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ILLINOIS UNIV AT URBANA DEPT OF ELECTRICAL ENGINEERING
NEAR MILLIMETER WAVE LOCAL OSCILLATOR SOURCES.(U)

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Near Millimeter Wave Local Oscillator Sources

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February 1981

Interim Report for Period 1 June 1980 - 31 December 1980

Approved for Public Release; Distribution Unlimited

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) This report describes research on proof of principle that a AlGaAs-GaAs heterostructure can display a negative differential resistance suitable for constructing an oscillator operating in the 100 GHz range. The conjecture is that if the electrons in the GaAs layer are heated by the application of an electric field parallel to the layer interface, they can be made to return to their parent donors in the Si doped AlGaAs layer where their mobilities are much smaller than in the GaAs.		

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Semi-Annual Report

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I. AlGaAs-GaAs Heterostructure Negative Differential Resistance Device

1.1. General Background - State-of-the-Art

R. Dingle¹ and colleagues in 1978 were the first to report enhanced electron mobilities in a layered AlGaAs-GaAs structure (Figure 1) by a modulation-doping technique that spatially separates conduction electrons and their parent donor impurity atoms.

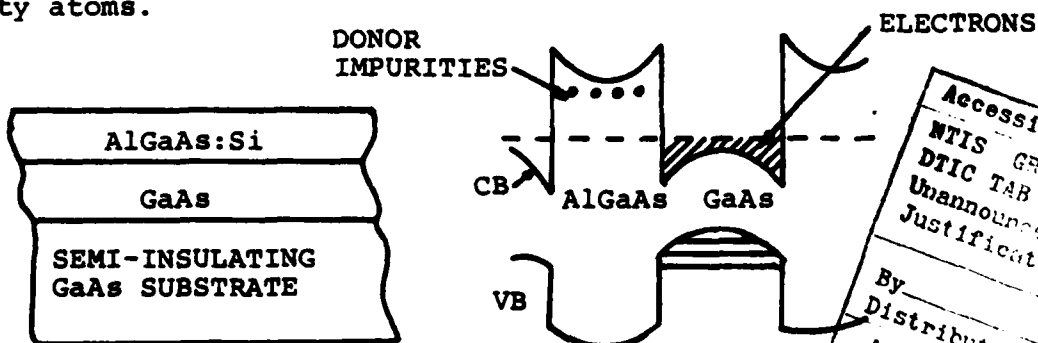


Figure 1. Layered AlGaAs-GaAs structure.

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Electrons in the Si doped AlGaAs layer move into the GaAs layer where the conduction band edge lies lower in energy than the AlGaAs donor states. The electron density in the GaAs channel greatly exceeds the density of impurity scattering centers which leads to a considerable enhancement of the mobility, especially at low temperatures.

Curves depicting Dingle's data is shown in Figure 2. At temperatures of the order of 50K, mobilities of the order of $15,000 \text{ cm}^2/\text{V-sec}$ were obtained versus the bulk value of $4,000 \text{ cm}^2/\text{V-sec}$.

Hadis Morkoç^{2,3} and colleagues have extended Dingle's work to achieve a mobility as large as $74,200 \text{ cm}^2/\text{V-sec}$ at 78°K by leaving an undoped AlGaAs interface layer of thickness $d_i = 50\text{\AA}$.

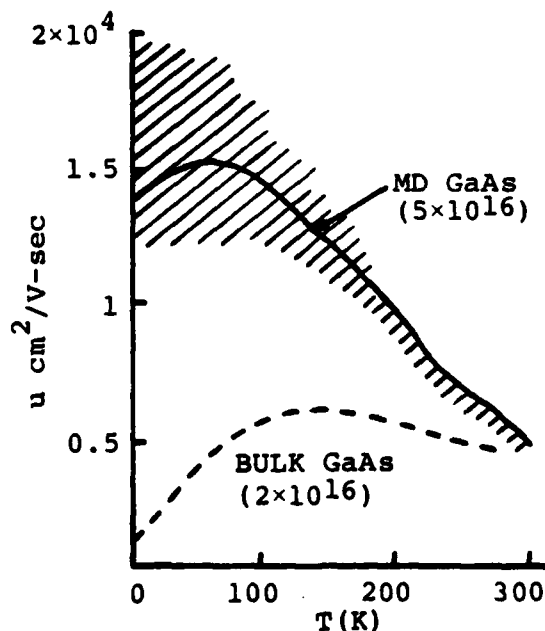


Figure 2. Electron mobility versus temperature for Bulk GaAs and modulation doped GaAs (Dingle).

In their first paper, Morkoç and colleagues studied interchanging semiconductor layers (Figure 3) and various "sandwich" configurations. Some of the results are displayed in Figure 4. The important result of this study was that little if any electron transfer or mobility enhancement occurred if the AlGaAs:Si layer was put down first on the semi-insulating substrate.

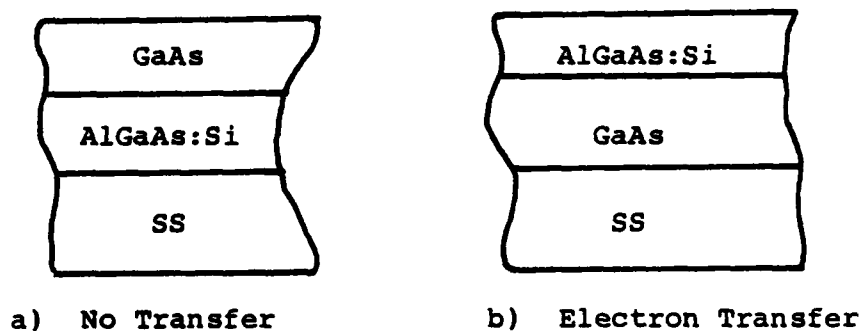


Figure 3. Interchange of semiconductor layers.

In the second paper, Morkoç was able to further reduce the Coulomb scattering by leaving a thin region ($0 \leq d_i \leq 200 \text{ \AA}$) of the AlGaAs at the interface undoped as seen from the data of Figure 5. Here a mobility of $74,200 \text{ cm}^2/\text{V-sec}$ was achieved at 78K for a value of d_i of $\sim 50 \text{ \AA}$.

The importance of this large enhanced mobility for a possible NDR device is the large peak-to-valley in the I-E curve (see Figure 6) that should result. If the peak is reflecting

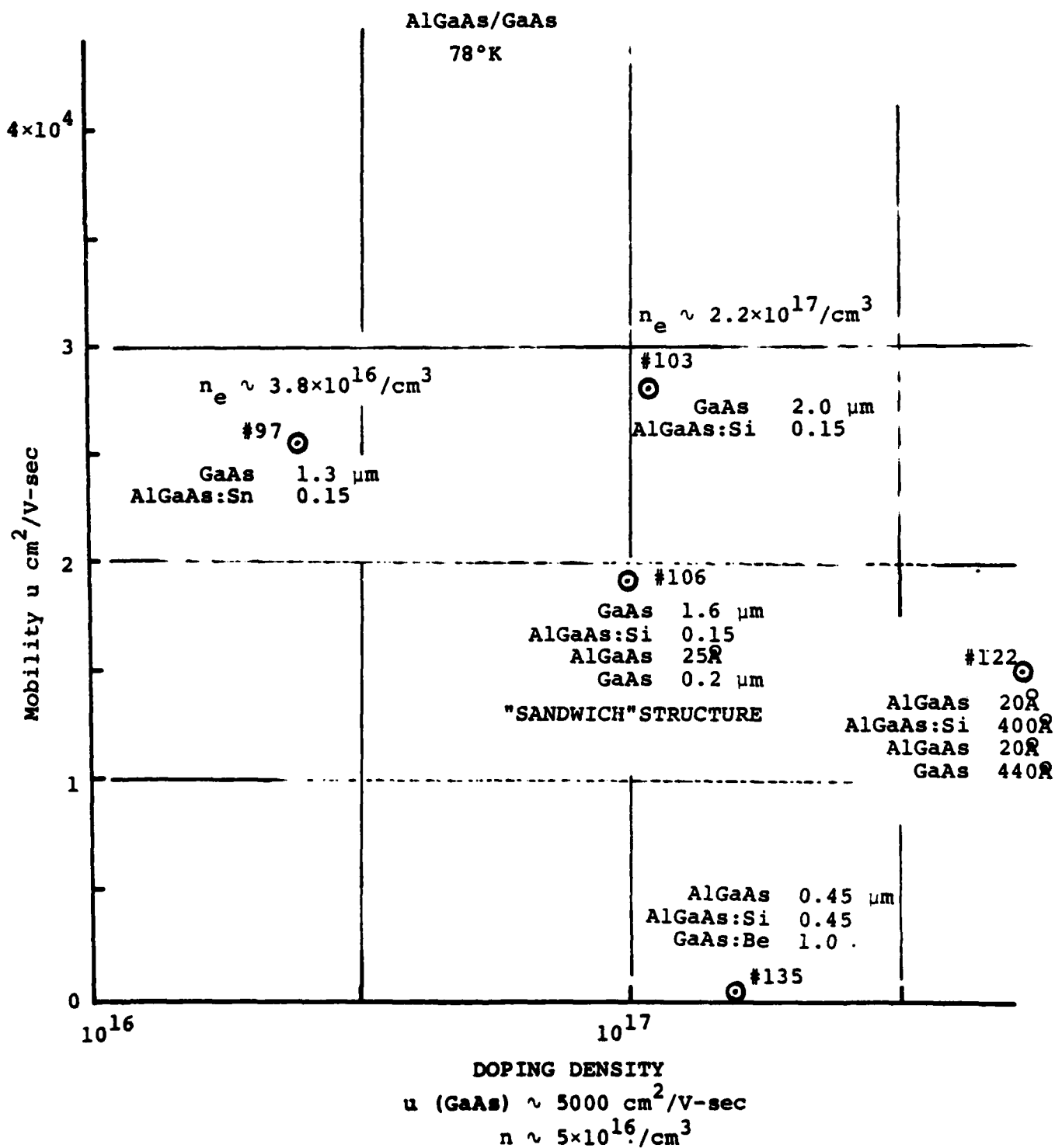


Figure 4. Mobilities of various "sandwich" configurations, Ref.2.

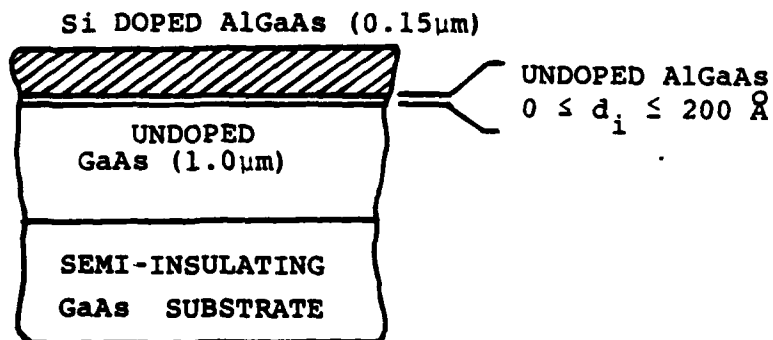
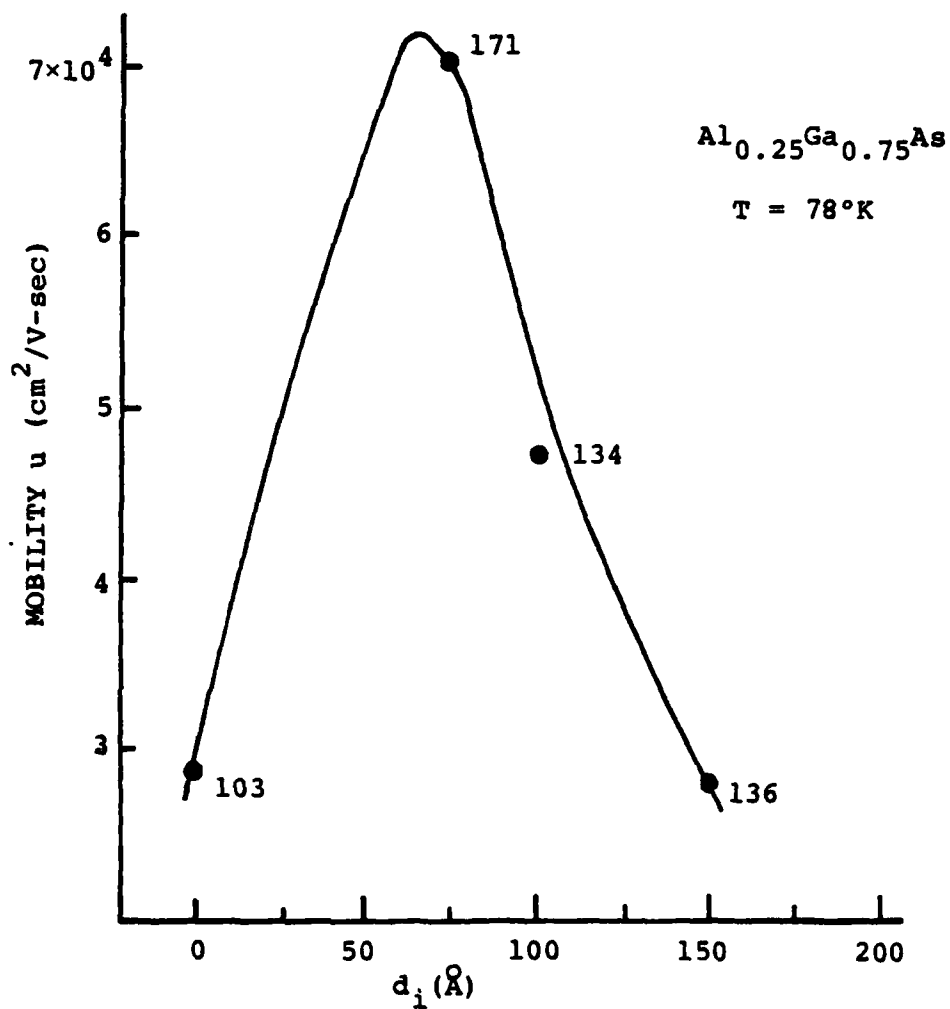


Figure 5. Various of enhanced mobility versus undoped AlGaAs interface layer thickness d_i .

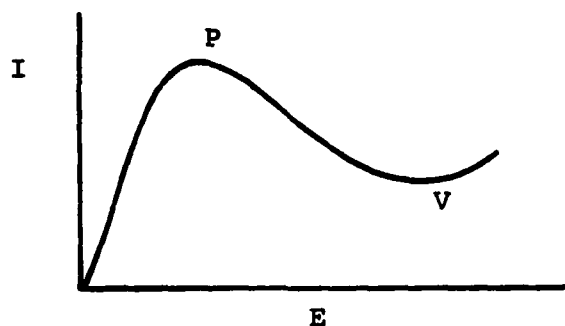


Figure 6. NDR I-E curve.

the high mobility in the GaAs and the valley the low mobility in the AlGaAs:Si, then the peak-to-valley ratio should be much larger than in a GaAs Gunn device.

The idea that a AlGaAs-GaAs heterostructure might be used as a negative differential resistance device appeared in a paper by Hess, Morkoç, et al.⁴ in 1979. Their suggestion was that if the electrons in the GaAs were heated by the application of an electric field parallel to the layer interface, the electrons would scatter and return to their parent donors in the AlGaAs:Si where their mobilities were low. Hess estimated and calculated switching times in the range 10^{-11} - 10^{-12} seconds.

In a second paper, Hess and colleagues using a Monte Carlo calculation method, determined the fraction of electrons in the GaAs and AlGaAs layers as a function of the heating field E and also calculated an I-E curve to show a peak around 3-4 kW/cm.

In our Letter Report #5, we constructed a very simple model wherein a heated Maxwellian electron distribution was assumed and the fraction of electrons surmounting a barrier of height ΔE calculated. This calculation was in good agreement with the Monte Carlo one.

1.2. Summary State-of-Art Fall 1980 on Layered NDR Structures

The work of Dingle and Morkoç was definitive in showing there was a real space transfer of electrons from the AlGaAs:Si to the GaAs layer as evidenced by the greatly increased electron mobility. The suggestion by Hess and colleagues that the electrons could be made to transfer back to the AlGaAs:Si by heating with a parallel electric field appeared on solid ground. However, questionable I-E curves were obtained on the first samples made by Morkoç and a NDR really never demonstrated in either an amplifier or oscillator circuit at any frequency.

2. Research Strategy on NDR Devices at Initiation of Contract

At the beginning of the contract on 1 June 1980, the Electro-Physics Laboratory was well equipped to study the amplifier and oscillator properties of a negative differential device, given the fabricated semiconductor structure with ohmic contacts in place. We did not have any semiconductor facilities of our own, only access to facilities existing elsewhere in the EE Department.

The strategy then was to obtain fabricated samples from Morkoç and Hess and work in a collaborative mode. This strategy

proved to be only partly successful. Original layered wafers made by MBE by Morkoç could be readily obtained, but it soon became apparent we needed to have our own limited fabrication facilities, particularly in the interest of time.

A re-evaluation of the research strategy indicated that it would be highly desirable to set up some limited semiconductor fabrication facilities. This possibility was anticipated in our original contract budget but it was hoped that it would not be necessary because of the time involved.

Time was spent during the last two months of this initial contract period planning for an initiating procurement of basic items such as vacuum deposition system, wire bonder, scribe, strip heaters, etc. It is expected all these facilities will be in place by early March 1981.

3. Initial Study on Limited Available Layered Samples

The AlGaAs-GaAs samples that were obtained from K. Hess of CSL were all fabricated from the same wafer labelled 0-10. A graduate student, Mark Keever, had measured the I-E curves of these samples by applying short voltage pulses to the samples and determining the resulting current with a sampling oscilloscope. One of Keever's curves is shown in Figure 7.

At first glance, the curve of Figure 7 indicates a NDR characteristic. However, the I-E curve peaks near a field strength of 100 volts/cm, a value of the order of 30-40 too low as predicted by theory.

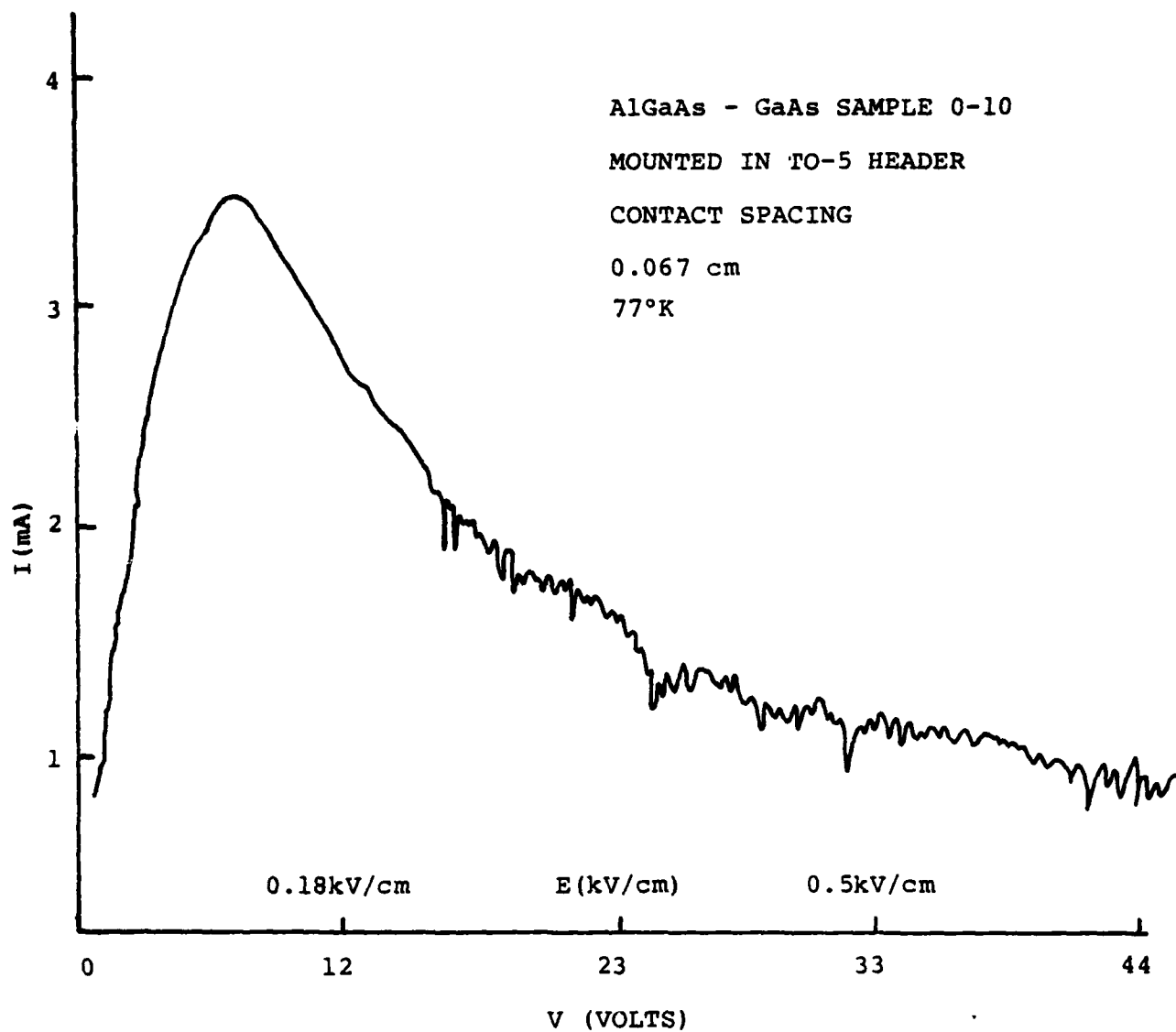


Figure 7. I-E or IV curve measured by Keever.

In a re-measurement of sample 0-10, not using a sampling oscilloscope, we found the current pulses were not flat-topped. Above 20 volts the current pulses become unstable showing sharp dips as illustrated in Figure 8. These dips have different depths and occur at different times relative to the start of the current pulse as discussed in Letter Report #3.

Taking point by point data to obtain an I-V curve is tedious using the pulsed voltage-pulsed current technique. Also, one gets little information about transfer times.

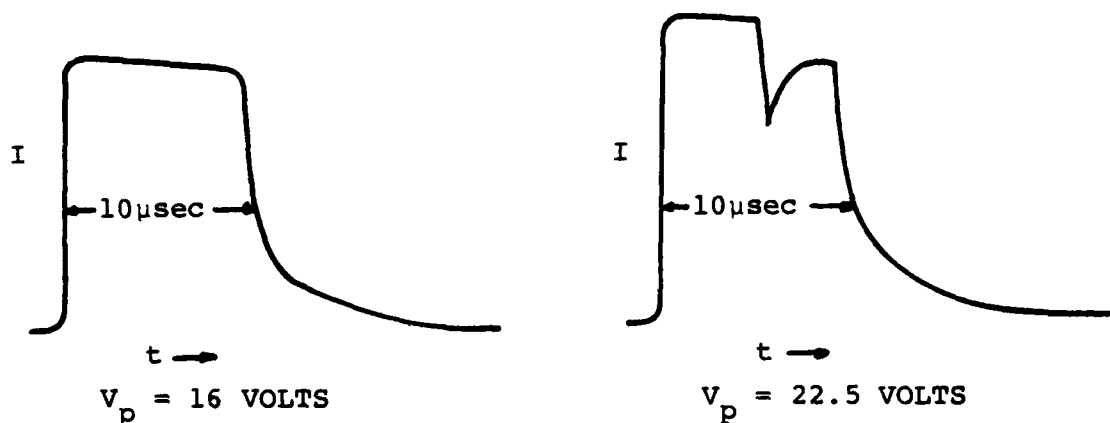


Figure 8. Current pulse behavior (no sampling).

It seemed to be preferable to use a sawtooth voltage and sweep out the I-V curve similar to a curve tracer.

It is seen from Figure 9, the condition to cut the I-V curve of the sample at just one point is $R < R_d$, where R_d is the negative slope of the sample I-V curve.

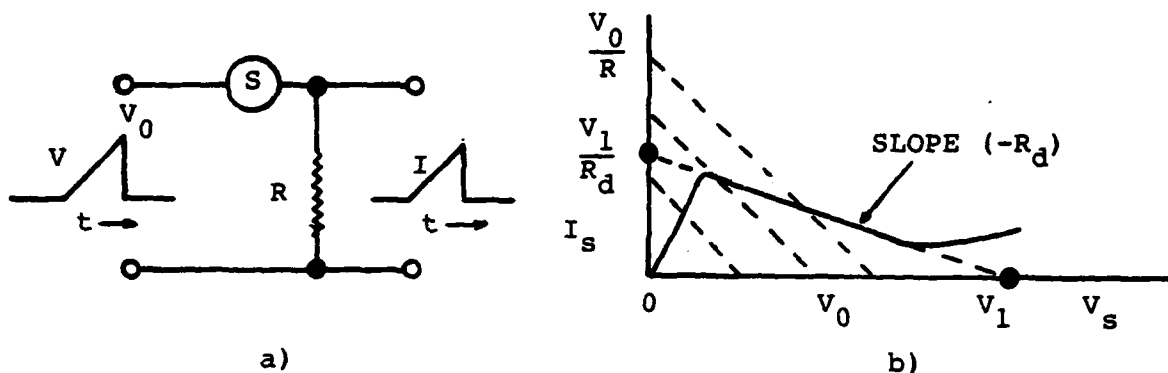


Figure 9. Saw-tooth voltage sweep to obtain I-V curves.

At the time of the measurement, a trigger saw-tooth voltage of just 110 volts was available. The resulting I-V curve using this swept voltage is shown in Figure 10.

It may be that our sample 0-10 has changed characteristics because of our testing, but the I-V curve of Figure 10 is quite different from that measured by Kever. It shows no NDR in the 0-110 voltage range, in agreement with theory. There is an oscillatory behavior in the 50-60 volt range of the order of 1 MHz, indicative of some acoustical phenomena.

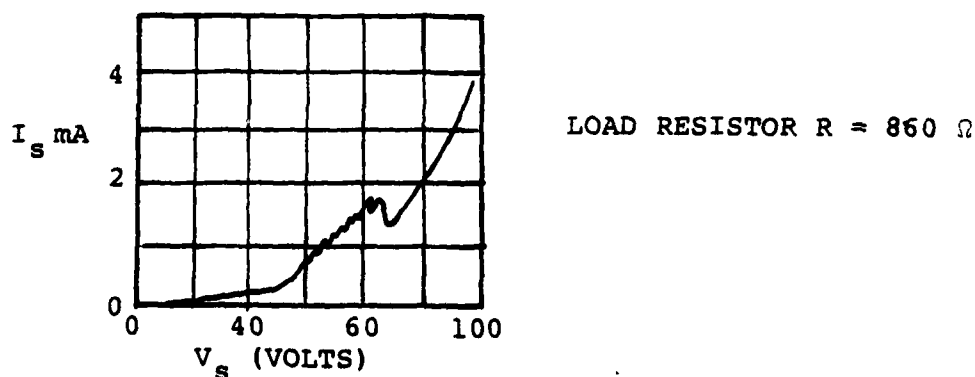


Figure 10. I-V curve of sample 0-10 using saw-tooth voltage.

To acquaint ourselves with NDR behavior, we made some simple amplifier circuits using tunnel diodes as shown in Figure 11.

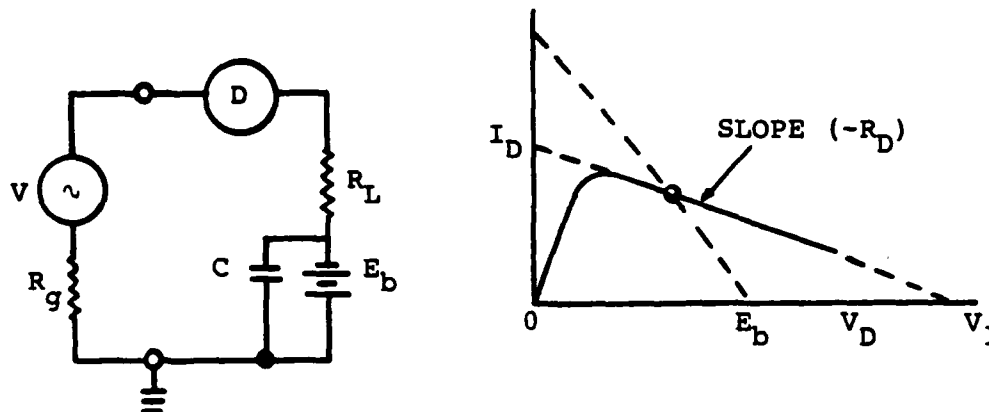


Figure 11. Series circuit tunnel diode amplifier.

Stability requires that

$$R_D > R_g + R_L \quad (1)$$

The AC voltage equation for the circuit is

$$V - i_D(R_g + R_L) = V_D = -i_D R_D \quad (2)$$

Hence the voltage amplification is seen to be

$$\left| \frac{V_{out}}{V} \right| = \left| \frac{i_D R_L}{V} \right| = \frac{R_L}{R_D - (R_g + R_L)} \quad (3)$$

Using MHz voltage signals, the tunnel diodes gave an amplification given by equation as expected. However, when sample

0-10 was placed in the same circuit, except for new appropriate values for R_g , R_L , and E_b , no amplification was observed.

Our conclusion from this study was that NDR could not be demonstrated for sample 0-10 at the voltage levels used. Since only units made from wafer 0-10 were available to us during this period, we were at an impasse for the moment.

4. Revision of Research Strategy

As discussed in Section 2 on initial research strategy, our experience during the first six months period indicates we need to set up a limited semiconductor fabrication facility in our laboratory. These items include a vacuum evaporation unit, a wire bonder, and strip heat plus some additional test equipment. Some \$25,000 for equipment and \$7,000 for supplies were originally budgeted for this contingency.

Plans are to obtain a used vacuum disposition unit from NRL early in 1981, purchase a used wire bonder from Evy Engineering in Vineland, NJ, and laboratory-build a strip heater, a high voltage (0-700V) trigger voltage saw-tooth generator and fabricate stainless steel masks for metal evaporation. We expect to be fabricating our own samples sometime in March 1981.

5. Personnel Associated with Contract During 1 June 1980-31 December 1980

P. D. Coleman - Principle Investigator

50% time 1 June-30 June 1980

10% time 1 Aug.-31 Dec. 1980

R. L. Miller - Research Assistant

50% time 1 June-31 Dec. 1980

J. Smith - Clerk Typist

15% time 1 June-31 Dec. 1980

6. Statement of Account of DAAK 70-80-C-0066 as of 12-31-80

<u>Item</u>	<u>Budgeted</u>	<u>Expenses To Date</u>	<u>Obligated</u>	<u>Balance</u>
Principal Investigator	\$14,050	\$ 9,110	\$ 5,229	\$ 289-
Research Assistants	8,650	3,052	5,214	384
Clerical	2,003	849	1,528	374-
Technical Services	6,500	53	0	6,447
Publications	0	6	0	6-
Misc. & Hourly	0	217	0	217-
Benefits	3,667	1,635	1,126	906
Equipment	25,000	2,030	0	22,970
Supplies	6,967	888	0	6,079
Travel	800	334	0	466
Reprints	800	112	0	688
Communications	345	26	0	319
Indirect Costs	<u>21,218</u>	<u>9,036</u>	<u>8,140</u>	<u>4,042</u>
TOTALS	\$90,000	\$27,348	\$21,238	\$41,414