) for these samples

$$\sigma = \sigma_0 * \exp[-(T_0/T)^{0,25}], \quad T_0 = \frac{2,5}{9\,\pi\,\lambda^3 k_b q}, \qquad (1)$$

where λ is the localisation length, q-is the state density.

Table 2

Dose dependence of relative intensity of **EPR** signal for photoresist (FP-383) films irradiated with **Ar^+** ions at energy 100 keV.

Dose, cm^{-2}	$I_{rel.}$	**Dose , cm^{-2}**	$I_{rel.}$
$7*10^{15}$	**0,29**	**$3*10^{16}$**	**1,00**
$1*10^{16}$	**0,40**	**$5*10^{16}$**	**0.74**
$2*10^{16}$	**0,65**	**$1*10^{17}$**	**0,71**

In fig. 2 low-temperature dependencies σ(T) for samples of the photoresist FP-383 and polyimide (PI) irradiated with **Ar^+** (100 keV) ions at doses $1*10^{16}$ and $2*10^{16}$ cm^{-2}, respectively, are presented. T_0 values determined on the basis of formula (1) are $2,2*10^5$ K (for FP-383) and $4,1*10^5$ K (for PI). Value of q was taken from Ref. [8]. It can be noted that under the irradiation doses of D > $3*10^{16}$ cm^{-2} the dependencies σ(T) similar to those represented in Fig. 1 were not detected. The films having dependence σ(T) described by formula (1) can be used as working elements for cryogenic temperature sensors.

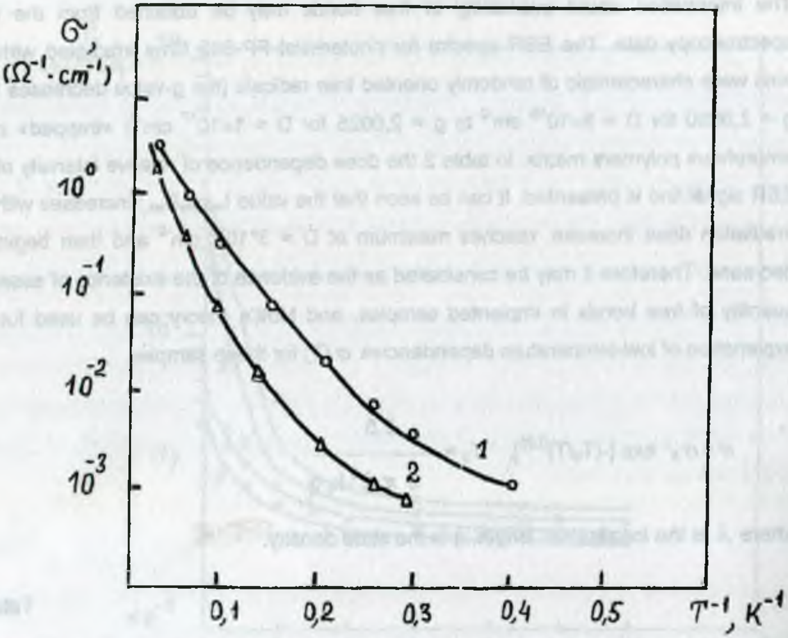

Fig. 2. Low temperature dependencies of conductivity σ(T) for FP-383 photoresist (curve 1) and polyimide (curve 2) irradiated with Ar^+ (100 keV) ions at the dose 1×10^{16} and 2×10^{16} cm^{-2}.

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