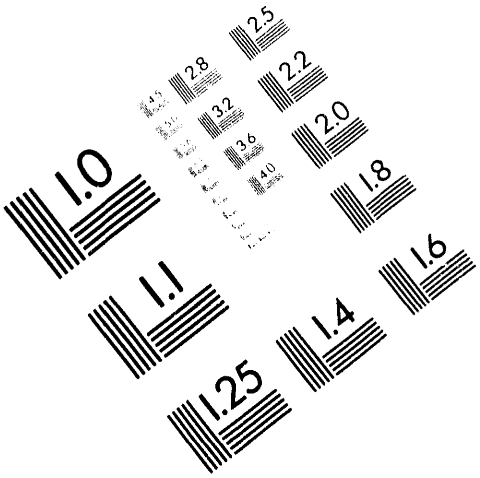

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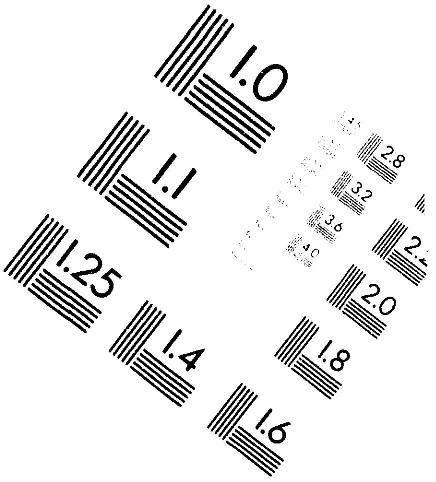

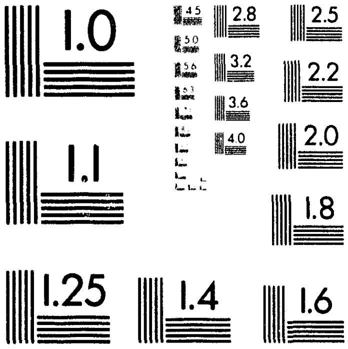

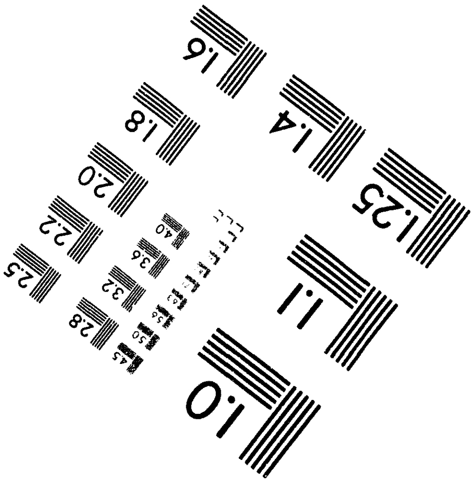

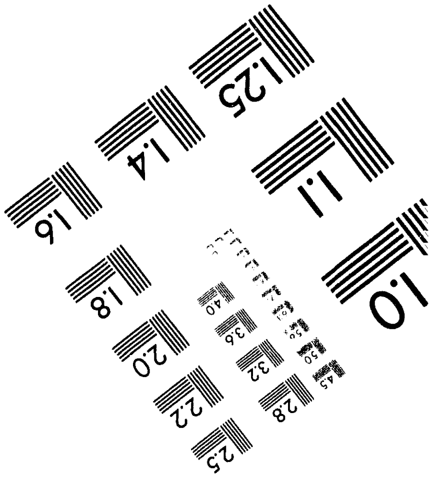

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Positron annihilation studies of defects in molecular beam epitaxy grown III-V layers

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1. Introduction

Variable energy positron beam (VEPB) experiments on molecular beam epitaxy (MBE) grown III-V materials are detailed. Vacancy related defects with Si doped AlGaAs and anneal induced vacancy defect formation in MBE GaAs are investigated.

Energetic positrons implanted into a condensed medium quickly thermalize in a few picoseconds and diffuse through the lattice (~100 nm in a defect free environment) before subsequent annihilation with an electron producing two nearly anti-collinear 511 keV gamma rays. Due to the finite momentum of the annihilation pair (dominated by the electron momentum) the gamma ray photons are Doppler broadened, thus, the 511 keV line width provides a sensitive probe to changes in the local electronic environment. Open volume defects, due to the absence of the ion core, provide a potential well which can trap positrons into a localized state. In such a localized state the overlap of the positron wavefunction with the high momentum core electrons is reduced, thereby, reducing the Doppler broadening of the 511 keV annihilation photon. The 511 keV line width of the gamma rays are parameterized using the S parameter defined simply as the number of counts in a central region of the spectrum divided by the total counts in the 511 photopeak. An increase in open volume defects is then observed as an increase in the S parameter.

2. Experimental

Samples investigated were prepared in a Varian GEN II MBE system at a growth rate of 1 μm/hr. Samples were grown to a thickness of 2 μm on (100) SI-GaAs substrates. The substrates were indium bonded to a wafer holder and a thermocouple utilized to monitor the growth temperature. An ionization gauge at the sample position was used to measure the As and Ga beam flux and a beam equivalent pressure (BEP) calculated. All LT-GaAs samples were grown with an As_4 species while the $Al_xGa_{1-x}As$ samples used the As_2 species.

The variable energy positron annihilation experiments used a slow positron beam described elsewhere[21]. The positron implantation energy was varied from 0.5 to 50 keV with approximately 10^6 annihilation events recorded at each energy. The S parameter was defined

Figure 2 shows the results of measurements before and after infrared irradiation on the doped sample at 25 K. The figure indicates that as the DX center undergoes the metastable transition to the simple donor state, an open volume defect is removed from the lattice. This observation is also consistent with an open volume associated with the microstructure of the DX center. The change in S parameter before and after irradiation is ~0.4% which is smaller than expected for an isolated vacancy in GaAs present in the 10^{18} cm^{-3} range. This is indicative that the open volume is small than an isolated mono-vacancy. These results are in agreement with thoses of Mäkinen *et al.* [20].

4.0 Low Temperature MBE GaAs

4.1 MBE Grown GaAs

The first report on the properties of the molecular beam epitaxy (MBE) growth of GaAs at substrate temperatures below the normal 580 to 600 °C range (LT-GaAs) was made by Murotani et al.[1] in 1978. The research included the first use of LT-GaAs as a buffer layer in a GaAs field effect transistor utilizing a 500 °C growth, however, the material received little interest until 1988 when Smith el al.[2] reported on the use of LT-GaAs grown at 200 °C and annealed at 600 °C as a buffer layer to eliminate backgating and light sensitivity. Since the publication of this now famous paper hundreds of reports on the properties and uses of LT-GaAs have appeared in the scientific literature. For a detailed review of the present understanding of the properties and device characteristics of LT-GaAs the reader is referred to ref. [3,4,5].

The as grown LT-GaAs materials show excellent crystalinity up to a critical thickness[6] after which the growing epitaxial layer becomes amorphous. The material, however, is nonstoichiometric with an excess arsenic concentration on the order of 1% with an expanded lattice parameter and an extremely high concentration of point defects[7]. Following a 600 °C anneal the excess arsenic remains, but, the lattice parameter relaxes back to that of bulk GaAs. Further, arsenic precipitates with diameters in the range 2-10 nm and concentration of $1x10^{17}$ cm^{-3} are observed in the 600 °C annealed layer[8]. The material also becomes highly resistive (~10^6 cm), of this increase on growth temperature for a series of samples grown with a BEP=20. The thermal instability to the formation of open volume defects for samples grown below 450 °C is directly evident. In general, as the growth temperature is lowered the vacancy related defect concentration in both the as grown and annealed samples increases. The increase in the S parameter was found to be commensurate with the relaxation of the lattice parameter observed by X-ray rocking curve measurements. It is interesting to note that the samples grown at 350 and 450 °C show no as grown vacancy related defects and both gave a single X-ray rocking curve peak, but, the annealed data on these two samples is quite different. Preliminary results also indicate an increase in vacancy defect concentration with increased BEP at a given growth temperature.

Keeble et al.[12] demonstrated that the dominant positron trapping defect produced during the anneal is physically distinct from the defect present in the as grown material. To investigate this defect formation, isochronal anneals were performed on samples grown at 230 and 350 °C and are shown in Figure 4. A distinct difference in the materials is clearly seen. First, the increase in S parameter of the 230 °C grown sample starts at a lower temperature and reaches a value of 1.035 at 525 °C which is similar to that reported for divacancies or larger open volume defects[22]. However, the S parameter for the 350 °C grown sample saturates at about 1.025 which is a typical value for mono-vacancies in GaAs[22]. Second, an increase in the S parameter for anneals above 600 °C is observed in the 230 °C grown sample, which is consistent with vacancy cluster formation, while the sample grown at 350 °C shows no change with anneals from 550 to 700 °C. If one assumes a first order rate equation for the defect formation and a linear dependence of the S parameter on the defect production, than for a series of equally spaced anneal temperatures of duration (sec) the activation energy for the defect formation can be expressed as[23];

$$\varepsilon = k_B T_m \ln\left[\frac{K_0 \tau}{\ln\left[\dfrac{T_f - T_i}{T_f - T_i - 2\Delta T}\right]}\right]$$

where: k_B is the Boltzman constant, K_0 is the vibrational attempt frequency, T_i is the starting temperature for the defect production, T_f is the final temperature for the defect production, and T_m

vacancy in the As rich limit.

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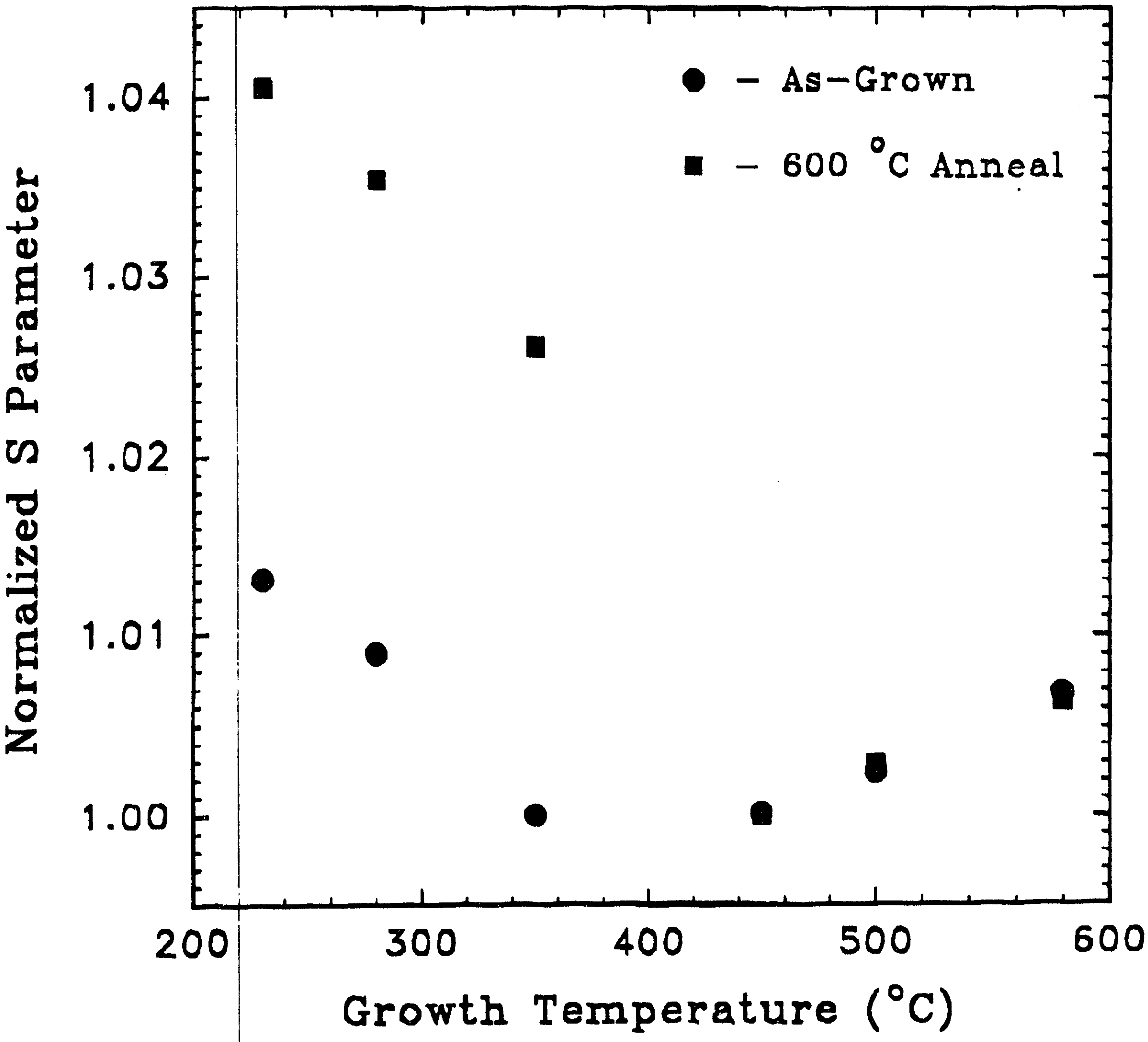
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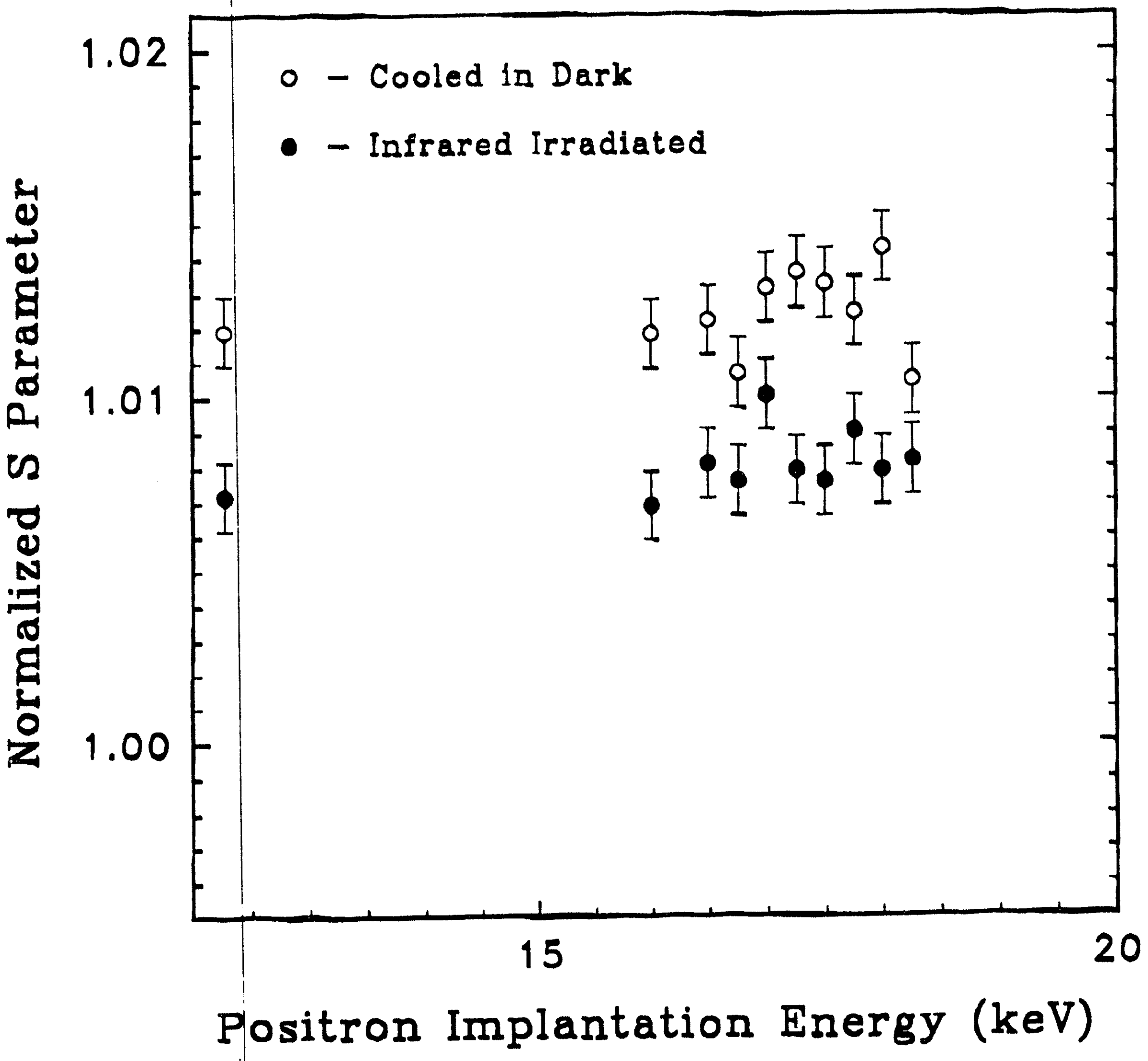
1.04
1.03
1.02
1.01
1.00
200
300
400
500
600
Growth Temperature (°C)
● – As–Grown
■ – 600 °C Anneal


Normalized S Parameter
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1.01
1.00
○ – Cooled in Dark
● – Infrared Irradiated
15
20
Positron Implantation Energy (keV)

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