Criteria for versatile GaN MOVPE tool: high growth rate GaN by atmospheric pressure growth

Koh Matsumoto[1, †], Kazutada Ikenaga[2], Jun Yamamoto[1], Kazuki Naito[2], Yoshiki Yano[2], Akinori Ubukata[2], Hiroki Tokunaga[2], Tadanobu Arimura[2], Katsuaki Cho[2], Toshiya Tabuchi[2], Akira Yamaguchi[3], Yasuhiro Harada[1], Yuzaburo Ban[1], and Kousuke Uchiyama[1]

[1]TN-EMC Ltd, 2008-2 Wada, Tama, Tokyo 206-0001, Japan
[2]Business Strategy Planning div. Electronics Group, TAIYO NIPPON SANSO Corporation, 10 Okubo, Tsukuba 300-2611, Japan
[3]Compound-semiconductor Division, TAIYO NIPPON SANSO Corp., 6-2 Kojimacho, Kawasaki-shi, 210-0861, Japan

Abstract: Growth rate has a direct impact on the productivity of nitride LED production. Atmospheric pressure growth of GaN with a growth rate as high as 10 μm/h and also $Al_{0.1}Ga_{0.9}N$ growth of 1 μm/h by using 4 inch by 11 production scale MOVPE are described. XRD of (002) and (102) direction was 200 arcsec and 250 arcsec, respectively. Impact of the growth rate on productivity is discussed.

Key words: MOVPE; GaN: AlGaN; atmospheric pressure growth; high growth rate

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1. Introduction

Recently, the white light emitting diode (W-LED) is going to be used for solid state lighting application to replace the incandescent lamp. Metalorganic vapour phase epitaxy (MOVPE) has been established for production of LEDs. A multi-wafer MOVPE reactor which is capable of growth on large diameter substrates with 4 inch or 6 inch is being employed to realize low cost production of high performance LEDs. Today, both very high quality materials and low cost are simultaneously required. To this end, a very large process window is essential as well as a large scale. Since indium incorporation is more efficient at a higher growth pressure, better quality multi-quantum well (MQW) is expected at a higher growth pressure[1]. There is a proposal of polarization compensating MQW by using AlInGaN as a barrier layer to improve droop of LED efficiency[2]. However, there is a problem of growing aluminum containing alloys at elevated pressure because of a parasitic reaction which generates particulates in vapour phase. It is also known that high quality GaN on sapphire is easily obtained at atmospheric pressure. Rather tedious process control is necessary to grow good quality GaN at low pressure. At any rate, recent LED structure is becoming more complicated than before. Complicated device structure has a negative impact on the productivity through a long process time to grow the structure. Therefore, a production MOVPE machine should have a capability of a large capacity, atmospheric pressure growth and high growth rate.

Therefore, our challenge to realize nitride semiconductor MOVPE, which meets the above requirements, is to suppress parasitic reaction at atmospheric pressure for a large scale machine.

In this paper, it is reported that the result of growing GaN and $Al_{0.1}Ga_{0.9}N$ at atmospheric pressure using the multi-wafer reactor. High growth rate as high as 10 μm/h is shown. Impact of the growth rate on productivity is also discussed.

2. Experimental

GaN and AlGaN layers were grown by a multiwafer MOVPE reactor (TAIYO NIPPON SANSO Corp., UR25K). Figure 1 shows a picture of the reactor. The reactor has a susceptor with a capacity of 4 inch wafers by 11 at a time. The susceptor and each wafer holder were mechanically rotated on their axis in planetarium motion. In this reactor, high-flow-speed design in combination with three layered precisely temperature controlled gas injection was adopted. The gas injector was located at the centre of a susceptor. Growth temperature of GaN and AlGaN is monitored by both thermocouples and optical sensor. The susceptor is transferred and exchanged by a robot arm between loading table, pass box and reactor. Top ceiling disc made of quartz is also automatically exchanged by

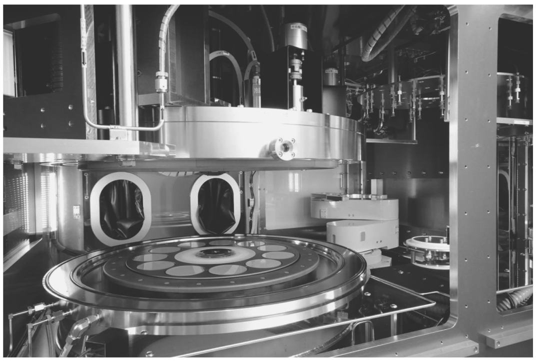

Fig. 1. Photograph of UR25k (TAIYO NIPPON SANSO). The wafer size is 4 inch. The robot arm is seen in the right hand side over the reactor.

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† Corresponding author. Email: Kou.Matsumoto@tnemc.tn-sanso.co.jp

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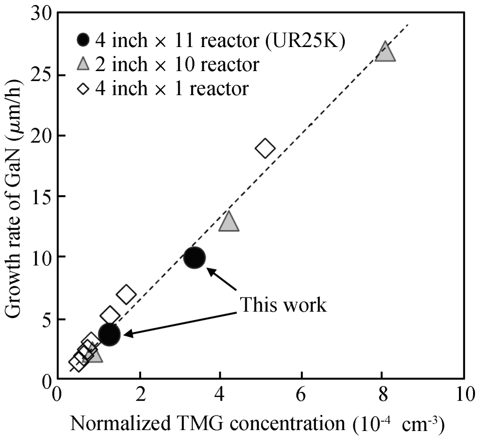

Fig. 2. Growth rate of GaN as a function of normalized TMG concentration in order to compare different scale reactors.

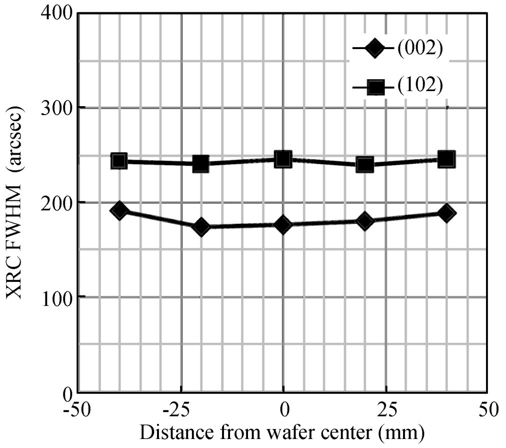

Fig. 3. FWHM of XRC of high growth rate GaN at a growth rate of 10 μm/h.

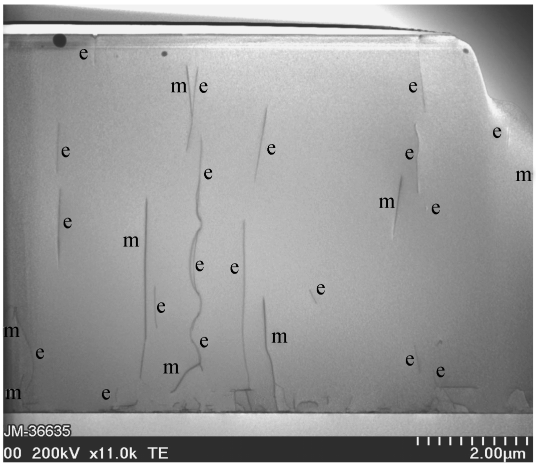

Fig. 4. Cross sectional TEM image of the high growth rate GaN sample. Most of the dislocation vanished within 0.5 μm near the interface between epitaxial layer and the substrate. In this figure, e denotes edge type dislocation and m denotes mixed dislocation. The TEM sample thickness was 0.2 μm. By considering the thickness and the area of this TEM sample, dislocation density was estimated to be 2 to 3 × 10^8 cm^{-2}.

the robot arm. The deposit on the reactor components are removed by using a chlorine gas dry etching furnace[3].

All layers shown in this article were grown at atmospheric pressure in this study. The precursors were trimethylgallium (TMG), trimethylaluminum (TMA), and ammonia (NH_3). Nitrogen and hydrogen were used as carrier gases. 4 inch diameter c-plane sapphire with an off-orientation of 0.15° towards the m-plane was used as substrate. Our typical growth rate of GaN was 3.7 μm/h. As for the high growth rate GaN sample, 1 μm-thick GaN at normal growth rate (3.7 μm/h) was grown at first. Then, 0.5 μm-thick GaN transition layer was grown continuously with increasing gradually both of TMG and NH_3 flow to keep V/III supply ratio about 800. Finally, GaN was grown at the constant growth rate of 10 μm/h.

The crystalline quality of GaN and the Al composition of AlGaN film were evaluated by X-ray diffraction (XRD). The thickness uniformity of GaN was measured by optical interference method. Surface morphology of GaN was observed by differential interference microscopy. The residual impurities concentration was evaluated by secondary ion mass spectrometer (SIMS).

3. Results and discussion

Figure 2 shows the growth rate of GaN as a function of normalized TMG concentration in order to compare different scale reactors. In a previous study for the reactor for 2 inch by 10, the growth rate was increased up to 28 μm/h by increase of TMG flow rate linearly[4, 5]. The data plot of the growth rate in this experiment aligned in line on the results of the previous experiment as a function of normalized TMG concentration. This shows a good scalability of our design. By assuming the growth rate of n-GaN, initial three dimensional growth i-GaN and InGaN wells as 2 μm/h, 1 μm/h and 0.1 μm/h, total growth time of whole LED structure would be up to near 10 h. The LED structure is as follows: 1 μm-thick i-GaN, 4 μm-thick n-GaN and 20 layers InGaN/GaN strained layer supper-lattice (SLS), 10 layers of MQWs, 10 nm p-$Al_{0.1}Ga_{0.9}N$, 100 nm p-GaN and 10 nm p^+-GaN. By employing high growth rate GaN of 10 μm/h as well as 3.7 μm/h initial three dimensional growth mode for i-GaN, the total growth time is reduced by 140 min, which improves the total throughput by 25%.

Figure 3 shows the FWHM of XRC of high growth rate GaN at a growth rate of 10 μm/h. FWHM of XRC for the (0002) direction was less than 200 arcsec and that for $(10\bar{1}2)$ was approximately 260 arcsec across the entire 4 inch wafer. The standard deviation of thickness for this sample was 0.74% in the centred 90 mm-diameter region. The variation among satellites was negligible.

Figure 4 shows a cross sectional TEM image of this sample. Most of the dislocation vanished within 0.5 μm near the interface between epitaxial layer and the substrate.

In previous study, we have reported that carbon concentration was increased over 1 × 10^{17} cm^{-3} when the TMG flow rate was increased with a constant NH_3 flow rate[4]. In the present study, V/III supply ratio was maintained as constant during the TMG supply rate increase. Figure 5 shows the SIMS depth profile of n-type GaN at a growth rate of 10 μm/h. The

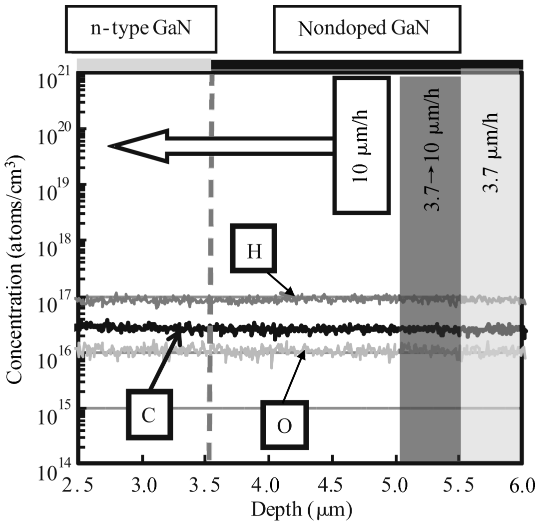

Fig. 5. SIMS depth profile of n-type GaN at the growth rate of 10 μm/h.

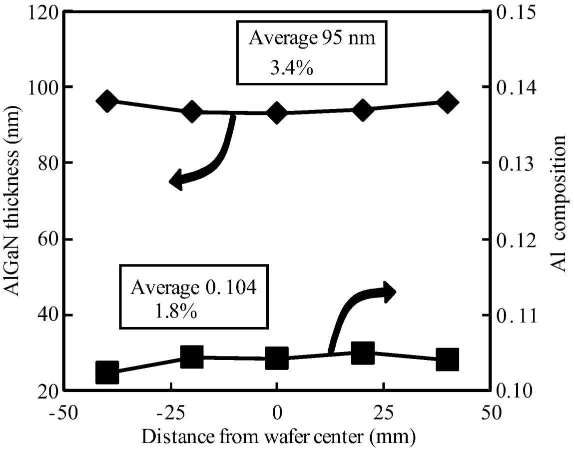

Fig. 6. Al composition and thickness variation of $Al_{0.1}Ga_{0.9}N$ in a 4 inch wafer. The layer was grown at atmospheric pressure with approximately 1 μm/h.

residual carbon level was exactly constant throughout the layers.

Also, the concentration of oxygen and hydrogen were under detection limit. From these results, the carbon concentration was not affected even at a growth rate of 10 μm/h, provided that V/III supply ratio was kept constant in this structure. We have made a Si doping for the high growth rate sample and obtained a comparable electrical properties.

Figure 6 shows the Al composition and thickness variation of $Al_{0.1}Ga_{0.9}N$ in a 4 inch wafer at a growth rate of approximately 1 μm/h. Averaged Al composition was 10% and its distribution was 1.8%. These plots have a concaved shape curve. It is supposed that this distribution is due to temperature distribution across the wafer. Al composition uniformity should be improved by optimization of temperature distribution in a wafer pocket.

Average thickness was 95 nm and its distribution was 3.4%.

From these results of AlGaN and high growth rate GaN, the parasitic reaction between NH_3 and metal-organics was suppressed effectively. If we employ low-pressure growth, AlGaN alloy with a full range of Al composition are easily grown. As an example, $Al_{0.24}Ga_{0.76}N$ was grown at 40 kPa. Al composition variation was 24 $\pm$ 0.11% and the thickness variation was $\pm$1.3%. As for InGaN MQWs of 450 nm, wavelength variation in full 11 wafers grown at atmospheric pressure was within 10 nm.

4. Conclusion

We have developed a multi-wafer nitride MOVPE reactor UR25k. The XRC FWHM for GaN at a growth rate of 10 μm/h was comparable with those of lower growth rate GaN, once that the surface was planarized. Surface morphology was very smooth, and residual carbon concentration of GaN was 2.5×10^{16} cm^{-3} at a growth rate of 10 μm/h. High growth rate as well as high crystal quality will improve both productivity and device performance of the high power InGaN LED.

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