GEORGIA INSTITUTE OF TECHNOLOGY

OFFICE OF CONTRACT ADMINISTRATION

PROJECT ADMINISTRATION DATA SHEET

[x] ORIGINAL [ ] REVISION NO. ______

Project No. A-3448 GTRI/~~GIT~~ DATE 1-11-83

Project Director: Dr. Don Blue & Dr. C. J. Summers ~~School~~/Lab EML

Sponsor: General Dynamics - Pomona Division

Type Agreement: Standard GTRI Research Agreement & P. O. #P0508260

Award Period: From 12/6/82 To ~~1/31/83~~ 1-16-84 (Performance) 1/31/83 (Reports)

Sponsor Amount: Total Estimated: $ 16,500 Funded: $ 16,500 & $500 Patent & Data Rights

Cost Sharing Amount: $ NA Cost Sharing No:

Title: Evaluation of CdS Crystals

ADMINISTRATIVE DATA

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Defense Priority Rating:

Military Security Classification:
(or) Company/Industrial Proprietary: See below

RESTRICTIONS

See Attached ______ Supplemental Information Sheet for Additional Requirements.

Travel: Foreign travel must have prior approval — Contact OCA in each case. Domestic travel requires sponsor approval where total will exceed greater of $500 or 125% of approved proposal budget category.

Equipment: Title vests with

COMMENTS:

Sponsor has option to review any publication arising from the project for a period of 1 year for patentable subject matter.

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GEORGIA INSTITUTE OF TECHNOLOGY OFFICE OF CONTRACT ADMINISTRATION

SPONSORED PROJECT TERMINATION/CLOSEOUT SHEET

Date February 9, 1984

Project No. A-3448 ~~School~~/Lab EML

Includes Subproject No.(s)

Project Director(s) Blue & Summers GTRI / ~~GIT~~

Sponsor General Dynamics

Title Evaluating CdS Crystals

Effective Completion Date: 1/31/83 (Performance) 1/31/83 (Reports)

Grant/Contract Closeout Actions Remaining:

- [ ] None
- [x] Final Invoice ~~or Final Fiscal Report~~
- [ ] Closing Documents
- [ ] Final Report of Inventions
- [ ] Govt. Property Inventory & Related Certificate
- [ ] Classified Material Certificate
- [ ] Other

Continues Project No. Continued by Project No.

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Interim Report No. 1

EVALUATION OF CdS CRYSTALS

Contract period covered
1 December 1982 through 31 December 1982
G.D. P.O. 508260

Submitted to

General Dynamics
Pomona Division
P.O. Box 2507
Pomona, California 91766

by

Georgia Institute of Technology
Engineering Experiment Station
Electromagnetics Laboratory
Atlanta, Georgia 30332

Contracting through
Georgia Tech Research Institute
Georgia Institute of Technology
Atlanta, Georgia 30332

Prepared by

C. J. Summers
M. D. Blue

December 1982

During this report period the emphasis has been to develop a more complete understanding of the theoretical properties of a Schottky-barrier detector and on performing preliminary material characterizations. Those investigations are described below.

Detector Modeling

An analytical model of a n-type CdS Schottky-barrier photon detector is being formulated with the purpose of identifying the key material and device parameters that affect its performance. The energy band structure for this detector is shown in Fig. 1 and at present assumes an ideal metal-semiconductor interface with no interface states. For this structure the principal mechanisms giving rise to charge carrier transport across the Schottky barrier have been identified as

1. the thermionic emission of electrons over the barrier potential
2. the generation and recombination of electrons and holes within the space-charge region
3. hole injection from the metal into the valence band of the semiconductor and
4. tunneling of conduction band electrons through the Schottky barrier.

Each of these mechanisms produces a current whose magnitude is dependent on the height and/or width of the barrier; the material properties of the semiconductor such as electron concentration, mobility and lifetime; and the detectors temperature and reverse bias voltage. From calculations of the dependence of the current terms on material and device parameters, the most crucial material parameters that affect device performance for different operating conditions can be identified. This information will then be used to define future material and device characterizations.

Material Characterization

Because of the importance of the electron concentration and mobility to all aspects of device modeling, the initial material investigation will concentrate on measuring these quantities as functions of sample temperature. Measurements of the resistivity and Hall coefficient of various CdS samples are being performed between 10-300K. The data will be analyzed to obtain the carrier concentration and mobility as well as information on the concentration and ionization energy of impurities and sample compensation levels.

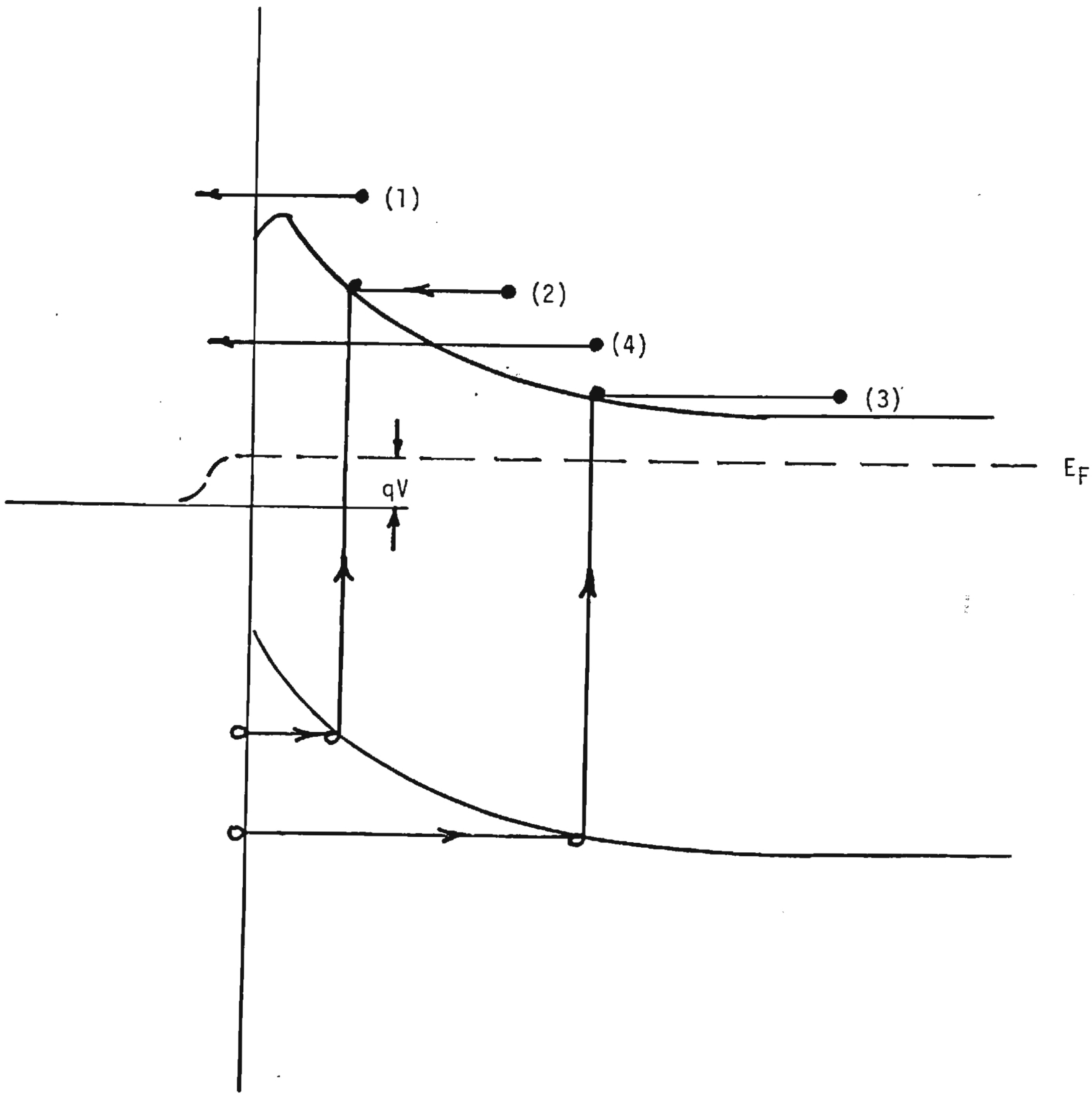

Figure 1. Metal n-Type Semiconductor Schottky Barrier

(1) Thermionic emission
(2) G-R of electrons and holes
(3) Hole injection
(4) Tunneling

Report No. 2

EVALUATION OF CdS CRYSTALS

Contract Period Covered
1 January 1983 Through 28 February, 1983

General Dynamics Purchase Order No. 508262
EES No. A-3448

Submitted To

General Dynamics
Pomona Division
P. O. Box 2507
Pomona, California 91766

By

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C. J. Summers
M. D. Blue

February, 1983

CdS Evaluation Progress

I. Introduction

The investigations reported here began in December, 1982. The initial efforts were concerned with study and characterization of CdS detector material. Discussions with GD/P representatives indicated that material quality was apparently not uniform from one crystal to another, and also varied among slices from the same crystal. Nonuniform etching and polishing, visible precipitates, and other crystal flaws were observed.

Among the measurement techniques available to us that could be quickly implemented were optical absorption, electroreflection, Hall effect measurements, resistivity measurements, and X-ray diffraction. Preliminary results were obtained using these techniques on selected samples. A major effort was made to examine several examples using X-ray diffraction for reasons discussed in the following section.

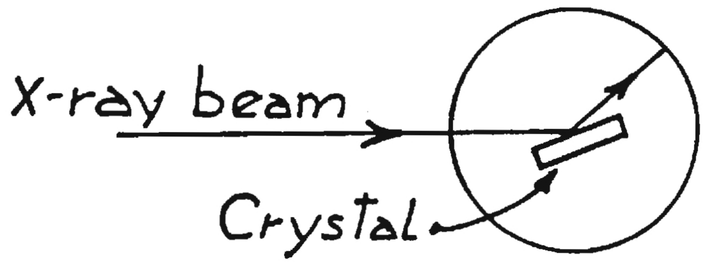
II. Results obtained

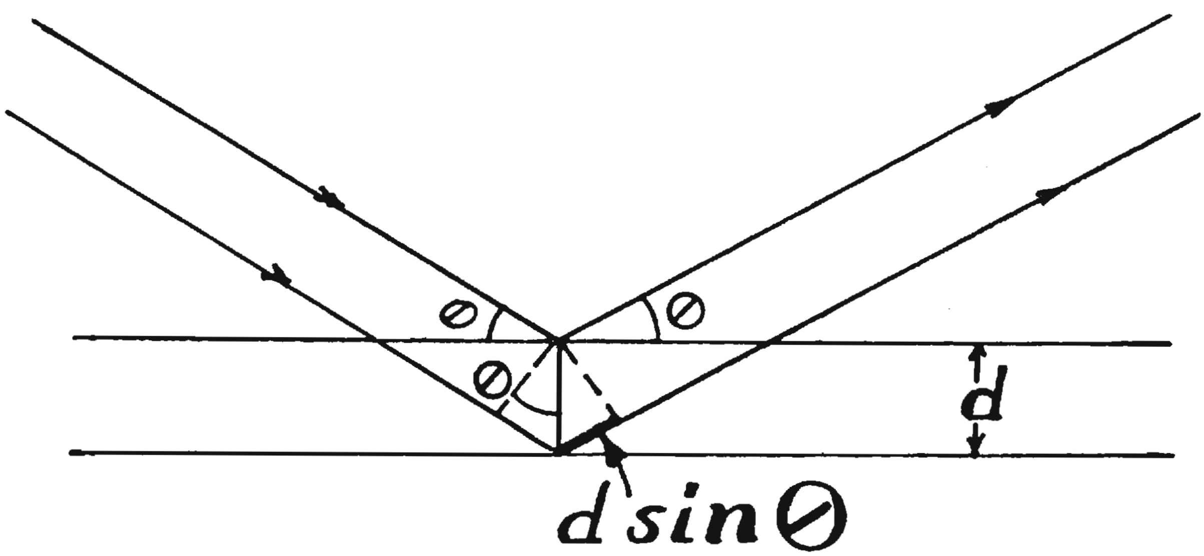
The problems which have been observed with materials, processing, fabrication, and detector performance seemed to suggest that material characteristics and uniformity could be a major source of difficulty. In particular, strain in the crystals, resulting from the growth technique in current use, was suspected. Therefore, X-ray diffraction techniques and visual inspection using a polarizing microscope immediately suggested themselves as useful techniques. We were unable to obtain useful and unambiguous results with optical microscopy because of the wealth of observable features in the early group of samples. Accordingly, we turned our attention to X-ray techniques.

Of the many X-ray techniques of potential use, we selected X-ray diffraction as a straightforward easily implemented technique for a quick look at several samples. Figure 1 illustrates the technique. The X-ray beam reflects off the crystal planes and peaks in intensity at angles where the wavelength and angle satisfy the Bragg equation as shown in the figure. The results for the 008 line of CdS are tabulated in Table I. Column 2, FWHM, indicates the effective width of the diffracted beam for the six samples selected. The sample population was chosen to include wafers believed to be strained and wafers believed to be uniform as well as an older wafer from Cleveland Crystals. The results, as indicated in Column 2, are in accord with our expectations. The wafers from regions containing strain or expected to give rise to microphonic detectors have much broader diffraction lines than wafers from more uniform regions.

The overall accuracy of these results can be improved with better sample holders permitting improved focusing of the X-ray beam. However, the present results are sufficiently clear so that minor adjustments to line shape will not alter our conclusions.

Figure 2 compares the measured diffraction line shape for two wafers from crystal 82070-21; sample5b and sample 6. As indicated in Table I, slice 6 was expected to be uniform and of good quality while





$$2d \sin \theta = n\lambda$$

FIGURE ONE

TABLE ONE

X-RAY DIFFRACTOMETER RESULTS
MEASUREMENTS ON THE 008 (2 THETA = 133.45) LINE

SAMPLE	FWHM*	COMMENT
82159-24 SLICE 6	6.10	SAME POLISH PROC. AS 70-26 VERY WEAK REFLECTION.
82070-21 SLICE 6	0.18	NEXT TO 82070-21 SLICE 5B NON-MICROPHONIC. SHARP LINES.
82236-22 SLICE 9	0.18	NEAR 82236-22 SLICE 11-B (UNIV. OF UTAH) NON-MICROPHONIC. SHARP LINES.
82070-21 SLICE 5B	3.75	STRAIN AND DEFECT STRUCTURE EXPECTED BROAD DIFFRACTION LINES.
82070-01 SLICE 11A2	2.50	SAMPLE FROM MICROPHONIC REGION BROAD DIFFRACTION LINES.
P0455247-E SLICE 1A	1.40	CLEVELAND CRYSTALS MATERIAL MODERATE LINE BROADENING.

*FULL WIDTH AT HALF MAXIMUM

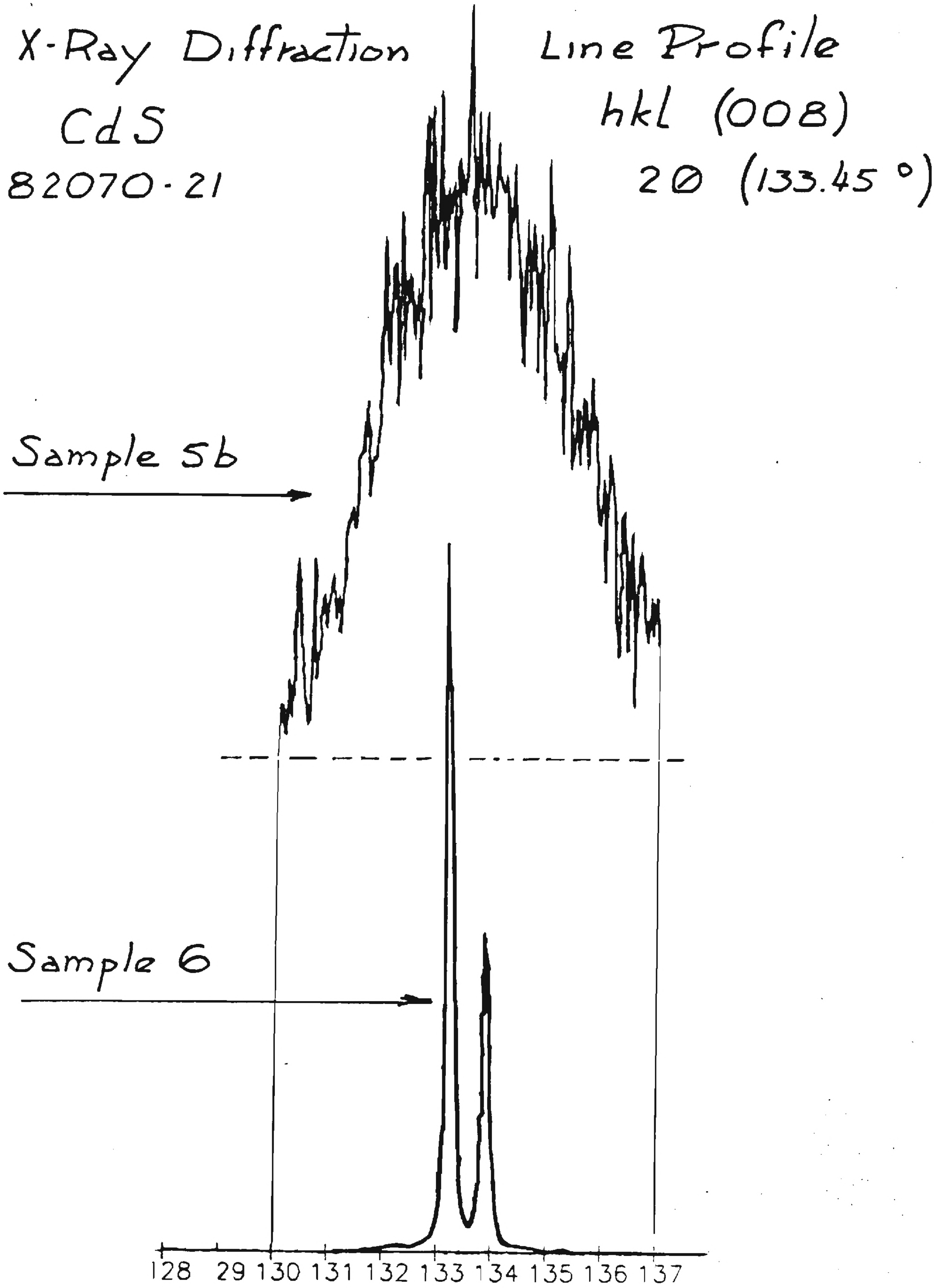

X-Ray Diffraction
CdS
82070-21
Line Profile
hkl (008)
2Ø (133.45°)
Sample 5b
Sample 6
128 29 130 131 132 133 134 135 136 137

FIGURE TWO

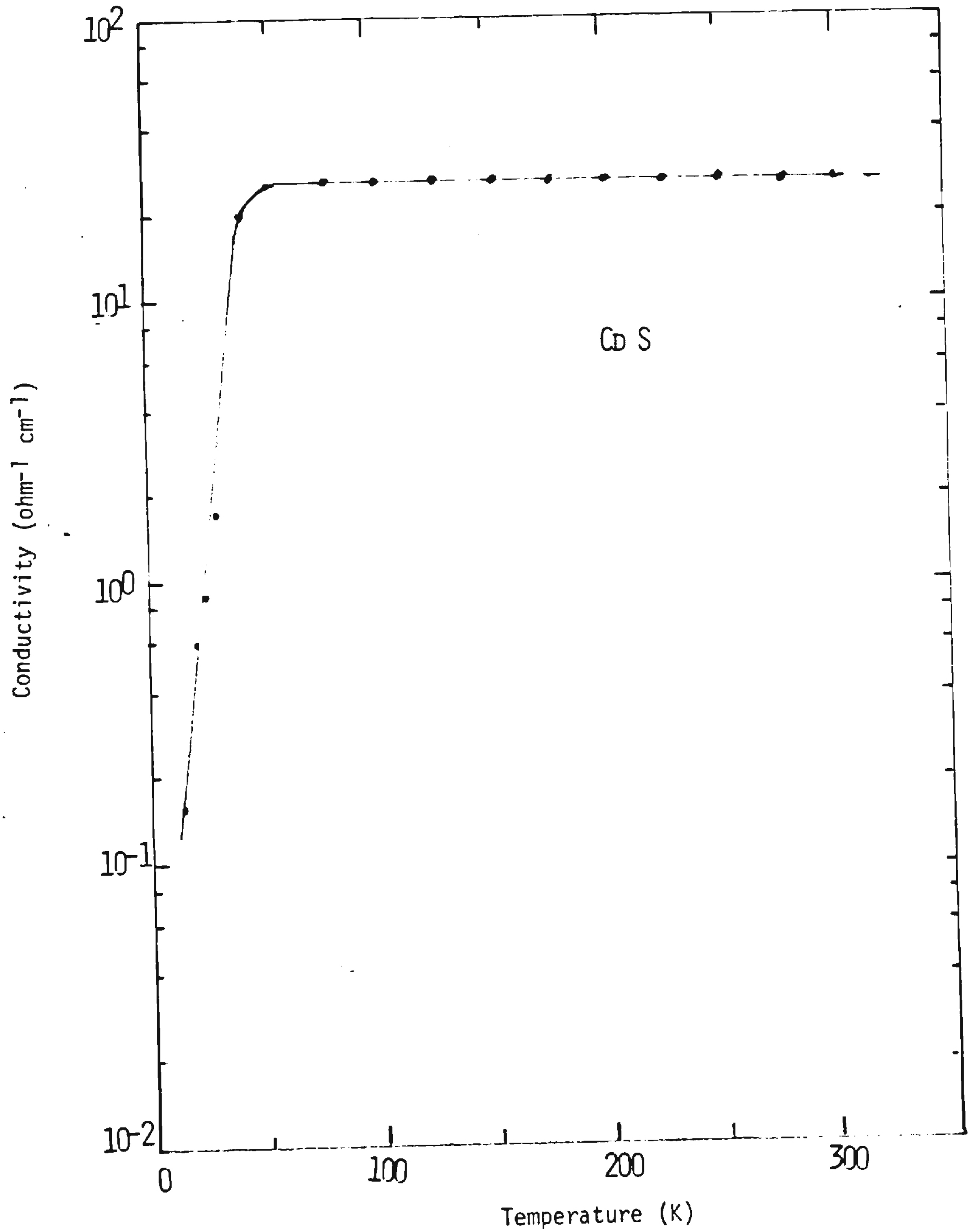
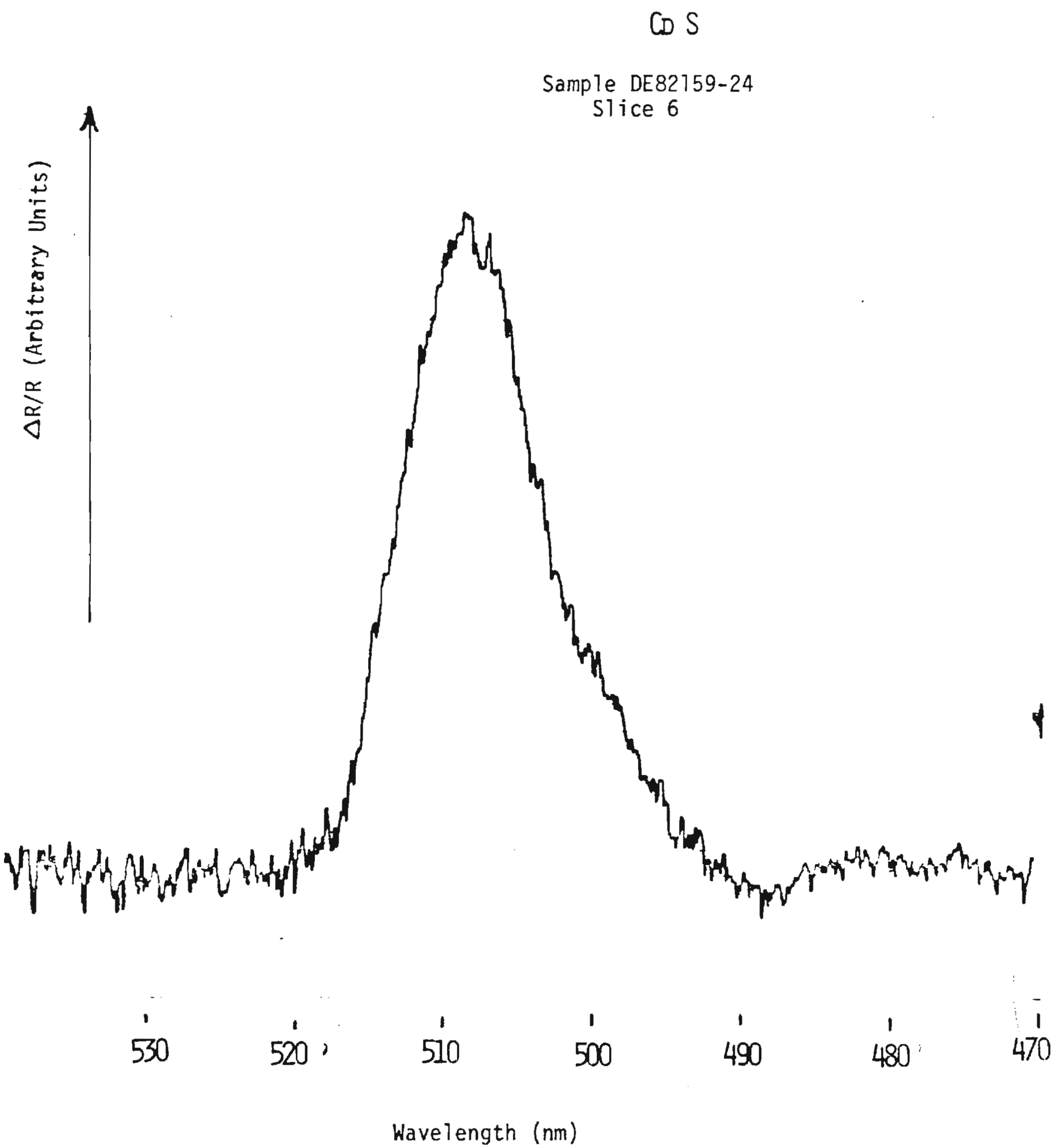


FIGURE THREE



CD S
Sample DE82159-24
Slice 6
ΔR/R (Arbitrary Units)
530
520
510
500
490
480
470
Wavelength (nm)

FIGURE FOUR

TABLE TWO

DEVICE MODELING

(1) THERMIONIC EMISSION

$$J = \left[q N_c V_R / (1 + V_R / V_D) \right] \exp\left(\frac{-q\phi_{Bn}}{kT}\right) \left[\exp\left(\frac{-qV}{kT}\right) - 1 \right]$$

$$= 7.7 \times 10^{-51} \left[\exp(116V) - 1 \right] \text{ Amp/cm}^2 \text{ at } 100K$$

(2) QUANTUM - MECHANICAL TUNNELING

$$J_t \sim \exp(-q\phi_{Bn}/E_{\infty})$$

$$\sim 4.6 \times 10^{-1763} \text{ Amp/cm}^2 \quad (\text{i.e., small})$$

(3) RECOMBINATION IN THE SPACE - CHARGE REGION

$$J_{rec} = (qW/2)\, \sigma\, V_{th}\, N_t\, n_i \exp(qV/2kT)$$

$$\sim 1.4 \times 10^{-78} \text{ Amp/cm}^2 \text{ at } 80K$$

(4) HOLE INJECTION

$$\gamma \equiv J_p / J_p + J_n$$

$$< 10^{-10} \quad \text{, all Temps.}$$

slice 5b was expected to show the effects of strain. In fact, slice 6 was uniform enough to permit the K α doublet to be resolved, while slice 5b showed significant broadening. These early results support a model for several observed effects in CdS to be described in the following section.

In addition to the X-ray studies, preliminary measurements were completed using several other techniques. An example of a conductivity measurement is shown in Figure 3. Contact problems on some samples indicate the need for further work in this area. Figure 4 shows the electroreflectance spectrum for a wafer measured at the absorption edge. This measurement would be expected to be sensitive to surface condition. The electroreflectance spectra at higher energy transitions would be expected to be more indicative of long-range order. These techniques should be useful as crystal quality improves.

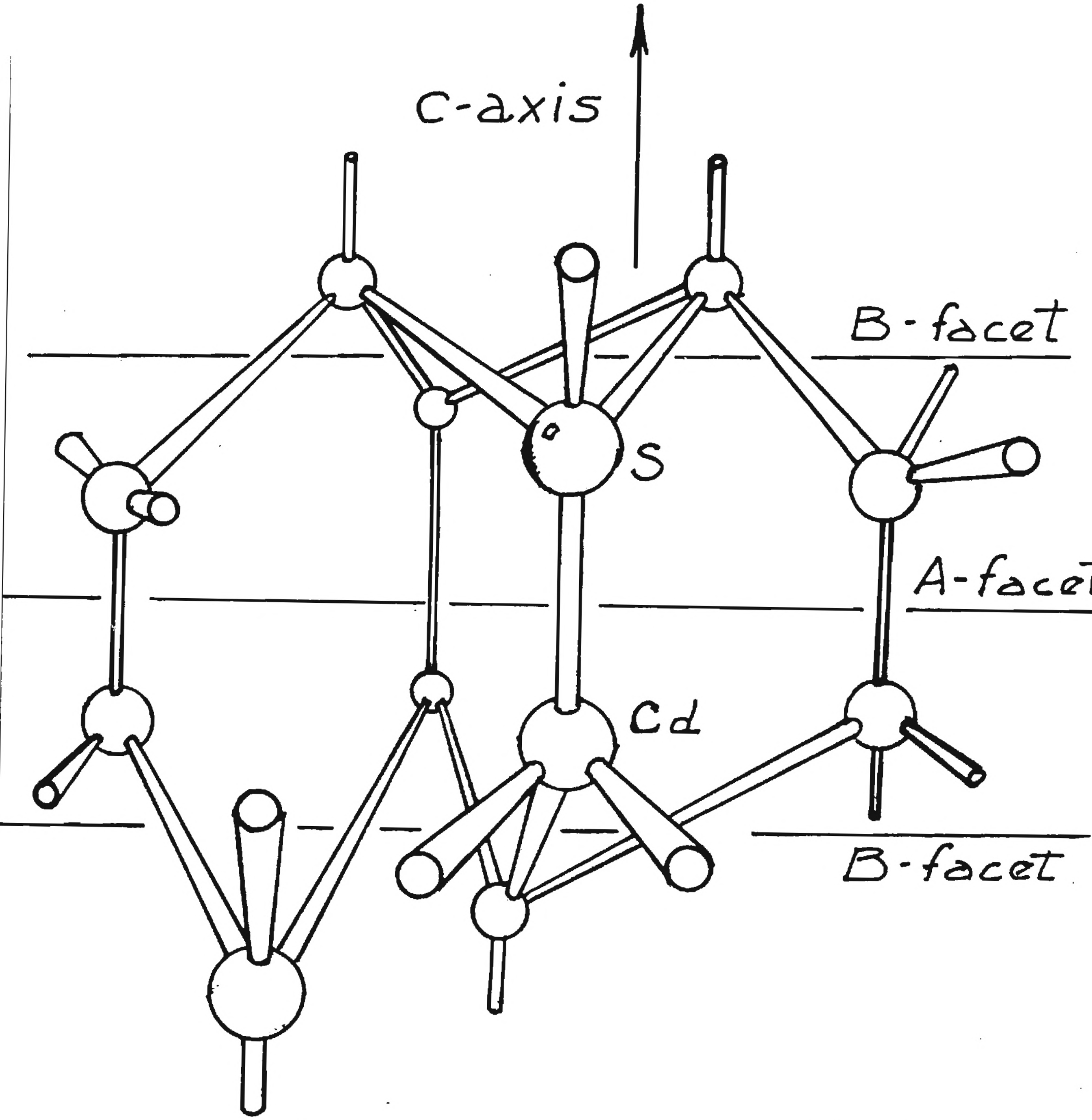
We have also examined the current-voltage characteristics of CdS Schottky barriers. In particular, the currents expected from the various mechanisms of thermionic emission, quantum-mechanical tunneling, space-charge region recombination, and hole injection are reported in Table II. While many parameters have been estimated and approximations made in order to obtain a numerical result, the values obtained are such that reasonable variations in the estimates will not change the result. We find that the ideal electrical characteristics of the barrier at 300°K and 77°K are determined primarily by thermionic emission. Departures from the ideal in actual CdS devices will reflect the effect of shunt resistance and series resistance.

III. Suggested Model

The data and results to date suggest that the following model may be useful in thinking about CdS material and detectors, and should provide a means of relating several different observations. For a CdS crystal cut normal to the C-axis, the atoms will be arranged as shown in the sketch of Figure 5. Alternate facets consist of all Cd atoms or all S atoms. Successive layers require breaking alternatively three bonds per atom and then one bond per atom. The reactivities of the two facets can be quite different in III-V compounds. Usually the A-facet, consisting of Type III atoms, is more inert than the B-facet which consists of Type V atoms. Thus the A-facet in CdS would contain Cd atoms and should be the most stable in accord with observations. It is believed that electron redistribution causes the B-facet to possess more electrons and be more readily oxidized than the A-facet.

Any strain effects which modulate the local density of atoms, and electrons, will have an effect on the etching rate because of the local variations in the availability of electrons for participation in the bonding reaction. Localized strain regions can be one source of inhomogeniety in the etched CdS surface.

Note also that the CdS bond contains a mixture of ionic and covalent bonding. The S atoms contribute some electrons to the Cd atoms creating charge exchange between these layers. Strain in the crystal causes gradients in the local dipole moment per unit volume, and causes localized deviations from the symmetry of the CdS structure. Mechanical stress on the crystal can alter this charge pattern. It is possible that high-frequency mechanical stress could lead to small ac voltages appearing at contacts on the CdS crystal.



Bonding In CdS

FIGURE FIVE

IV. Future Work

The next several weeks will be used to continue many of the measurements initiated during the past months. In particular we wish to measure properties of better wafers in considerable detail. Further measurements on the samples believed to show strain effects will also be completed. At present, the X-ray diffraction technique appears to be the most satisfactory means of differentiating between strained and unstrained crystals. We will be interested in finding a simpler and quicker method of accomplishing the same result.