MAGNETIC CIRCULAR DICHROISM OF LOW-TEMPERATURE-GROWN $Al_xGa_{1-x}As$

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ABSTRACT

We study magnetic circular dichroism of absorption (MCDA) of LT $Al_xGa_{1-x}As$ as a function of aluminum content. The MCDA spectrum of LT $Al_xGa_{1-x}As$ is distinctly different from the MCDA spectrum of LT GaAs, which has one paramagnetic and one diamagnetic peak at 0.95 eV and 1.18 eV, respectively. As the aluminum content increases, the spectrum of LT $Al_xGa_{1-x}As$ is dominated by a diamagnetic peak similar to the 1.18eV peak of the $EL2^0$-like defects in LT GaAs. However, the peak shifts to higher energies as x increases. The photoquenching and temperature dependence of this peak indicates an association with the EL2 defect. The paramagnetic peak observed in LT GaAs also shifts to higher energies but faster and eventually merges with the diamagnetic peak as the Al content increases. The study of the MCDA spectrum of LT $Al_xGa_{1-x}As$ as a function of aluminum content allows a better understanding of the MCDA phenomena of LT $Al_xGa_{1-x}As$ and LT GaAs, as well as the EL2-related transitions in bulk semi-insulating GaAs.

INTRODUCTION

Low-temperature-grown (LT) III-V semiconductors, especially LT GaAs, in the recent years have generated extensive interest in both academia and industry. The high resistivity and short carrier lifetime of LT GaAs have led to its use in various devices such as GaAs MESFETs and fast photodetectors[1,2]. This material has a high intrinsic defect concentration (As on a Ga site, As_{Ga}) which controls the material properties in both the as-grown[3] and most likely even the annealed states[4]. Scientists are in pursuit of understanding this defect and its effects on the material properties. Recently LT AlGaAs has been shown to have an even higher resistivity[5], and is being used in LT-GaAs/AlGaAs superlattices[6]. Electrical measurements indicate that the As antisite also might in this material play an important role[7]. To further the understanding of the influence of As_{Ga} on LT AlGaAs, and vice-versa, we study this defect as a function of Al content. This may increase our understanding of As_{Ga} in LT AlGaAs as well as in LT GaAs and bulk semi-insulating (SI) GaAs.

Magnetic circular dichroism of absorption (MCDA) is a good tool with which to obtain a fingerprint of the As antisite defect as well as determine its concentration. It is sensitive to paramagnetic defects. However, high concentrations of diamagnetic defects can also contribute to the signal. A contribution from only the paramagnetic As_{Ga}^+ is observed in bulk GaAs[8] (Figure 1). This spectrum has the typical one negative (0.94 eV) and two positive bands (1.1 eV and 1.35 eV). In comparison, the MCDA of LT GaAs (Figure 1) has two negative peaks (0.94 eV and 1.18 eV). From previous studies[4,9-11], it

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has been shown that the 0.94 eV peak is paramagnetic and that the 1.18 eV peak is mostly diamagnetic, as evidenced by the independance of the MCDA from the temperature. It has previously been suggested that this diamagnetic peak is related to the $A_1 \longrightarrow T_2$ internal transition associated with the diamagnetic state of the As antisite, As_{Ga}^0. Occurrence of the diamagnetic band in the MCDA is due to the high concentration of As_{Ga}^0, ~10^{20} cm^{-3}. Such a high concentration is present only in LT GaAs and As implanted GaAs. Similarly, LT $Al_xGa_{1-x}As$ should also have a high concentration of the antisite. Via MCDA we may determine the concentration of the antisite in this new material and how the Al content affects the incorporation and MCDA spectrum of As_{Ga}.

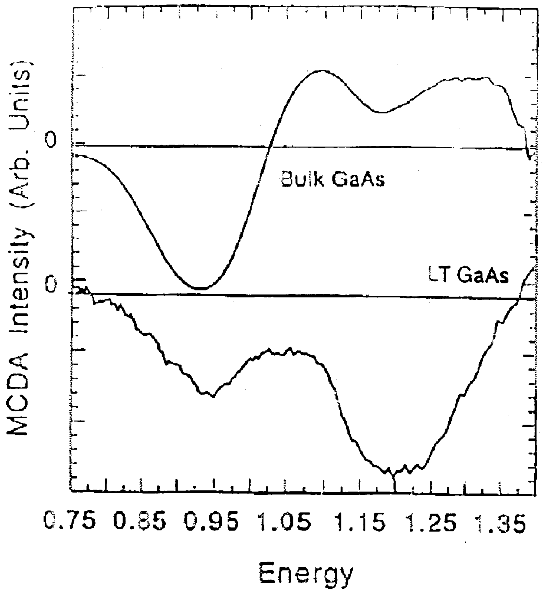

Figure 1: Typical MCDA spectra of As_{Ga} defects in bulk SI GaAs and LT GaAs grown at 210°C. The spectra are measured at T=1.8 K and B=2 T.

EXPERIMENTAL

The LT $Al_xGa_{1-x}As$ samples studied here are fabricated using a Varian Modular Gen II MBE chamber. On an n^+ GaAs substrate, first a buffer layer (~0.1 µm at 600 °C) of n^+ GaAs is grown and then the 1.5 µm epilayer of interest is grown at the substrate temperature of 230°C. The Al contents studied are x=0.0, 0.05, 0.1, 0.13, 0.16, 0.2, and 0.3. Substrates of n^+ doping are used to minimize the MCDA signal from the As antisites present in the GaAs substrate[12]. However, the sample with x=0.3 is grown to a 1 µm thickness on a semi-insulating (SI) GaAs. To further reduce the substrate influence on the MCDA spectrum, the substrate is polished down to less than 100 µm and the remaining the signal from the SI substrate is subtracted out by the computer.

For MCDA measurements the samples are placed in an optical cryostat at a temperature of 1.8K. The cryostat also houses a 6 T superconducting magnet, which is set to 2 T for MCDA. A 250W tungsten-halogen lamp is used as the light source. The generated photons which are dispersed by a grating monochromator are then polarized linearly. They then transverse through a long pass filter (λ>780 nm) and a quartz stress modulator operating at 42 kHz. The transmission of the alternating left and right circularly polarized light through the LT $Al_xGa_{1-x}As$ samples is collected by the liquid-N_2-cooled Ge-detector and the difference is taken by the lock-in. The MCDA spectrum thus obtained is corrected for the system response by subtracting the MCDA signal at 0 T and then dividing by the transmission (the modulator is replaced by the chopper) of the system plus sample. Finally, to remove the substrate influence, the spectrum of the substrate is subtracted.

Photo-quenching studies are made as well to correlate the MCDAsignal with the EL2 defect. First, spectra are collected with the sample cooled in the dark. Then the samples are exposed to white light illumination. After removing the light, new spectra are collected. If the spectra are associated with EL2 then the signal should decrease, implying that the illumination transformed the EL2 into its metastable state. To recover the full EL2 signal the sample has to be heated to above 140 K.

RESULTS

The MCDA spectra of LT $Al_xGa_{1-x}As$ and LT GaAs are similar as seen in Figure 2. At low Al percentage the MCDA spectrum of LT $Al_xGa_{1-x}As$ has the same features of two negative peaks. As the amount of Al increases the two peaks still exist but they start to shift to higher energies with the paramagnetic peak shifting faster than the diamagnetic peak. Eventually the paramagnetic peak merges into the diamagnetic peak (around x=0.2), but a definite shoulder at lower energies is visible. Even the shoulder disappears near x=0.3. For x=0.3 the only MCDA band observed is located at 1.35 eV.

Photo quenching studies indicate that these two peaks and eventually the one peak are associated with the EL2 defect. Unlike in LT GaAs[11], the peaks in LT $Al_xGa_{1-x}As$ are quenchable to a greater extent, ~ 80-90%. Temperature dependent MCDA is performed on the x=0.2 and 0.3 samples. The samples are first cooled in the dark to 1.8 K and MCDA spectra are collected at different, increasing temperatures. Next, the samples are cooled down to 1.8 K again and then quenched with white light. MCDA spectra are

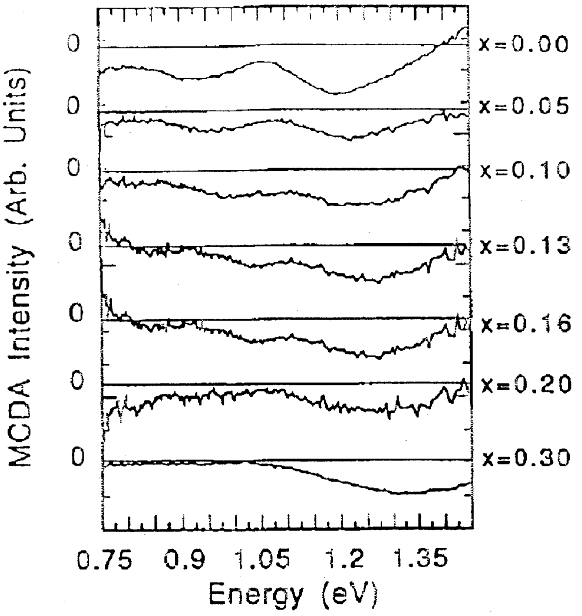

Figure 2: MCDA spectra of LT $Al_xGa_{1-x}As$ as a function of increasing Al content. The two negative peaks shift to higher energies with increasing x. The paramagnetic band starting at 0.94 eV shifts faster than the diamagnetic band at 1.18 eV for x=0.0, and eventually only the one peak is observable.

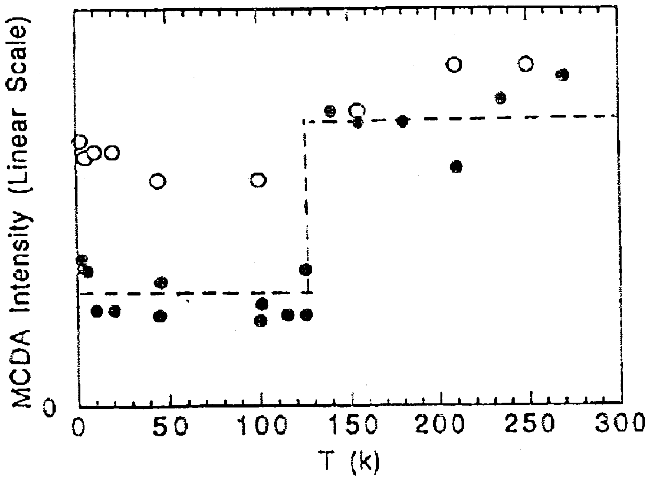

Figure 3: Recovery from photo quenching as a function of temperature for the 30% Al sample. Open circles are the MCDA signal of the unquenched sample while the filled circles represent the signal from the photo quenched sample.

collected for these samples at increasing temperatures as well. As seen from Figure 3, the original unquenched signal is fully recovered from the quenching process around 140 K, which is identical to the recovery process of quenched EL2 in bulk GaAs[13].

DISCUSSION

As mentioned earlier, MCDA is a sensitive technique for studying paramagnetic defects. Previous studies on bulk GaAs have shown that the As_{Ga} defect in its paramagnetic form (As_{Ga}^+) has a signal composed of two derivative like bands[8]. When added together, the resulting spectrum has a negative peak at 0.94 eV and two positive peaks at 1.1 eV and 1.35 eV. However, studies done by Pilikuat et al.[14] show that a diamagnetic peak associated with the As_{Ga} defect can also be detected by MCDA. A temperature scan enables one to distinguish between paramagnetic and diamagnetic contributions. The diamagnetic part is temperature independent, whereas the paramagnetic part decreases with tenperature. Recently, a diamagnetic peak has also been observed in LT GaAs[4].

Large quantities of As_{Ga} defects present in LT GaAs have been shown to control the properties of this material. The antisite defect has been shown to have high concentration in both neutral and positive charge states, $[As_{Ga}^0]=10^{20}$ cm^{-3} and $[As_{Ga}^+]$ $=5*10^{18}$ cm^{-3}, respectively. Previous MCDA measurements[4] show that the negative diamagnetic contribution at 1.18 eV is most likely related to the As_{Ga}^0. The two postive peaks observed in bulk GaAs are overlapped with the diamagnetic band in LT GaAs. The strong intensity of the As_{Ga}^0-related peak overshadows the postive peaks; therefore, only two negative MCDA bands are visible in LT GaAs. The two negative peaks are also observed in LT $Al_xGa_{1-x}As$, though, they shift to higher energies as a function of increasing Al content. The paramagnetic band shifts faster than the diamganetic band. The two MCDA peaks eventually merge into the one broad peak around x=0.3.

In the past, two models, the internal-transition model[8] and the valence-band-transition model[15], have been proposed to explain the MCDA spectrum of bulk SI GaAs. According to Meyer et al.[8], in the internal transition model, the MCDA transitions of As_{Ga}^+ are intra-center from the A_1 ground state to the two T_2 excited states of the defect. This A_1 state is at 0.52 eV above the valence band, and the two T_2 states are 1.05 eV and 1.29 eV above the A_1 states and are resonant with the conduction band. Because the transitions are internal, they are not expected to be strongly affected by the change in bandgap that arises when Al is incorporated into the system as derived from pressure dependence studies done on EL2 in GaAs[16].

The valence-band-transition model proposed by Kaufmann et al.[15] postulates that the two MCDA transitions of bulk GaAs are the photoneutralization transitions $As_{Ga}^+ + h\nu \longrightarrow As_{Ga}^0 + \text{hole}$ to the spin orbit splitting of the valence band. The transitions from the s-like ground state to p-like excited states are allowed by the dipole transition selection rules. These are satisfied in the valence band because of the band's p-like nature. The transitions are specifically to the heavy and light hole states of the Γ_8 valence band and the spin-orbit-split band. Thus, the hole transitions are from the ground As_{Ga}^+ defect to the excited valence band states. If this model is applied to the behavior of As_{Ga}^+ in LT $Al_xGa_{1-x}As$, it would require the valence band to shift with the increasing Al content. Studies done by J. Menéndez et al. show that the valence band of $Al_xGa_{1-x}As$ shifts with the Al composition[17,18].

From our results in LT $Al_xGa_{1-x}As$ the large shift in energy of the paramagnetic MCDA band seems to be in good accord with the shifting valence band. The internal transition model cannot account for the large shift. Thus, this shift is in better agreement with the valence band model. A more detailed discussion will be presented in a forth coming publication[19]. Also, the diamagnetic band in the MCDA spectra shifts slower than the paramagnetic band to higher energies with Al content, which is clearly indicated by the merging of the two spectra (Figure 2). The shift is still slightly larger than expected from the pressure dependence of the internal transition of EL2[16]. However, the deviation is not large enough to make a conclusive statement about this tentatively assigned transition, further studies are needed.

CONCLUSION

Our study of MCDA of LT $Al_xGa_{1-x}As$ indicates a high concentration of As_{Ga} in the material. The energy shift of the MCDA transitions observed in LT $Al_xGa_{1-x}As$ cannot be explained by ascribing the transitions to the internal T_2 states, however the shift is more consistent with the transitions to the valence band.

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