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RADIATION EFFECTS ON SILICON

Eighth Quarterly Progress Report Covering the Period
October 1, 1966, through December 31, 1966

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1. INTRODUCTION

This eighth quarterly progress report on Contract NAS7-289, "Radiation Effects in Silicon Solar Cells," covers the period October 1, 1966, through December 31, 1966.

During this period, transient and quiescent electrical conductivity in high-purity n-type silicon were investigated by the microwave technique after irradiation by 30 MeV electrons at room temperature. Dc electrical conductivity transient measurements on silicon samples of carrier concentration about 10^{14} cm^{-3} are being performed.

2. MICROWAVE CONDUCTIVITY

Quiescent and transient electrical conductivity in high-purity n-type silicon were investigated by the microwave technique. As reported in the last quarterly report, GACD-6249 (9/30/66), for the high-resistivity n-type silicon samples irradiated at room temperature, the electron flux was not controlled sufficiently so that the radiation-induced recombination center was not detected. Only a trapping center was detected. During this quarter, a high-resistivity n-type silicon sample was irradiated at room temperature and the flux was controlled so that the introduction of the recombination center was detected.

2.1 LINAC IRRADIATION

The sample used was n-type silicon of 10^4 ohm-cm resistivity and an initial lifetime of 10^3 μsec at room temperature. The sample was vacuum float zone. The pre-irradiation lifetime measurements on this sample were obtained using the General Atomic flash x-ray machine. The pre-irradiation quiescent electrical conductivity results are shown in Fig. 1. Figure 2 shows the pre-irradiation lifetime as analyzed using the Shockley-Read theory.[1] The lifetime of this high-purity n-type silicon at room temperature for a 0.5 rad (Si) injection level was about 1,300 μsec.

The samples and the microwave apparatus were then moved to the General Atomic electron linear accelerator (Linac) where extra precautions were taken so that during Linac tuning the sample was not irradiated with high-energy electrons. At low Linac dose rate (about 0.5 rad (Si)), the lifetime before high-energy electron irradiation was still about 1,300 μsec.

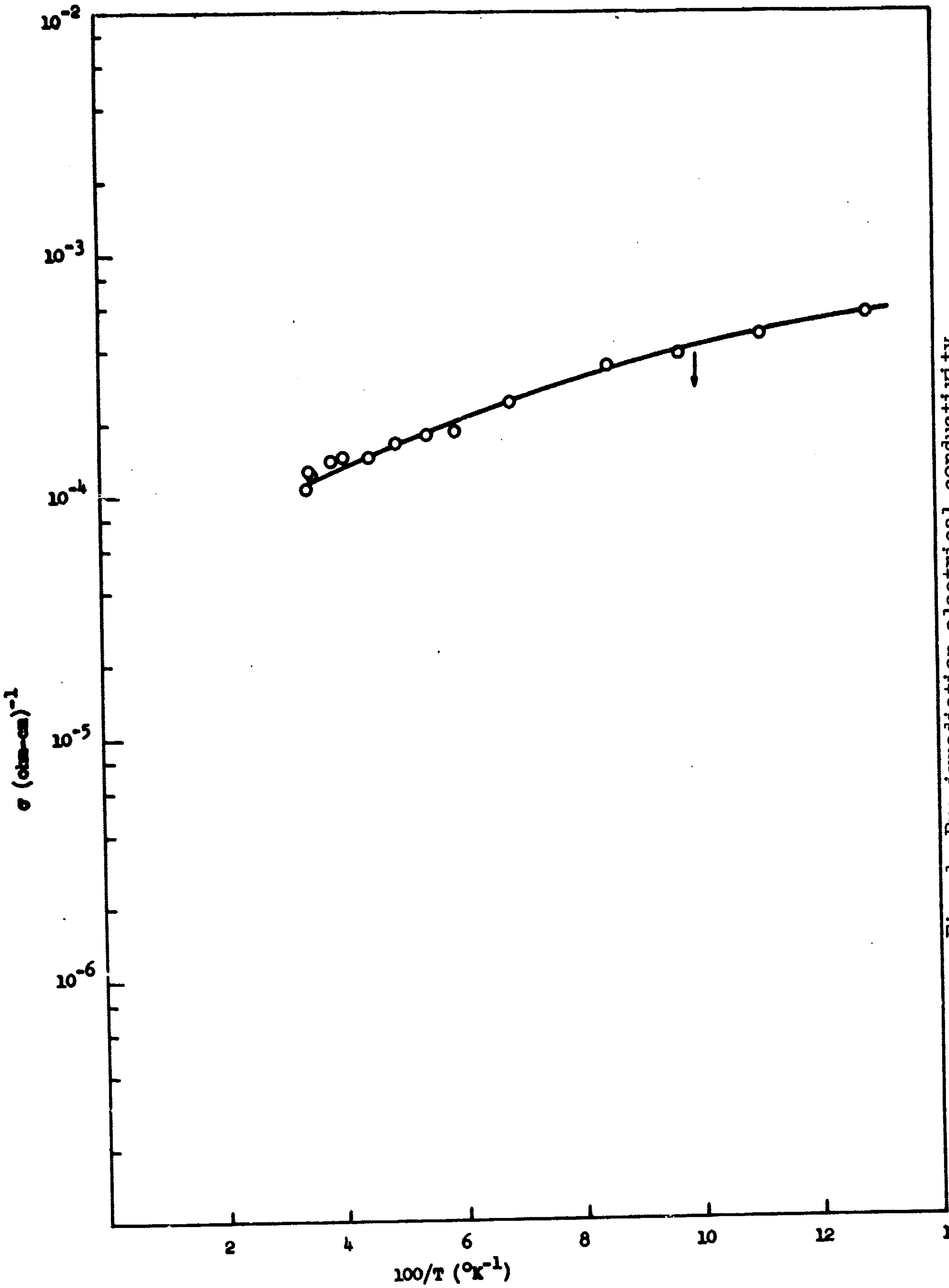

Fig. 1--Pre-irradiation electrical conductivity as a function of inverse temperature

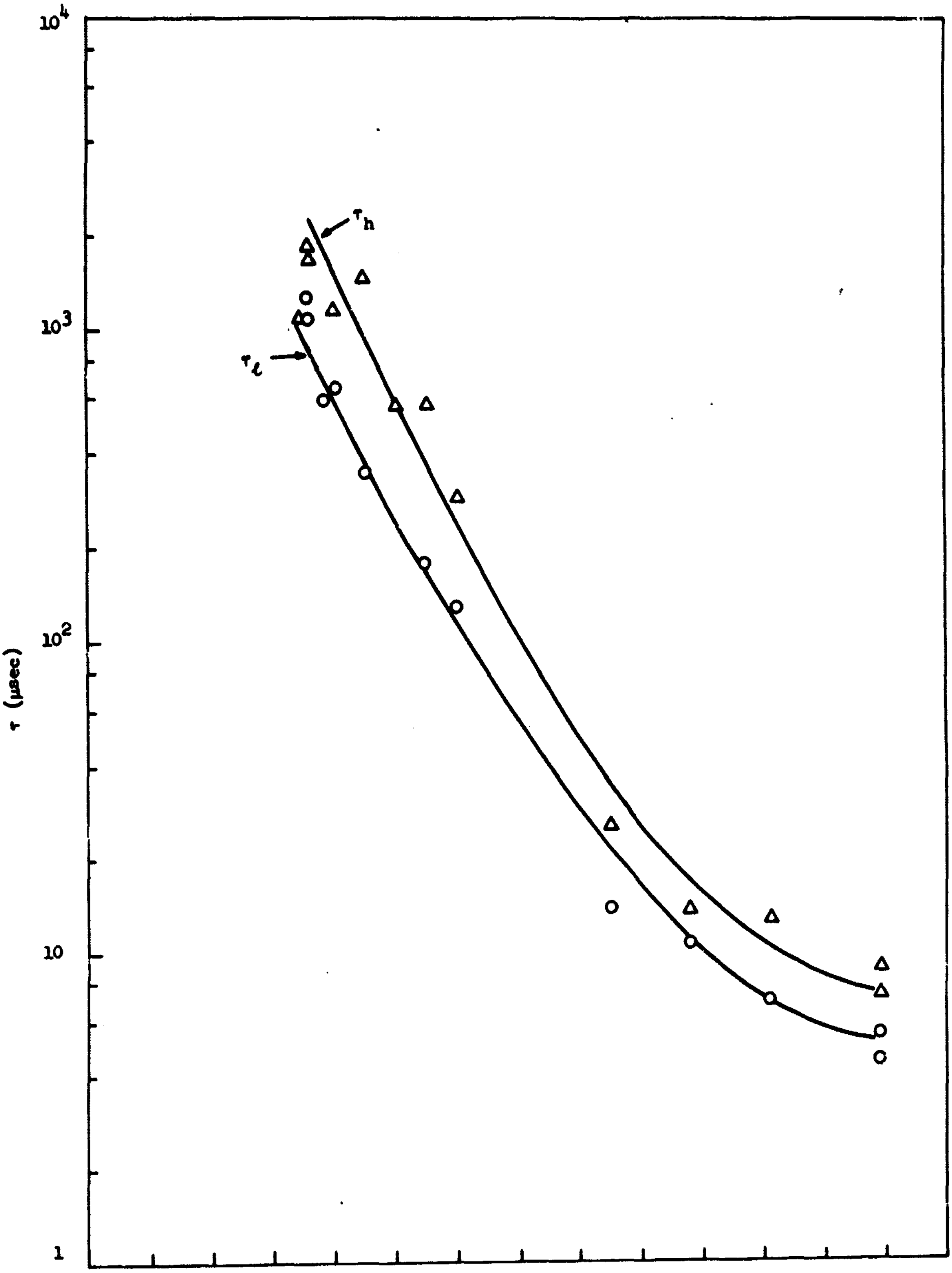

Fig. 2--Pre-irradiation carrier lifetime as a function of inverse temperature

Therefore, during tuning the lifetime was not degraded. The sample was then irradiated with 30 MeV, 0.1 μsec, 5 rads (Si) pulses of electrons. The lifetime degradation was plotted according to the relationship

$$\frac{1}{\tau} = \frac{1}{\tau_o} + K\varphi$$

where τ_o is the initial lifetime before irradiation, φ is the integrated flux, K is the damage constant, and τ is the lifetime after an integrated flux φ. Figure 3 shows the degradation of the lifetime of the high-resistivity n-type silicon sample where $1/\tau$ is plotted as a function of φ. The slope of the curve is the damage constant (K) equal to 2.2×10^{-8} cm^2/sec at room temperature. During this irradiation the lifetime was degraded at room temperature by a factor of 4. At this point the irradiation was halted and the sample and microwave equipment were moved to the flash x-ray facility where the temperature dependence of the lifetime was checked. Figure 4 shows the results of this experiment. This plot shows presence of both a recombination and a trapping center. Figure 5 shows the quiescent conductivity after the initial high-energy electron irradiation.

The sample was then taken back to Linac and irradiated again with 30 MeV electrons. This time the lifetime at room temperature was degraded to about 70 μsec. The temperature characteristics of the lifetime of these additional centers were then investigated at the flash x-ray facility. The data for the experiment described in this paragraph has not been completely analyzed. The analysis will be completed in the near future.

2.2 COMMENTS

The pre-irradiation lifetime of the high-resistivity silicon sample was analyzed using the Shockley-Read theory. Figure 1 shows the inverse temperature dependence of τ_l and τ_h as defined in GACD-6249 (9/30/66). Comparison of Figures 1 and 5 shows that during the Linac irradiation there was no detectable change in electrical conductivity. However, a comparison of Figures 2 and 4 shows a definite change in the inverse temperature characteristics of the lifetime. The post-irradiation figure indicates two centers present in the irradiated sample, one a recombination center and the other a trapping center. The value of

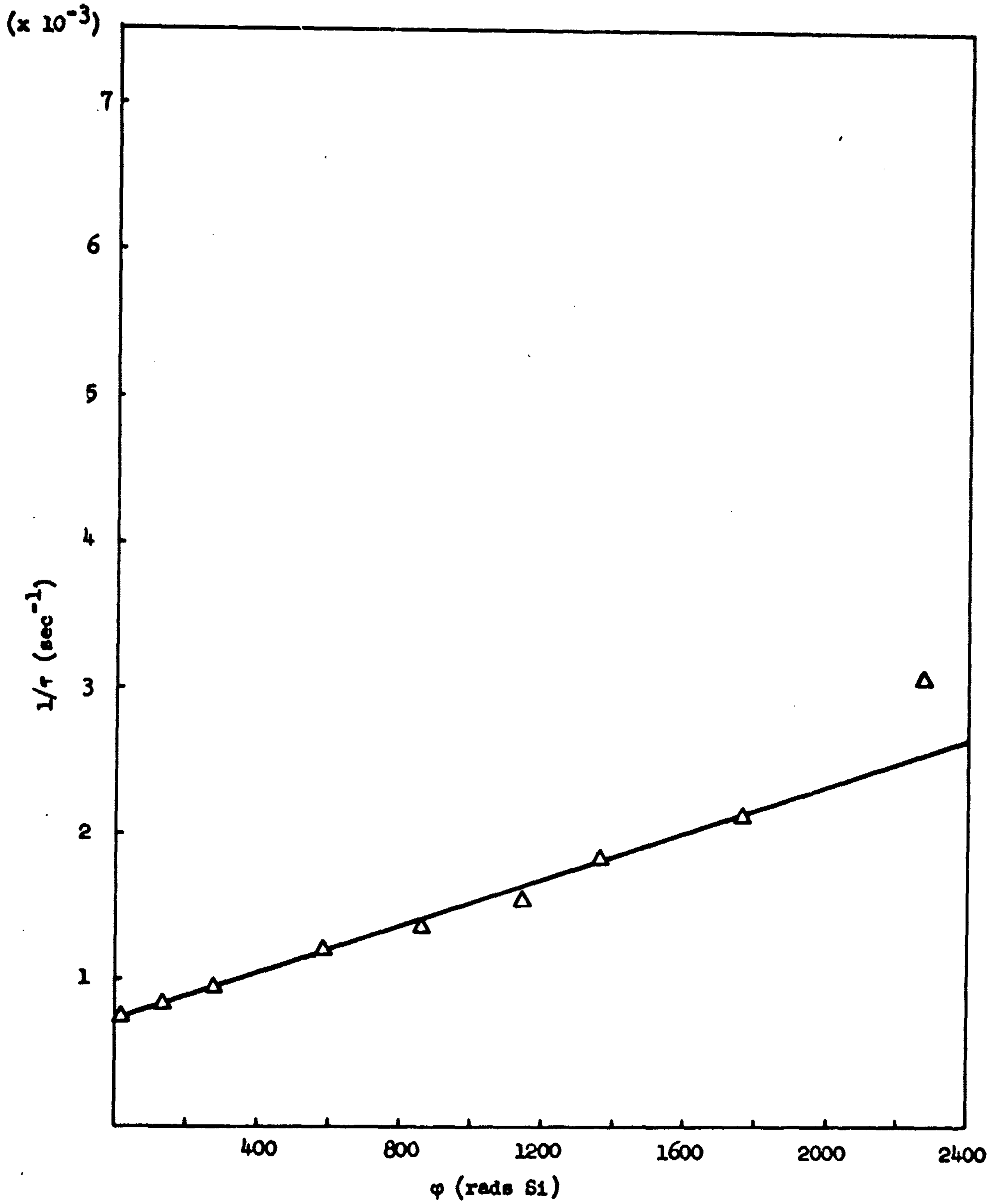

Fig. 3--Inverse Lifetime as a function of integrated electron flux

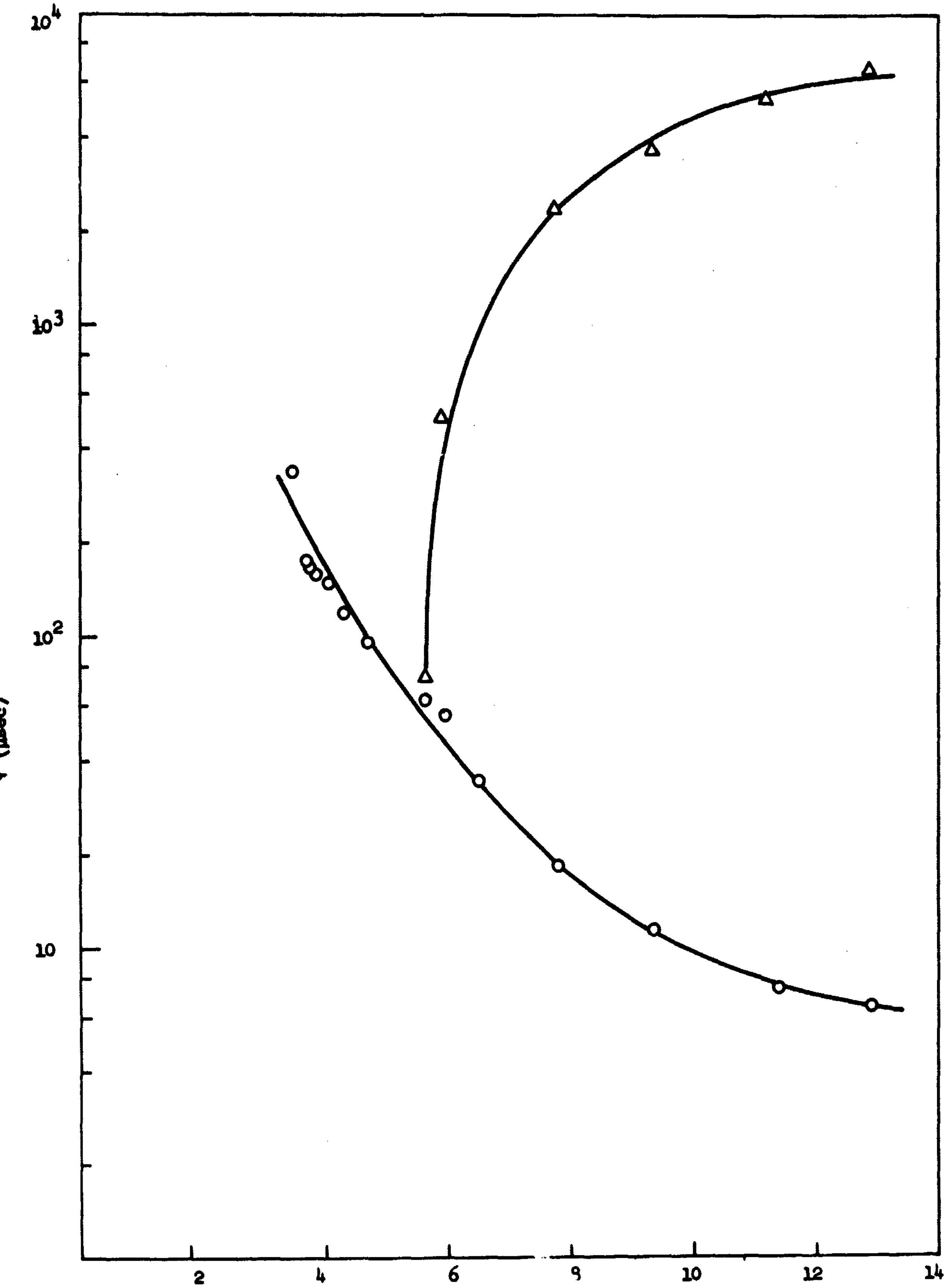

Fig. 4--Carrier lifetime as a function of inverse temperature after Linac irradiation

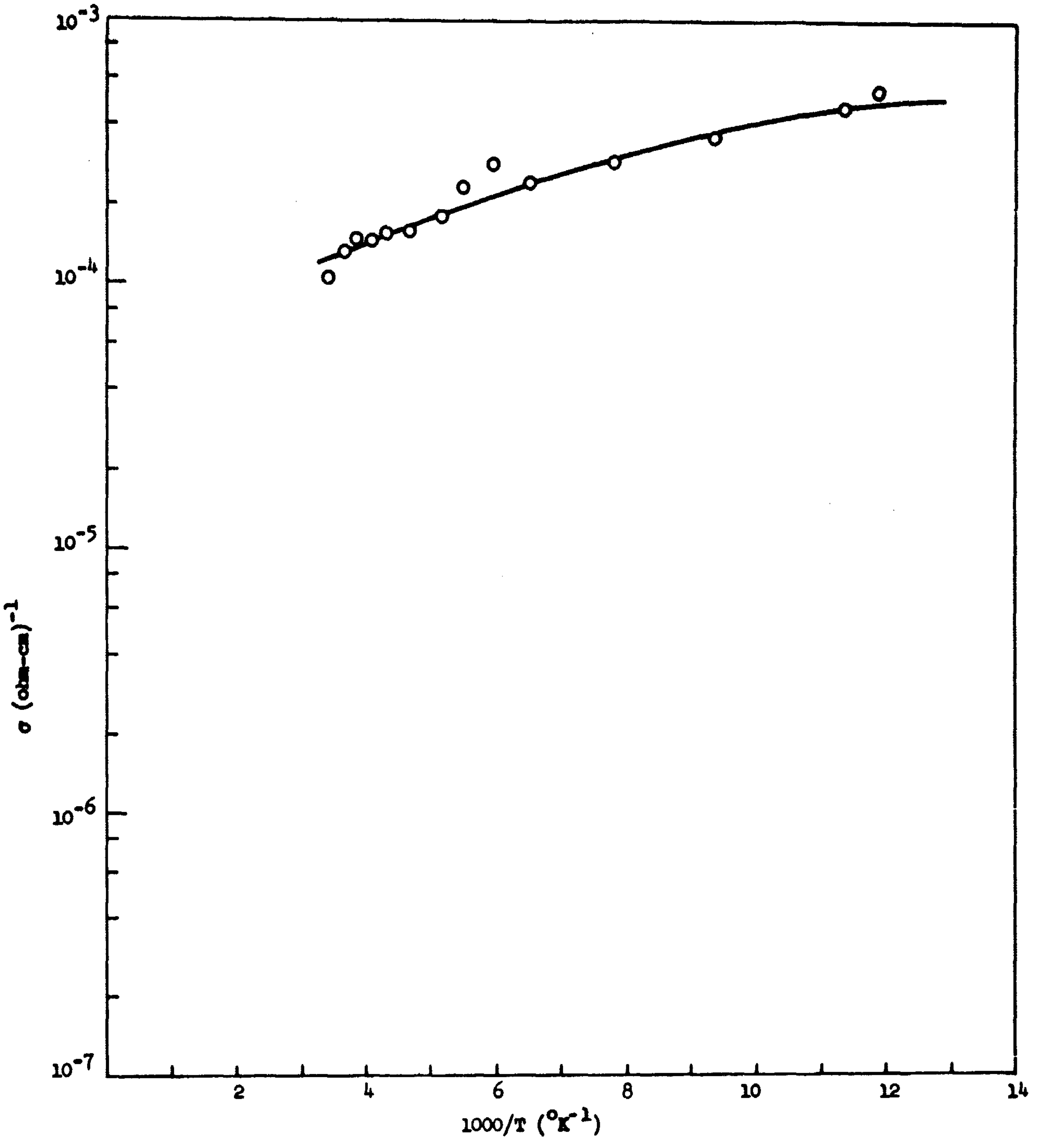

Fig. 5--Electrical conductivity after Linac irradiation as a function of inverse temperature

2.2×10^{-8} cm^2/sec for the damage constant is about the same as has been reported previously for n-type silicon.[2]

It should be noted that the trapping center introduced after the room-temperature Linac irradiation is similar to the trapping center introduced in high-resistivity n-type silicon irradiated by high-energy electrons at 4.2°K.[3]

Further information about the recombination and trapping center no doubt will be available after the remainder of the experiment is analyzed.

2.3 FUTURE PLANS

Once the remainder of the Linac irradiation data on this high-resistivity n-type silicon is analyzed, 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 ESR work.[4] Future plans call for the investigation of the type of defects introduced in high-resistivity p-type silicon irradiated with 30 MeV electrons at room temperature.

3. DC CONDUCTIVITY

Carrier lifetime experiments are being extended to include dc measurements. The circuitry being used has been described previously.[4]

The center responsible for the degradation of the lifetime had been considered[2] to be deeper than 0.4 eV for n-type silicon samples of carrier concentrations of 10^{15} cm^{-3}. Presently we are using n-type silicon samples of carrier concentrations of the order of 10^{14} cm^{-3}. In this way we hope to probe deeper into the energy gap and possibly get into a region where the temperature dependence of the carrier lifetime is exponential and thus obtain the defect energy level directly. Experiments on p-type silicon samples will be similarly extended.

REFERENCES

1. V. A. J. van Lint, et al.,"Radiation Effects on Silicon Solar Cells," General Atomic Report GA-3872 (2/15/63) p. 61.

2. V. A. J. van Lint and D. P. Snowden,"Radiation Effects on Silicon Solar Cells," General Atomic Report GA-6556 (7/21/65), p. 27.

3. H. Yoriye, et al., "Radiation Effects on Silicon," General Atomic Report GACD-6249 (6/30/66).

4. G. D. Watkins, <u>Radiation Damage in Semiconductors</u>, Academic Press, p. 98, 1964.