Variation of vertical direction breakdown voltage of the AlGaN/GaN HEMTs on AlN/Si template substrate as a function of growth temperature of initial Al layer

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Abstract In this study, the relationship between the growth conditions of initial Al layer and vertical direction breakdown voltage (VDBV) of AlGaN/GaN high-electron-mobility-transistors (HEMTs) was investigated by growing an HEMT structure simultaneously on the identical structure of AlN layer on Si substrates (AlN/Si template) manufactured under different growth conditions. Screw-type dislocation density of the AlN layer decreases by an increase in the growth temperature of the Al layer. In addition, the VDBV of the HEMT structure increases. The decrease of VDBV of the HEMT structure might have originated from the screw-type dislocations generated from the Al layer and SI interface. HEMTs on Si with both thinner epitaxial layer and high breakdown voltage can be realized by controlling the interface state of the initial layer and Si substrate.

1. Background and Purpose of this study

One of the issues of AlGaN / GaN high-electron-mobility-transistors (HEMTs) on Si is lower vertical direction breakdown voltage (VDBV).The breakdown voltage of HEMT on Si can be improved by thicker epitaxial layer.

Disadvantage of thicker HEMT on Si;

➔ Difficult to control the wafer warp; and Long growth time;

HEMT on Si with both thinner epitaxial layer and high breakdown voltage is required.

Factors affecting the breakdown voltage

- Structure of epitaxial layers [1]
- Carbon impurity in GaN layer [2]
- **Dislocation of AlN layer (Fig. 1) [3]**

Origin of dislocations in the AlN layer;

➔ Interface of the AlN layer and Si substrate

The relationship between the growth temperature of the interface of AlN layer and Si substrate (initial Al layer) and the VDBV of the AlGaN/GaN HEMTs was investigated.

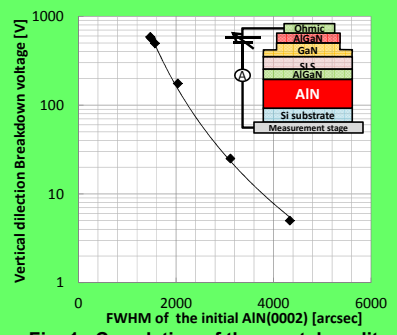


Fig. 1 Correlation of the crystal quality of the initial AlN layer and vertical breakdown voltage of the HEMT structure.

2. Experiment (Growth of the samples in this study)

Table 1 List of AlN/Si template

Item	Sample A	Sample B	Sample C
Growth temperature of initial Al layer [℃]	622	811	1000

Table 2 List of HEMTs on AlN/Si template

Item	Sample A'	Sample B'	Sample C'
AlN/Si template	Sample A	Sample B	Sample C

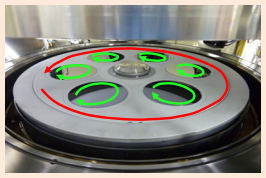


Fig. 2 Reactor of MOVPE

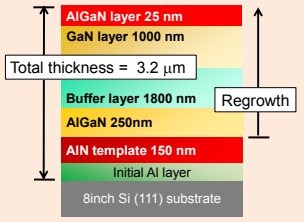


Fig. 4 Structure of HEMT on the AlN/Si template

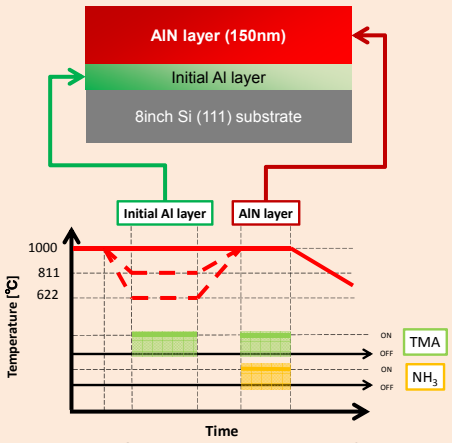


Fig. 3 Structure and growth profile of the AlN/Si template

All samples used in this study were grown using the multiwafer metal organic chemical vapor deposition tool (Fig. 2, Taiyo Nippon Sanso Corp., UR26K, 8 inch × 6 wafers).

The HEMT structure on each AlN/Si template was regrown simultaneously using UR26K.

3. Results and Discussion

3.1. Characterization of the AlN/Si template

Table 3 Characterization results of the AlN/Si template

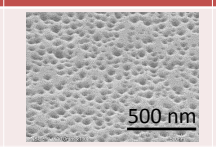
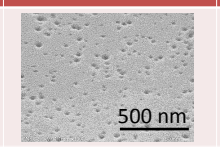
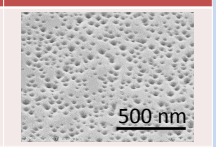
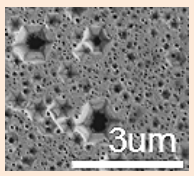
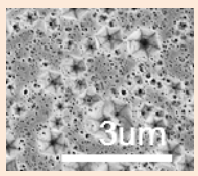
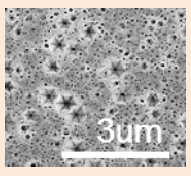
Item	Sample A	Sample B	Sample C
Growth temp. of Initial Al layer [℃]	622	811	1000
Surface SEM image	 500 nm	 500 nm	 500 nm
Pit density [× 10^{10} cm^{-2}]	2.52	1.44	3.84
XRD FWHM AlN(0002) [arcsec]	2471	2224	2194
Surface SEM image after KOH etching	 3um	 3um	 3um
Diameter of Screw-type dislocation [μm]	1.14	0.85	0.59

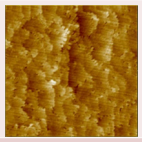
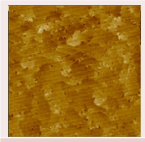
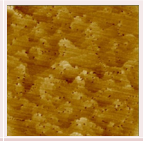
Table 4 Relationship between the dislocation and etch pit [4]

Item	Screw	Edge
SEM image [1 μm × 1 μm]		
3D image		

The growth temperature of the initial Al layer has an effect on the screw-type dislocations of the AlN layer.

3.2. Characterization of HEMTs on the AlN/Si template

Table 4 Surface AFM image of the HEMTs on the AlN/Si template

Item	Sample A'	Sample B'	Sample C'
Growth temp. of Initial Al layer [℃]	622	811	1000
Surface AFM image [2 μm × 2 μm]			
Rms [nm]	0.348	0.238	0.278

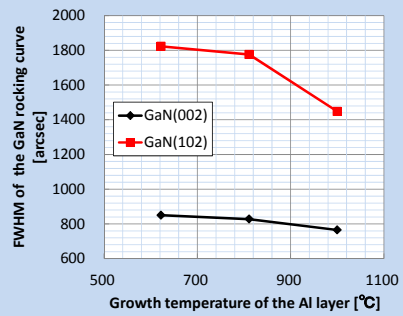


Fig. 5 Relationship between the growth temperature of the Al layer and the crystal quality of the GaN layer

- **The surface morphology of the HEMT structure might be improved by decreasing the surface pit of the AlN layer.**
- **The dislocations generated from the interface of Al and Si affect up to the GaN layer.**

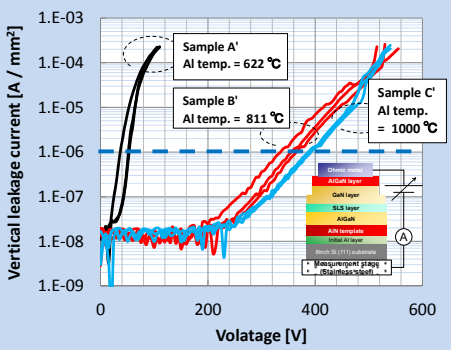


Fig. 6 Characteristics of the current-voltage curve of the HEMTs on the AlN/Si template

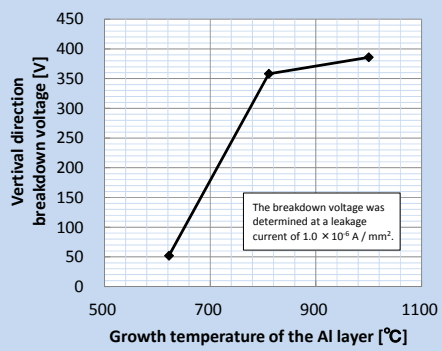


Fig. 7 Correlation of the growth temperature of the Al layer and the vertical breakdown voltage of the HEMTs

The decrease in the VDBV of the HEMT structure might have originated from the screw-type dislocations generated from the Al layer and Si interface.

4. Summary

The modified growth temperature of the initial Al layers and their influence on the VDBV of the HEMTs were compared. The decrease in the breakdown voltage of the HEMT structure might have originated from the screw-type dislocations generated from the Al layer and Si interface. HEMTs on Si with both thinner epitaxial layer and high breakdown voltage can be realized by controlling the interface state of the initial layer and Si substrate.

References

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