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SPECIAL NUCLEAR EFFECTS LABORATORY

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RADIATION EFFECTS ON SILICON

Seventh Quarterly Progress Report Covering the Period July 1, 1966, through September 30, 1966

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1. INTRODUCTION

This seventh quarterly progress report on Contract NAS7-289, "Radiation Effects in Silicon Solar Cells," covers the period July 1, 1966, through September 30, 1966.

During this period, electrical conductivity in high-purity n-type silicon was investigated by the microwave technique after irradiation by 30 MeV electrons at room temperature. Electron-spin resonance studies were made on high-resistivity material to establish a correlation between the microwave resonance and carrier lifetime studies. Further experiments were performed on the formation of the Si-G8 center at $80^{\circ}K$, with subsequent annealing to $300^{\circ}K$.

A portion of the results presented here were obtained under Contract DA-49-186-AMC-65(X).

2. MICROWAVE CONDUCTIVITY

Electrical conductivity in high-purity n-type silicon was investigated by the microwave technique. The n-type silicon was first irradiated at room temperature by 30 MeV electrons and then the effects of these high-energy electrons were investigated at the flash x-ray facility.

2.1 PRE-IRRADIATION MEASUREMENTS

The sample used was n-type silicon cut from the same boule as the sample which was reported in GACD-6249 (6/30/66) and irradiated at $4.2^{o}K$. The electrical conductivity and lifetime data were reproducible and showed the same injection-level dependence at temperatures from room temperature to liquid nitrogen temperature.

The Shockley-Read recombination theory was used to analyze the injection-level dependence of this n-type silicon sample before irradiation. The Shockley-Read recombination theory for a single-level defect is based on the assumption that the concentration of recombination centers is sufficiently small relative to the excess-carrier density that a negligible fraction of the excess carriers are used to readjust the occupation fraction of the recombination center. The excess carriers must flow through the recombination center and the excess electrons and holes must have equal densities and lifetimes in either steady state or transient recombination. The lifetime is then a function of excess-carrier concentration and is given by:

$$\tau = \frac{\tau_{\ell} + \tau_h \frac{\Delta n}{n_o}}{1 + \frac{\Delta n}{n_o}}$$

$$\tau_{\ell} = \tau_{po}\left(1 + \frac{n_1}{n_o}\right) + \tau_{no}\frac{p_1}{n_o}$$

$$\tau_h = \tau_{no} + \tau_{po}$$

where the above symbols are defined in GA-3872 (15 February 1963). Figure 1 shows the plot of $\tau(1 + \frac{\Delta n}{n_o})$ versus $\frac{\Delta n}{n_o}$ at liquid nitrogen temperature.

Figure 2 shows the inverse temperature dependence of τ_ℓ and τ_h. The interpretation of this data has not yet been determined.

2.2 LINAC IRRADIATION

This sample was irradiated at the electron linear accelerator facility (Linac) with 0.1 μsec, 30 MeV electrons. Before irradiating at room temperature the carrier lifetime at room temperature was about 700 μsec, but the first measurements at Linac showed a lifetime in the neighborhood of 70 μsec. This decrease in lifetime was no doubt due to scattered electrons during tuning of the Linac even though precautions were taken to guard against these stray electrons. This portion of the experiment will be rerun in the immediate future.

Although the carrier lifetime was unexpectedly changed, the electrical conductivity as a function of total integrated flux was recorded. This is plotted on Figure 3. If the mobility is assumed to be constant during this irradiation, then the calculated carrier removal rate is about 0.11 cm^{-1}. After this irradiation of 1.53×10^{11} electrons/cm^2, the injection-level dependence of the lifetime at room temperature is not present. The temperature dependence of the lifetime below room temperature shows that the damage introduced by the Linac irradiation is a trapping center. Figure 4 gives the carrier lifetime as a function of $10^3/T(^\circ K)^{-1}$ over a limited temperature range. Further Linac irradiation on this same sample at room temperature did not produce any noticeable change in the lifetime of the excess carriers at room temperature. The sample was irradiated to an integrated flux of 2.84×10^{13} electrons/cm^2. At these high flux levels with high-energy electrons at room temperature, it is known that the introduced defects are not of a simple nature but may be quite complicated and therefore difficult to identify. The trapping center (increasing τ with increasing $10^3/T(^\circ K)^{-1}$) seems to be the same center that was introduced with liquid helium temperature irradiations (GACD-6249, 6/30/66).

2.3 COMMENTS

Even though the room-temperature irradiations of the high-purity n-type silicon are not finished, it is possible to comment on the nature of the introduced damage. The trapping center introduced by the room-temperature irradiation is very much like the trapping center introduced by the irradiation at liquid helium temperature. The inverse temperature dependence of the lifetime of the excess carriers is the same after the liquid-helium-temperature and room-temperature irradiations, and there is no injection-level dependence of lifetime of the excess carriers for this trapping center. Continued electron irradiation at room temperature does not change the nature of the trapping center.

2.4 FUTURE PLANS

In the immediate future, the high-resistivity n-type silicon sample will again be irradiated at room temperature, but this time the flux will be controlled so that the radiation-induced recombination center can be detected. The recovery of the excess-carrier lifetime as a function of annealing temperature above room temperature will be investigated. In this manner, the recombination and trapping center may be associated with one of the known centers as identified by electron-spin resonance work(1). Future plans also call for the investigation of the type of defects introduced at liquid nitrogen temperature in high-resistivity n-type silicon by 30 MeV electrons. The rest of the program calls for the investigation of high-resistivity p-type silicon.

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1) G. D. Watkins, Radiation Damage in Semiconductors, Academic Press, p. 98, 1964.

3. ELECTRON-SPIN RESONANCE EXPERIMENTS

The electron-spin resonance studies have concentrated on establishing a correlation between the microwave resonance and carrier lifetime studies. Most of the lifetime studies must be carried out on high-resistivity material, namely in the resistivity region between 10^4 to 10 ohm-cm. Therefore, it was considered necessary to perform the resonance experiments on similar material with the major effort being placed on the more available 10 ohm-cm samples. Thus far, the introduction rates of the observed centers seen by resonance techniques have been at least an order of magnitude below that observed with the galvanomagnetic techniques, including lifetime measurements. Consideration is now being given to the role of the ratio of the number of initial chemical impurities to the number of radiation-induced defects in determining the lifetime degradation in order to plan future experiments.

Additional experiments were performed on the formation of the Si-G8 center (the vacancy phosphorus complex) at 80°K, and the influence on the resonance as the sample was annealed to 300°K. The experimental procedure was to irradiate the sample at 80°K and, before warming it, measure the resonance intensity at 50°K, using both pulled and floating-zone material. Again, as explained in the last quarterly report, no change in the number of Si-G8 centers was observed upon annealing except that due to a change in the charge state of this center.

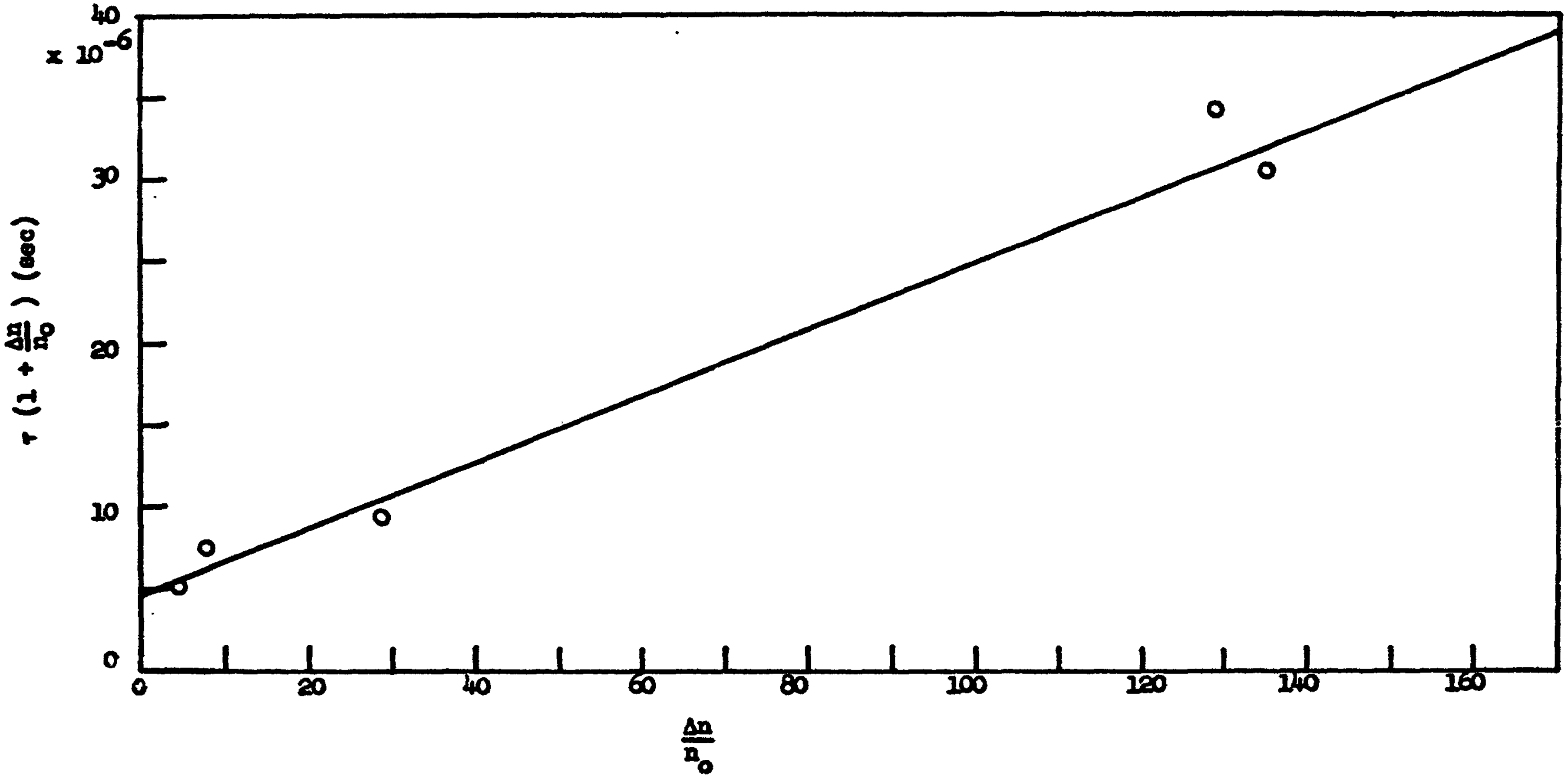

Fig. 1--Injection level dependence at liquid nitrogen temperature

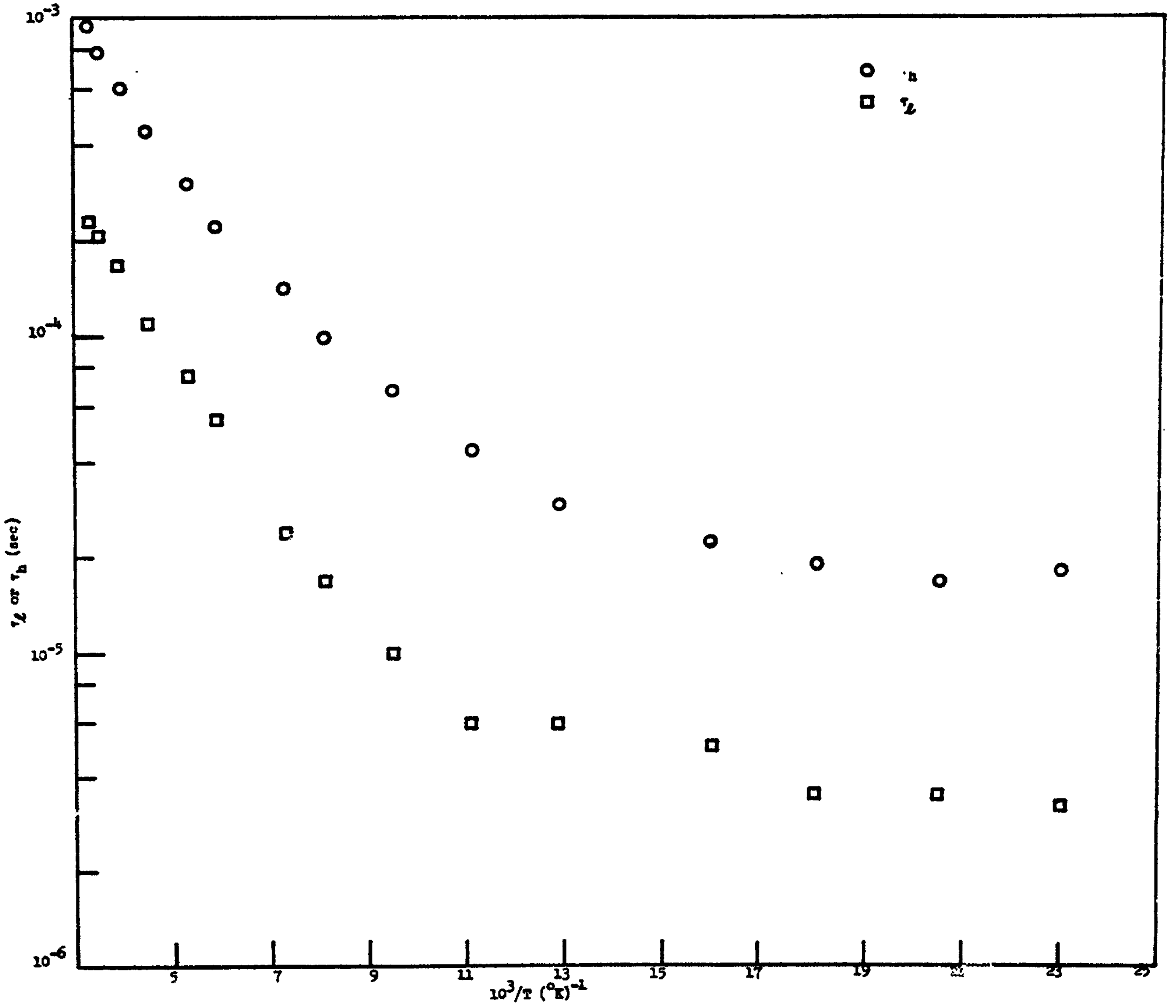

Fig. 2--Inverse temperature dependence of lifetime from Shockley-Read theory

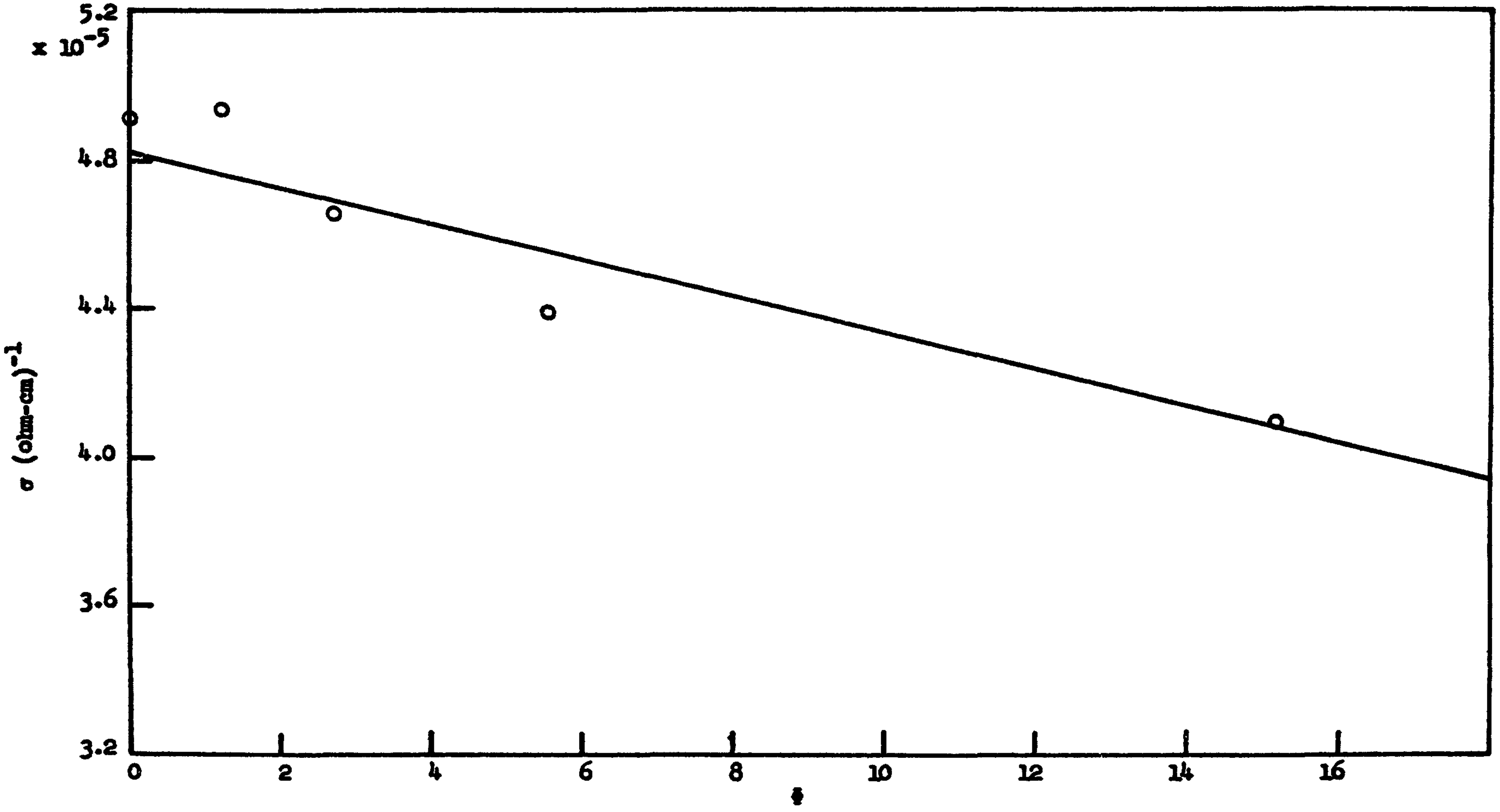

Fig. 3--Electrical conductivity as a function of totel integrated flux

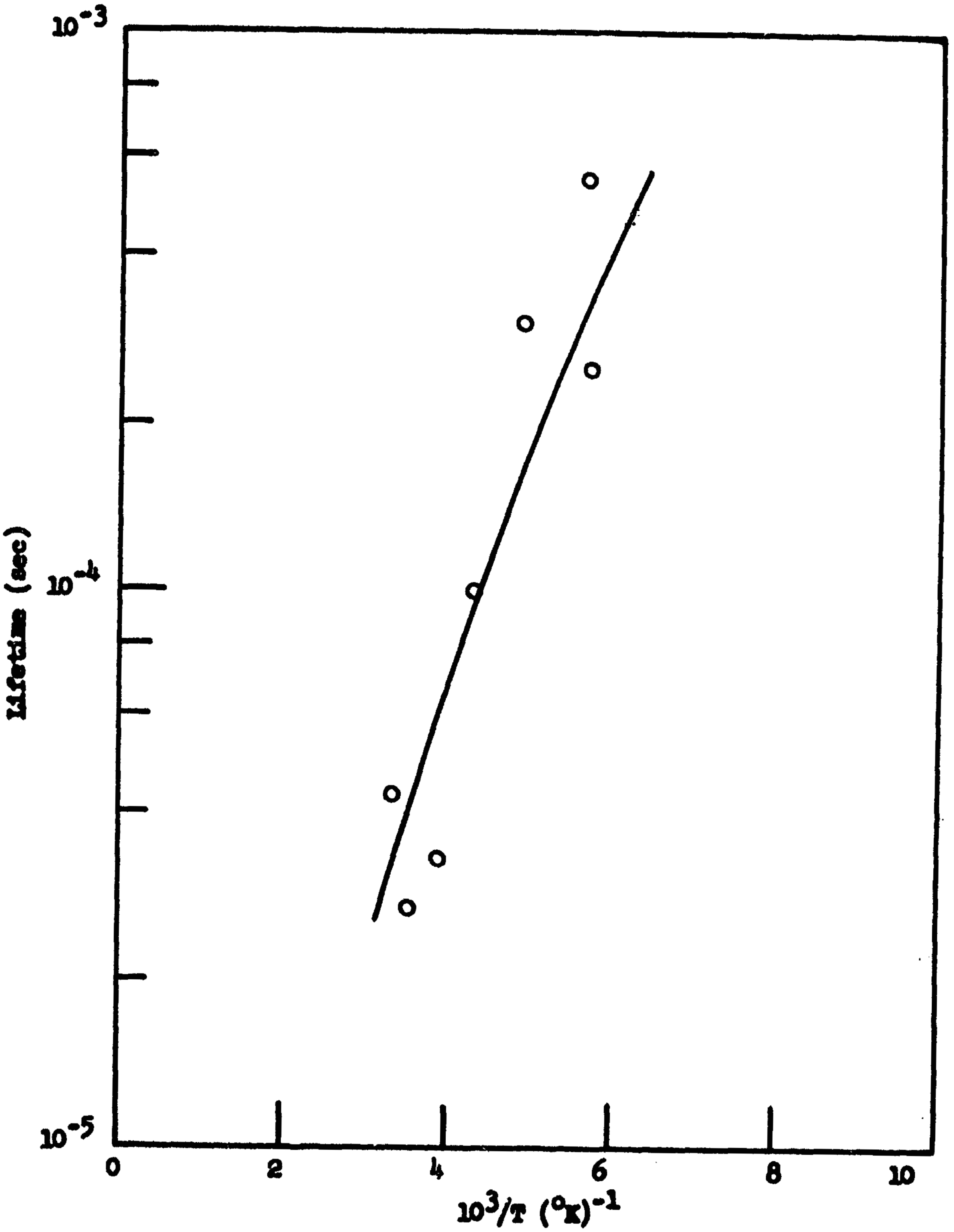

Fig. 4--Excess carrier lifetime as a function of $10^3/T$ ($^\circ$K)$^{-1}$