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INVESTIGATION OF ADVANCED TECHNOLOGY AND HIGH FIELD ELECTRONIC PROPERTIES OF InP FOR MICROWAVE DEVICES

FINAL REPORT

Covering the Period
November 15, 1975 - November 14, 1978

by

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for

U.S. Army Research Office
P.O. Box 12211
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INVESTIGATION OF ADVANCED TECHNOLOGY AND HIGH FIELD ELECTRONIC PROPERTIES OF InP FOR MICROWAVE DEVICES

Final Progress Report on Contract No. DAAG29-77-G-0076;

Progress in the understanding of preparation and properties of InP material has been made in the following main areas.

First in the area of liquid phase epitaxial growth a breakthrough has been made in the understanding of parameters required for the preparation of high purity material.

By secondary ion mass spectrometry the single most important residual donor impurity in layers was found to be silicon.[1] The silicon is present from two sources and has been reported to have a segregation coefficient ~ 30.[2] First, source indium as supplied contains silicon which can be reduced by baking in a hydrogen ambient containing a few ppm of H_2O vapor according to

$$Si_{In} + H_2O \rightleftarrows H_2 + SiO\uparrow \; .$$

Second, there is a dynamic production of volatile SiO which contaminates the melt from the walls of the growth tube according to

$$SiO_2 + H_2 \rightleftarrows SiO + H_2O \; .$$

Calculations of the thermodynamics of these systems showed that the silicon content could be reduced by baking a lower and lower temperatures, however, at 680°C the kinetics of Si_{In} removal becomes too slow for practical interest ($\sim$ 4-5 days).[3] It was predicted, however, that H_2O vapor introduced into the growth tube during bakeout will reduce the Si much faster, a procedure that was successfully used by S. Groves of Lincoln Labs to obtain high purity ($\mu_{77} \sim 60,000$ $cm^2/Vsec$) epilayers after an overnight bakeout. (Reported at St. Louis GaAs Conference 1978).[4]

The state-of-the-art L.P.E. InP is now held at Cornell with $(N_D-N_A) \sim 4x10^{14}$ cm^{-3} with 77K mobilities as high as 94,000 cm^2 $V^{-1}sec^{-1}$. It is now possible to produce material of this quality on a semi routine basis. Several films have been supplied to external laboratories for further characterization, notably Oxford University (Prof. Stradling's group) for photoconductivity analysis and to Wright Patterson Air Force Base fo photoluminescence studies.

An instability effect has been found for these high purity films. After a shelf life of several months or heating at $\sim 100^oC$ for several days, the 77K mobility was found to rise to as high as 140,000 $cm^2/Vsec$ and the donor density to drop anomalously. In certain cases the resistivity became too high to allow measurement of electrical properties. This effect, since confirmed on Cornell material at Lincoln Labs, was not, however, found with back doped films (using Sn dopant) and appears only with residual (N_D-N_A) initially below $1x10^{15}$. We feel that this effect is possibly due to silicon site exchange or to intrinsic point defects. We are currently endeavoring to relate this effect to the presence of certain deep levels found by optical D.L.T.S. (see below).

Material produced in this program was subsequently used for

Be^+ ion implantation in cooperation with J. Comas of Naval Research Labs to produce shallow P^+ n junction which could be used for studies of the breakdown properties of InP. Subsequent study of implant profiles by S.I.M.s at Cornell before and after annealing at 625°C for 15 minutes showed it was possible to produce ideal profiles and hence good abrupt junctions when the implant dose was below 3×10^{13} cm^{-2}, however, much above this figure (6×10^{13} cm^{-2}) anomalous diffusion occurred on annealing making junctions graded.[5]

With the 3×10^{13} cm^{-2} implanted films, good $1/C^2$ Vs V characteristics were found enabling impurity profiles to be obtained and breakdown voltages of the order 40% higher than the equivalently doped GaAs were found. This effect subsequently has been confirmed by workers at Varian Associates[6] and the University of Southern California.[7]

The diodes produced in this implantation study were also used for optically stimulated deep level transient capacitance spectroscopy (ODLTS) using a YAG laser. No electron traps were found in concentrations above the detection limit ($\sim 2\times10^{12}$ cm^{-3}), however, two hole traps were found with ionization energies $\sim$ 0.1 eV and 0.5 eV believed similar to those observed in L.P.E. GaAs. The concentrations of these traps were respectively $> 6\times10^{13}$ cm^{-3} and $\sim 4\times10^{12}$ cm^{-3}.

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Silicon has been identified as the most important single donor in InP grown by Liquid Phase Epitaxy. The conditions for minimizing this impurity have been defined. State-of-the-art purity by L.P.E. is now held at Cornell with μ_{77} = 94,000 cm^2/V.s and $N_D-N_A \sim 4x10^{14}$ cm^{-3}.

Be ion implantatior has allowed good shallow p^+n junctions to be prepared which have subsequently been used to profile donor

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concentration through epitaxial layers, to determine that the bulk breakdown fields in InP are ~40% higher than in equivalently doped GaAs and to find (for the first time) two hole traps by optical transient capacitance spectroscopy. (~0.1 eV and ~0.5 eV) above the valence band.

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