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Growth and Evaluation of GaAsN Films With Different N Distribution Grown by Atomic Layer Epitaxy

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Abstract

GaAsN films with different N distributions have been grown using the atomic layer epitaxy method to evaluate the effects of N distribution on the electrical properties of GaAsN. Three films, which had the same N composition with different N distribution, could be grown. The densities of N induced scattering center in the grown GaAsN films were different from each other instead of the same N composition. These results directly indicate that inhomogeneous N distribution modifies electrical properties of GaAsN. Note that controlling N distribution intentionally not only degraded but also improved electrical properties of GaAsN films.

1. Introduction

InGaP/(In)GaAs/Ge triple junction solar cells suffer from heat loss due to the difference in the energy gap between GaAs and Ge. To reduce the heat loss, it is suggested insertion on new cells between GaAs and Ge, which makes 4 junction solar cells. As a new material, InGaAsN has been suggested[1, 2]. However, introduction of N atoms into InGaAs degrade electrical properties of InGaAsN[3]. The origin of this degradation is considered to be inhomogeneous distribution of N. N induced scattering centers for carriers could be reduced by controlling the surface during growth[4]. This method might improve homogeneity of N distribution, however, it was difficult to observe N distribution in the GaAsN films. Therefore, we are trying to grow GaAsN thin film using the atomic layer epitaxy (ALE) method, which could control the growing surface at the atomic layer level[5]. Because the growth can be controlled by an atomic layer unit such as the ALE method, it is possible to change the spatial distribution of N atoms. In this study, we evaluated electrical properties of GaAsN thin films of which the N distribution was intentionally changed using the ALE method.

2. Experimental procedure

We grew GaAsN thin films on semi-insulating GaAs (001) substrates using the ALE method. GaAsN precursor gases were $(CH_3)_3Ga$ (TMGa), $H_3N_2CH_3$ (MMHy), and $[N(CH_3)_2]_3As$ (TDMAAs). The growth temperature was 480°C. To control N distribution in the film, two gas flow sequences, as shown Fig. 1, were used in combination. One cycle of sequence Fig. 1(a) and Fig. 1(b) could grow one monolayer (ML) of GaAsN and GaAs, respectively. *M* and *N* cycles of sequences indicated in Fig. 1(a) and (b) were repeated to grow GaAsN films. Hereafter, the films grown in these sequences were called (*M*: *N*). For example, (1: 3) means the superlattice structure repeating 1 ML of GaAsN and 3 ML of GaAs (Fig. 2(b)). (1: 3), (1: 5) and (1: 0) films as shown in Fig. 2 were grown in this work. To equalize the average N composition in all films, the N composition in each GaAsN atomic layer was controlled by changing duration of the N precursor. N composition and superlattice structures of the films were evaluated by X-ray diffraction (XRD). All films grown in this study showed p-type conductivity. Temperature dependence of carrier mobility of the films at 20 to

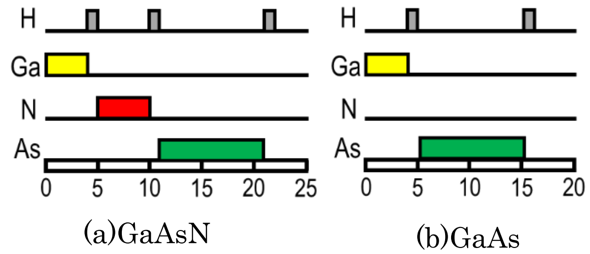

Figure 1. Gas sequences for monolayer growth for (a)GaAsN and (b)GaAs. N precursor gas supplied at 0.53 to 5.39 seconds.

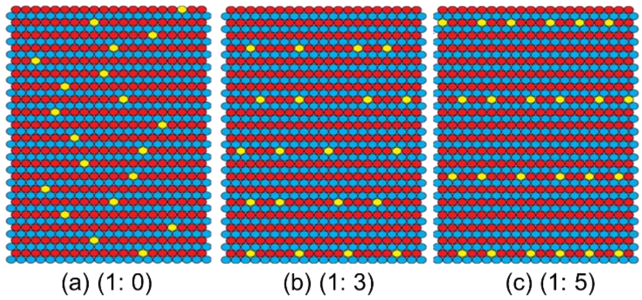

Figure 2. Schematic models of GaAsN films grown in this study. The blue, red and yellow circles indicate Ga, As and N atoms, respectively.

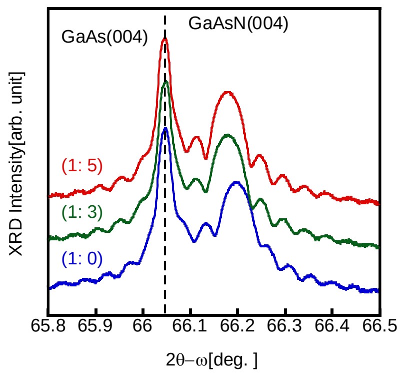

Figure 3. X-ray diffraction patterns of GaAsN thin films grown by different gas sequences.

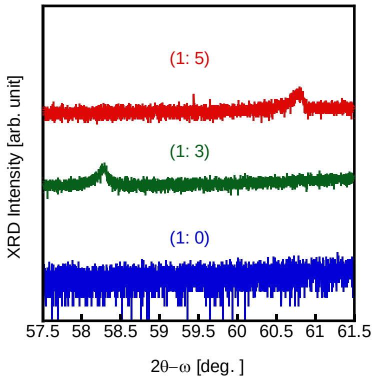

Figure 4. This figure shows degree of superlattice structure diffraction peak are different.

300 were evaluated by Hall-effect measurement.

3. Results and Discussion

XRD patterns around (004) diffraction for the GaAsN thin films with different N distributions are shown in Fig. 3. Peak positions of GaAsN (004) for all films are almost the same and clear thickness interference fringes were observed. These indicated good crystallinity of films and average of N composition are the same (0.4%). On the lower side of (004) diffraction, as shown in Fig. 4, diffraction peaks attributed to superlattice were observed at around 60° and 58° for the (1: 5) and (1: 3) films, respectively. Positions and intensities of the peaks were consistent with the simulation using the growth condition. These results support that grown films had different N distribution while average N compositions were the same.

Temperature dependence of carrier mobility for the (1: 5) film is shown in Fig. 5. The contribution of scattering process on carrier mobility is separated by parameter fitting. Ionized impurity scattering (μ_{II}), alloy scattering (μ_{AL}), and acoustic phonon scattering (μ_{AC}) were considered. By assuming by Mattiessen's rule, the total hole mobility (μ_{total}) given by following equation.

$$\frac{1}{\mu_{total}} = \frac{1}{\mu_{II}} + \frac{1}{\mu_{AL}} + \frac{1}{\mu_{AC}} \tag{1}$$

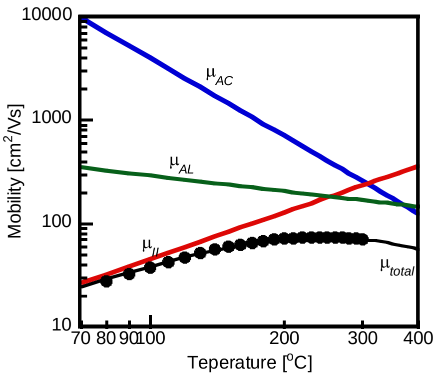

Figure 5 Experimental and calculated hole mobilities for GaAsN (1:5) as a function of temperature. Filled circle are experimental data. The black, blue, green, and red solid lines are the total hole mobility, acoustic phonon, alloy, and ionized impurity scattering.

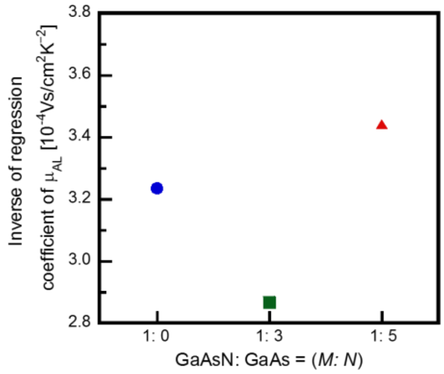

Figure 6 Relationship between inverse of regression coefficients (${C_{AL}}^{-1}$) and GaAs:GaAsN = (*M: N*).

Here, μ_{AC} was fixed as the same value as that of GaAs[6]. μ_{AL} and μ_{II} were assumed to be $C_{AL}T^{-1/2}$ and $C_{II}T^{3/2}$ [7], where C_{AL} and C_{II} were fitting parameters and T was measurement temperature (K). ${C_{AL}}^{-1}$ and ${C_{II}}^{-1}$ are in proportion to the density of each scattering centers. According to the previous study, N induced scattering was proportional to $T^{-1/2}$, which had the same temperature dependence to the alloy scattering. Thus, it will be large when GaAsN film had large N induced scattering. The fitting results for the (1: 5) were also shown in Fig. 5 (μ_{total}) and were in good agreement with the experimental results.

The values of ${C_{AL}}^{-1}$ for all films are shown in Fig. 6. Although the average N composition was the same in all films, (1: 3) shows the lowest value while (1: 5) shows the highest. These indicate that inhomogeneous N distribution as (1: 5) increases the N induced scattering. Here, we would like to note that the controlling N distribution could improve electrical properties of GaAsN films as shown by (1:3).

4. Conclusions

In this study, GaAsN films with different N distribution were grown using the ALE method to evaluate the effects of N distribution on the electrical properties of GaAsN. Three films which had the same N composition with different N distributions could be grown. The density of N induced scattering was different for the three films instead of having the same N composition. These results directly indicate that inhomogeneous N distribution modifies the electrical properties of GaAsN. It is noted that controlling N distribution intentionally not only degraded but also improved the electrical properties of GaAsN films.

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