Single-wafer Multi-Reactor MOCVD Tool for GaN Based Devices

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Abstract

We have developed a single-wafer MOCVD tool for GaN growth on 200 mm Si substrate. The tool is based on high speed wafer rotation technology which is preferable for achieving high in-wafer uniformity. Effect of growth parameters on InGaN/GaN MQW and AlGaN/GaN HEMT structure was investigated and good in-wafer uniformity was confirmed. Also good wafer-to-wafer uniformity with parallel operation of four-process-module configuration is shown.

INTRODUCTION

For production of GaN based light emitting and electronic devices, MOCVD tools for large scale substrate and of high uniformity are highly demanded. Rotating disk MOCVD rector is one of well investigated reactors [1 - 4] and has been applied to real production of GaN based devices. We developed a single-wafer MOCVD tool for GaN growth on 200 mm Si substrate to achieve improved in-wafer uniformity. The tool is based on high speed wafer rotation technology of rotating disk MOCVD reactor. Although a single-wafer tool is expected to show higher in-wafer uniformity and simpler parameter tuning, the throughput is lower than a large scale multi-wafer tool. To achieve higher throughput by the single-wafer tool, we also developed a tool of multi PM configuration. In this paper, growth results of the tool, EPIREVO G8™, will be shown.

EXPERIMENTAL

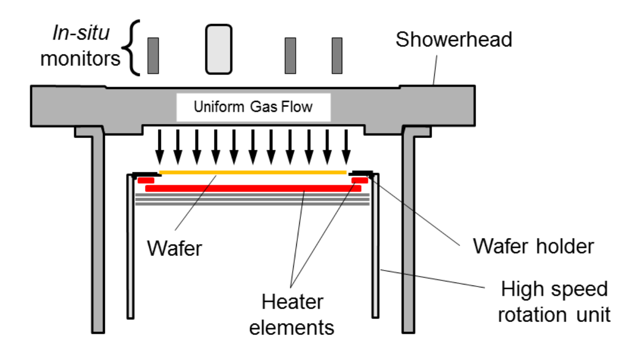

Fig. 1. Cross-sectional view of the reactor.

Figure 1 shows a schematic cross sectional view of the reactor. A 200 mm Si wafer is set on a wafer-holder. The wafer holder is ring-shaped and contacts with the wafer only at the edge. In this configuration, the wafer is heated by radiation from the heater elements directly, and deformation of the wafer during a process does not affect temperature uniformity of the wafer. This is an advantageous point over a reactor configuration where substrates are heated by heat transfer from the susceptor.

Epi-growths were conducted on 200 mm (111) Si substrates using AlN/AlGaN buffer layers. Typical rotation speed (ω) of the wafer is 800 - 1900 rpm. This high speed rotation with uniform gas flow from the showerhead is one of the key points to achieve high in-wafer uniformity. Typical standard deviation of thickness of GaN is less than 1% (EE: 4 mm).

For higher throughput, we developed a configuration of a tool where 4 PMs are connected to one gas panel and the PMs are operated in parallel (see Figure 2). In this configuration, a material gas flow is divided into an equal amount of 4 sub-flows. Each sub-flow is fed to each PM. Some growth parameters like rotation speed, temperature, etc. are set for each PM independently.

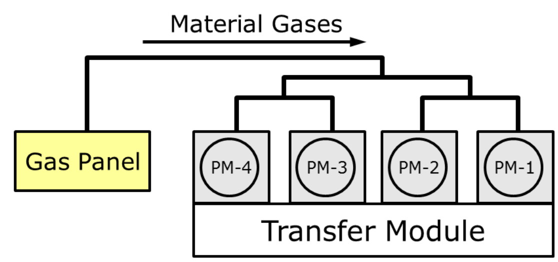

Fig. 2. Tool configuration with 4 PMs.

RESULTS AND DISCUSSION

To check the basic epi-growth behavior of the reactor, GaN was grown at several different rotation speeds. Thickness distribution of GaN for the different rotation speeds is shown in Figure 3(a) and the growth rate is plotted against $\sqrt{\omega}$ in Figures 3(b). The flow condition was optimized at 1200 rpm, and growth parameters other than rotation speed were kept the same for runs of other rotation speeds. From Figure 3(b), the growth rate fits well with proportional relation to $\sqrt{\omega}$ with a small negative offset. The linear dependence on $\sqrt{\omega}$ is well known for the rotating disk type reactor [1, 2]. The negative offset would indicate etching of the film occurs during the epi-growth of the film [5, 6].

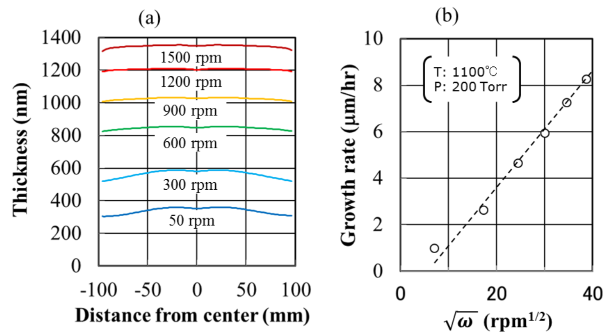

Fig. 3. (a) Thickness distribution of GaN across a 200 mm wafer at different wafer rotation speeds and (b) growth rate dependence on $\sqrt{\omega}$.

For growth of InGaN/GaN MQW, effect of the wafer rotation speed on relative MQW pair thickness (~ growth rate) and average [In] is shown in Figure 4(a). Increasing rotation speed by 10 % causes ~ 5 % increase in growth rate which is expected from $\sqrt{\omega}$ dependence of the growth rate. On the contrary, the rotation speed has almost no effect on [In]. Using the results, PM-to-PM tuning of MQW pair thickness and [In] can be achieved independently. MQW pair thickness can be tuned by setting rotation speed and [In] by growth temperature for each PM independently. The in-wafer distribution of the pair thickness and [In] for 4-PMs in a run after PM-to-PM tuning is shown in Figure 4(b).

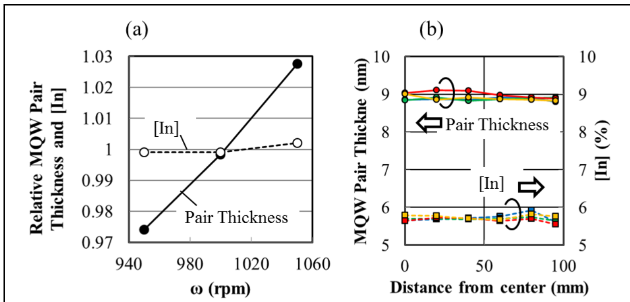

Fig. 4. (a) Effect of rotation speed on MQW pair thickness and [In] and (b) in-wafer distribution of MQW pair thickness and [In] of 4 wafers grown in a run after PM-to-PM tuning.

Table I summarizes growth rate of GaN deduced from MQW pair thickness grown at different growth conditions. It also includes ratio between the growth rate and growth rate factor (GRF), ξ, which describes effects of growth parameters on growth rate from a simple boundary layer model [7]. ξ is defined as $\xi = \sqrt{P\omega} f/\Omega$, where P, ω, f and Ω are growth pressure, rotation speed, MO source flow and total amount of gas flow fed to the reactor, respectively. It is seen in this table that the growth rate is fairly proportional to ξ with different growth parameters. The results suggest the growth process is well described by the simple model.

TABLE I
Summary of growth condition of MQW, growth rate and growth rate/ξ.

run	P	ω	Ω	Growth Rate		Growth Rate /ξ	
	Torr	rpm	slm	10^{-2} nm/sec		(relative to run #1)	
1	300	1000	57.5	2.91	-	1.00	-
2	400	1000	57.5	3.31	(+14 %)	0.99	(-1 %)
3	500	800	57.5	3.28	(+13 %)	0.98	(-2 %)
4	500	800	62.5	3.00	(+3 %)	0.97	(-3 %)

PL wavelength uniformity (standard deviation, σ) for a wafer was 0.97 and 0.79 nm for MQWs grown at 300 and 500 Torr, respectively (average; 450 nm, EE; 4 mm), and was excellent for largely different growth pressures. The results indicate good uniformity of the boundary layer and the wafer temperature.

Thickness uniformity of AlGaN barrier layer of HEMT structures showed rather large rotation speed dependence. Uniformity of the AlGaN thickness was +/- 2.5 % at 800 rpm and was improved to +/- 1 % at 1500 rpm or a higher rotation speed. This rotation speed dependence is thought to be effect of parasitic gas phase reaction between TMA and NH_3 [8]. The gas phase reaction is quite complicated [9], but

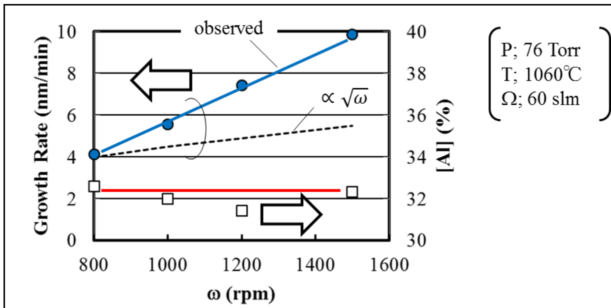

Fig. 5. Effect of rotation speed on AlGaN growth rate and [Al].

since the uniformity of the boundary layer and the wafer temperature seems to be good as mentioned above, rather poor AlGaN uniformity at low rotation speed would be caused by poor uniformity of the temperature boundary layer.

Figure 5 shows effect of rotation speed on AlGaN thickness and [Al]. In this figure, the thickness is shown to have much higher dependence on rotation speed than $\sqrt{\omega}$. This would mean the parasitic gas phase reaction is suppressed much more at a higher rotation speed due to thinner temperature boundary layer. Therefore a higher rotation speed would prevent temperature boundary layer fluctuation more effectively from affecting AlGaN thickness uniformity.

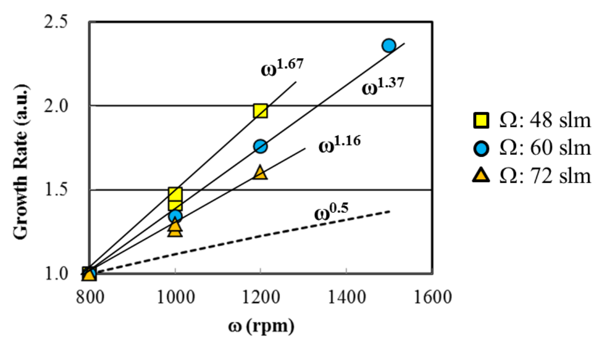

Fig. 6. Growth rate dependence of AlGaN layer on ω for different total gas flows.

From Figure 5, we see AlGaN growth rate is dependent on rotation speed, whereas [Al] isn't. It is quite similar to the results shown in Figure 4(a). Therefore the same approach for PM-to-PM tuning of MQW can be also applied to the AlGaN layer.

Figure 6 shows rotation speed effect on the AlGaN growth rate for different total gas flows by changing carrier gas flow rate. Increase in total gas flow lowers the concentration of the material gases. It is seen that the dependence on rotation speed approaches $\sqrt{\omega}$ as the total gas flow increases. This is well understood as results of MO gas diffusion in the boundary layer with the parasitic gas phase reaction which depends on the MO gas concentration.

TABLE II
Uniformity of AlGaN and MQW with 4-PM operation.

layer	item	unit	average	Δ/ σ	
AlGaN	Thickness	nm	19.6	1.2(Δ)	0 - 95 mm
	[Al]	%	24.9	1.2(Δ)	
HEMT	μ	$cm^2/Vsec$	1390	95 (σ)	3 points/wafer
	Nc	$10^{13}/cm^2$	1.01	0.06 (σ)	(0, 50, 90 mm)
MQW	Wavelength	nm	452.5	1.4 (σ)	EE: 4 mm

Table II summarizes achieved uniformity for MQW and the AlGaN layers with 4-PM operation in a run. It shows fairly good overall uniformity for four wafers.

CONCLUSION

Epi-growth behavior of newly developed fast rotating single-wafer MOCVD tool is shown to be explained quite well by a simple boundary layer model. The tool shows excellent in-wafer uniformity. The tool of 4-PM configuration for higher throughput showed good wafer-to-wafer uniformity by parallel operation of PMs. These results indicate high potential of the tool for the real production.

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ACRONYMS

EE: Edge Exclusion
HEMT: High Electron Mobility Transistor
MO: Metalorganics
MOCVD: Metalorganic Chemical Vapor Deposition
MQW: Multiple Quantum Well
Nc: Sheet Carrier Concentration
PM: Process Module
TMA: Trimethylaluminum