AD-A088 446 HUGHES RESEARCH LABS MALIBU CA F/G 20/12
ELECTRONIC PROCESSES IN INP AND RELATED COMPOUNDS.(U)
JUL 80 K V VAIDYANATHAN, C L ANDERSON N00019-79-C-0533
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ELECTRONIC PROCESSES IN InP AND RELATED COMPOUNDS

K.V. Vaidyanathan, C.L. Anderson, H.L. Dunlap, D.E. Holmes and G.S. Kamath

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July 1980

Contract No. N00019–79–C–0533
Quarterly Progress Report 3
13 March 1980 through 12 June 1980

[redacted]

Prepared for:
NAVAL AIR SYSTEMS COMMAND
Washington, DC 20361

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER

2. GOVT ACCESSION NO. AD-A088446

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)
ELECTRONIC PROCESSES IN InP AND RELATED COMPOUNDS

5. TYPE OF REPORT & PERIOD COVERED
Quarterly Progress Rpt. 3
13 Mar [redacted]-12 Jun[redacted]980

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)
K.V. Vaidyanathan, C.L. Anderson, H.L. Dunlap
D.E. Holmes [redacted] G.S. Kamath

8. CONTRACT OR GRANT NUMBER(s)
N00019-79-C-0533

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Hughes Research Laboratories
3011 Malibu Canyon Road
Malibu, CA 90265

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS

11. CONTROLLING OFFICE NAME AND ADDRESS
Department of the Navy
Naval Air Systems Command
Washington, D.C. 20361

12. REPORT DATE
July[redacted]980

13. NUMBER OF PAGES
9

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)

15. SECURITY CLASS. (of this report)
UNCLASSIFIED

15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)
[redacted]

APPROVED FOR PUBLIC RELEASE:
DISTRIBUTION UNLIMITED

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)
Ionization coefficient measurements
Liquid phase epitaxy of InP

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

An experimental system to measure ionization coefficients in InP and related compounds is described. The current-voltage characteristics of Schottky barriers on p-type InP are presented. A set of masks designed to fabricate guarded Schottky diodes for making ionization coefficient measurements is described.

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TABLE OF CONTENTS

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1. INTRODUCTION AND SUMMARY

The major purposes of this research program are to study the electronic processes in InP and related compounds, to develop device structures suitable for making photocurrent measurements, and to analyze the bias dependence of the photocurrent to obtain the ionization coefficients of electrons and holes in these materials. Such measurements will be useful in the optimal design of avalanche photodiodes for optical communications systems.

During this reporting period, the experimental equipment for photoresponse measurements has been assembled. Schottky-barrier devices were fabricated on lightly doped p-type bulk InP single crystals and their current-voltage characteristics studied. The current-voltage (I-V) characteristics of the Schottky diodes have been analyzed to yield the Schottky barrier height and the ideality factor of these devices. Experiments to control the doping level and surface morphology in liquid phase epitaxial (LPE) growth are in progress.

2. IONIZATION COEFFICIENT MEASUREMENTS

The noise and gain-bandwidth product limitations of avalanche photodiodes are strongly dependent on the ionization coefficients of electrons (α) and holes (β) in the material. These coefficients are obtained from a study of photocurrents. To obtain this information, it is necessary to achieve photomultiplied currents from pure electron and pure hole injection into the high-field region of the device structure. In addition, the electric field variation in the avalanche region must be known accurately.

In our experimental system, we will accomplish the pure electron and pure hole injection by the absorption of either 0.638 μm or 1.152 μm radiation. Two stable He-Ne lasers, one capable of operation at 0.638 μm and the other at 1.152 μm, provide the necessary illumination. Chopped light from the two lasers is focused onto optical fibers, labeled 1 and 2 in Figure 1. The two fibers are fused together in the middle, allowing coupling of radiation between the fibers. Approximately 50% of the radiation couples from fiber 1 to fiber 2 and vice versa.

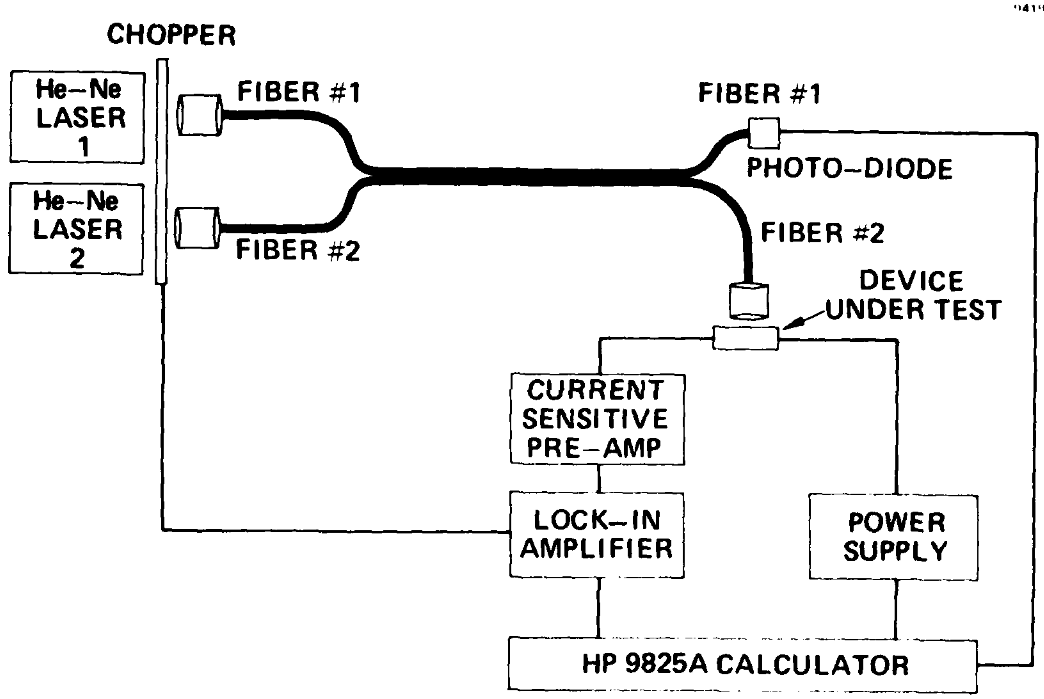

Figure 1. Schematic of ionization coefficient measurement system.

Radiation from fiber 2 is focused by a microscope objective onto the device structure, as shown in Figure 1. The radiation from fiber 1 is detected by a reference photodetector and provides a measure of the laser intensity incident on the test device at any given time. This feature will allow us to account for any fluctuations in the laser intensity during the time it takes to complete the measurement. The photo-induced currents will be measured by a current-sensitive preamplifier and a lock-in amplifier. The voltage applied to the device under test and the measurements will be controlled by a HP 9825A calculator. The system including the interface between the calculator and the lock-in amplifier has been assembled. The interface and the measurement system have been tested using some of the test devices. The photo-response measurements on preliminary devices are being made.

3. DEVICE STRUCTURES — SCHOTTKY BARRIER STUDIES ON p-InP

Schottky-barrier devices were fabricated on lightly doped p-type InP using the mask set described in detail in the preceding progress report. The p-type InP crystals were obtained from Varian Associates and have carrier concentrations of $\sim 6 \times 10^{15}$ cm^{-3}. Ohmic contact to this material was formed by sputtering Au-Zn alloy onto the backside of the wafer and alloying it at 340°C for $\sim$5 min in a forming gas ambient. The Schottky barriers were formed by evaporating Al onto the front side of the wafers. Typical I-V characteristics of such diodes in the reverse direction are shown in Figure 2. The reverse leakage currents in these diodes are quite low ($\sim 1 \times 10^{-8}$ A at 20 V). There is considerable uncertainty concerning the voltage drop across the Schottky diode in the dark because of the excessively high series resistance associated with the lightly doped p-type material. Even in the presence of illumination (which substantially increases the conductivity of the material surrounding the diode), the leakage current is still low with a breakdown voltage of $\sim$20 V. The breakdown is quite sharp, and there appears to be no problem associated with microplasmas. Figure 3 shows the forward characteristics obtained from such Schottky diodes with different diameters. The I-V curves can be expressed by the classical equation

$$J = A^*T^2 e^{\frac{q\phi_B}{kT}} \left[\exp\left(\frac{qV}{nkT}\right) - 1\right] \quad ,$$

where A* is the Richardson's constant, ϕ_B is the Schottky barrier height, T is the absolute temperature, V is the applied voltage, and n is the ideality factor. For Al, we estimate the Schottky barrier height to be 0.9 eV and the ideality factor to be 1.059. The measurements also show that, in Schottky diodes on p-InP, the leakage current is dominated by bulk leakage.

To perform the ionization coefficient measurements, it is necessary to thin the samples after the Schottky devices have been fabricated. We have developed a chemical etching procedure to thin the samples

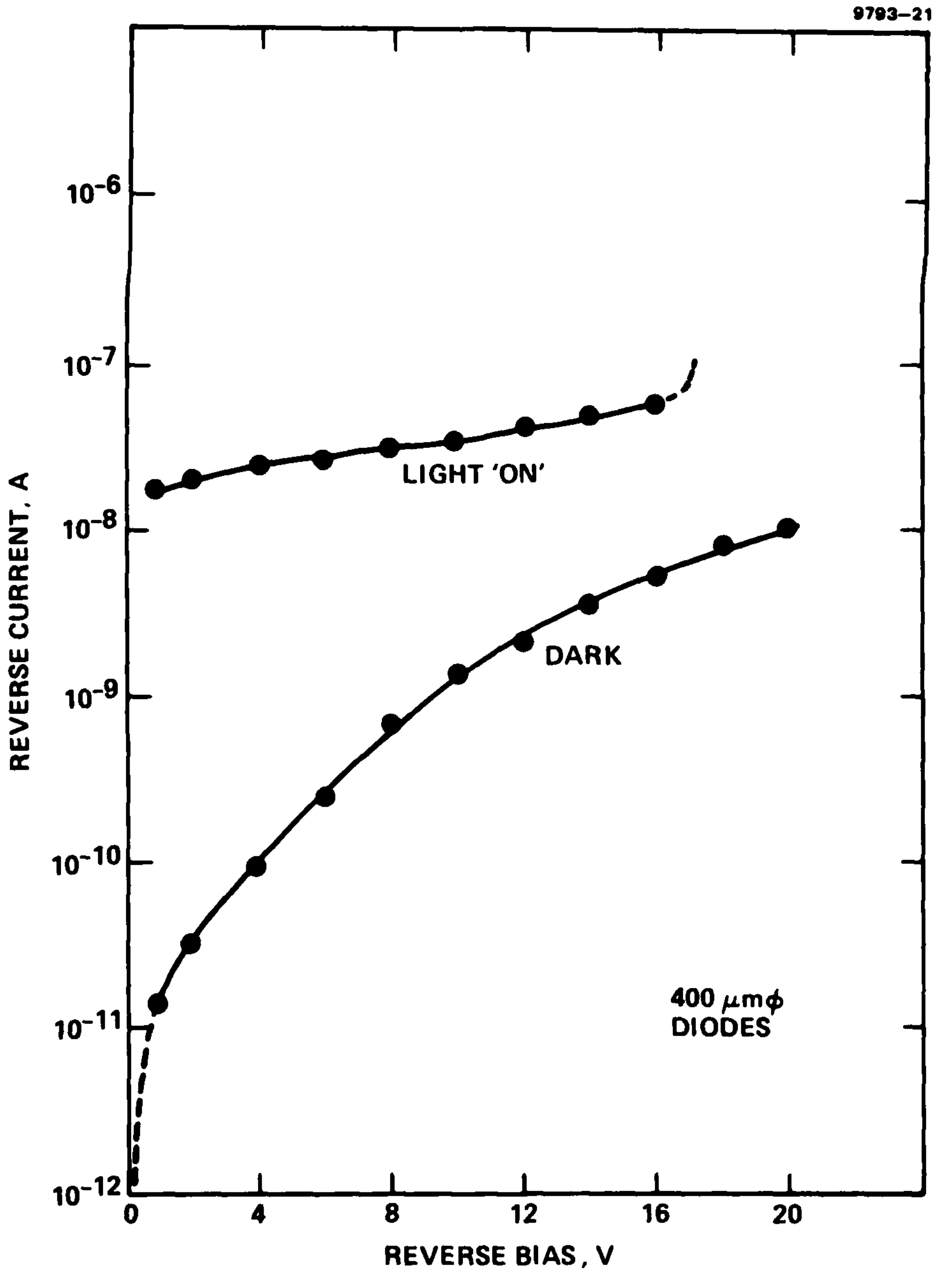

Figure 2. Current-voltage characteristics of 400-μm-diameter reverse-biased Schottky diodes on p-InP.

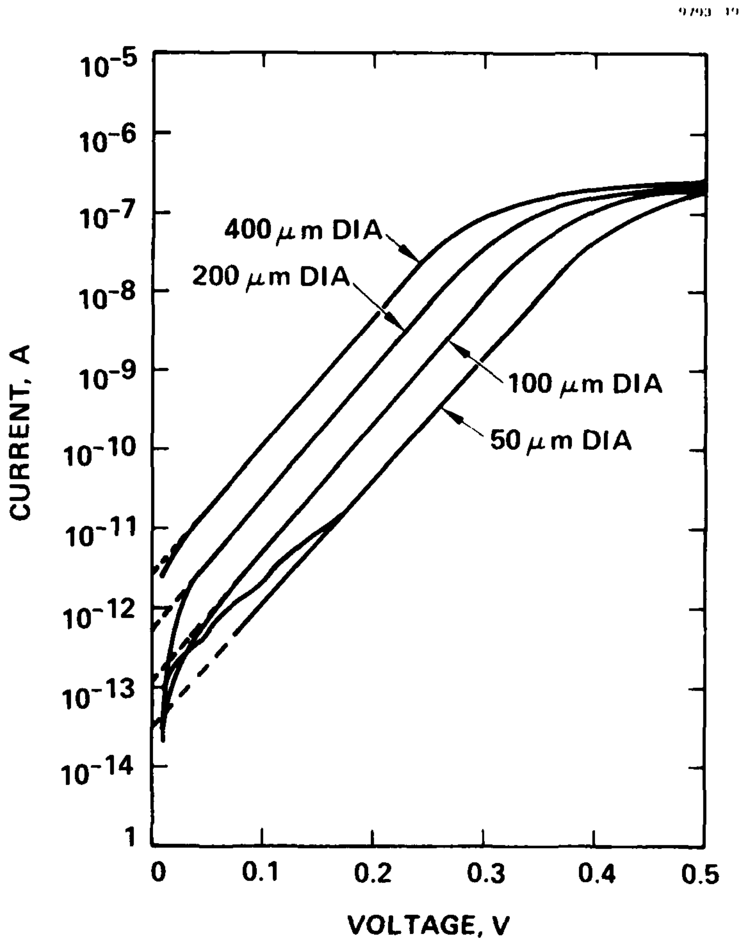

Figure 3. Current-voltage characteristics of forward-biased Schottky diodes on P-InP.

uniformly. The procedure consists of mechanically thinning the sample followed by etching in a solution of 2% bromine in methanol. During this etching procedure, it was observed that more reproducible and uniform etching occurs if a jet of the etching solution impinges on the sample. The uniformity of the etching and etch rate are strongly dependent on the position of the sample with respect to the jet. Typical etch rates of $\sim$1 μm/min appear to provide smooth, uniform etching.

4. LIQUID PHASE EPITAXY OF InP

During this quarter, we have continued the growth of both high-purity and heavily doped (n^+) InP epitaxial layers, paying particular attention to morphological control. We have demonstrated that control of growth ambient using a proprietary growth process results in a reduction in carrier concentration by 10^2 in the layers grown from several solutions. More recent results suggest that not all solutions respond in the same fashion. More experiments are underway.

5. PLANS FOR NEXT QUARTER

In liquid phase epitaxial growth, we will investigate the growth of lightly doped p-type layers by controlled addition of Be to high-purity n-type solution. We will measure the photo-multiplied currents in thinned guarded and unguarded Schottky diodes as a function of reverse bias and analyze the data to obtain the ionization coefficients $\alpha(E)$ and $\beta(E)$. We will also evaluate the properties of Ag and Au as Schottky barriers on p-InP.

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