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Growth of β-Ga_2O_3 Layers on a 6-inch Wafer Using Halide Vapor-Phase Epitaxy

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Introduction

Gallium oxide (Ga_2O_3) exhibits a wide band gap and large Baliga's figure of merit compared with those of Si, and is employed to improve the power conversion efficiency of power devices for a low carbon application. For the practical application of Ga_2O_3 devices, mass production using epitaxial growth equipment compatible with large-diameter substrates is vital. We have developed a 6-inch single-wafer HVPE system equipped with an external Ga source generator and demonstrated β-Ga_2O_3 film growth on the wafers. The thickness variation was less than ±10% with wafer rotation.

Experimental

1. $GaCl_3$ generation by external generator
$GaCl_3$ was generated by reacting Ga metal and Cl_2 gas.
2. Growth of Ga_2O_3 layers by HVPE system
β-Ga_2O_3 was grown by reacting $GaCl_3$ and separately supplied O_2, with N_2 as a carrier gas.

Table 1 Process conditions of the $GaCl_3$ generator.

Parameter	Setting Value
Reaction Pressure	Atmospheric Pressure
Reaction Temperature	850°C/boat temp
Reaction Time	60 min
Total Gas Flow	Cl_2: 25–200 sccm N_2: 950–2975 sccm
Purge Gas in Quartz Tube	N_2: 2000 sccm

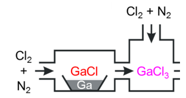

Fig.1 Reaction between Ga metal and Cl_2 gas.


Fig.2 Photo of $GaCl_3$ generator.

Table 2 Growth conditions of β-Ga_2O_3 layers.

	pressure (kPa)	temperature (°C)	P^0_{GaCl3} (atm)	VI/III	Growth time (min)
UID-Ga_2O_3	100	1000	5.3×10^{-3}	200	60

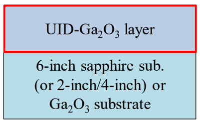

Fig.3 Structure of β-Ga_2O_3 growth.

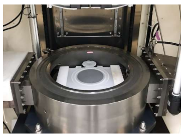
Fig.4 Photo of HVPE reactor.

Growth system
HVPE reactor with an external $GaCl_3$ generator
(6 inch × 1 or 4 inch × 1 or 2 inch × 5)

【 Ga_2O_3-HVPE system 】
- Wafer size: 6 inch × 1
- Wafer holder type: face down
- Wafer rotation: < 10 rpm
- Reactor: stainless steel
- Nuzzle: 3-layer laminar flow
- Precursor:
  - -Ga(III) source: $GaCl_3$
  - -O(VI) source: O_2
- Carrier gas: N_2 or Ar
- External supply of $GaCl_3$

Characteristics:
- Large diameter wafer (6-inch)
- Low material cost (*vs.* MOCVD)
- Decrease in powder generation


Fig.5 Photo of the HVPE system.

Measurement methods
- Film thickness: Cross-sectional scanning electron microscopy (SEM)
- Surface morphology: Optical microscopy

1. $GaCl_3$ generation by external generator

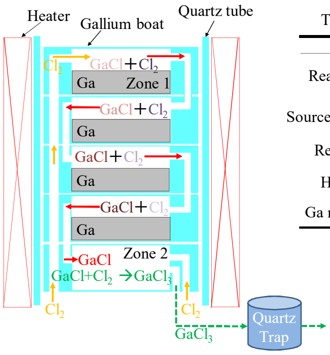

Fig.6 Cross sectional view of $GaCl_3$ generator (prototype).

Table 3 Specifications of $GaCl_3$ generator.

	Specification
Reaction	Ga + 1/2Cl_2 → GaCl (Zone 1) GaCl + Cl_2 → $GaCl_3$ (Zone 2)
Source zone	Multi series graphite boat
Reactor	Vertical quartz reactor
Heater	3-zone electric furnace
Ga metal	3 kg/boat

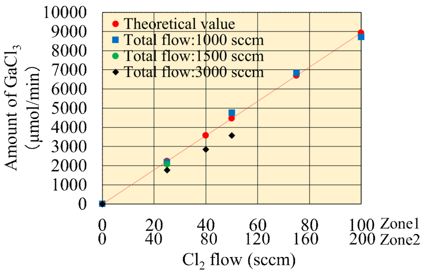

Fig.7 Relationship between Cl_2 flow rate and amount of $GaCl_3$ generation*.

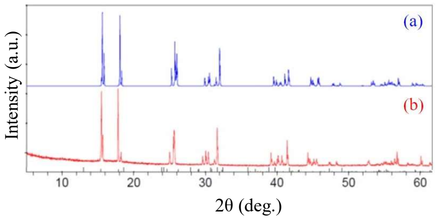

Fig.8 XRD data of solidified powder in a quartz trap*.
(a) Calculated $GaCl_3$ data from crystal structure [1].
(b) Measurement result of powder trapped in quartz trap.

◆**The maximum $GaCl_3$ generated by the external generator was approximately 9000 μmol/min.**
◆**By optimizing the structure of the boat filled with Ga metal and gas flow conditions, we successfully increased efficiency of the reaction between Ga metal and Cl_2 gas to >99%.**

*Results of prototype $GaCl_3$ generator

2. Growth of Ga_2O_3 layers by HVPE system

Ga_2O_3 layer on 6-inch sapphire substrate

Fig.9 β-Ga_2O_3 film on a 6-inch sapphire wafer.

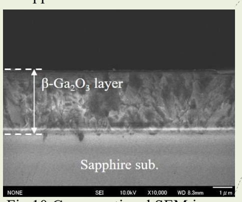

Fig.10 Cross-sectional SEM image of β-Ga_2O_3 layer grown on a 6-inch sapphire wafer.

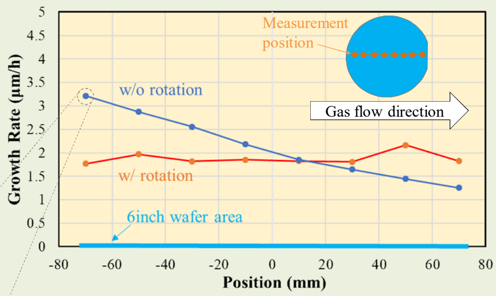

Fig.11 Thickness distribution of β-Ga_2O_3 layer grown on a 6-inch sapphire wafer (along the gas flow direction).

Ga_2O_3 layer on 2-inch Ga_2O_3 substrate

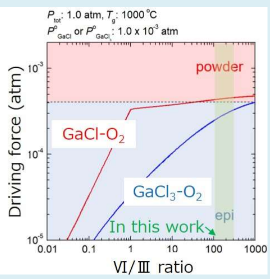

Fig.12 Comparison of the ΔP_{Ga2O3} in GaCl-O_2-N_2 and $GaCl_3$-O_2-N_2 systems [2].

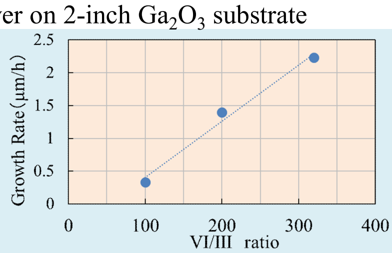

Fig.13 Growth rate of Ga_2O_3 as a function of VI/III ratio.

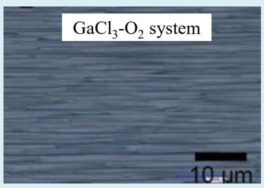

Fig.14 Optical microscopy image of β-Ga_2O_3 surfaces after HVPE growth.

◆**The thickness variation was less than ±10% with wafer rotation on a 6-inch sapphire wafer.**
◆**Growth of Ga_2O_3 without the formation of powder is expected even with high input VI/III ratio in the $GaCl_3$-O_2-N_2 system.**

Summary

We developed a 6-inch single wafer HVPE system and installed an external generator for the Ga source for the growth of β-Ga_2O_3 layers. We successfully grown β-Ga_2O_3 films on 6-inch sapphire wafers with a thickness variation of less than ±10%. These results will pave the way for the mass-production of large diameter β-Ga_2O_3 homoepitaxial wafers.

Acknowledgement
This research is based on results obtained from a project subsidized by the New Energy and Industrial Technology Development Organization (NEDO).

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References
[1] The International Centre for Diffraction Data : "https://www.icdd.com/"
[2] T. Kamo et al., 2019 International Workshop on Gallium Oxide and Other Related Materials (IWGO 2019).