Thin Film Formation of Gallium Nitride Using Plasma-Sputter Deposition Technique

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ABSTRACT

The formation of gallium nitride (GaN) thin film using plasma-sputter deposition technique has been confirmed. The GaN film deposited on a glass substrate at an optimum plasma condition has shown x-ray diffraction (XRD) peaks at angles corresponding to that of (002) and (101) reflections of GaN. The remaining material on the sputtering target exhibited XRD reflections corresponding to that of bulk GaN powder. To improve the system's base pressure, a new UHV compatible system is being developed to minimize the impurities in residual gases during deposition. The sputtering target configuration was altered to allow the monitoring of target temperature using a molybdenum (Mo) holder, which is more stable against Ga amalgam formation than stainless steel.

INTRODUCTION

A number of studies have been made on GaN thin film formation for its wide range of applications not only in the area of optoelectronics, but also in the production of high-power and high-speed electronic devices. The crystal quality of the GaN thin films has been considerably improved by employing different growth techniques. Among the popular methods are metal-organic chemical vapor deposition (MOCVD) and molecular beam epitaxy (MBE) (Sun et al., 2000; Strite et al., 1992; Nakamura et al., 1999; Shen et al., 2001).

High-quality GaN had been fabricated with MOCVD using trimethylgallium (TMG) and ammonia (NH_3) as the Ga and N sources (Nakamura et al., 1999). One of the earlier problems in MBE was the generation of sufficient nitrogen radical atoms to react with the Ga source material (Shen et al., 2001). The use of plasma-assisted MBE employing radio frequency (RF) or electron cyclotron resonance (ECR) microwave sources was recently revitalized to enhance the nitrogen reaction to that of Ga and also to avoid the use of ammonia, which is highly toxic. However, the fundamental reaction mechanism for film formation is still unclear, and in particular, the role of excited nitrogen species responsible for the formation of good quality GaN film has not yet been fully understood (Morkoc, 1999).

The N_2 plasma-sputter Ga deposition can be an alternative technique to form GaN thin film. In this paper, a deposition technique using a multi-cusp plasma sputter source is used to deposit GaN thin film.

BASIC PRINCIPLE

The plasma parameters and the principle of depositing GaN thin film were investigated and confirmed using a plasma chamber sealed with rubber o-rings, as shown in Fig. 1.

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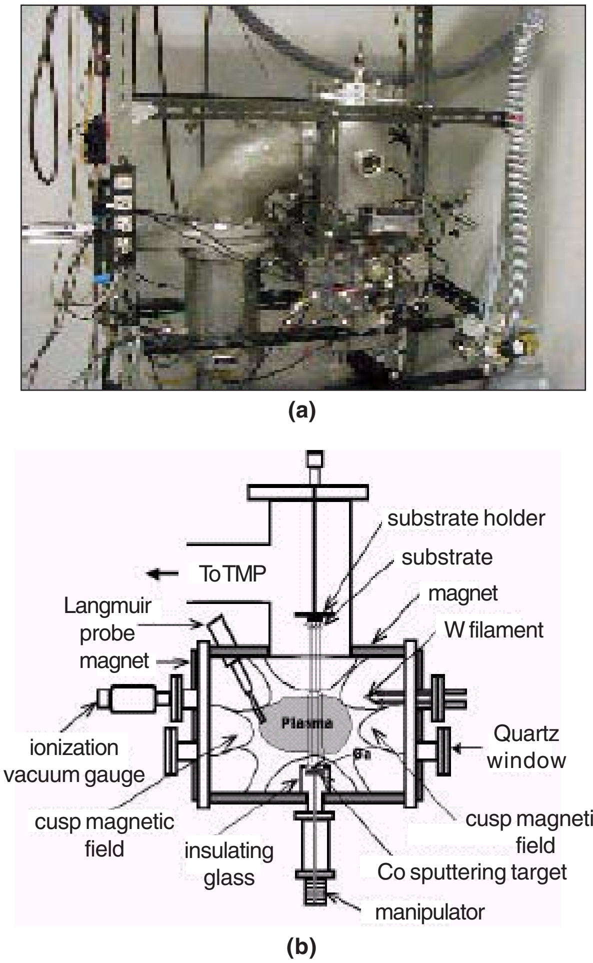

Fig. 1. (a) Photo and (b) schematic diagram of the multi-cusp plasma-sputter-type ion source.

The basic principle of the system is that the neutral Ga is sputtered out of the negatively-biased target and the plasma is formed inside the chamber, surrounded by the magnetic cusp on the chamber wall, as illustrated in Fig. 2. The formation of excited gallium and nitrogen molecules is through electron impact given in Eq. (1) and Eq. (3), respectively. The formation of excited atomic nitrogen is by dissociation process, as given in Eq. (2). The reaction rate, given in Eq. (4), is determined from the reaction cross-section, σ, and the electron velocity distribution function, $f(v_e)$. The plasma confinement magnetic field forbids ions to reach the substrate to avoid ion bombardment leading to film damage. The fluxes of the excited species of Ga, N, and N_2 contribute to the formation of GaN thin film on the substrate. Plasma diagnostics were conducted to confirm these reaction mechanisms as reported in the previous paper (Flauta et al., 2001).

$$N_2 + e \rightarrow N_2^* + e \tag{1}$$

$$N_2 + e \rightarrow N^* + N + e \tag{2}$$

$$Ga + e \rightarrow Ga^* + e \tag{3}$$

$$K = \langle \sigma(v_e) v_e \rangle = \int_0^\infty f(v_e)\sigma(v_e) v_e dv_e \tag{4}$$

PRINCIPLE CONFIRMATION

The system consisting of a plasma chamber (lower part) and a process chamber (upper part), both shown in Fig. 1, was used to confirm the principle of plasma-sputter GaN deposition. The plasma chamber (300-mm length, 210-mm diameter) has 10 rows of Sm-Co magnets, with four rows of Sm-Co magnets on each end plate arranged to produce a multi-line-cusp magnetic field. The plasma chamber houses the filament attached to the current feedthroughs inserted from the side of the chamber. Langmuir probe, sputtering target to hold Ga, and the quartz window for spectra analysis are also installed. The substrate holder is attached to the upper end of the process chamber away from the magnetic cusps. The electron emission from two 0.3-mm diameter, 9 cm long tungsten filaments sustains the plasma. Both chambers

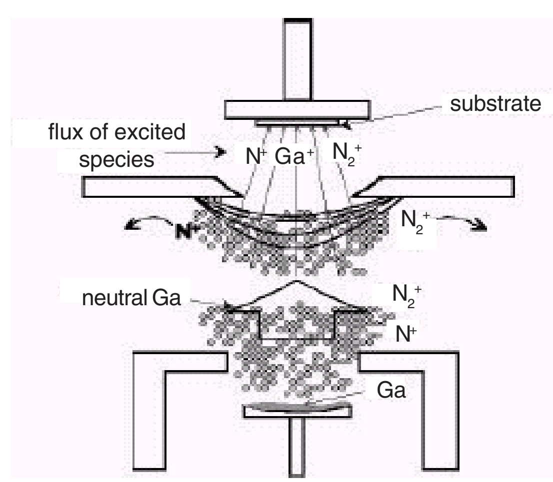

Fig. 2. The basic principle of a multi-cusp plasma-sputter-type ion source system.

are evacuated by a 160-l/s turbo molecular pump (TMP) coupled to a 300 l/min rotary pump at a base pressure of low 10^{-4} Pa.

Gallium pellet of 99.9999% purity was used in the experiment. It was preheated and melted using an incandescent lamp and was spread evenly on the surface area of the sputtering target. The sputtering target was made of a circular stainless steel disk 30 mm in diameter and 3 mm thick. The disk had a 28-mm diameter and 1-mm deep hollow to hold the molten Ga by gravity.

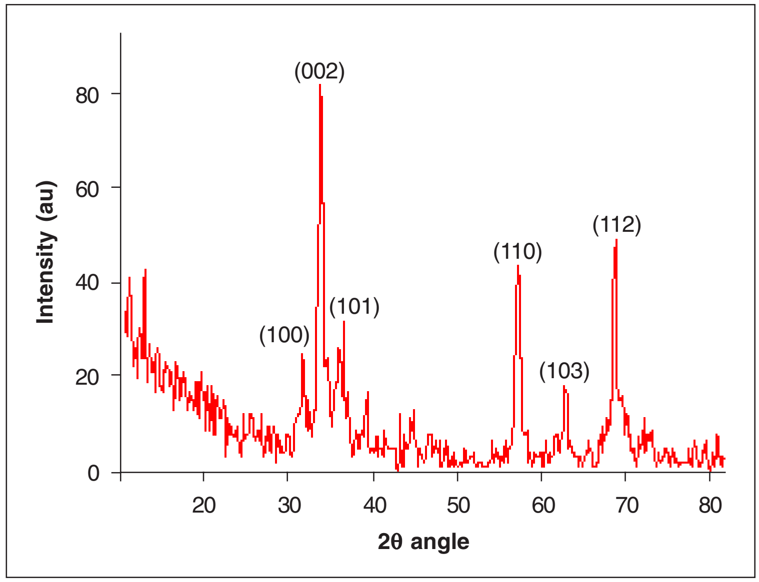

Fig. 3. XRD spectrograph of remaining GaN material on the sputtering target after film deposition.

The plasma characteristics of a multi-cusp plasma sputter-type ion source were optimized and resulted in a deposit of GaN thin film. The electron density, n_e, and electron temperature, T_e, directly affected the film growth. At higher pressure, n_e increased, but T_e decreased, thus reducing the rate of excitation of N as observed by optical emission spectroscopy. The GaN film deposited at an optimum condition for the N_2 excitation was characterized using an X-ray powder diffractometer and showed a crystalline orientation corresponding to that of (002) and (101) reflections of GaN (Flauta et al., 2001). The remaining material left on the sputtering target was also examined using XRD and exhibited numerous peaks corresponding to that of bulk GaN powder as shown in Fig. 3. This is due to the exposure of the Ga sputtering target to the N_2 plasma during the deposition process. The bulk GaN powder has a dark grayish color while the GaN film was transparent with a reddish yellow color as shown in Fig. 4.

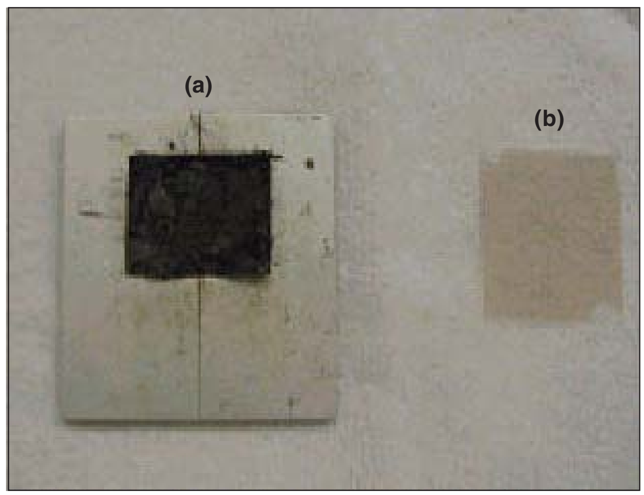

Fig. 4. (a) Photo of the bulk GaN and (b) GaN thin film on SiO_2 substrate.

FURTHER INVESTIGATION

Ultra-high vacuum compatible system

The background pressure of the system cannot be improved better than 3 x 10^{-4} Pa. For this reason, an ultra-high vacuum system is being developed to improve its performance. Using the UHV system, better base pressure can be achieved and impurities in residual gases can be minimized prior to film deposition. The ultra-high vacuum compatible multi-cusp plasma-sputter type ion source has a length of 216 mm and a diameter of 102 mm and 12 rows of So-Co magnets for the plasma confinement. The system utilizes copper gaskets to achieve better vacuum for cleaner deposition environment.

Sputtering target

It is important that the Ga is applied evenly on the surface area of the sputtering target. However, the formation of amalgam of the metallic Ga on the stainless steel

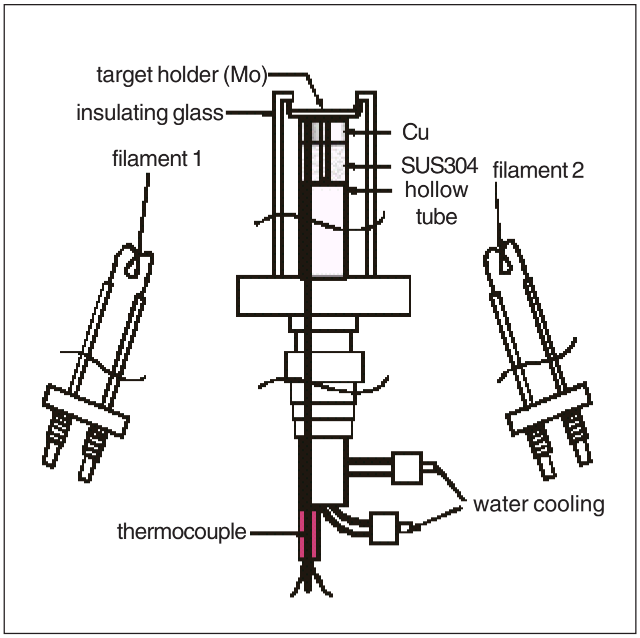

Fig. 5. The sputtering target assembly of ultra-high vacuum-compatible multi-cusp plasma-sputter-type ion source.

circular disk target was observed in the experiment. For this reason, the new sputtering target, 20 mm in diameter and 2 mm thick and made of Mo was used as the target holder, since Mo holds Ga better. This disk has an inner diameter of 18 mm and a 1 mm deep hollow to hold the molten Ga by gravity. This further minimizes the incorporation of other material aside from that of Ga to be sputtered out during film deposition. The Mo sputtering target is attached to a Cu base that is supported by hollow stainless steel rods through which sheathed thermocouple pass through and touch the bottom part of the sputtering target, as shown in Fig. 5. This allows the monitoring of the target temperature during plasma discharge and film deposition.

Ion source

The filaments are placed below the sputtering target covered with glass insulator, exposing the metallic Ga applied all over the surface area of the Mo target to the plasma. This setup minimizes the exposure of the filaments and other supporting materials of the sputtering target to the plasma .

Spectroscopy analysis

Optical spectrometer will be installed to detect the excited nitrogen species in the plasma. The Ga flux will be measured with a magnetic deflection type momentum analyzer during plasma discharge and film deposition.

SUMMARY

The formation of GaN thin film was confirmed using plasma-sputter technique. An ultra-high vacuum (UHV)-compatible multi-cusp plasma-sputter type ion source is now being assembled together with diagnostic equipment to study in which condition the plasma characteristics of the ion source becomes suitable to deposit polycrystalline GaN thin film.

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REFERENCES

Flauta, R., T. Kasuya, T. Ohachi, & M. Wada, 2001. *Proc. 13th International Conference on Crystal Growth*. ICCG-13. 194.

Morkoc, H., 1999. Nitride semiconductors and devices. Berlin Heidelberg, Springer-Verlag.

Nakamura, S., S. Pearton, & G. Fasol, 1999. The blue laser diode: A complete story. Berlin Heidelberg, Springer-Verlag.

Shen, X.Q., T. Ide, M. Shimizu, & H. Okumura, 2001. High-quality InGaN/GaN multiple quantum wells grown on Ga-polarity GaN by plasma assisted molecular beam epitaxy. *J. Appl. Phys*. 89: 5731-5733.

Strite, S. & H. Morkoc, 1992. GaN, AlN, and InN: A review. *J. Vac. Sci. Technol. B*. 10: 1237-1266.

Sun, X.L., H. Yang, Y.T. Wang, L.X. Zheng, D.P. Xu, D.G. Zhao, S.F. Li, & Z.G. Wang, 2000. Effect of buffer layer growth conditions on the secondary hexagonal phase content in cubic GaN films on GaAs (001) substrates. *J. Cryst. Growth*. 212(3-4): 397-401.