Improvement of Opt-Electrical Properties in GaAsN by Controlling Step Density During Chemical Beam Epitaxy Growth

Hidetoshi Suzuki, Makoto Inagaki, Takahiko Honda, Yoshio Ohshita, Nobuaki Kojima, Masafumi Yamaguchi

> Toyota Technological Institute 2-12-1, Hisakata, Tempaku, Nagoya 468-8511, Japan Phone: +81-52-809-1830 E-mail: ssk@toyota-ti.ac.jp

1. Introduction

(In)GaAsN alloys have attracted a great deal of attentions due to their potentials for super high efficiency multi-junction solar cells [1]. So far, the conversion efficiency of (In)GaAsN solar cells is still low due to their poor electrical properties. Carrier mobilities and minority carrier lifetimes of both electron and hole are deteriorated by N incorporation [1, 2]. Although several growth techniques have been applied for fabrication of (In)GaAsN films, sufficient properties have not been obtained. In the point of hole mobility, for example, GaAsN films grown by molecular beam epitaxy (MBE) and metal organic chemical vapor deposition (MOCVD) were the same in spite of difference in their residual impurity concentrations [1, 2]. The mobilities were lower than the values calculated from ionized impurity scattering, phonon scatterings, and alloy scattering [3]. The amount of another scattering centers were proportional to N composition [3]. This indicated that N induced the scattering centers (SC_N) . Such centers might degrade the other opt-electrical properties. However, SC_N could not be reduced by MBE and MOCVD as mentioned above. To overcome this, we have been developing chemical beam epitaxy (CBE) method that is using gaseous sources under low pressure ($\sim 10^{-2}$ Pa). CBE growth will be sensitive to surface morphology such as step and terrace compared with MBE and MOCVD, because gaseous N molecules react more softly at the surface than radical N and reactions at vapor phase can be ignored by low growth pressure. Especially for N atoms, both step and terrace are act as incorporation site into solid phase [4, 5].

In this study, the effects of surface morphologies during the growth on opt-electrical properties of GaAsN films grown by CBE are investigated. The amount of SC_N is used as an indicator of the electrical property.

2. Experimental

Growth and measurement conditions

Un-doped p-type GaAsN thin films were grown by CBE. The details of our CBE system were described in previous papers [6]. To control lattice lengths (L) separated by two adjacent steps, 2, 6, 10° off GaAs (001) substrates were used. Tilted direction was [010] to obtain both Ga and As -terminated steps.

The hole mobilities of grown GaAsN were obtained by Hall effect measurements by the van der Pauw method at

80 ~ 400K.

Fitting procedure

The temperature dependence of the hole mobilities was analyzed by parameter fitting to evaluate the amount of SC_N . Ionized impurity scattering (μ_{II}) , alloy scattering (μ_{AI}) , acoustic phonon scattering (μ_{AC}) , polar optical phonon scattering (μ_{PO}) , and the scattering by $SC_N(\mu_N)$ were considered. The temperature dependences of both acoustic and polar optical phonon scatterings were calculated using the equations that consider the valence band structure using empirical parameters [7]. The parameters such as deformation potential and effective mass of light/heavy holes were assumed to be equal to those of GaAs, because the N compositions in these films were low and the modification of the valence band structure by incorporating N atoms is minimal in dilute N semiconductor alloys [8]. The alloy scattering was calculated by N composition and energy difference in valence band maximum of GaAs and GaN [9]. The typical temperature dependence of ionized impurity scattering can be written as $\mu_{II} = K_{II} T^{3/2}$ [10]. Inverse numbers of K_{II} is proportional to concentrations of ionized impurity. μ_N was assumed to be $\mu_N = K_N T^a$. Three parameters $(K_{II}, K_N, \text{ and } \alpha)$ were calculated by parameter fitting. Index α reflect the property of SC_N . Due to difference in index α of films, it was difficult to discuss K_N itself. Thus, μ_N^{-1} at 300K was used to evaluate the amount SC_N .

3. Results and discussion

Typical temperature dependence of hole mobility of GaAsN films grown on 2° and 10° off GaAs (001) substrates are shown in Fig. 1. The calculated curves (solid lines) are in good agreement with the experimental data under 320K. K_{II} values were consistent with impurity concentrations. The deviation above 320K is attributed to underestimation of phonon scatterings. This influence becomes small at low temperature region, and μ_N is dominant at middle temperature region (150 ~ 300K). These results support the accuracy of our fitting procedure and the calculated parameters (α and K_N).

The mobility of the film grown on 10° off substrate is larger than that grown on 2° off substrate at whole temperature region. α values of both films are the same (0.6 ± 0.2). The increase of mobility in the film grown on 10° off is attributed to the reduction of SC_N .



Fig. 1: Experimental and calculated hole mobilities as function of temperature for GaAsN films grown on 2° and 10° off substrates.

The relationship between N composition and SC_N is shown in Fig. 2. In the films grown on 2° off substrate (*long terrace*), μ_N^{-1} are proportional with N composition, and the line is the same with that of other growth techniques. On the other hand, μ_N^{-1} were lower than that line and slightly decrease with increasing [N] in the case grown on vicinal substrates (*short terrace*). This result demonstrates that the electrical property of GaAsN can be improved by modifying the surface during growth.



Fig. 2: The relationship between μ_N^{-1} at 300K and N composition. Off angles of substrates are 2° (*low*) and 2° ~ 10° (*high*). Dashed line is guide to the eyes.

We propose that formation probability of SC_N at terrace

is higher then that at steps. With decreasing *L*, the ratio of N source molecules that reach steps will increase. In other words, the amount of N incorporated at terrace will decrease as a function of $(L-2\lambda)/L$, where λ is diffusion length of the N source at the surface. The relationship between μ_N^{-1} and *L* can be fitted by $A_0(L-2\lambda)/L$ (as shown in Fig. 3). The calculated λ is consistent with previous results [11]. These results support our proposal.



Fig. 3: Relationship between μ_N^{-1} and terrace length (*L*). Dashed line is explained in the text.

4. Conclusions

The effects of steps and terraces during the growth on electrical properties of GaAsN films grown by CBE were investigated, and improvements of the electrical properties were demonstrated.

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References

- [1] A. J. Ptak, et al., J. Cryst. Growth 251 (2003) 392.
- [2] T. Matuura, et al., Jpn. J. Appl. Phys. 42 (2004) L433
- [3] T. Hashiguchi, et al., in preparation
- [4] H. Saito, et al., Jpn. J. Appl. Phys. 35 (1996) L1644.
- [5] H. Suzuki, et al., J. Cryst. Growth: to be published.
- [6] H.-S. Lee, et al., J. Cryst. Growth **275** (2005) e1127.
- J.D. Wiley: in Semiconductors and Semimetals, ed. R.K.
 Willardson and A.C. Beer (Academic Press, New York, 1975)
 Vol. 10, Chap. 2, p. 91.
- [8] P. Perlin, et al., Appl. Phys. Lett. 76 (2000) 1279.
- [9] L. Makowski and M. Glicksman, J. Phys. Chem. Solids 34 (1973) 487.
- [10] S.M. Sze: in Semiconductor Devices (Wiley, New York, 1985) p. 23.
- [11] K. Mochizuki, et al., Jpn. J. Appl. Phys. 27 (1988) 1585.