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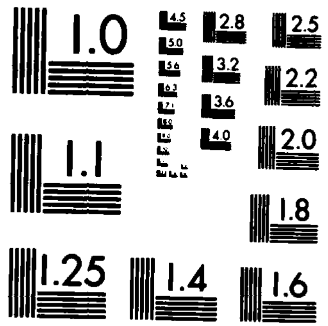

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Our "Investigation of Defects and Electronic Interactions Associated with GaAs Device Processing" has been designed as a three-year program with first-year tasks focussing on the effects of thermal annealing.

During this one-year period (August 15, 1983-August 14, 1984) we have modified the design of the annealing ampul in order to achieve stoichiometry controlled annealing conditions and we have completed the construction of the ultra-high purity annealing apparatus (co-sponsored by a grant from Microgravity Research Associates).

Our study of as-grown and annealed GaAs crystals has led to the identification of new defect related midgap levels. We have also discovered that defect interactions in a critical temperature range 800°C to 900°C are controlled by stoichiometry and by the Fermi energy.

We have initiated a collaborative study with Avionics Laboratory of Wright Patterson Base

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on ion implantation and defect characterization by the photoluminescence technique.

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ANNUAL TECHNICAL REPORT

to

AIR FORCE OFFICE OF SCIENTIFIC RESEARCH
BOLLING AIR FORCE BASE, D. C. 20332

on

INVESTIGATION OF DEFECT AND ELECTRONIC INTERACTIONS ASSOCIATED WITH GaAs DEVICE PROCESSING

(F49620-83-C-0139)

For Period

August 15, 1983 to August 14, 1984

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Submitted by

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Cambridge, Massachusetts 02139

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I. SUMMARY

Our "Investigation of Defects and Electronic Interactions Associated with GaAs Device Processing" has been designed as a three year program with first year tasks focussing on the effects of thermal annealing.

During this one year period (August 15, 1983 - August 14, 1984) we have modified the design of the annealing ampul in order to achieve stoichiometry controlled annealing conditions and we have completed the construction of the ultra-high purity annealing apparatus (cosponsored by a grant from "Microgravity Research Associates").

Our study of as-grown and annealed GaAs crystals has led to the identification of new defect related midgap levels. We have also discovered that defect interactions in a critical temperature range 800°C to 900°C are controlled by stoichiometry and by the Fermi Energy.

We have initiated a collaborative study with Avionics Laboratory of the Wright Patterson Base on ion implantation and defect characterization by the photoluminescence technique. The results of our activity are outlined below and in preprints of two publications enclosed with this report.

II. GaAs THERMAL ANNEALING

Role of Arsenic Pressure

In our previous study we found that for GaAs there is an optimum partial pressure of arsenic at which the surface morphology and the deep levels were not altered by annealing. We have continued this study, however, using a modified ampul (see Progress Report for Period August 1983 to March 1984) which made it possible to quench the arsenic source at first and then cool down the GaAs samples to avoid arsenic condensation. Representative results obtained with the new ampul are shown in Fig. 1. It is seen that the

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surface quality is optimized by proper selection of temperature of the arsenic source. For temperature below the optimum arsenic source temperature (i.e. gallium rich conditions) there is a significant deterioration of the surface quality. For arsenic rich ambient the surface morphology is much better than that for the gallium rich ambient. Slight changes of morphology observed under arsenic rich conditions represent most likely the islands of residual arsenic.

Annealing of GaAs in arsenic-rich ambient was found to create a new deep level of an activation energy very similar to that of the EL2. Deconvoluted DLTS Spectra showing a contribution of the new level ETX are presented in Fig. 2. Fig. 3 shows the electron emission rate activation plots of ETX and El2. The difference in emission rates is caused by the large capture cross section of ETX, which is about one order of magnitude larger than that of EL2.

High Purity Annealing Apparatus

Contamination of GaAs with fast diffusing metalic impurities Cu and Fe increases the concentration of acceptors and can lead to conversion of the electrical conductivity from n- to p-type or to conversion from the high resistivity to the low resistivity p-type. Photoluminescence analysis (performed at the Avionics Laboratory of Wright Patterson Air Force Base) and SIMS analysis of our samples annealed in standard quartz ampuls had indeed showed an increased concentration of Cu and Fe.

In order to eliminate this contamination process we took elaborate steps including the use of ultra-high purity fused quartz, new ampul sealing method, gas purging and evacuation of the system. A new apparatus has been completed and tested. Annealing experiments (including capping and proximity annealing) in various gaseous ambients are currently in progress.

III. DEFECT CONTROL BY FERMI ENERGY

The effects of thermal annealing and also of other device processing steps are determined to a large extent by the state of defects in the as-grown crystal. According to the current knowledge we can distinquish three major factors affecting defects in melt-grown GaAs:

1. non-stoichiometry of the melt (controlled by the melt composition or by As-pressure).
2. thermal stress in the growing crystals.
3. the Fermi Energy at elevated temperatures 800°C-900°C at which the migration of defects and their condensation into dislocation loops take place.

We have discovered the importance of non-stoichiometry in our previous study on deep levels and dislocations in GaAs crystals grown under optimum stoichiometry. We have varied the Fermi Energy by intentional doping with shallow donor and shallow acceptor impurities. We have found (see Fig. 4) that Fermi Energy changes from about 0.2 eV below to 0.15 eV above the intrinsic Fermi Energy at 1100°K increases the dislocation density by as much as five orders of magnitude. It is also seen in Fig. 4 that the Fermi Energy change leads to a change in the concentration of midgap levels. The corresponding data cover only the n-type region due to experimental difficulties in deep level determination in p-type material (related to poor quality of Schottky diodes on p-type GaAs).

In order to extend our deep level study to p-type GaAs we have sent a series of p-type samples from crystal grown under different conditions to the Avionics Laboratory for preparation of p-n junctions by ion implantation technique. These p-type samples are currently being studied at the Avionics Laboratory by the photoluminescence technique, which offers a comparative means for determination of the deep level concentration.

We believe that the Fermi Energy control of defects in GaAs taking place during the postsolidification cooling of the crystals should also be of importance during thermal annealing which employs similar temperature range. Reliable studies of deep levels in p-type GaAs are needed in order to test this hypothesis. Thus, we plan to increase our collaboration with the Avionics Laboratory equipped with photoluminescence and ion implantation facilities.

IV. IMPLICATIONS OF OXYGEN RELATED MIDGAP LEVEL ELO

It has been recently established that the compensation mechanism in "undoped" melt grown GaAs involves midgap levels other than EL2. Especially important seems to be the oxygen related level ELO which is often present in crystals grown by the Bridgman Method and by the Liquid Encapsulated Czochralski. For control and understanding of defect interactions during annealing it is of importance to re-examine the results of previous studies which took into account only EL2. According to present knowledge ELO might have also been present in the majority of cases. We have initiated such re-examination using GaAs crystals containing EL2 only and the crystals containing both levels ELO and EL2. A comparative study of the annealing behavior is in progress.

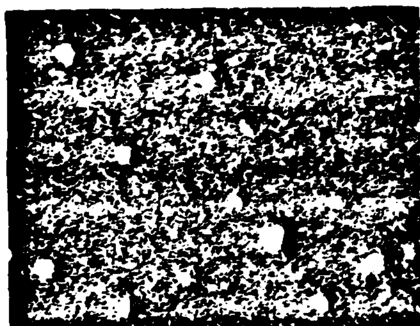
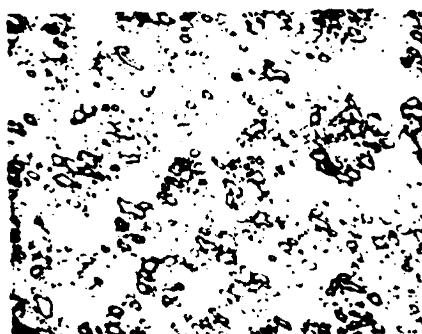
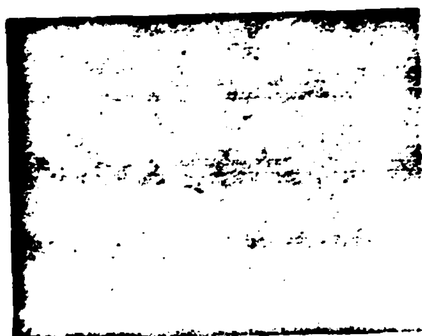
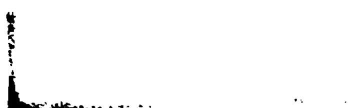
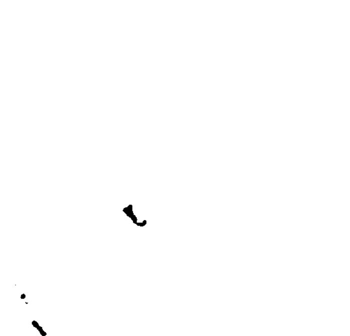
T_{As}	T_{GaAs} = 900°C	T_{GaAs} = 800°C	T_{As}
494°C (48 Torr)			440°C (10.4 Torr)
521°C (94 Torr)			480°C (33 Torr)
570°C (288 Torr)			520°C (92 Torr)
	200 μm (2.92 cm)	200 μm (2.31 cm)	

Figure 1

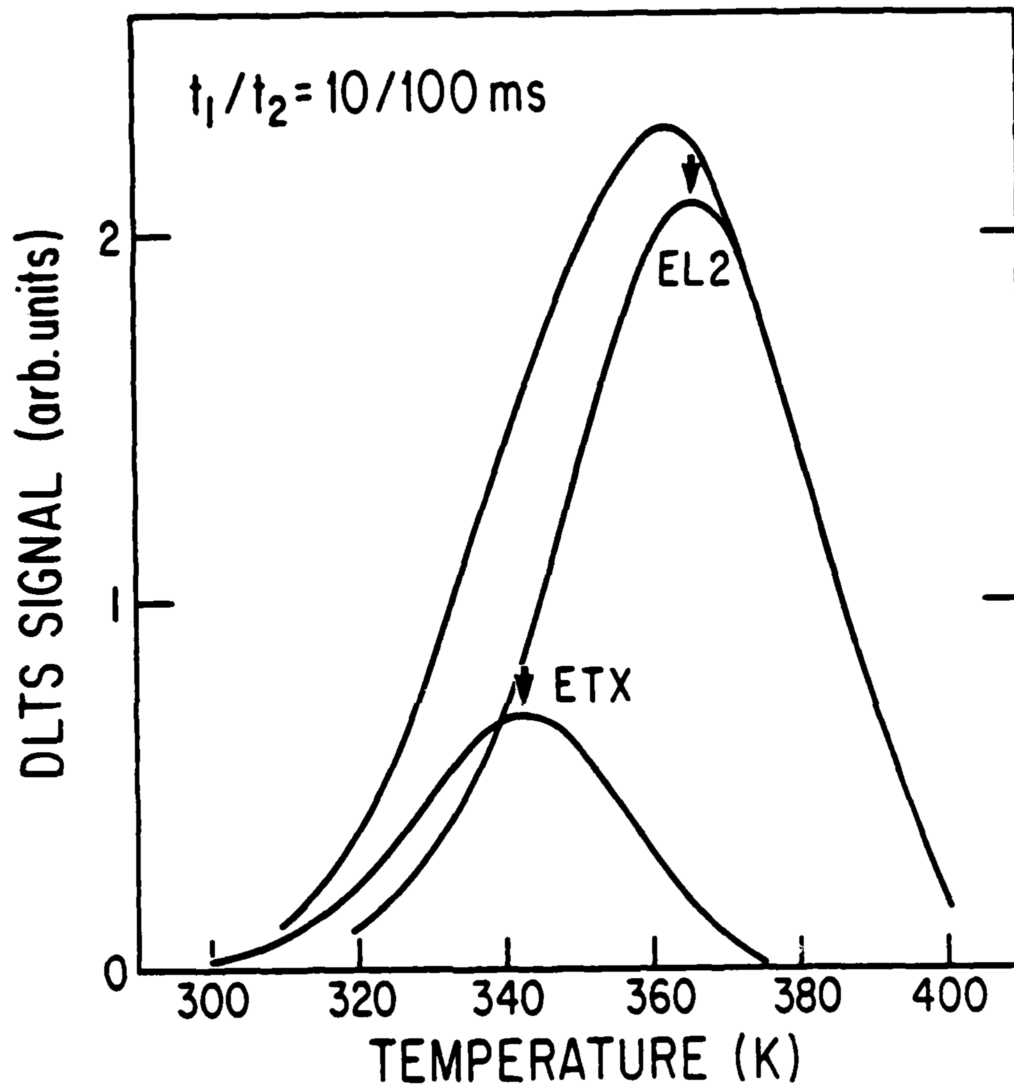


Fig. 2. DLTS spectrum deconvoluted from experimentally determined emission rates of EL2 and a new midgap level as a function of temperature.

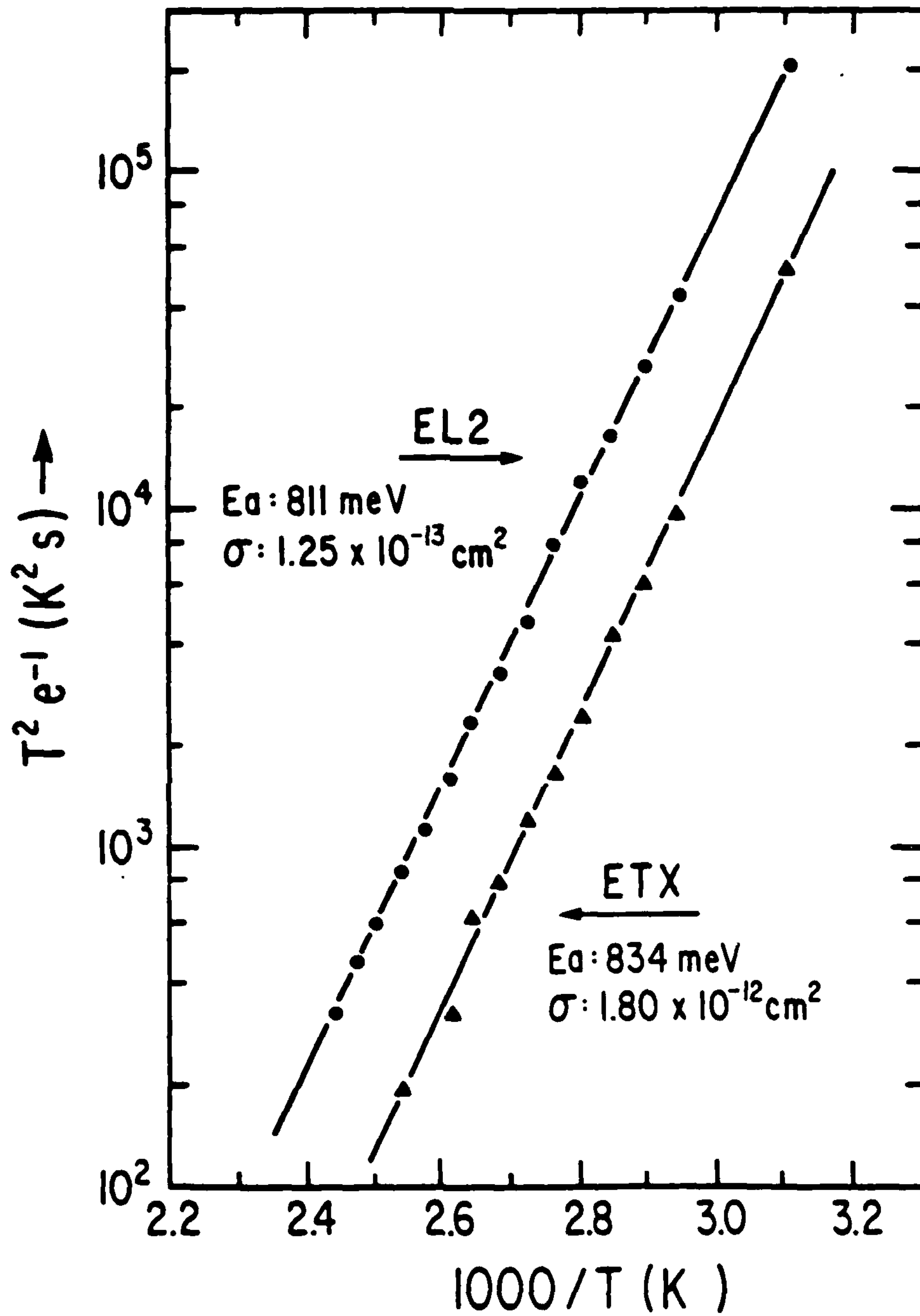


Fig. 3. Emission rate thermal activation plot T^2e^{-1} vs. $10^3/T$ for EL2 and a new midgap level (ETX).

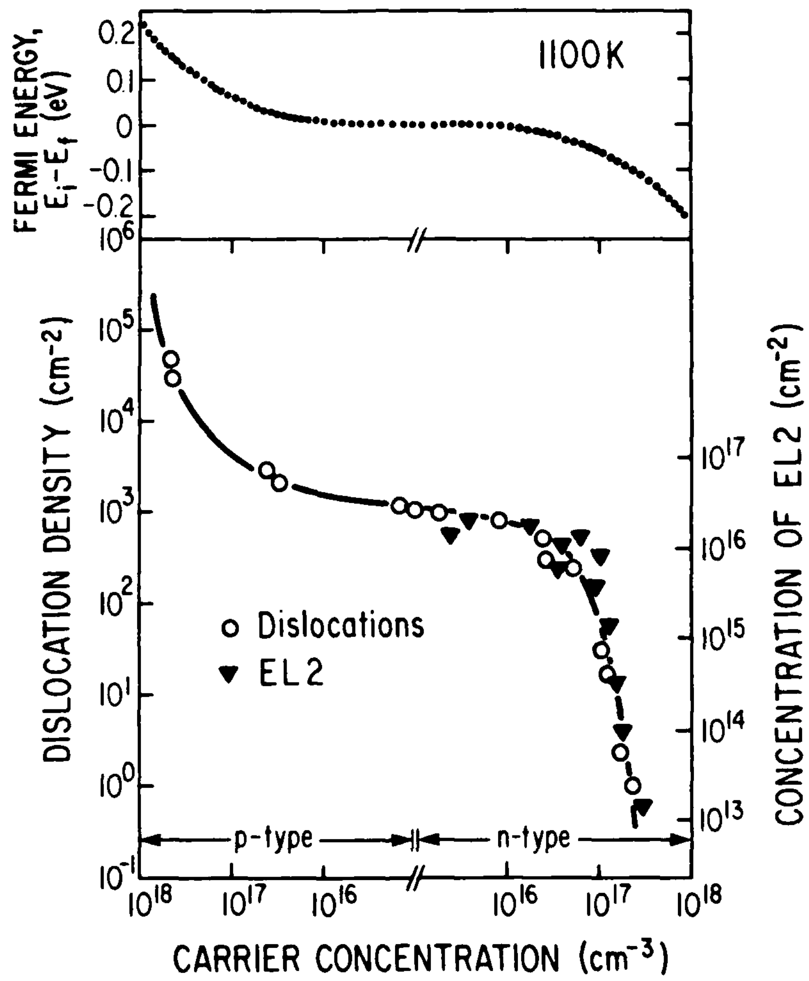


Figure 4.

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