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Author

Hansen, William L.

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William L. Hansen and Eugene E. Haller

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AMORPHOUS GERMANIUM AS AN ELECTRON OR HOLE BLOCKING CONTACT ON HIGH-PURITY GERMANIUM DETECTORS*

William L. Hansen and Eugene E. Haller

Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720 U.S.A.

ABSTRACT

Experiments were performed in an attempt to make thin n^+ contacts on high-purity germanium by the solid phase1) epitaxial regrowth of arsenic doped amorphous germanium. After cleaning the crystal surface with argon sputtering and trying many combinations of layers, it was not found possible to induce recrystallization below 400°C. However, it was found that simple thermally evaporated amorphous Ge made fairly good electron or hole blocking contacts. Excellent spectrometers have been made with amorphous Ge replacing the n^+ contact.

As presently produced, the amorphous Ge contact diodes show a large variation in high-voltage leakage current.

INTRODUCTION

Typically high-purity Ge detectors are made using a metal Schottky barrier on one surface and a lithium n^+ layer on the opposite side. These contacts are compatible with the need to use only low-temperature processes (< 400°C) in order to preserve the quality of the starting crystal. In general, these contacts have proven to be adequate for most detector applications although a more rugged contact than a metal Schottky barrier would be desirable. However, the

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recent demand for high-purity Ge detector telescopes for use as high-energy charged particle spectrometers has focussed attention on the weaknesses of the lithium diffused contact: 1) the contact as initially made is thick enough to be only marginally suitable from the point of view of energy resolution and 2) the neutron background which is normally present in high-energy particle experiments produces damage which must be annealed periodically at about 100°C, and this treatment further thickens the lithium contact.

In contrast to p-type contacts attempts to make low-temperature, large-area n-type contacts by liquid phase[2)] and solid phase[1)] epitaxy has proved technically very difficult or impossible. Some success has been achieved only recently by ion implantation[3)]. While attempting to induce arsenic-catalysed regrowth of evaporated germanium, it was found that simple amorphous Ge made a fairly good blocking contact for both electrons and holes.

SOLID PHASE EPITAXY EXPERIMENTS

Solid phase epitaxy of n-type germanium is made difficult by the low-solubility and high-eutectic temperatures of group V impurities in Ge. With the exception of phosphorous, which has too high a vapor pressure to make highly doped alloys, arsenic has the highest solubility of the group V elements in Ge. Therefore, the following kinds of layers were formed:

1) c-Ge, As, a-Ge
2) c-Ge, a-Ge, As, a-Ge
3) c-Ge, As, a-Ge, As
4) Evaporation of As-doped Ge alloys which form, by fractionation, c-Ge, As → a-Ge, (i.e., a graded alloy).

where c and a indicate the crystalline and amorphous phases respectively.

The germanium and germanium alloys were thermally evaporated from a carbon boat and the As from a Al_2O_3 boat. All evaporations were carried out in an oil diffusion pump system with a LN trap at $< 10^{-6}$ Torr pressure. The germanium crystal was cleaned with 1% HF in H_2O just before evaporation and could also be sputtered in situ with argon ions.

All attempts to induce recrystallization from the Ge bulk at < 400°C proved unsuccessful. The evaporated layers all exhibited high resistivity after prolonged heating at 400°C and the lack of crystallization was confirmed by alpha backscatter measurements.4) However, all samples showed a slight n-type thermoelectric effect at room temperature. Diodes were fabricated from these samples by forming a Pd Schottky barrier on the back side and covering the amorphous layer with an evaporated metal (Al, Cr or Pd) to reduce the spreading resistance.

Despite the lack of crystallization of the layer, it was found that the amorphous layer made a fairly good blocking contact at 77°K with leakage currents in the range of 10^{-6} to 10^{-8} A for a 10 cm^2 contact area with an electric field of about 1000 V cm^{-1} at the p-type germanium amorphous junction.

UNDOPED AMORPHOUS GERMANIUM CONTACTS

Further experiments showed that simple evaporated germanium layers made even better blocking contacts than doped and heat treated layers. Figure 1 shows the I-V characteristics of two diodes made by evaporating first 5000 Å germanium and then 500 Å aluminum on one side of a 10 cm^2 slice of high-purity germanium and 500 Å of Pd as the other contact. The n-type device is 8 mm thick and the p-type 10 mm. The arrows on the curves indicate where full depletion occurred as measured by the C-V characteristic. Figure 2 shows a combined ^{60}Co and ^{241}Am alpha spectrum taken on the p-type device of Fig. 1. The FWHM of the 1.33 MeV ^{60}Co line is 2.1 KeV while the Am alpha line exhibits 120 KeV resolution. The line width for the alpha particle peak is consistent with a dead layer of 5000 Å of amorphous germanium.

Other experiments were carried out on devices employing a lithium-diffused back contact on n-type germanium. Here the amorphous layer plays the role of a hole blocking or p-type contact. The results were similar to the n-type or electron blocking case.

DISCUSSION

Although amorphous semiconductors have been the focus of much recent interest(5-10) the amorphous-crystalline junction has not been investigated extensively. Grigorovici, et al[11)] first studied germanium amorphous junctions at a time when there was little theoretical background by which to interpret the results. English and Hammer[12)] proposed amorphous silicon as a back contact on thin, room temperature dE/dx detectors. These authors suggested that the blocking action was due to surface states. Döhler and Brodsky[13)] later made a more detailed theoretical analysis of amorphous-crystalline junctions in light of more modern theory. This analysis concluded that the forward biased junction should be indistinguishable from "ideal rectifier" characteristics and the reverse current should have no saturation but should show an exponential increase as the space charge lowers the barrier height.

This barrier height is due to the fact that the Fermi level in amorphous semiconductors is clamped near the center of the forbidden gap by a very high density of defect states (10^{19} to $10^{21}/\text{cm}^3$) so that intrinsic conduction is seen at all temperatures and the conductivity and Fermi level is uneffected by impurities. For amorphous germanium the temperature dependence of the conductivity gives an energy gap of about 0.85 eV 11) with the Fermi level about 0.40 eV from the valance band so that a rectifying barrier can be formed against either n or p-type crystals. Due to the density of states and position of the Fermi level, metal-amorphous junctions are nearly ohmic.

Figure 3 shows the forward characteristic of a diode made on a 4 mm thick n-type germanium slice of 10 cm^2 area with a donor concentration $N_D = 2.3 \times 10^{10}$ cm^3. The amorphous contact consists of 5000 Å germanium with a 500 Å Al surface layer and the back contact is 500 Å Pd. Since for an 'ideal rectifier'

$$\frac{dV}{d\ln I} = \frac{kT}{q} = 0.0066 \text{ eV at } 77^\circ\text{K} \qquad (1)$$

the slope of Fig. 3 of 0.0078 eV would correspond to an ideal rectifier at 91°K. Thus, within the measurement errors of slope and temperature, the diode has ideal forward characteristics as predicted by Döhler and Brodsky. 13) The series resistance of the diode is 1.66 KΩ which consists of 870 Ω from the bulk and 790 Ω from the amorphous layer. This amorphous layer resistance corresponds to a bulk resistivity of 1.6 x 10^8 Ω cm which is typical of literature values. 11) Also from Fig. 3 the barrier height ($\emptyset_B$) can be estimated from

$$\emptyset_B = \frac{kT}{q} \ln\left(\frac{AT^2}{J_S}\right) \qquad (2)$$

where A = Richardson constant = 120 A/cm^{2}K^2

and J_S = Saturation current = 10^{-11} A/cm^2 at T = 77°K

so that $\emptyset_B = 0.26$ eV, which is about the expected Fermi level difference for the n-type crystal and the amorphous germanium, i.e., the distance of the Fermi level for high-purity n-type germanium from the middle of the forbidden gap. The influence of the Pd Schottky barrier has not been included in this estimate.

In reverse bias the agreement with the theory of Döhler and Brodsky[13)] is not so good. All evaporated contacts made so far seem to show very low leakage (~ 10^{-10} A for 10 cm^2 device) for fields of a few hundred volts per cm, but at higher fields there is a great variation from one evaporation to another. This observation seems to be in contradiction to the idea that the high density of gap states makes the properties of amorphous Ge independent of impurities. However, as can be seen in Fig. 1, the leakage current rises steadily from fairly low voltages whether the depletion region starts from the amorphous layer or the Schottky barrier. One explanation for this phenomenon may be that surface currents are dominant. Experiments with guard-ring structures which will allow the separation of contact and surface contributions to the reverse current are in progress. Preliminary experiments using a lithium-diffused guard ring at the perifery of the amorphous contact show that these devices have greatly reduced leakage currents at high voltage.

CONCLUSION

It has been shown that potentially useful blocking contacts can be made with amorphous germanium on high-purity germanium. These can act as replacements for lithium diffused layers in some detector applications. While the leakage currents achieved are not nearly as good as with lithium junctions, they may be adequate for those charged-particle detectors where the high-energy resolution of X-ray or gamma-ray detectors is not needed. Experiments are in progress to determine the reproducibility of the amorphous contact and to determine its long-term stability.

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FIGURE CAPTIONS

Fig. 1. Reverse I-V characteristic of two detectors with amorphous germanium-palladium Schottky barrier contacts. Device 473-8.0 is p-type and the depletion region grows from the amorphous contact. Device 494-7.9 is n-type and the depletion region grows from the palladium contact.

Fig. 2. Simultaneous ^{60}Co gamma-ray and ^{241}Am alpha-particle spectra made with device 473-8.0. The alpha-particles are incident on the amorphous germanium contact. The resolution of the 1.33 MeV gamma peak is 2.1 KeV FWHM.

Fig. 3. Forward I-V characteristic of an amorphous contact device. The initial slope of 7.8 meV shows that the device behaves as an 'ideal rectifier'. The series resistance indicates that the amorphous Ge resistivity is 1.6×10^8 Ω cm while from the saturation current is consistent with a barrier height of 0.26 eV.

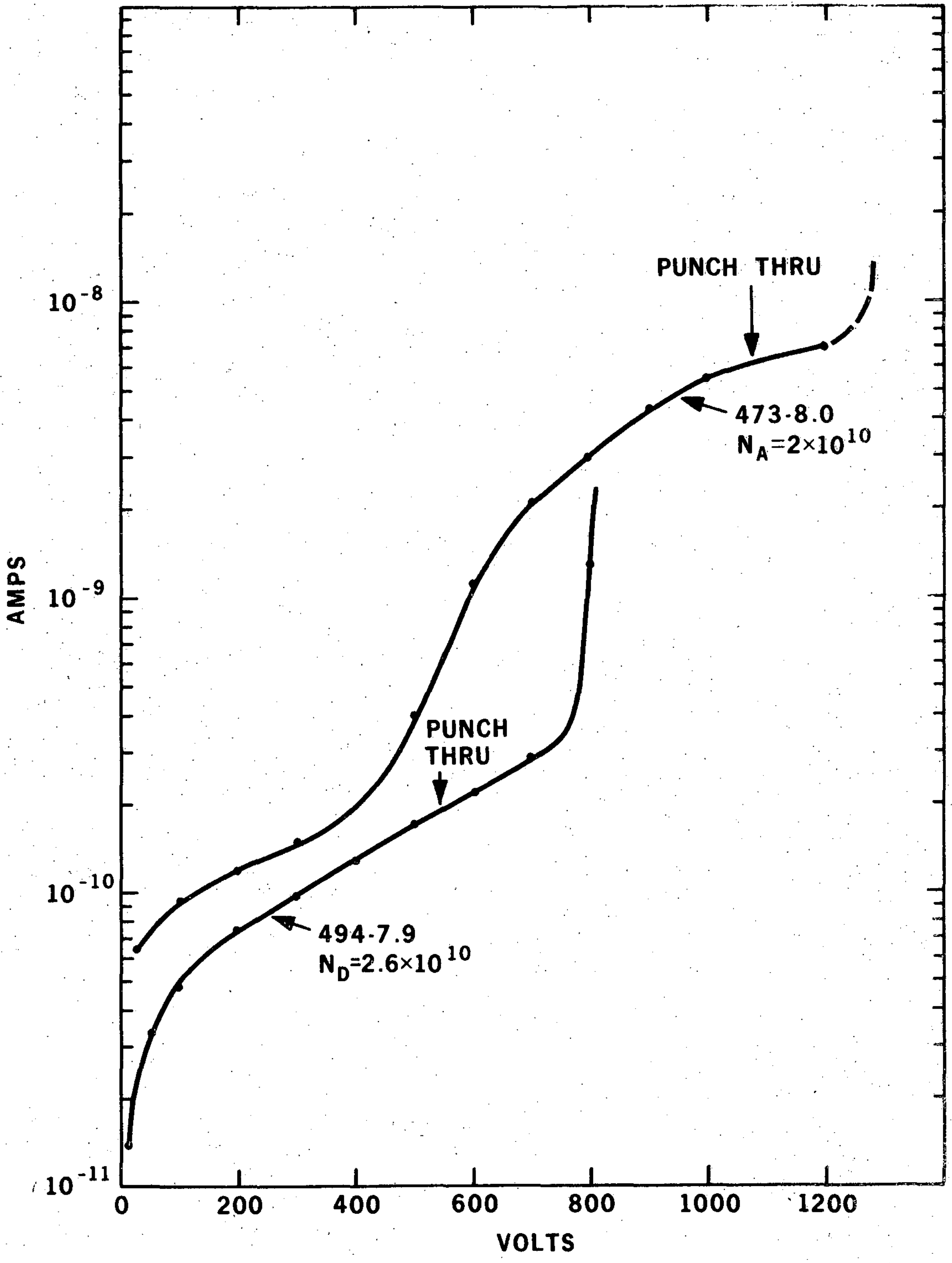

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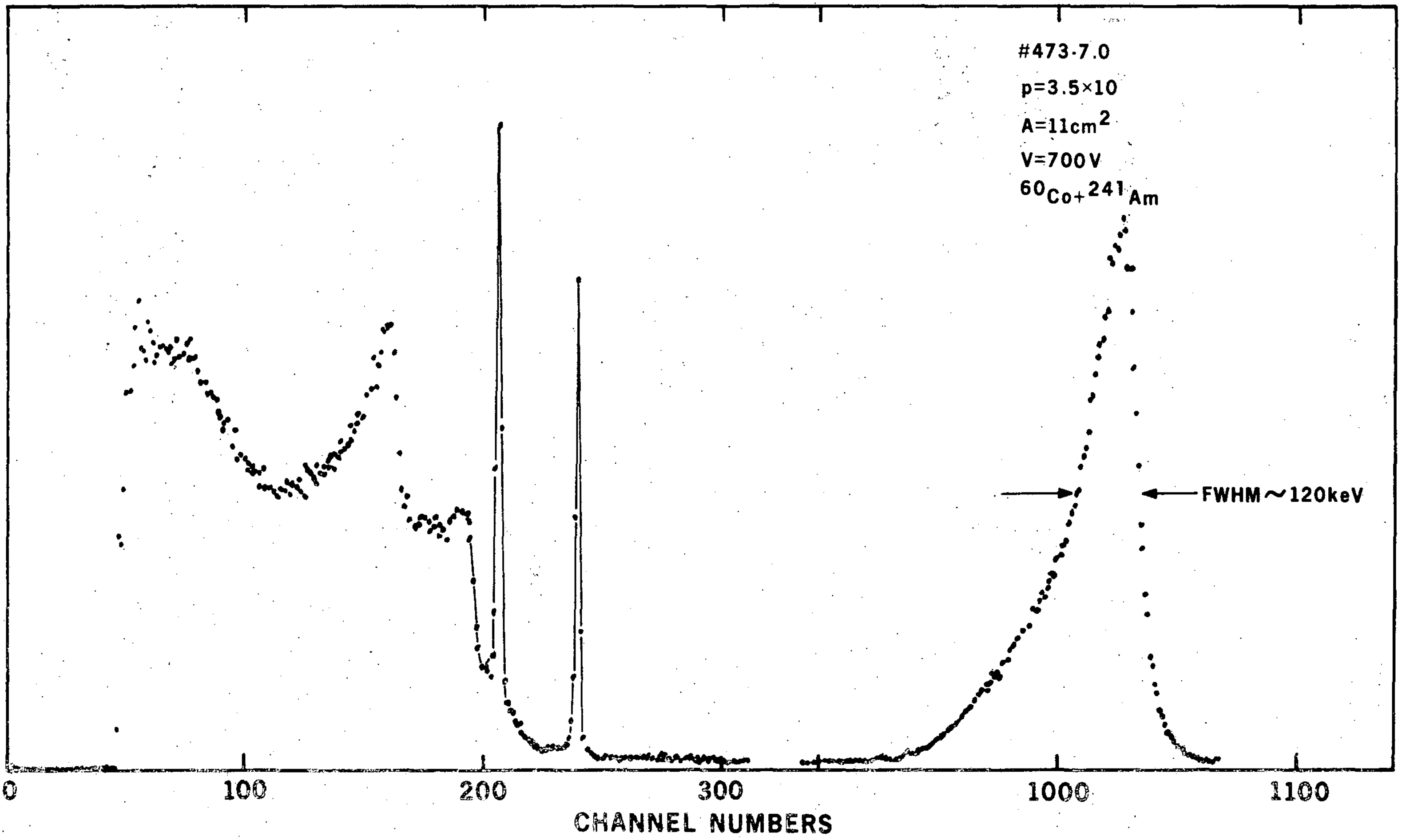
Fig. 1



XBL 765-1761

Fig. 2

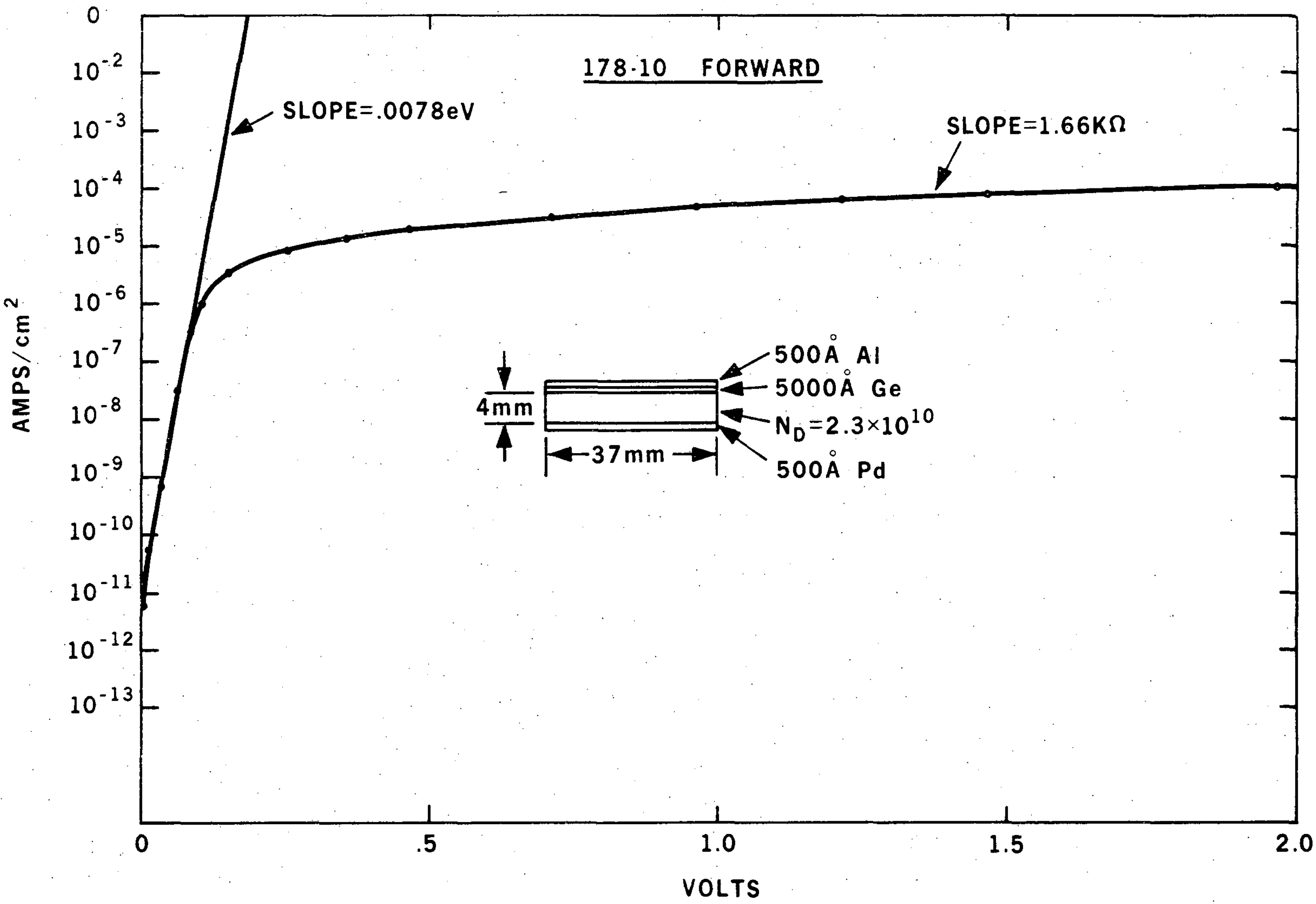


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Fig. 3

TECHNICAL INFORMATION DIVISION
LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720