PHOTOSTIMULATED DIFFUSION IN SILICON

L.N. Zyuz', A.E. Kiv, O.R. Niyazova, and F.T. Umarova
Nuclear Physics Institute, Uzbek Academy of Sciences
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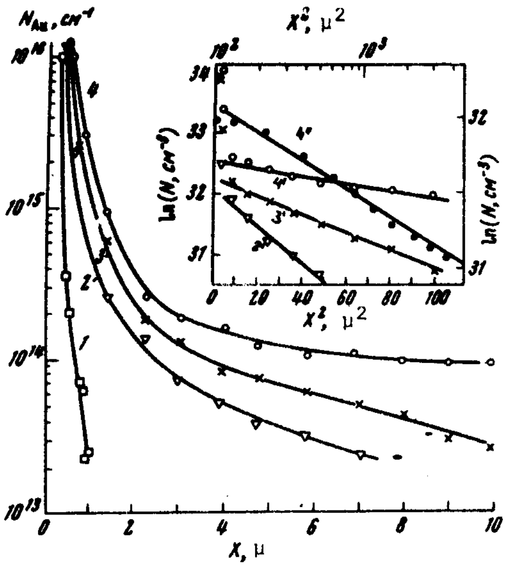
At the present time there are known experimental results on photostimulated annealing of radiation defects [1 - 3]. We describe in this article the effect of considerable acceleration of diffusion of gold in silicon following intense illumination.

The investigation was carried out by the tracer-atom method. Prior to sputtering on the sample, the gold was irradiated in the VVR-S reactor (25 hours in a flux of 1.8×10^{13} neut/cm^2sec). Samples of p-type silicon (doped with boron, resistivity 10 ohm-cm) were cut in such a way that the plane of the surface was perpendicular to the <111> direction. The surface was ground with M-5 and M-3 abrasives, polished by etching with CP-4, and washed with



Profiles of gold distribution in silicon: 1 - control sample, 2,2' and 3,3' - samples with gold introduced by photostimulated diffusion (exposure times 30 and 50 hours), 4,4', 4" - samples with gold introduced by high-temperature diffusion (T = 1070°); curve 4" pertains to the right-hand ordinate axis and the upper abscissa axis.

carbon tetrachloride. The gold film was sputtered on the surface in a vacuum of 10^{-5} Torr at T = 120°K. The sample thickness was ∿300 μ, and the film thickness 0.1 - 0.3 μ.

The samples with the sputtered radioactive gold were illuminated with a 340-W incandescent lamp. Since illumination of the gold film would lead to large losses of light flux by reflection [4], the sample was illuminated from the opposite side. During the time of illumination, the samples were cooled with liquid nitrogen. The temperature of the illuminated surface did not exceed 120°K.

Two series of samples were investigated. The samples of the first series, with the sputtered gold, were illuminated for 30 and 50 hours, while the samples of the second series were stored at room temperature without illumination.

After the diffusion, layers were removed successively [5, 6] by etching with a mixture 40 NHO_3:1 HF and with CP-4. The thickness of the removed layer was determined by weighing the samples before and after each succeeding etching. The thickness of the removed layers was 1.5 - 2 μ. The error in the determination of the layer thickness did not exceed 0.5 μ.

The concentration of the gold in the removed layer was determined by measuring the residual activity of the sample after etching. The standard was Au^{198} weighing 8×10^{-11} g. To prevent adsorption of the gold in the etchant by the surface of the silicon, the sample was thoroughly washed in aqua regia after each session. As a control, non-irradiated samples with sputtered gold were investigated layer by layer.

In the control samples, the gold did not penetrate into the crystal deeper than 1 - 1.5 μ. In the irradiated samples, the gold penetrated up to 10 μ into the silicon crystals after the exposure time. For comparison, experiments were also performed with high-temperature diffusion of gold in analogous silicon samples at T = 1070°K. The corresponding results are shown in the figure. On the basis of these results, a value $\sim 10^{-12}$ cm^2/sec was obtained for the effective coefficient of photostimulated diffusion. In the case of high-temperature diffusion, the dependence of ln C on x^2 (see the figure) is characterized by a kink (similar to that described in [7]), as a result of which the value obtained for the diffusion coefficient is $\sim 10^{-10}$ cm^2/sec up to a depth of 10 μ, and 10^{-9} cm^2/sec for deeper layers.

The aforementioned results on photostimulated annealing of radiation defects in [1 - 3] are attributed to charge exchange of the diffusing centers. They can be explained, however, also by using other models. The acceleration of the defect migration may be connected with local release of heat in nonradiative transition, and with the change of the position of the Fermi level [8].

In our experiments we observed, for the first time, photostimulated heterodiffusion. The charge-exchange hypothesis can hardly be regarded as applicable in our case. If the gold atoms in the silicon are in an ionized state, the capture of an electron should not influence noticeably the diffusion rate, since the time that the gold stays in the neutral state is much shorter than the time of the diffusion jump. In the case of the inverse transition of a neutral gold atom into a positively charged one, the Coulomb part of the potential barrier increases. Estimates show that in our experiments the concentration of the photocarriers is smaller than the concentration of the dark carriers, so that the filling of the levels should be determined by the "dark" Fermi level [9].

Taking into account the value of the activation energy of gold diffusion in silicon, we can conclude that to overcome the potential barrier and simultaneously release heat in a nonradiative transition there should occur an appreciable thermal fluctuation, the probability of which is low at the temperature of the experiment.

A model more probable than the foregoing one is that of photostimulated diffusion, according to which the excitation of the chemical bonds in the vicinity of the saddle point leads to a lowering of the potential barrier [10]. We consider the jump of the gold atom from an equilibrium interstice with coordinates [1/2, 1/2, 1/2] into a neighboring one with coordinates [3/4, 3/4, 3/4]. If we look at the diffusing atom in the saddle point along the <111> direction, we can see that the overcoming of the potential barrier is connected with passing through a deformed hexagonal ring. An appreciable part of the energy is due to the need for overcoming the geometric barrier - the stretching of the hexagonal ring on passage of the atom through the saddle point. The localization of the electronic excitations in the vicinity of the saddle point can lead to an appreciable stretching or breaking of the hexagonal ring [11], meaning, in particular, a decrease of the geometric barrier.

The described effects of "cold" photostimulated diffusion of impurities in semiconductors can serve as a basis for the development of new doping methods, which may find important practical applications.

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