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Hole Trap Associated with High Background Doping in P-type GaAsN Grown by Chemical Beam Epitaxy

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Abstract

The hole trap H2 at 0.16 eV above the valence band maximum in GaAsN grown by chemical beam epitaxy, is confirmed to play an acceptor, since the energy level from deep level transient spectroscopy (DLTS) compares well with that from Capacitance-Temperature (C-T) method. In addition, the estimated carrier concentration assuming its energy level and density obtained by C-T explains the experimental carrier density from Capacitance-Voltage (C-V) measurements at room temperature. Therefore, this hole trap is the main cause of high residual carriers in the film. This hole trap defect is not thermally stable, its density increases and its energy level decreases due to the annealing after the growth.

1. Introduction

GaAsN alloy is a potential candidate for high efficiency multi-junction solar cell [1]. However, the electrical properties of this alloy are significantly degraded with incorporating a small amount of nitrogen, compared with those of the host material [2]. One of the serious problems, that decreases the conversion efficiency of (In)GaAsN based solar cell, is the high carrier concentration in undoped p-type films. However, the acceptor defect which is responsible for the high background doping is not yet understood. Previous DLTS results show five hole traps in CBE-grown GaAsN [3]. The H1, H3 and H5 defects appear in GaAs and recent results (under publishing) show that H5 is a recombination center. Therefore H2 is expected to be an acceptor. However, the role of H2, its contribution in background doping and its thermal stability are not reported yet.

2. Experimental procedure

GaAsN epitaxial layer was grown on p-doped GaAs (001) tilted 2° toward [110] substrate by the CBE method. Triethylgallium ($(C_2H_5)_3Ga$), tridimethylaminoarsenic ($[(CH_3)_2N)]_3As$,) and monomethylhydrazine ($H_3N_2CH_3$) were used as gallium, arsenic, and nitrogen source materials, respectively. The gas flow rates of these sources were 0.1, 1, and 6.4 sccm. The growth temperature and pressure were 440°C and 2×10^{-2} Pa, respectively. After growth, the samples were annealed under N_2 gas with a GaAs layer on top to prevent the loss of arsenic during the annealing process. The annealing times were from 1 to 40 min at 500°C.

3. Results and discussions

The DLTS signals of as-grown and annealed samples are shown in Fig. 1. The energy level and the capture cross section of the H2 hole trap, respectively E_{H2} and σ_{H2}, were determined from the slope and intercept values of the Arrhenius plot of the DLTS signals, according to

$$e_{H2} = v_{th}\, \sigma_{H2}\, N_V\, \exp\left(-\frac{E_{H2}}{kT}\right) \quad (1)$$

where e_{H2} is the emission rate for holes from the level into the valence band, v_{th} the thermal velocity of holes, N_V the effective density of states, and k the Boltzmann constant

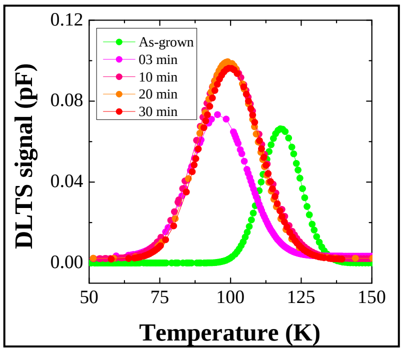

Fig. 1 DLTS signal of as-grown and annealed samples.

E_{H2} and σ_{H2} are shown in Figs. 2 and 3. They decreases with increasing annealing time and then saturates. Therefore, this defect is not thermally stable and its structure and electrical properties changed by the annealing.

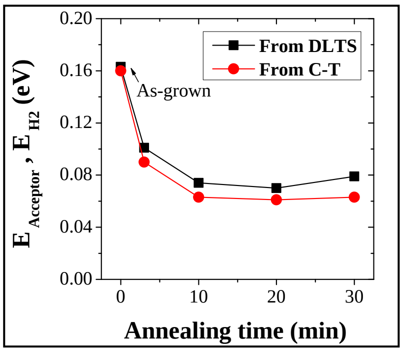

Fig. 2 Annealing time dependence of energy levels of H2 defect obtained by DLTS and C-T measurements

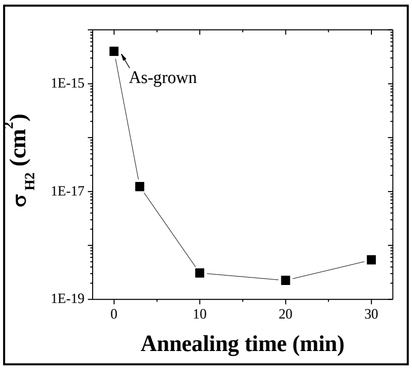

Fig. 3 Capture cross section of H2 defect of as-grown and annealed samples

To prove that H2 hole trap is an acceptor state, E_{H2} will be compared with $E_{Acceptor}$ from C-T measurement. Figure 4 shows the temperature dependence of the capacitances of as-grown and annealed p-type GaAsN Schottky junctions. The capacitances reveal a rapid change in a narrow range of temperature. After that, they saturate until room temperature. This behavior was explained by the existence of free carriers in the space-charge region of the film provided by the thermal ionization of impurities or acceptor defects.

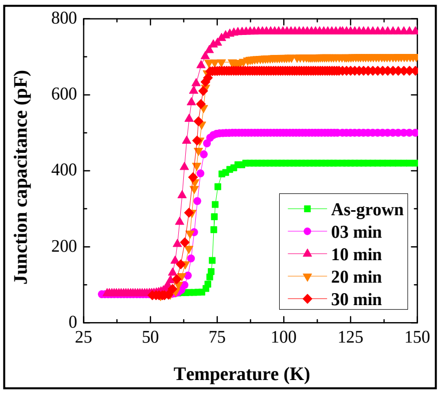

Fig. 4 Temperature dependence of junction capacitance measured at a reverse bias voltage V_R = -2 V

The acceptor density, $N_{Acceptor}$, was calculated based on the difference between the junction capacitance before and after its thermal ionization. Its energy level, $E_{Acceptor}$, is obtained from the slope of the rapid change. As shown in Fig. 2, there is a similarity between $E_{Acceptor}$ obtained from C-T measurement and E_{H2} obtained from DLTS results.
Therefore the H2 hole trap plays the role of an acceptor. $N_{Acceptor}$ increases significantly by annealing. This results confirm again that this defect is not thermally stable and its structure and electrical properties changed by the annealing. Based on the junction capacitance results, the estimated carrier concentration provided by the thermal ionization of the H2 acceptor defect was calculated according to

$$N_{Carriers(C-T)} = \frac{N_{Acceptor}}{1+\frac{1}{4}\exp\left(\frac{E_{Acceptor}-E_F}{kT}\right)} \qquad (2)$$

where E_F is the Fermi level. The evolution of $N_{Carriers(C-T)}$ with the annealing time is shown in Table I. To clarify the effect of the H2 acceptor defect on background doping in the film, the estimated carrier concentration from C-T measurements will be compared with the experimental carrier concentration at room temperature from C-V measurements, $N_{Carriers(C-V)}$.
As shown in Table I, the estimated $N_{Carriers(C-T)}$ considering the thermal ionization of the H2 acceptor defect has a good relation with $N_{Carriers(C-V)}$. Therefore this acceptor state is mainly responsible for the high background doping in unintentionally doped GaAsN grown by CBE.

Table I Estimated and experimental carrier concentrations, respectively from C-T and C-V results

	As-grown	03 min	10 min	20 min	30 min
$N_{Carriers(C-T)}$ (10^{17} cm^{-3})	0.55	0.78	2.60	2.45	1.81
$N_{Carriers(C-V)}$ (10^{17} cm^{-3})	0.67	1.10	3.05	2.89	2.16

4. Conclusions

It was found that the hole trap H2, obtained 0.16 eV above the valence band maximum plays the role of acceptor, since its energy level from DLTS and C-T are similar, and the estimated carrier concentration using its energy level and density from C-T has a good relationship with that obtained by C-V at room temperature. This hole trap is the main cause of high background doping. This defect was not thermally stable, its energy level and capture cross section decreased due to the annealing.

Acknowledgements

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