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Observation of a 0.7 eV electron trap in dilute GaAsN layers grown by liquid phase epitaxy

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The growth of GaAsN layers by liquid phase epitaxy, using polycrystalline GaN as the source of nitrogen, is reported. The presence of nitrogen in the grown layer is indicated by a nitrogen-related shoulder in the Fourier transform absorption spectrum and a resultant band-gap reduction of 90 meV is measured by optical transmission and photocurrent techniques. Data from photocurrent and photocapacitance measurements show the presence of a 0.7 eV electron trap in the material which originates due to nitrogen. Compared with earlier published data on GaAsN, grown by other techniques, the trap is tentatively related to (N–N) defects at As sites. © *2004 American Institute of Physics*. [DOI: 10.1063/1.1779346]

Dilute III–V nitrides have emerged as a kind of material where the band gap of the parent III–V semiconductor is substantially reduced by the incorporation of very little amounts of nitrogen.[1] Such behavior indicates that the material has a large bowing parameter and has been a subject of intensive theoretical investigation. From the application point of view, dilute nitrides show the promise of their use in the fabrication of lasers with suitably tailored wavelengths. Several III–V dilute nitrides have been grown so far, such as, GaAsN,[2] InPN,[3] AlGaAsN,[4] and InGaAsN.[5] GaAsN and InGaAsN are being studied most for their applications in photodetectors and lasers in the 1.3–1.55 μm range.[1,6–8] Molecular-beam epitaxy (MBE) and metalorganic vapor phase epitaxy techniques have been used for the growth of dilute nitrides. A major problem associated with these growth techniques is the observed degradation of the crystalline quality, as nitrogen content in the material is increased.[9] Ion implantation techniques have been used to incorporate nitrogen in GaAs, InP, and AlGaAs.[4,10] However, ion implantation is associated with increased damages on the crystal surface and less activation efficiency and pulsed laser melting has been used to partly mend the defects and to enhance nitrogen activation.[11]

For the past four decades, liquid phase epitaxy (LPE) has been used to grow III–V compound semiconductor layers for commercial production of lasers and light-emitting diodes (LEDs). The advantage of LPE is that it is able to produce very high-quality materials with relative ease and low cost. However, LPE has not been used for the growth of dilute nitrides although the growth of nitrogen-doped GaP and GaAsP by LPE is an early established technology for the fabrication of visible LEDs and nitrogen up to 2×10^{20} cm^{-3} could be incorporated in LPE grown GaP.[12] In this letter, we describe the growth of dilute GaAsN layers by LPE using polycrystalline GaN as the source of nitrogen. The presence of nitrogen in the grown layer has been shown by a number of experiments. Our study further indicates that an electron trap is produced in the material whose origin is distinctly related to nitrogen.

Growth of the epitaxial layers was done in a horizontal LPE reactor employing the sliding boat technique. 5N purity Ga was first loaded in the growth melt and etch melt bins of the boat and baked at 750–800 °C for 10–15 h under Pd-diffused ultrapure hydrogen flow to reduce the residual impurities and the dissolved oxygen in Ga. Next, precisely weighted quantity of polycrystalline GaN powder was added to Ga in the growth bin and baked again at 750 °C for 2–3 h to completely dissolve GaN in Ga. Polycrystalline GaN, used in this work, was grown at Crystal Growth Centre, Anna University, Chennai by a chemical vapor deposition technique. Finally, the mixture of GaN and Ga was moved over a polycrystalline GaAs wafer to saturate the melt with As at the growth temperature. Since nitrogen has the tendency to outdiffuse at high temperatures, temperature of growth was typically kept within 750 °C. Growth was done on ⟨100⟩ oriented semiinsulating or n^+-GaAs substrates under a melt supersaturation of 8–10 °C and a cooling ramp of 0.4–0.5 °C/min. The grown layers were mirror smooth and free from any surface defects, as observed under a *Nomarski Interference Contrast* microscope.

The material was first characterized by Fourier transform infrared (FTIR) absorption measurements at room temperature. Figure 1 shows a typical absorption plot. The shoulder observed at 471 cm^{-1} is known to be due to the local vibrational mode of nitrogen at As site in GaAs.[13] Since LPE GaAs is grown under a hydrogen ambient in a pure carbon boat, the observed signature of nitrogen is due to that incorporated from the GaN containing melt.

In order to get an estimate of the nitrogen content in the material, infrared transmission measurements were done at room temperature on thinned samples with the substrate face polished. A typical transmission spectrum is shown in Fig. 2. Infrared absorption edge is found to be located at 915 nm, which corresponds to a material band gap of 1.35 eV. The room-temperature band gap of GaAs is 1.44 eV and hence

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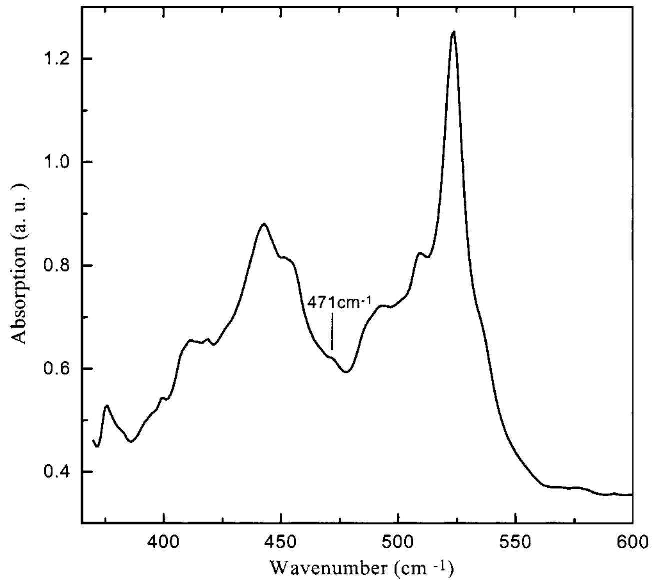

FIG. 1. FTIR absorption spectrum for LPE GaAsN.

the band-gap reduction by nitrogen incorporation is 90 meV, indicating about 0.5% nitrogen in the material.

To further establish our results, we have performed room-temperature photocurrent experiments on thin gold Schottky barrier diodes, deposited on the layer surface. Light from a tungsten halogen lamp, dispersed by an *Oriel 0.25-meter* monochromator was focussed on the gold film and the resultant photocurrent of the device, held at −1 V reverse bias, was monitored in a *Keithley model 236 Source-Measure unit*. Figure 3 shows the variation of reverse photocurrent of the device with incident photon energy. The prominent photocurrent peak at 1.3 eV is obviously due to the band edge absorption in the material. Hence, the material band gap is 1.3 eV, in agreement with that obtained from the optical transmission experiment. We also observe a second photocurrent peak at 0.7 eV photon energy. This is not due the to second-order dispersed light from the monochromator as we have used a cutoff filter to block all second-order dispersed beams falling on the sample. The only possibility is that the

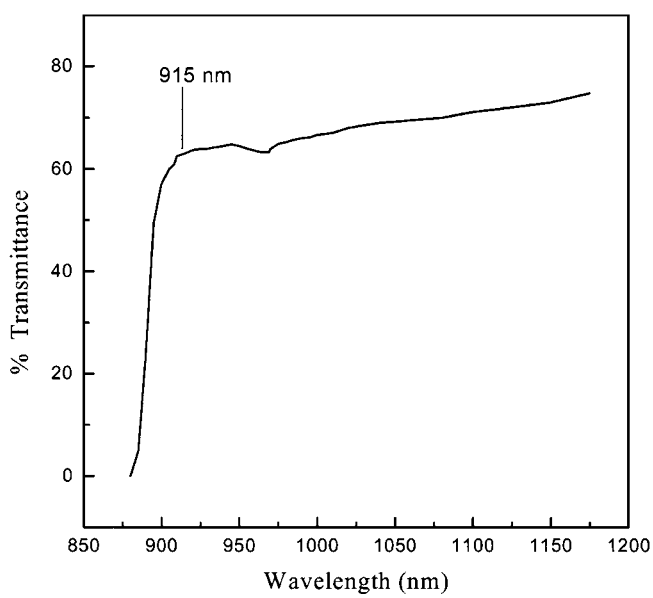

FIG. 2. Room-temperature optical transmission spectrum for LPE GaAsN.

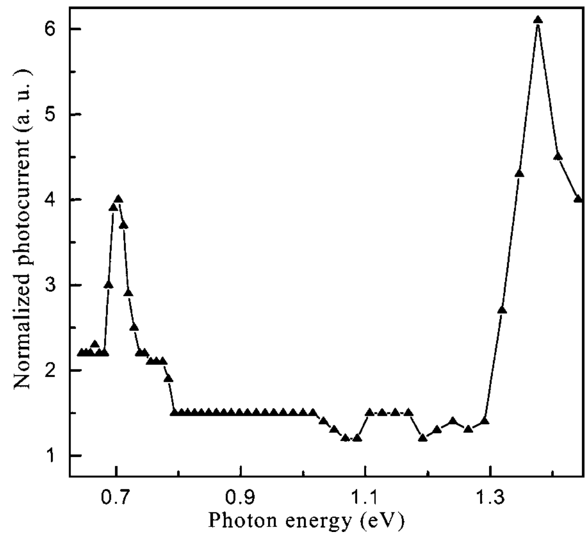

FIG. 3. Room-temperature photocurrent spectrum for LPE GaAsN.

observed photocurrent rise is due to carrier emission from a deep level at a depth of 0.7 eV with respect to either the conduction band or the valence band.

In the next step, photocapacitance experiments were done on the same Schottky barrier diodes, held at 10 K. The sample was mounted on the cold head of an *APD Cryogenics Displex* closed-cycle helium cryogenic system and illumination was provided through a sealed quartz window. The diode was cooled in the dark down to 10 K and then subjected to a reverse bias of −1 V. At this stage, the device was illuminated with photons in the energy range 0.6–1.5 eV and the corresponding variation of capacitance was recorded in a *MSI Electronics* capacitance meter. The resultant photocapacitance spectrum is shown in Fig. 4. As the energy of the incident photon is increased, photocapacitance started falling. This fall in photocapacitance is usual in LPE GaAs and is attributed to emission from the hole traps A and B located at energies 0.4 and 0.7 eV, respectively, above the valence band.[14] No electron trap is reported in LPE-grown GaAs at this energy range. In our case, however, we see a sharp rise in capacitance at 0.7 eV which indicates emission from an electron trap. This result agrees with that obtained from photocurrent experiments. We have repeated the experiments on

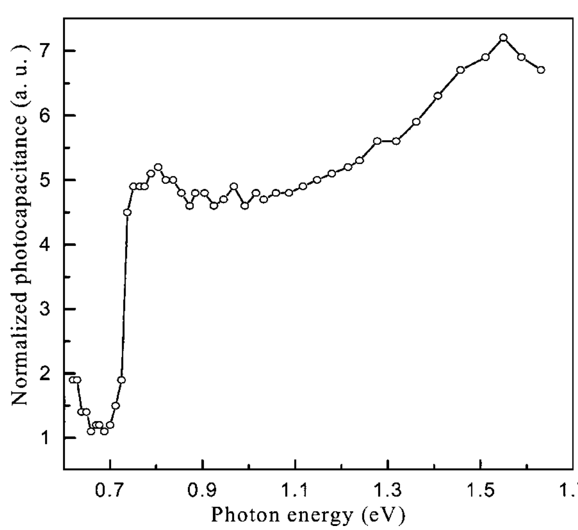

FIG. 4. 10 K photocapacitance spectrum for LPE GaAsN.

some more GaAsN samples and in all cases the presence of the electron trap at 0.7 eV energy is confirmed. This trap is thus related to the presence of nitrogen in our material. Earlier data on MBE-grown GaAsN have shown that the material contains a number of electron traps and at least two of them are related to nitrogen.[15,16] It has been suggested that the traps are due to either As–N-related complexes at As sites or N–N defects at As sites. Electron traps with energies of 0.6 or 0.66 eV were detected in MBE-grown GaAsN and were related to $(N-N)_{As}$ defects.[16–18] The 0.7 eV electron trap, observed in our LPE-grown samples, may be the same as one of these traps and accordingly we can assign $(N-N)_{As}$ as the possible origin of the trap.

In conclusion, we have used LPE technique to grow dilute GaAsN layers using polycrystalline GaN as the source of nitrogen. A band-gap reduction of about 90 meV is observed in the material. An electron trap with an optical ionization energy of 0.7 eV has been detected in the material. The trap is supposed to be related to $(N-N)_{As}$ defects.

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