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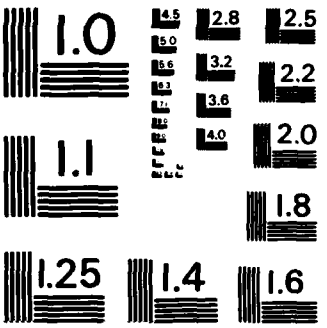

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Squeezable tunnel junctions set the current state of the art for resistance stability of mechanically adjustable tunneling structures at $\Delta R/R \approx 0.1\%$. This is sufficient for spectroscopies as subtle as phonon spectroscopy, but it is marginal and cannot be maintained to high enough bias voltabe to permit molecular vibrational spectroscopy at present. Squeezalbe junctions have been used for characterizing bulk samples and for C-V analysis on semiconductors.

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Squeezable Tunnel Junctions

by P.K. Hansma

Squeezable tunnel junctions set the current state of the art for resistance stability of mechanically adjustable tunneling structures at $\Delta R/R \approx 0.1\%$. This is sufficient for spectroscopies as subtle as phonon spectroscopy, but it is marginal and cannot be maintained to high enough bias voltage to permit molecular vibrational spectroscopy at present. Squeezable junctions have been used for characterizing bulk samples and for C-V analysis on semiconductors.

1. Introduction

The success of Binnig, Rohrer, and co-workers[1] in obtaining atomic resolution images has inspired a worldwide research effort in the field of tunneling microscopy. One of the most interesting questions is: how far can the stability be pushed? This is an important question since there are increasingly subtle levels of spectroscopy that can be done with increasing stability.

If stability in the tunneling resistance of order 50% can be obtained, tunneling microscopy and some electronic state spectroscopy can be done[1]. With stability of order 10%, superconducting energy gaps can be measured[2]. With stability of order 1%, some phonon spectroscopy could be done. With stability of order 0.1% most phonon spectroscopy and some molecular vibration spectroscopy could be done. Finally, with stability of order 0.01%, detailed molecular vibration spectra could be obtained.

Squeezable tunnel junctions[3] sacrifice x-y translation, at least temporarily, in an effort to explore the maximum stability in tunneling resistance that can be obtained in a mechanically adjustable tunneling structure.

2. Fabrication

Figure 1 shows a schematic view of a squeezable tunnel junction. Two flexible substrates are separated by evaporated spacers. A squeezing force adjusts the gap between the electrodes.

Figure 2 shows one type of actual squeezable tunnel junction. The flexible substrates are two halves of one 2.5 cm x 7.5 cm glass

microscope slide. The evaporated spacers and electrodes are made of lead. The electrodes are narrowed where they cross to minimize the chance of having a dust particle in the junction area.

In fact, dust minimization is the one key to success since the electrodes must be brought to of order 1nm apart. One dust particle of order 1μm in diameter will clearly cause serious problems. Happily, the standard sort of dust minimization developed for the semiconductor industry - in particular submicron water filters for the water used in cleaning the substrates and laminar flow benches for keeping the substrates clean until the junctions are completed - are sufficient when coupled to a good inspection system - for example, a binocular microscope with strong, nearly tangential illumination of the sample.

3. Experimental Results

Figure 3 demonstrates that squeezable tunnel junctions can be operated with various materials in the gap. The liquid, oil, was introduced by capillary action on a drop placed near the edge of a completed junction. The solid, napthalene, was introduced while the junction was heated with heat lamps above the napthalene's melting point. The junction was then adjusted with a squeezing force and the napthalene was allowed to solidify. These data were obtained by squeezing with an electromagnetic squeezer that has been described elsewhere[4].

Figure 4 demonstrates that squeezable tunnel junctions can be operated with negligible leakage current. Leakage current, due, for example to microshorts, shows up as current below the superconducting energy gap. Note that this current is negligible for this junction showing that essentially all of the current flow is due to electron tunneling. Figure 4

also demonstrates the second plateau of stability mentioned in the introduction. For the superconducting energy gaps, Δ_{Pb} and Δ_{Al}, to be measured requires a resistance stability of order 10%. (The stability in this figure is higher than required).

Figure 5 demonstrates achievement of the fourth plateau of stability, at least at low bias voltages. The peaks labeled TA and LA are the transverse acoustic and longitudinal acoustic phonon peaks of the aluminum electrode. Observation of these relatively weak phonons requires a resistance stability of order 0.1%. Unfortunately this stability is not maintained beyond 40mV where molecular vibrations would be observed[5]. Peaks from molecular vibrations are of the same order of magnitude as the aluminum phonons[5]. They cannot, however, be seen in this curve because of the noise that increases dramatically beyond 40mV.

The reason for this noise is not understood at present. Possibilities include 1) switching between different current paths in the junction, 2) motion of mobile species (atoms?) into and out of regions of high current density, 3) coupling between electromagnetic forces in the junction and the mechanical structure.

Further investigation with different roughness electrodes, different absorbed species, and different mechanical structures should shed light on this present limit on the stability of mechanically adjusted tunneling structures.

3. Applications

Figure 6 demonstrates the extension of squeezable tunnel junction technology to include the possibility of tunneling to bulk samples - in this case[6] filaments of superconducting wire. Moreland and Ekin are

presently profiling the superconducting energy gap through wire by successive etching and tunneling.

Squeezable tunnel junctions have also been made to bulk semiconductor samples including silicon and mercury-cadmium telluride[7].

Figure 7 demonstrates the extension of squeezable tunnel junction technology to C-V analysis of semiconductors[8]. The variable air capacitor is adjusted by changing the spacing between the electrode and silicon surface by squeezing. The variable capacitor shown in the silicon is due to the changes in surface charge depletion by the electric field as the voltage between the electrode and the silicon is changed. This changing capacitance versus voltage can be used to help determine surface properties such as the ionized donor density. The promise of the technique is to follow the surface properties through a sequence of processing steps without modifying the surface by forming conventional, oxide-barrier M-I-S capacitors.

4. Summary

Squeezable tunnel junctions can be set to different resistances by changing a mechanical squeezing force from an electromagnet. Typical values of resistance are 10kΩ to 10MΩ for a 50μm x 50μm junction. Resistance stability of order 0.1% can be obtained with no vibration isolation. There is an inherent immunity to vibration that comes from immersing the junctions in fluids: for the two substrates to approach or separate fluid must flow into or out of the junction. The time constant for this flow is of order 1 second.

Future research opportunities include: 1) understanding the current limits to stability, 2) extending those limits and thus making molecular vibration spectroscopy possible, and 3) applying the basic principles to a variety of technological problems including semiconductor characterization.

5. Acknowledgements

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Figure Captions

1. A schematic view of a squeezable tunnel junction.
2. An actual squeezable tunnel junction after cycling to 4.2K and squeezing.
3. Current vs Voltage curves for squeezable tunnel junctions operated with vacuum, air, oil and solid napthalene in the gap.
4. Current vs Voltage curves for a squeezable tunnel junction operated submerged in liquid helium.
5. Second derivative curves for an Al - Barrier - Pb squeezable tunnel junction operated submerged in liquid helium.
6. Current vs Voltage curves for film-film and film-filament squeezable tunnel junctions.
7. Differential capacitance vs Voltage curves for a squeezable junction with a larger electrode, 1mm diameter, than for previous figures. The estimated air-gap thicknesses for curves a-d are 1700, 2200, 2900, and 3600Å, respectively.

Paul Hansma, Department of Physics, University of California, Santa Barbara, CA 93106. Dr. Hansma received his Ph.D. from the University of California at Berkeley in 1972. He was appointed a Presidential Scholar in 1964 and has held an Alfred P. Sloan Foundation Fellowship. His research interests include inelastic electron tunneling spectroscopy, tunneling microscopy and epitaxial film growth.

Figure 1

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Figure 2
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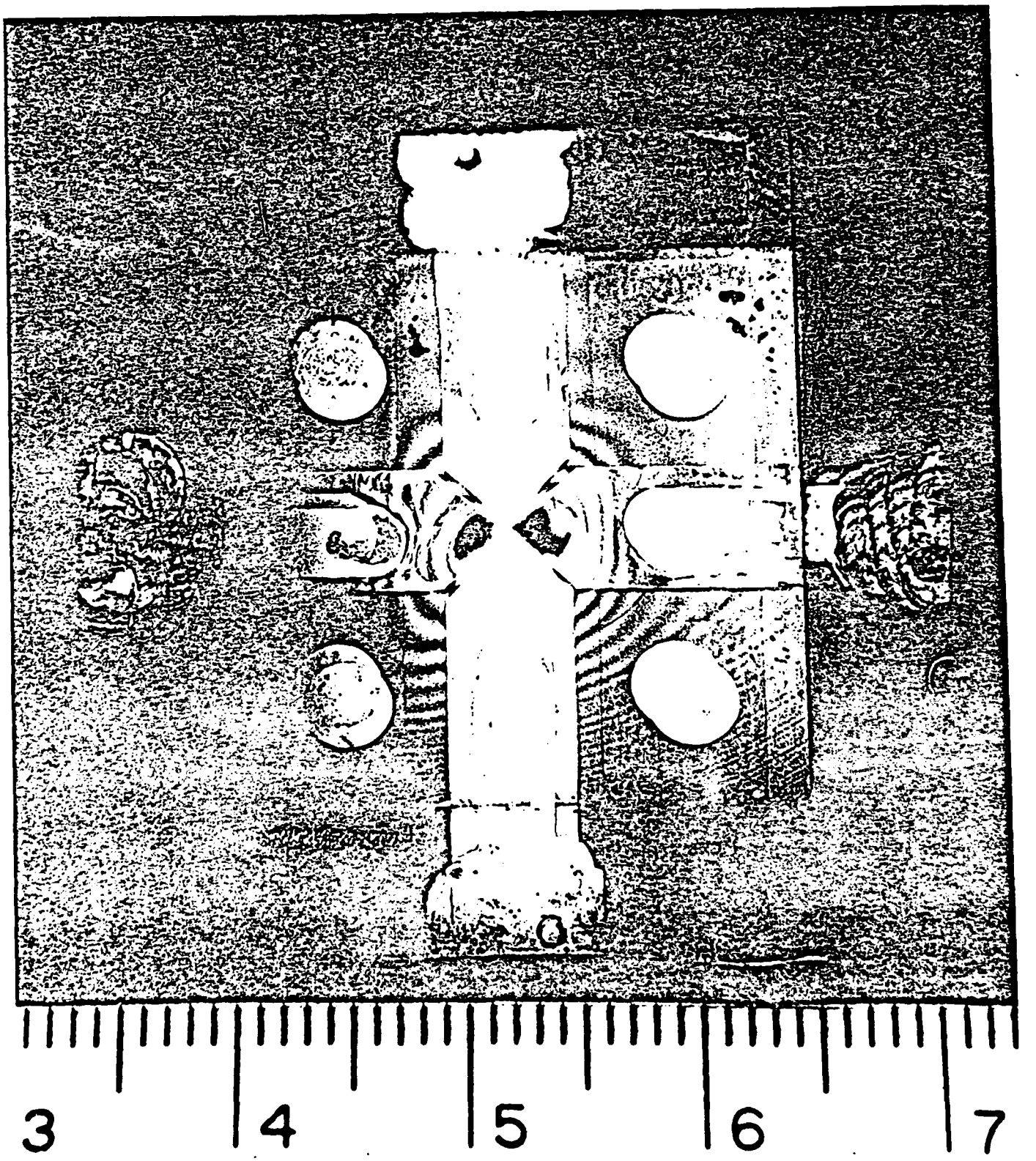

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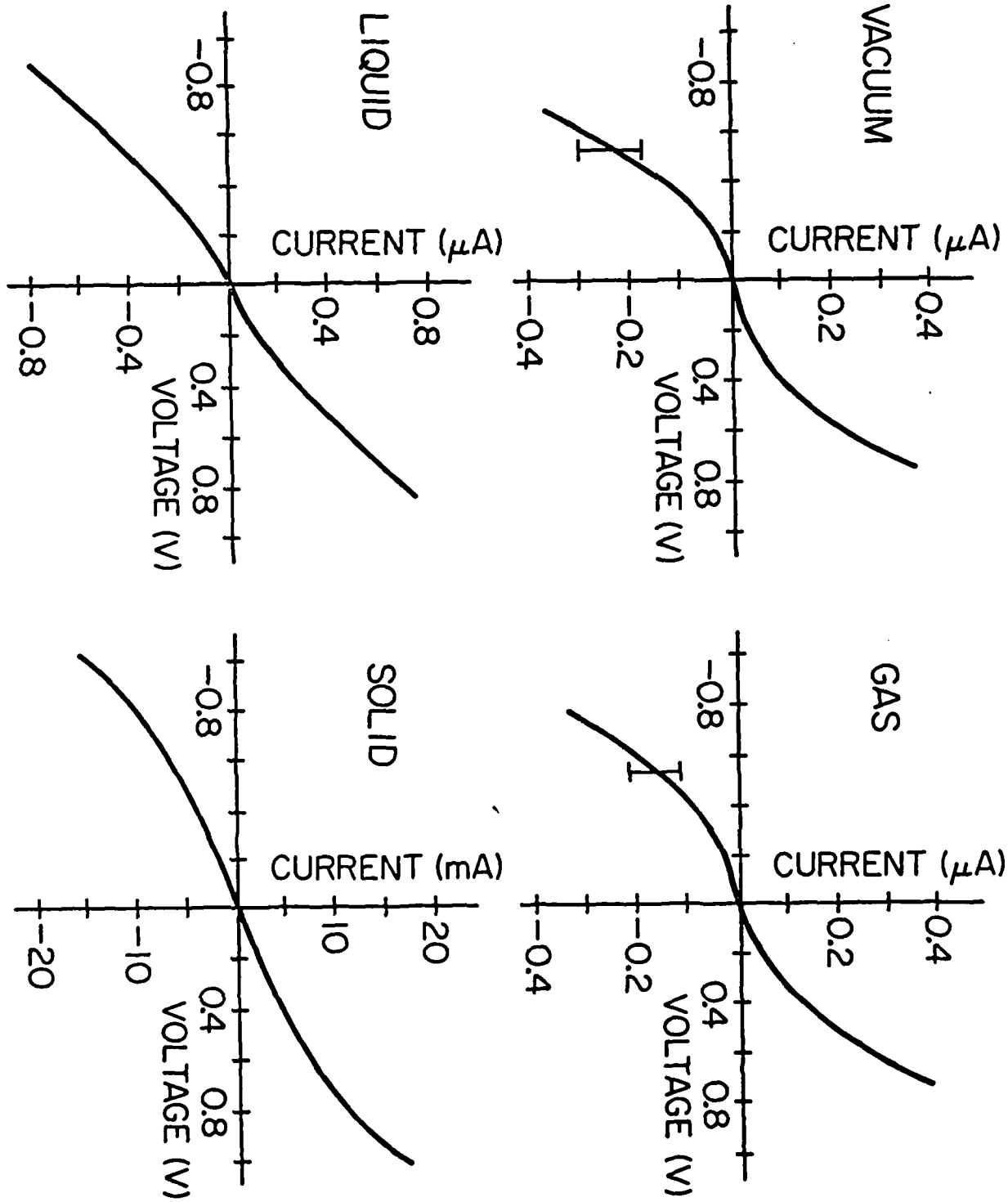

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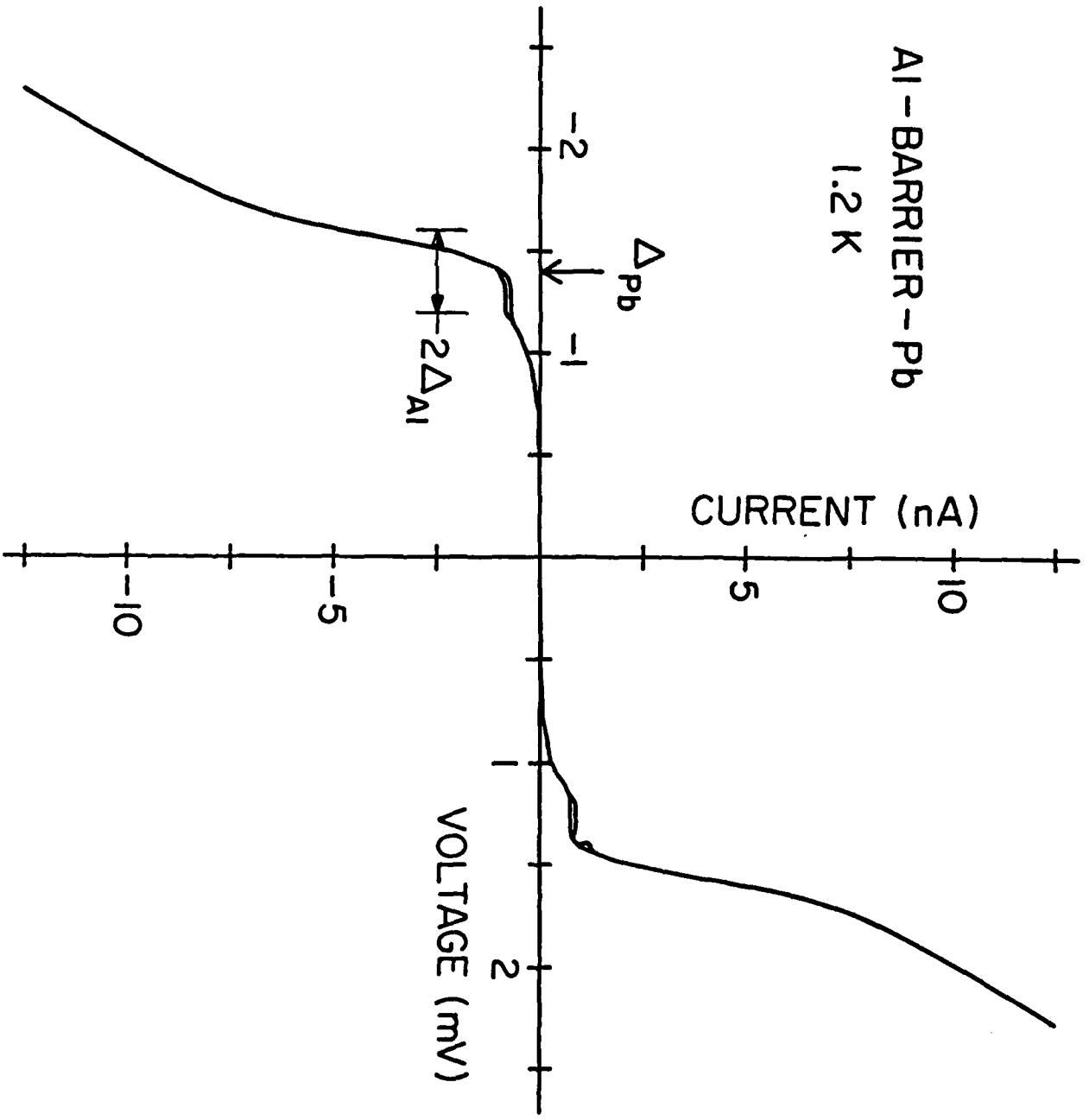

Figure 5

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Figure 6
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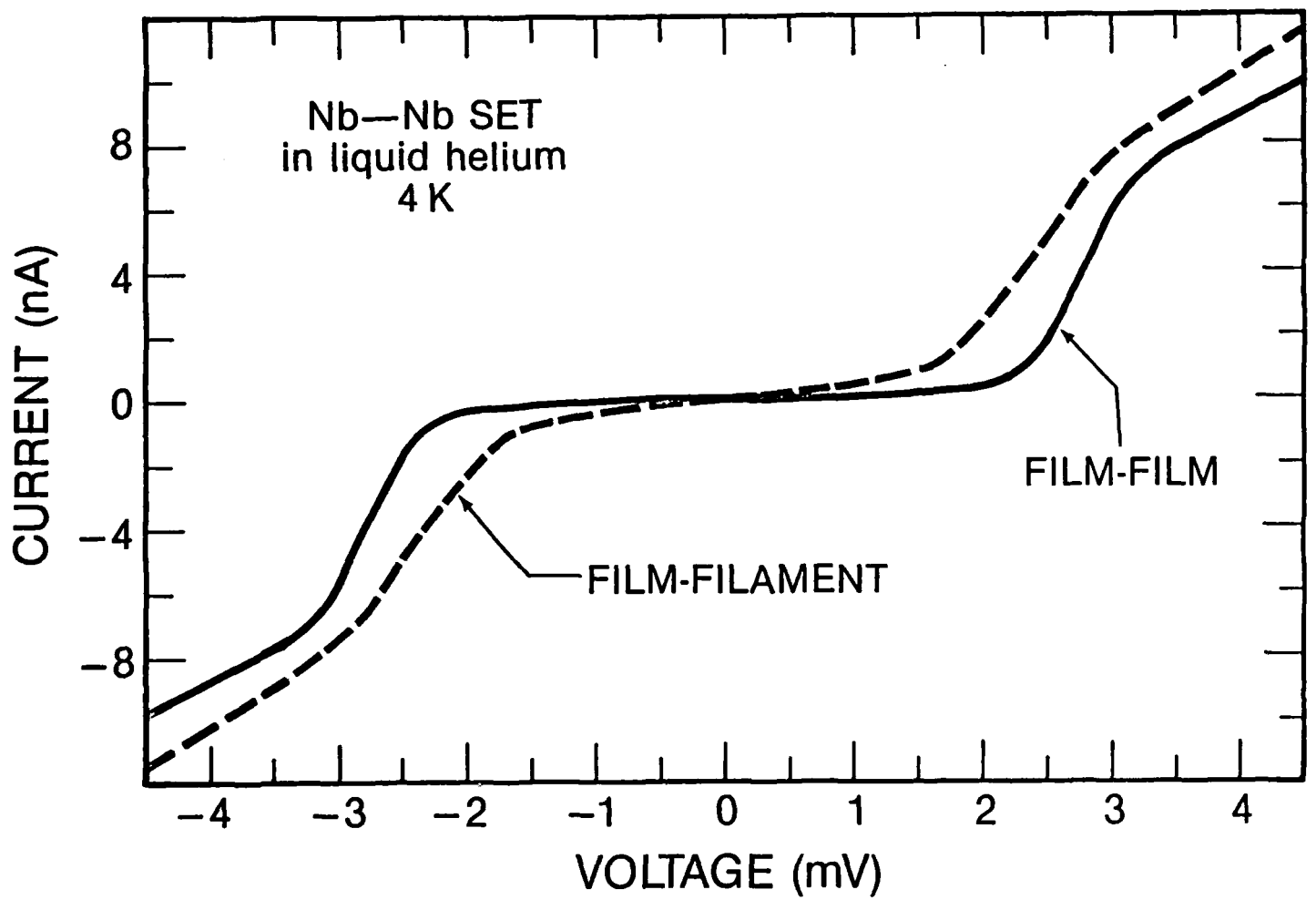

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Figure 7
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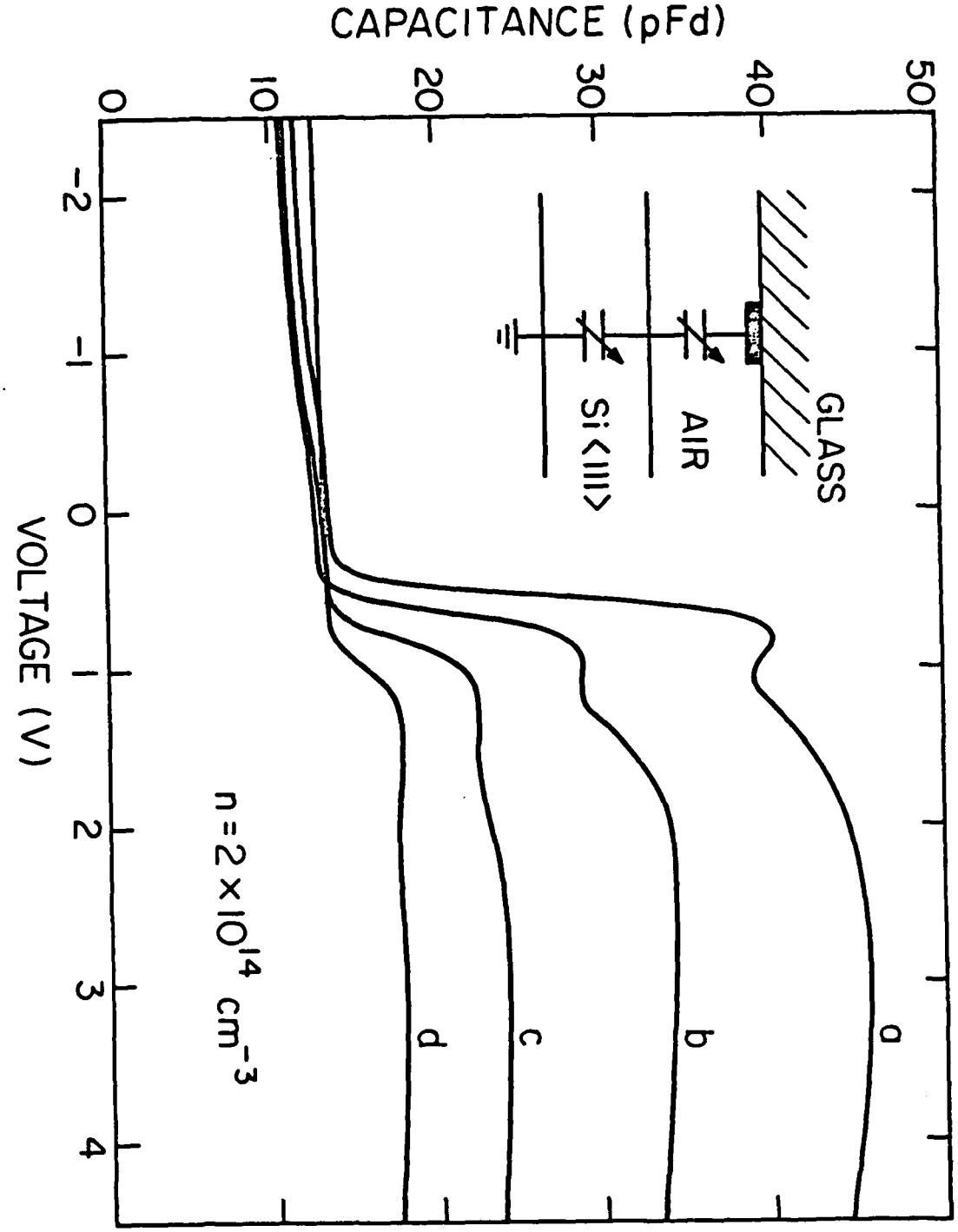

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