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REORDERING PROCESSES IN NEUTRON IRRADIATED P-TYPE GERMANIUM

by

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LIST OF ILLUSTRATIONS

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Reordering kinetics should be an aid in determining the nature of defects involved in reordering processes. We have examined the kinetics of processes in pulse neutron irradiated p-type Ge. Unstable electrical properties were used as an indication of defect reordering. The irradiation was obtained in the form of a pulse from Godiva II and the reordering occurred under isothermal conditions. The operating procedure was to stabilize the sample at a selected temperature and record the electrical parameters, with 1-second resolution, for a period of 1 hour before to 1 hour after the irradiation pulse. Temperatures were controlled within ± 0.03°C.

Figure 1 shows, in block diagram form, the type of instrumentation used in the experiments for measuring the electrical parameters. For resistivity, a constant-current 400-cycle AC is used to supply the sample and a bias network. The IR drop across the resistor in the bias is made equal to the IR drop across the sample. The outputs go to a difference amplifier and a phase sensitive detector and on to a strip chart recorder. For carrier concentration, a magnetic field is introduced and the voltage across the bias resistor is made equal to the voltage from the Hall Probes. For mobility measurements, the system is similar to that for carrier concentration except a constant voltage is used rather than a constant current.

The system for measuring photoconductivity changes employs a DC constant current source and a light source chopped at 60 cps. The voltage variation induced by the photoconductivity is then amplified and detected.

At 73°K, the conductivity and mobility are stable following the irradiation pulse. At 150°K, parts of two processes are observed as shown in Fig. 2. This is a plot of the normalized conductivity change versus time following the irradiation pulse, where σ_t is the conductivity at time (t), σ_o the original conductivity, and σ_{min} the minimum conductivity. The conductivity decreases, goes through a minimum, then increases. Mobility changes are near the limit of resolution at these temperatures and have not been reproduced here; however, they indicated a decrease in mobility for process A and an increase for process B. By comparison with the work of other investigators, namely Cleland and Crawford on neutron irradiated p-type Ge and Brown et al. on electron irradiated p-type Ge, process A is probably a release of trapped minority carriers.

Process B can be clearly resolved by going to higher temperatures. Figure 3 shows the process at 193°K. The solid circles represent the process when the sample is maintained in the dark. We note that the conductivity increases, goes through the original value, and the sample ends up more p-type than before irradiation. This shows the reordering is more than a simple recovery. The open circles represent the process when a small amount of light from a tungsten filament is incident upon the sample during reordering. The illumination decreases the time constant between one and two orders of magnitude.

Figure 4 shows the result of obtaining the halflife of process B for a number of different temperatures, both with and without the light, then plotting the ln of these halflives versus 1/T to obtain the activation energies. We note that the illumination decreases the activation energy from 0.3 to 0.2 ev. This is similar to results obtained by Brown in electron irradiated p-type Ge; however, the activation energy reduction here is smaller, the time constants are smaller, and the kinetics are nearly second order whereas Brown observed first-order kinetics. Perhaps these differences are due to a difference in special distribution of defects for the two cases. Process B is undoubtedly the process observed by Cleland and Crawford in neutron irradiated p-type Ge which increased the hole concentration and occurred in the temperature range from 150 to 230°K.

A large photoconductivity recovery was observed in the temperature range near 200°K and hence presumably a recovery in lifetime. Figure 5 shows the recovery process normalized and compared with the normalized conductivity change under light on conditions for 181°K. We note that the two processes behave nearly the same, and the same defect reordering is probably observed in both measurements.

Our results are consistent with an unstable donor defect which is doubly charged positive, provided that during the reordering with the light only a small fraction of the defects are occupied by an electron but a sufficient number must be occupied to dominate the reordering. Comparison of the DC photoconductivity with the hole concentration change during the process suggests this fraction is about one tenth. The same fraction is obtained from calculations of the number of jumps a defect must make before annihilation in the light on and light off cases. This possibility should be easily enough checked experimentally by varying the intensity of the light source.

Near 300°K, a third process was observed as shown in Fig. 6. This process decreases the hole concentration, is unaffected by light, has a small temperature dependence, and has given some indication of being sample and sample history dependent. All the traces shown were taken from one sample. Mobility changes are too small to resolve at these temperatures and photoconductivity changes are also small; thus we are unable to determine if this process decreases acceptor density or increases the donor density.

We will be continuing our work with Ge by examining the effects (if any) of different impurities and impurity concentrations on the reordering processes.

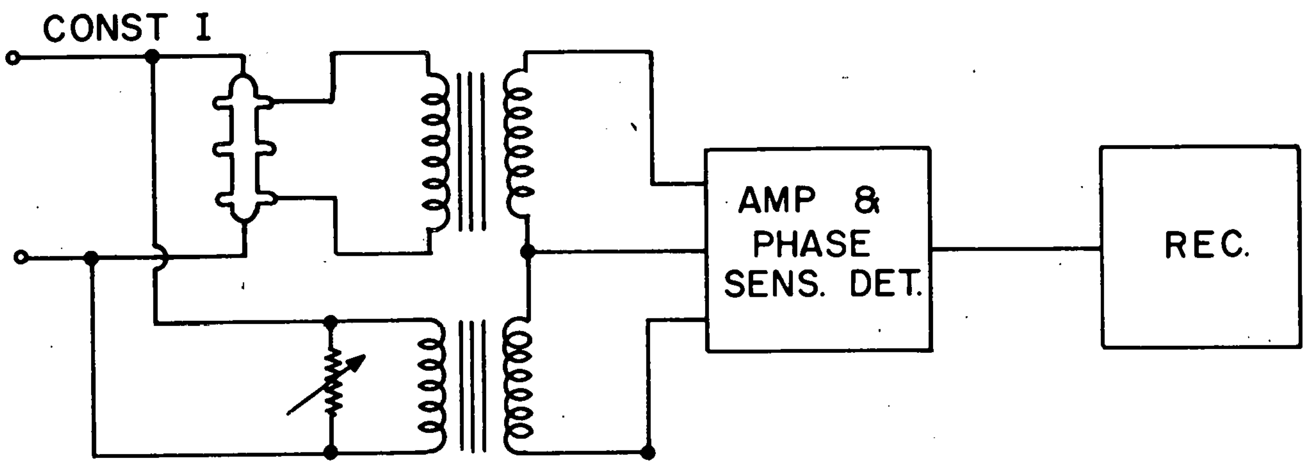

Fig. 1a -- System for measuring resistivity change

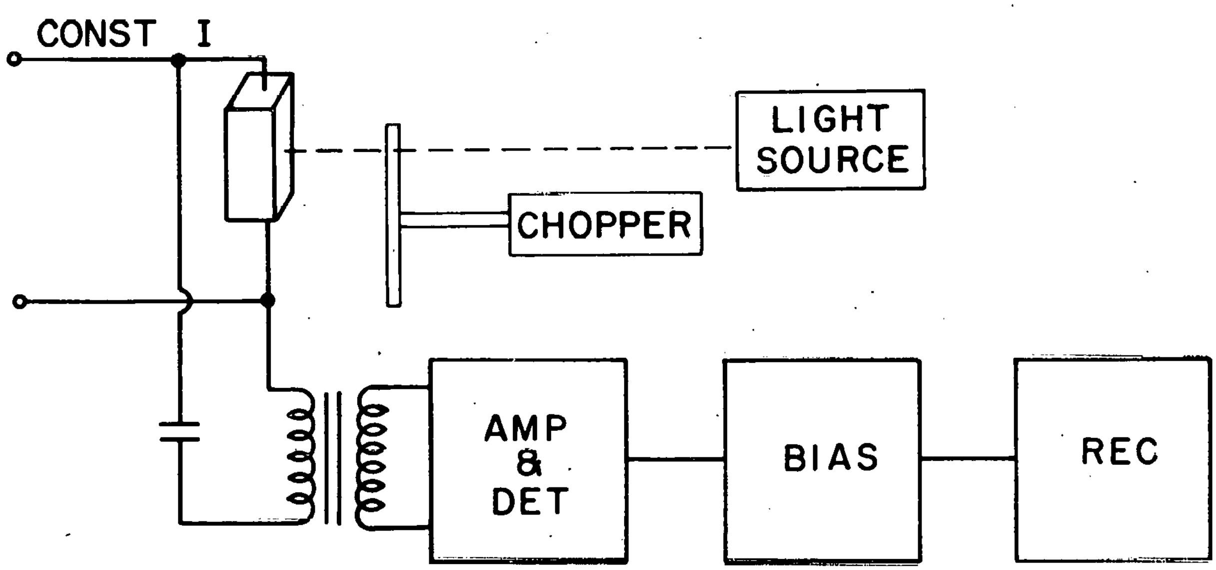

Fig. 1b -- System for measuring photovoltage change

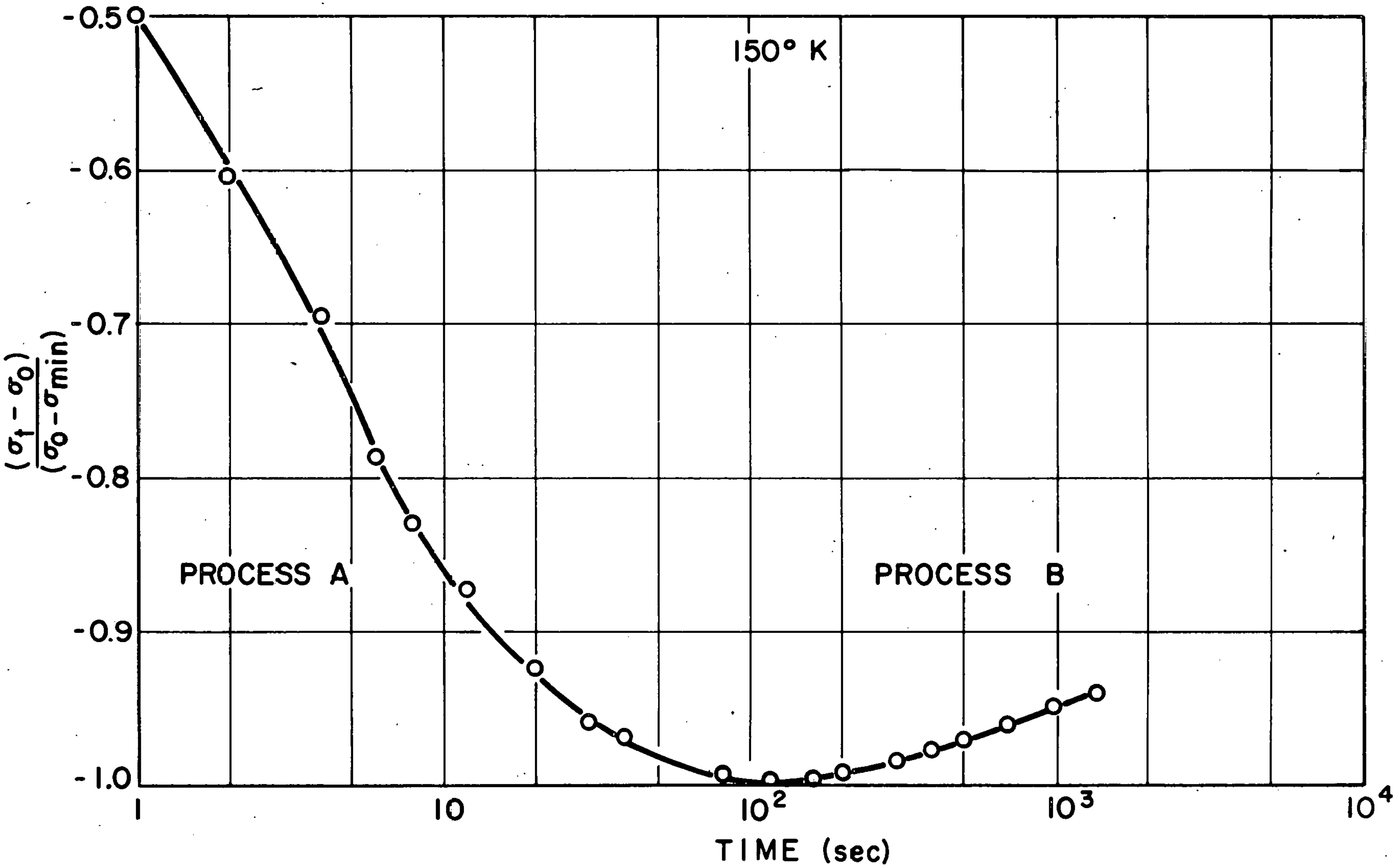

Fig. 2 -- Normalized conductivity changes at 150°K following 5.7×10^{12} n/cm^2

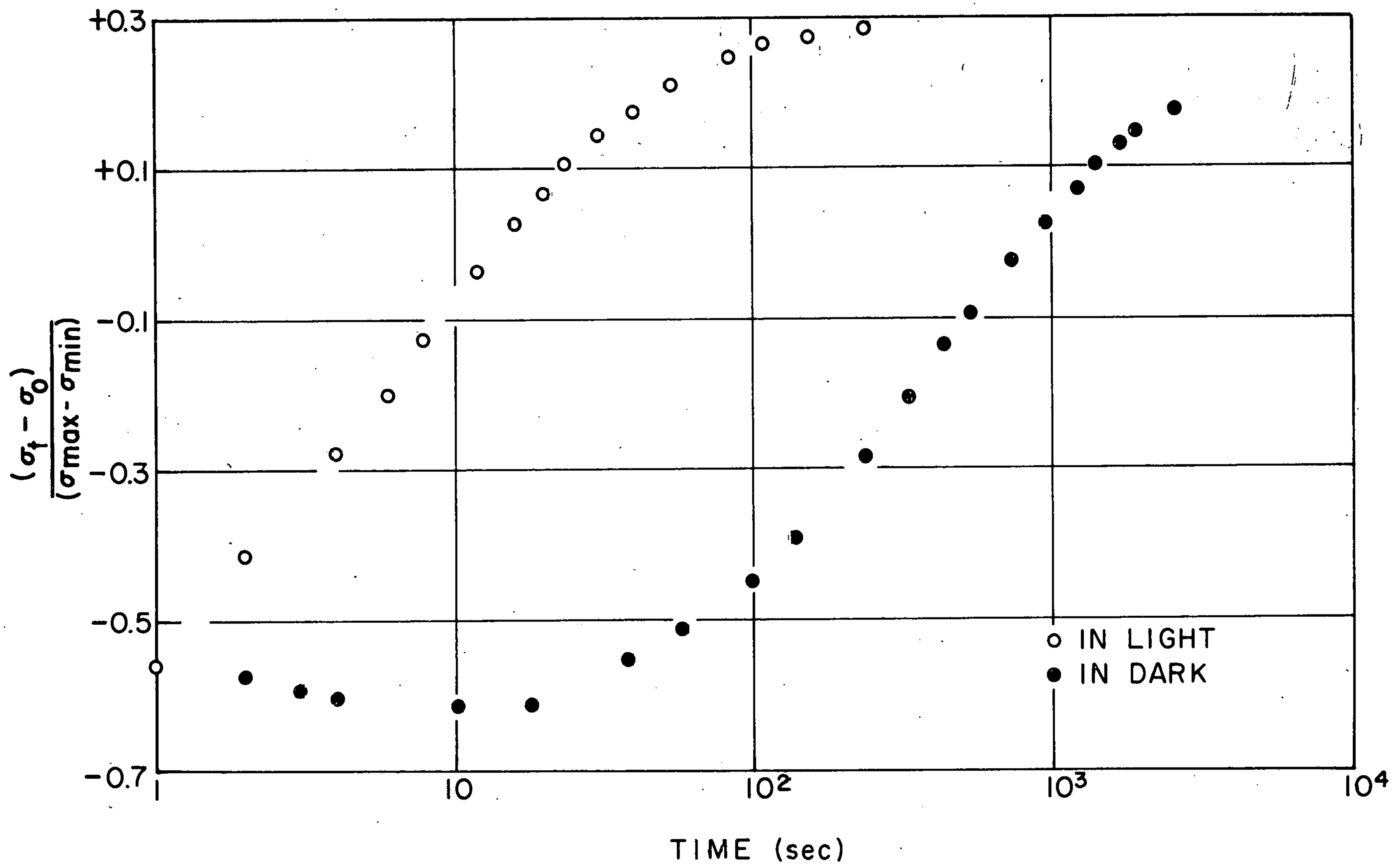

Fig. 3 -- Effect of light on process B at 193°K

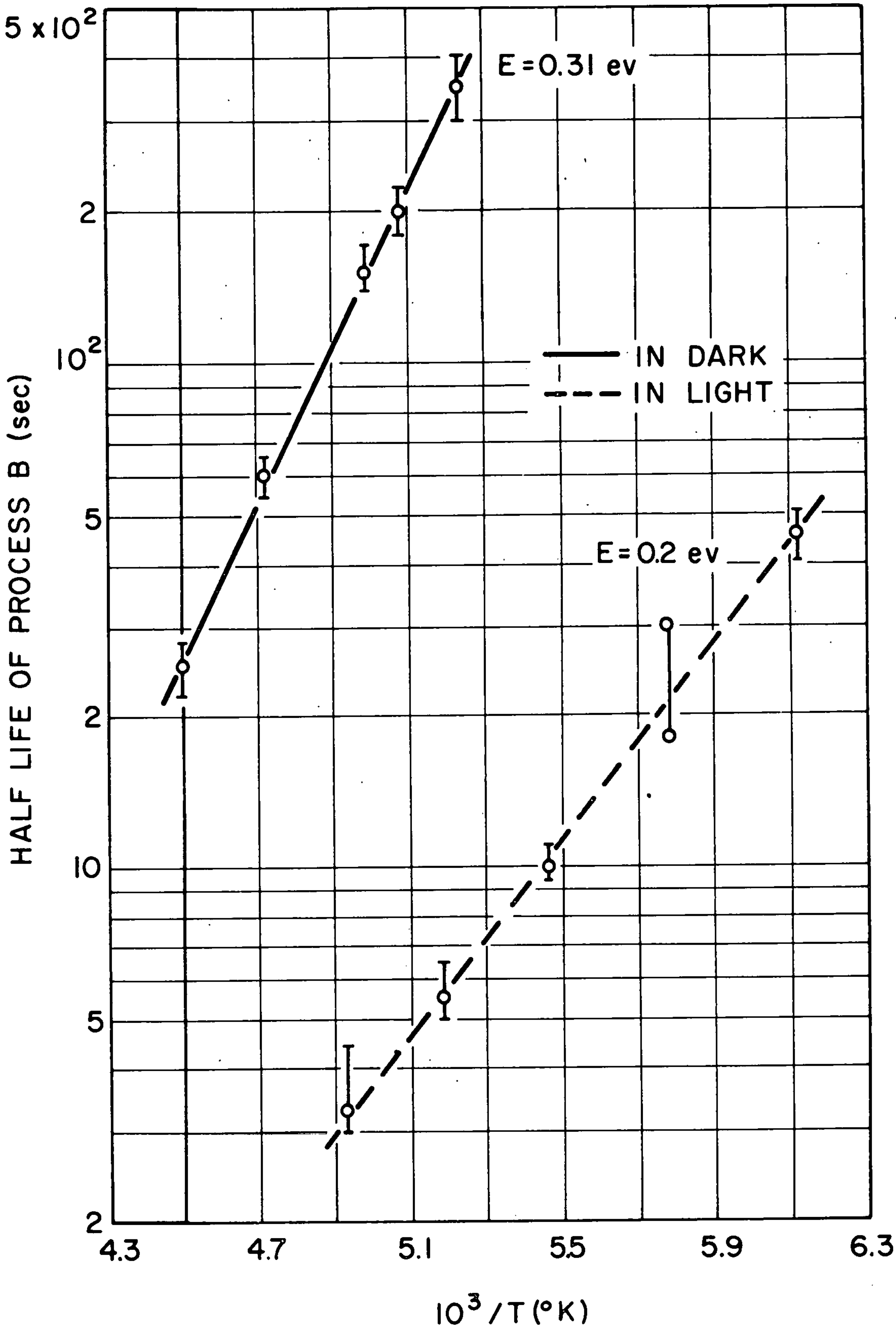

Fig. 4 -- Activation energies with and without light

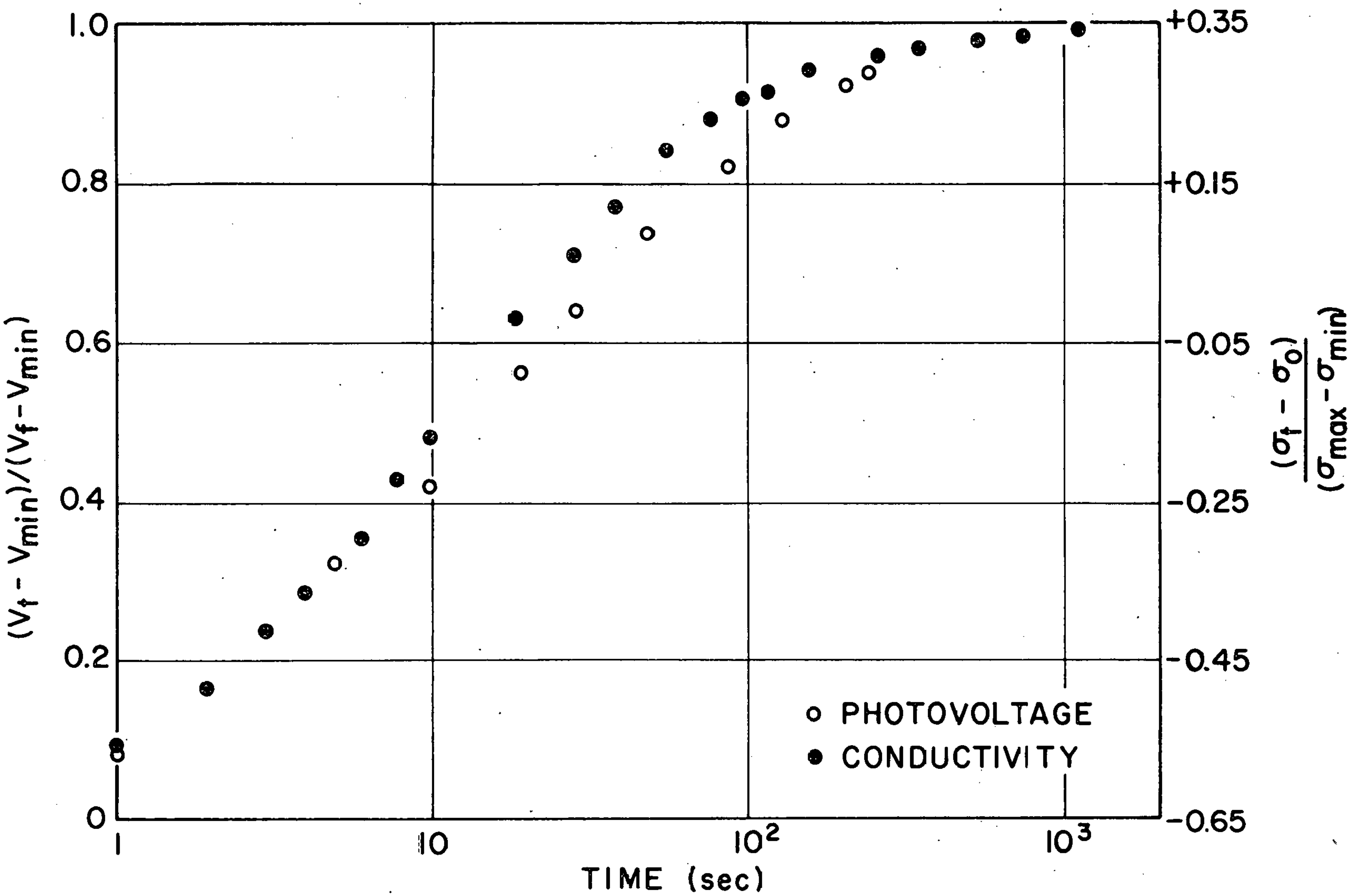

Fig. 5 -- Normalized photovoltage and conductivity changes at 181°K following neutron irradiation, process B

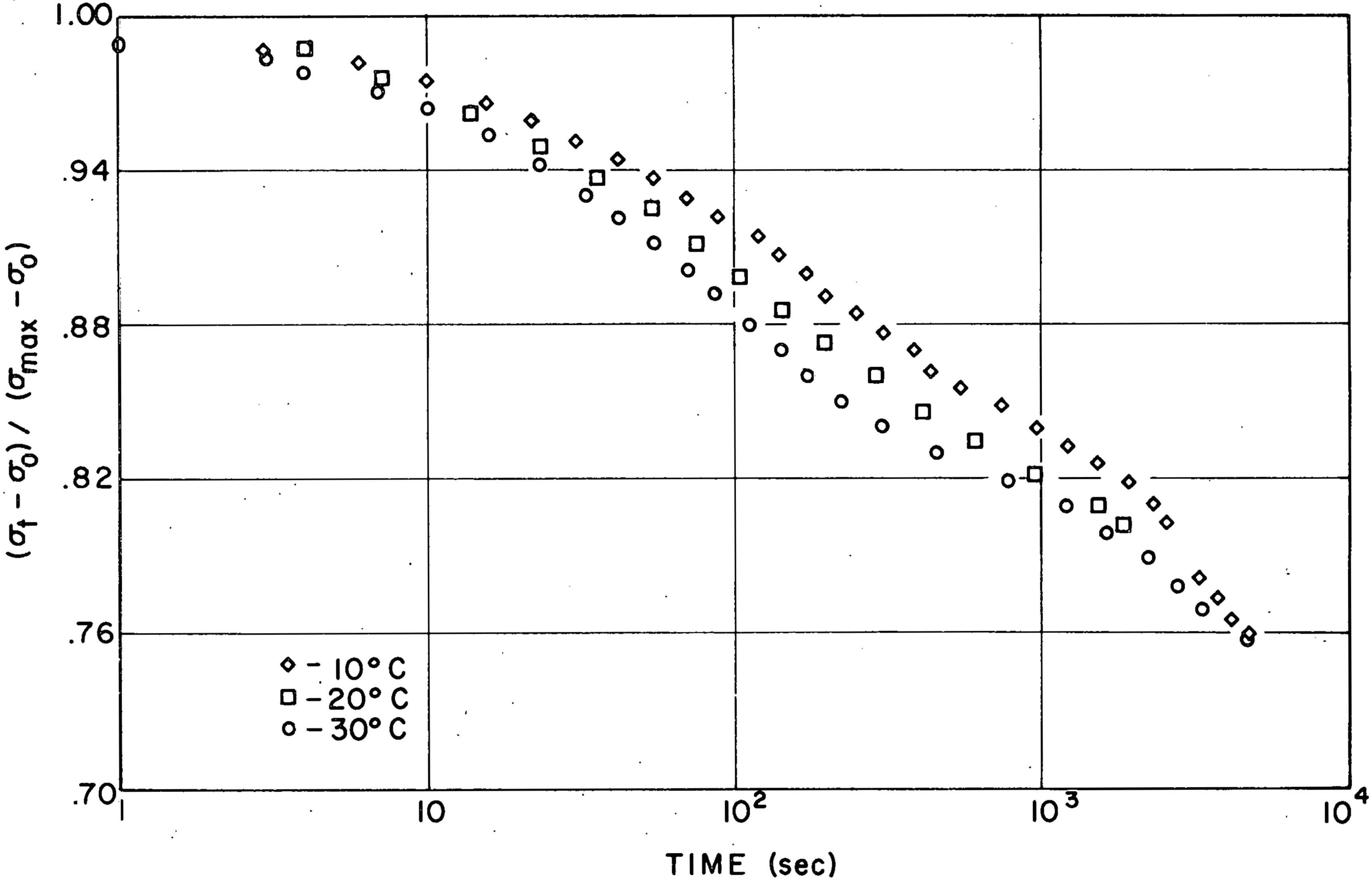

Fig. 6 -- Recovery from initial conductivity increase at different temperatures near 300°K

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