Effects of Annealing on the Electronic Properties of GaAsN

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Abstract:

In this work, we have investigated the influence of post-growth annealing on the electronic properties of gallium arsenide nitride (GaAsN) alloys films. Following annealing, substantial improvements in the electron mobility and free carrier concentration were observed. Temperature dependent Hall measurements reveal a thermally activated increase in free carrier concentration for temperatures higher than 150K, presumably due to N-related deep-level defects within the GaAsN bandgap. Post-growth annealing leads to a temperature-independent free carrier concentration, suggesting that annealing reduced the concentration of these N-related deep-level defects.

MATS

Introduction:

Indium gallium arsenide nitride ((In)GaAsN) alloys with a few percent nitrogen have potential applications in infrared laser diodes, high efficiency solar cells, and other electronic devices [1-4]. However, as-grown films often exhibit photoluminescence (PL) efficiencies and electron mobilities substantially lower than those of (In)GaAs [5]. Although post-growth annealing has been extensively used to improve the PL efficiency of (In)GaAsN [4], the mechanisms for this improvement are not well understood, and the influence of annealing on the electronic properties remains unknown. In this work, we have investigated the influence of annealing on the electronic properties of bulk GaAsN films. We find that annealing substantially improves the transport properties of GaAsN, presumably by reducing the concentration of N-related deep-level defects.

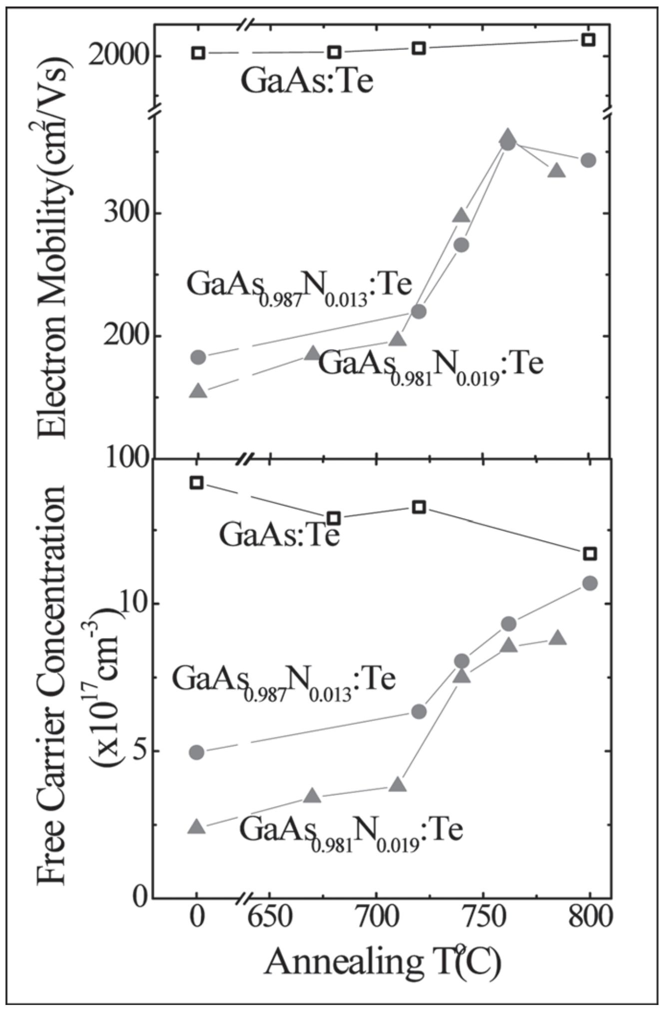

Figure 1: Electron mobility (a) and free carrier concentration; (b) for GaAs(N):Te films as a function of annealing temperature.

Methods/Materials:

$GaAs_{1-x}N_x$ films, with N composition up to x = 0.019, were grown by plasma-assisted molecular beam epitaxy, using Ga, As_2 and an N_2 radio frequency (rf) plasma source. For all films, n-type doping was achieved using a GaTe source for Te. Post growth annealing was performed from 650 to 800°C for 60s in a N_2 ambient, with a GaAs proximity cap to prevent As out-diffusion. To determine the electron mobility and free carrier concentration, transport measurements were implemented in both Van der Pauw and Hallbar geometries. Variable temperature resistivity and Hall measurements were performed from 50K to room temperature (300K).

Results and Discussion:

Figure 1 (a) and (b) show the free carrier density, [n], and electron mobility, μ, as a function of annealing temperature,

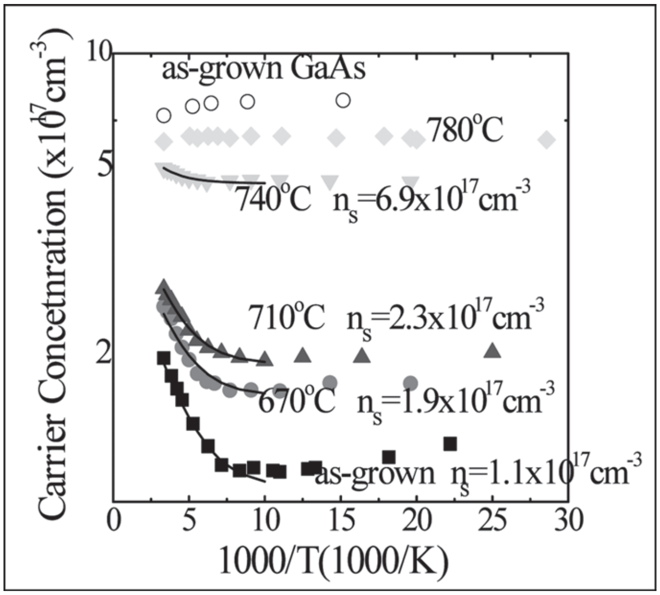

Figure 2: Free carrier concentration as a function of measurement temperature for as-grown GaAs:Te and GaAsN:Te films annealed at different temperatures.

for GaAsN films in comparison with GaAs control films, doped with the same target Te doping concentration. For GaAs:Te, insignificant variations in [n] or μ with annealing temperature were observed. However, for GaAsN:Te films, we observed a remarkable increase in both [n] and μ as the annealing temperature is increased.

Figure 2 shows the log of the carrier density vs. reciprocal temperature for an as-grown bulk GaAs:Te films, in comparison with GaAsN:Te films annealed at various temperatures. For GaAs:Te, [n] is temperature-independent in the explored temperature range, 50 to 300K, typical of degenerate III-V semiconductors [6]. However, for the as-grown GaAsN:Te films, [n] decreases exponentially as the temperature decreases down to 150K, indicating the presence of thermally activated deep donor levels within the GaAsN bandgap, presumably N-related deep-level defects. The saturation of [n] at low temperature (T < 150K) is attributed to shallow donors such as Te donors. As the annealing temperature increases, the saturation value of [n] increases. Finally, for 780°C annealed GaAsN:Te films, the carrier concentration is temperature independent.

To extract the activation energy of the N-related deep donor level, E_N, we use an expression for semiconductors with two distinct donor levels [6],

$$\sqrt{n(n-n_S)} \propto \exp(-\frac{E_N}{2k_BT})$$

where k_B is Boltzmann constant, n is the apparent carrier concentration, and n_s is the saturated shallow donor concentration. As shown in Figure 2, n_s increases with annealing temperature, suggesting that the deep-level defect concentration is reduced as the annealing temperature increases. For all annealing temperatures, the activation energy of the deep-level trapping centers, E_N, is 57 meV, which is much greater than the activation energy of hydrogen-like shallow donor levels in GaAs, which are typically 5-6 meV. Thus, the deep donors act as carrier trapping/scattering centers, leading to the low [n] and μ in the as-grown GaAsN:Te films. After annealing, as shown in Figure 1, [n] and μ are substantially increased, suggesting that the annealing-induced improvement in electronic properties of GaAsN is due to the removal the N-related deep-level defects.

Summary and Conclusions:

In summary, we have studied the effect of rapid thermal annealing on the electronic properties of GaAsN films. For the as-grown films, the free carrier concentration increases exponentially with increasing measurement temperature up to room temperature, suggesting the presence of N-related deep-level defects within the GaAsN bandgap. An analysis of temperature-dependent Hall and resistivity measurements reveals a 57 meV activation energy for the N-related deep-level defects. For the annealed films, the free carrier concentration and electron mobility are substantially improved with increasing annealing temperature, which is presumably related to the removal of the N-induced deep level trapping centers.

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References:

[1] M. Fischer, D. Gollub, and A. Forchel, Jpn. J. Appl. Phys. Part 1 - Regul. Pap. Short Notes Rev. Pap. 41, 1162 (2002).

[2] J. F. Geisz and D. J. Friedman, Semicond. Sci. Technol. 17, 769 (2002).

[3] S. R. Kurtz, A. A. Allerman, E. D. Jones, J. M. Gee, J. J. Banas, and B. E. Hammons, Appl. Phys. Lett. 74, 729 (1999).

[4] J. S. Harris, Semiconductor Science & Tech 17, 880 (2002).

[5] M.Reason, Y.Jin, H.McKay, N.Mangan, D. Mao, R.Goldman, X. Bai, and C. Kurdak, J. Appl. Phys 102, 103710 (2007).

[6] E. F. Schubert, Doping in III-V semiconductors (Cambridge University Press, UK, 1993).