Extended Abstracts of the 2004 International Conference on Solid State Devices and Materials, Tokyo, 2004, pp. 810-811

D-8-1

Low-dislocation AlGaN thin films grown using $Al_{1-x}Si_xN$ nano-disks (x= 0.07~0.17)

Tetsuya Akasaka, Yoshitaka Taniyasu, Makoto Kasu, and Toshiki Makimoto

NTT Basic Research Laboratories, NTT Corporation,
3-1 Morinosato- Wakamiya, Atsugi, Kanagawa 243-0198, Japan

1. Introduction

Nitride semiconductors are generally grown on sapphire or SiC substrates heteroepitaxially because GaN bulk substrates are still expensive and have small areas. Many cracks and threading dislocations (TDs) form in these nitride semiconductor films grown on such foreign substrates because of large mismatches in the lattice constants and thermal expansion coefficients between nitride semiconductors and the substrates. Furthermore, even when a GaN bulk substrate is used, methods for reducing the threading dislocation density (TDD) are essential because lattice constants and thermal expansion coefficients of nitride semiconductors vary widely depending on their composition. In this paper, we propose the use of $Al_{1-x}Si_xN$ ternary alloys [1] with a Si molar fraction ranging typically from 0.07 to 0.17 in order to reduce TDD of AlGaN thin films on SiC. We found that thin $Al_{1-x}Si_xN$ forms nano-sized disks that change propagation of TDs and diminish them. The AlGaN film required for this technique is as thin as 1 μm. So, one can grow crack-free AlGaN films with low TDD.

2. Experimental

Samples were grown on (0001) Si oriented n-type 6H-SiC substrates by metalorganic vapor phase epitaxy (MOVPE). A sample structure is schematically shown in Fig. 1. The sample consisted of a Si-doped 400-nm-thick $Al_{0.1}Ga_{0.9}N$ layer, seven pairs of an $Al_{1-x}Si_xN$ nano-disk interlayer and a Si-doped 100-nm-thick $Al_{0.1}Ga_{0.9}N$ layer, a Si-doped 150-nm-thick GaN layer, and a Si-doped 100-nm-thick $In_{0.15}Ga_{0.85}N$ layer. The averaged height of the $Al_{1-x}Si_xN$ nano-disks was eight monolayers. The Si molar fractions of the $Al_{1-x}Si_xN$ nano-disk interlayers were varied from 0 to 0.29. We assumed that the Si molar fractions were equal to the molar flow rate ratio $[SiH_4]/([SiH_4]+[TMA])$ during the growth of $Al_{1-x}Si_xN$. The TDD was estimated by two methods: observing growth pits on the surface of the Si-doped 100-nm-thick $In_{0.15}Ga_{0.85}N$ with a scanning electron microscope [2], and measuring the rocking curve of X-ray diffraction (XRD) of the sample. The symmetrical (0002) and asymmetrical (10-10) rocking curves of AlGaN were used to estimate the screw-type and edge-type TDs, respectively [3]. For XRD measurements, samples without the top GaN and $In_{0.15}Ga_{0.85}N$ layers were used in order to obtain the asymmetrical (10-10) rocking curves of AlGaN. TDs were also observed by cross-sectional transmission electron microscopy (X-TEM).

3. Results and discussion

Figure 2 shows the TDD of AlGaN estimated by observation of growth pits by SEM (a), and by rocking curves of XRD (b). In Fig. 2(a), the TDD of AlGaN without the $Al_{1-x}Si_xN$ nano-disk interlayers is $3x10^9$ cm^{-2}. Then, TDD gradually decreases with increasing Si molar fraction and reaches the minimum value of $6x10^8$ cm^{-2} at x=0.17. It can be seen that the edge-type TDD estimated by XRD [Fig. 2(b)] and its dependence on the Si molar fraction are almost similar to those by SEM. On the other hand, the screw-type TDD is one order magnitude lower than the edge-type TDD and nearly independent of the Si molar fraction. Thus, most of TDs in AlGaN films are pure edge dislocations, and they are effectively eliminated by the $Al_{1-x}Si_xN$ nano-disk interlayers with the optimized Si molar fraction.

The AFM image shown in Fig. 3 was taken for $Al_{0.83}Si_{0.17}N$ of eight monolayers deposited on an $Al_{0.1}Ga_{0.9}N$ film. The deposited $Al_{0.83}Si_{0.17}N$ forms nano-disks whose diameter, height, and density are 30~40 nm, 3~6 nm, and $1.6x10^{11}$ cm^{-2}, respectively.

Figure 4 shows an X-TEM image near the $Al_{0.93}Si_{0.07}N$ nano-disk interlayers. Two threading dislocations run parallel to each other and are terminated at the top $Al_{0.93}Si_{0.07}N$ nano-disk interlayer. As described above, TDs eliminated by this technique are pure edge dislocations. It can be considered in Fig. 4 that two pure edge dislocations having opposite Burgers vectors bend at an $Al_{0.93}Si_{0.07}N$ nano-disk and make a half-loop. Large biaxial strain between the $Al_{0.1}Ga_{0.9}N$ and $Al_{0.93}Si_{0.07}N$ nano-disk is probably the reason for the elimination of the TDs.

4. Conclusions

TDs in AlGaN thin films grown directly on SiC were successfully eliminated by inserting multiple $Al_{1-x}Si_xN$ nano-disk interlayers. The lowest TDD was $6x10^8$ cm^{-2}. The formation of the dislocation half-loops at the $Al_{1-x}Si_xN$ nano-disk reduced the TDD of AlGaN thin films on SiC.

Acknowledgements

The authors would like to thank Dr. T. Nishida for helpful discussion about MOVPE growth and Dr. Y. Hirayama, Dr. K. Torimitsu, and Dr. H. Takayanagi for their encouragement through this work.

References

[1] M. Kasu, Y. Taniyasu and N. Kobayashi, Jpn. J. Appl. Phys. **40** (2001) L1048.
[2] Y. Kawaguchi, M. Shimizu, M. Yamaguchi, K. Hiramatsu, N.

Sawaki, W. Taki, H. Tsuda, N. Kuwano, K. Oki, T. Zheleva, and R. F. Davis, *Proceedings of the Second International Conference on Nitride Semiconductors* (1997) 22.
[3] T. Metzger, R. Hopler, E. Born, O. Ambacher, M. Stutzmann, R. Stommer, M. Schuster, H. Gobal, S. Christiansen, M. Albrecht, and H. P. Strunk, Philosophical Magazine A **77** (1998) 1013.

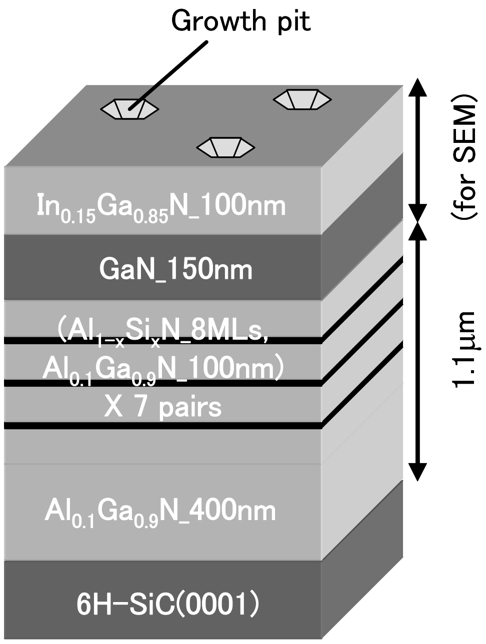

Fig. 1: A schematic illustration of sample structure.

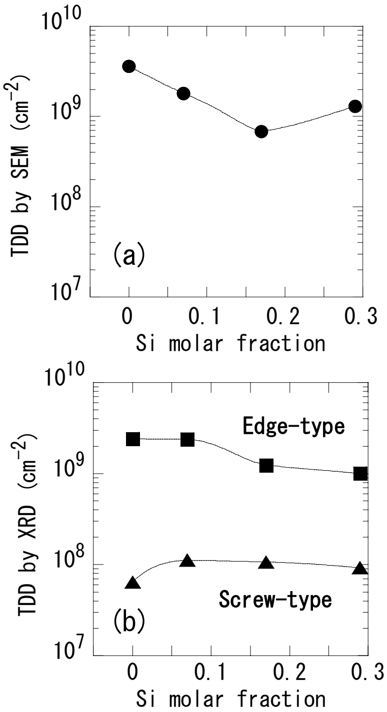

Fig. 2: TDD in AlGaN thin films plotted as a function of Si molar fraction in $Al_{1-x}Si_xN$ nano-disk interlayers estimated by SEM (a), and XRD (b), respectively. In Fig. 2(b), closed squares and triangles show the edge-type and screw-type dislocations, respectively.

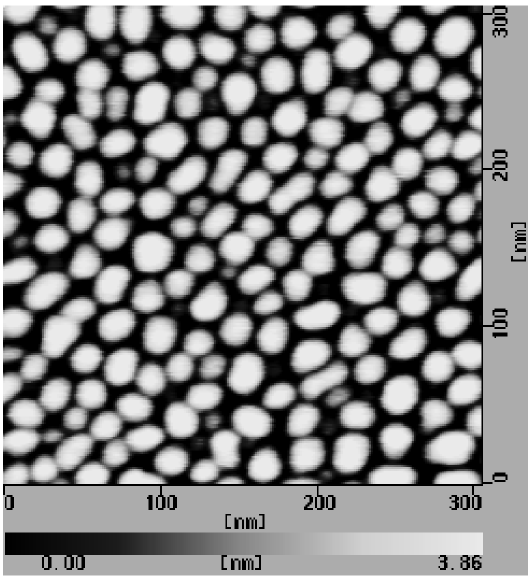

Fig. 3: An AFM image shown for $Al_{0.83}Si_{0.17}N$ nano-disks deposited on an $Al_{0.1}Ga_{0.9}N$ film

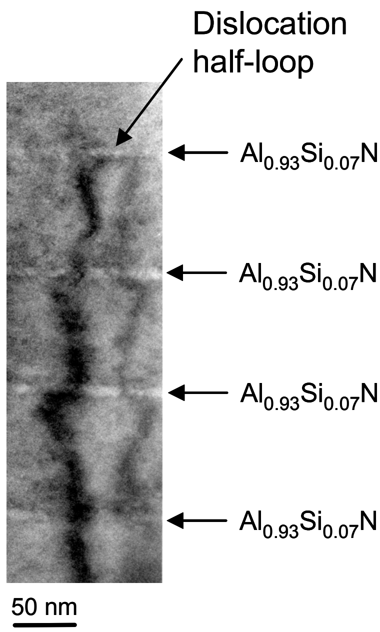

Fig. 4: An X-TEM image around the $Al_{0.93}Si_{0.07}N$ nano-disk interlayers.