Development of Non-Core 4-inch GaN Substrate

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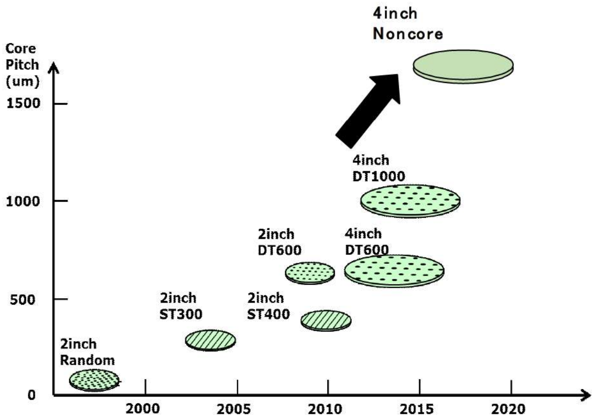
Abstract

In this paper, we report on newly developed 4-inch-diameter GaN substrates with reduced cores using hydride vapor phase epitaxy (HVPE). The reactor design and growth conditions were optimized to reduce the core density. Also, by optimizing the wafer processing condition, we have developed 4-inch GaN substrates with core count as low as 10s in number, and of off-angle variation less than 0.2 degrees over the entire surface.

INTRODUCTION

GaN based LEDs on freestanding GaN substrates with low dislocation density, have characteristics such as high efficiency, high reliability, and high luminous flux, compared to those on sapphire substrates [1]. Moreover, power devices on GaN substrates with performances over SiC limits have been demonstrated [2]. The demand for larger diameter GaN substrates with smaller off-angle variation, which affects the surface morphology of epitaxial layers [3], is growing rapidly to reduce production costs. Sumitomo Electric Industries (SEI) has manufactured 2-inch-diamiter freestanding GaN substrates with periodically positioned inversion domains called "cores" since 2002, as shown in Fig. 1 [4], currently used for high-reliability devices due to low dislocation densities. We developed 4-inch-diameter freestanding GaN substrates with cores in 2010. However, cores in a line sometimes prevent flexibility of designing device size, so the device size has to be adjusted based, on the distance between cores in line. To increase the flexibility to meet various chip sizes, we have developed non-core 4-inch-diameter GaN substrates with small off-angle variation.



ST : Stripe Core
DT : Dot Core

Fig. 1. Development history of GaN substrates in SEI.

EXPERIMENT

Non-core 4-inch GaN substrates are produced from GaN bulk crystals grown by hydride vapor phase epitaxy (HVPE). The growth is carried out under atmospheric pressure using H_2 as the carrier gas. GaCl is formed in the upstream region of the reactor, by the reaction between molten Ga and HCl, and the crystal is grown in the downstream region where, the GaCl and NH_3 are mixed. The HVPE reactor is schematically shown in Fig. 2.

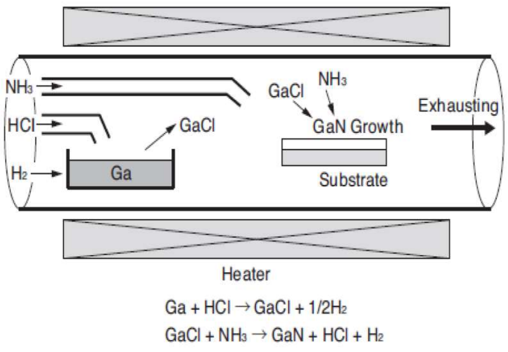


Fig. 2. Schematic diagram of GaN crystal growth by HVPE (hydride vapor phase epitaxy).

A non-core GaN crystal is grown on the GaN base layer, which is formed on a specially prepared core substrate. Epitaxial lateral over-growth (ELO) technique is also used to bury the cores in the crystal. After the growth, few cores exist on growth surface. By adjusting the ELO condition, the in-plane off-angle variation of the substrate is improved. The design of the reactor, and the growth conditions, were optimized to obtain the best uniformity of crystal quality. The lapping and polishing process was modified to be suitable for non-core GaN substrates. The condition of wafer processing was also optimized to make it possible to control the uniformity of surface quality and other parameters of substrate quality.

RESULTS

Fig. 3 shows a photograph of a non-core 4-inch GaN substrate. No cracks are observed in the whole area of the substrate.

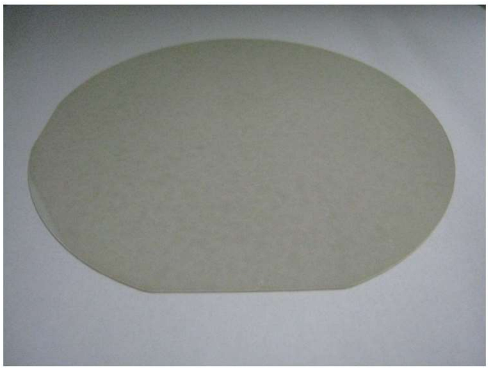


Fig. 3. Photograph of non-core 4-inch GaN substrate.

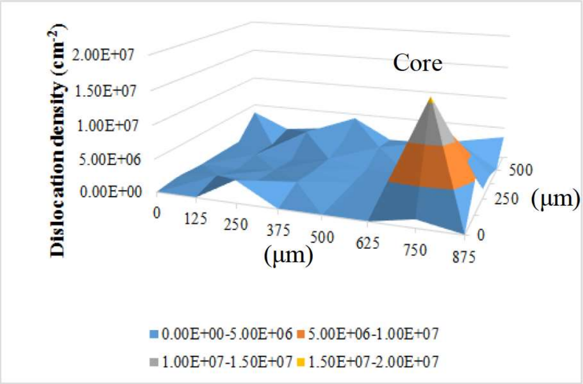
The characteristics of both non-core and typical core GaN substrates are listed in Table I.

TABLE I
CHARACTERISTICS OF GAN SUBSTRATES

Wafer type	Core A	Core B	Non-Core
Wafer Diameter	φ4”	φ4”	φ4”
Core Pitch (μm)	600	1000	-
Core (/φ4”)	21800	7850	10~300
carrier concentration (cm^{-3})	1-4E+18	1-4E+18	1-4E+18
Off-angle variation (degree)	<0.2	<0.2	<0.2
Dislocation density (cm^{-2})	<3E+6	<1E+7	<1E+6
Warp (μm)	±30	±30	±30

The threading dislocation densities of both non-core and core GaN substrates, measured by cathode luminescence observation, are shown in Fig. 4. The dislocation density is not uniform for core GaN substrates, and more than 1.0E+7cm^{-2} dislocations exist around the core region. In contrast, there are fewer, and more uniform dislocations for non-core substrates over the entire surface. This means that our ELO technique for burying cores is critical for drastically reducing dislocations in the crystal. This will allow us to form any size of devices without the core pitch limitation by stripe or dot core substrates.

Core A GaN Ave: 1.6E+6(cm^{-2})



Non-Core GaN Ave: 8.7E+5(cm^{-2})

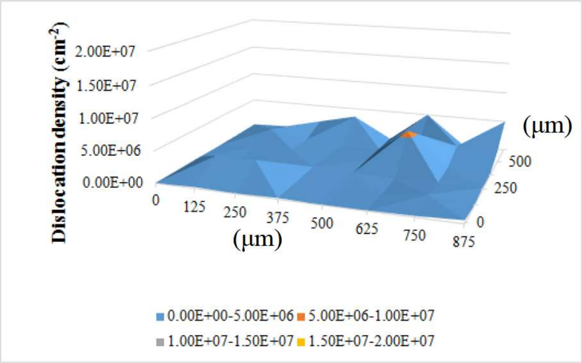


Fig. 4. Comparison of the threading dislocation density between core substrate and non-core substrate.

Fig. 5 shows the histogram of carrier concentration at the center position for both non-core and core GaN substrates. This result shows the same controllability of carrier concentration. The relationship between carrier concentration and electron mobility is plotted in Fig. 6, which shows that both the crystal quality and the purity of non-core substrates are comparable to those of core substrates.

Ave (σ)
None-core : 1.8E+18 (3.8E+17)
Core A : 1.6E+18 (3.0E+17)

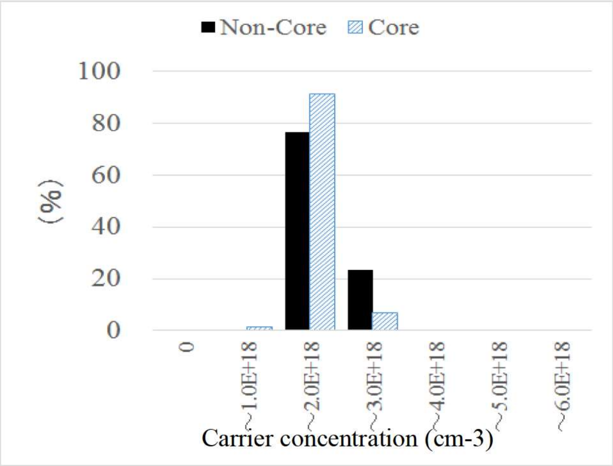


Fig. 5. Carrier concentration histogram for GaN substrate.

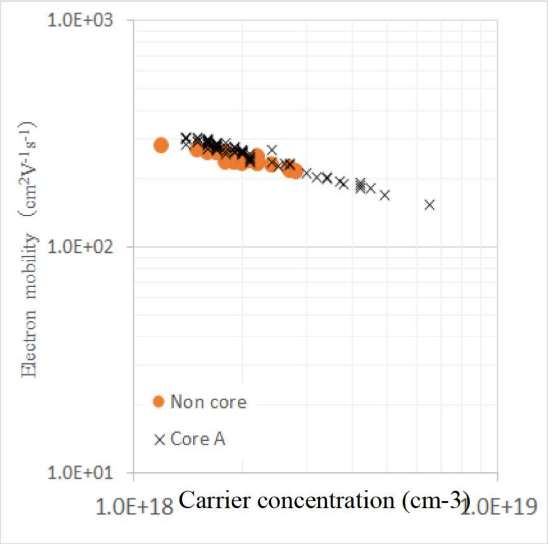


Fig. 6. Relationship between carrier concentration and electron mobility.

Fig. 7 shows the histogram of off-angle variation of the substrates. Measurements were taken at two positions, one is at wafer center position and the other is at the position 40mm from the center toward <1-100> direction on both core and non-core GaN substrates. Off-angle variation is nearly in symmetry with respect to wafer center position. Off-angle variation in Fig. 7 reveals the difference of off-angle between these two positions. The non-core substrates made by our method had smaller off-angle variation than that of core substrates. In our experiment (not shown here), GaN substrates without core formation during the initial growth stage have larger off-angle variation than those of our non-core GaN substrates. This will also allow us to produce devices with more uniform characteristics on the non-core substrates.

Ave (σ)
Non-core: 0.08 (0.02)
Core A : 0.12 (0.07)

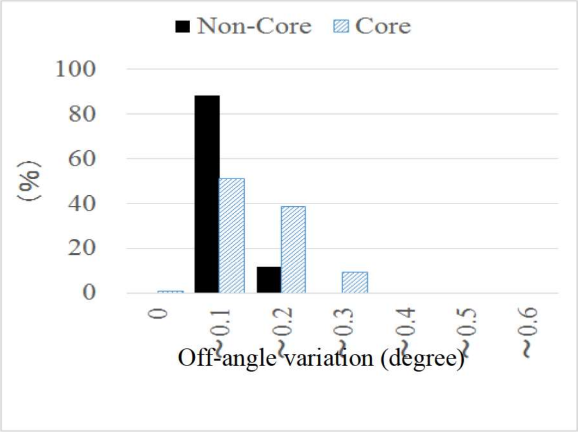


Fig. 7. Off-angle variation histogram for GaN substrate.

Fig. 8 shows the histogram of warp for both non-core and core GaN substrates. This result also shows the same controllability of WARP.

Ave (σ)
Non-core: -0.2 (7.8)
Core A : -1.0 (6.6)

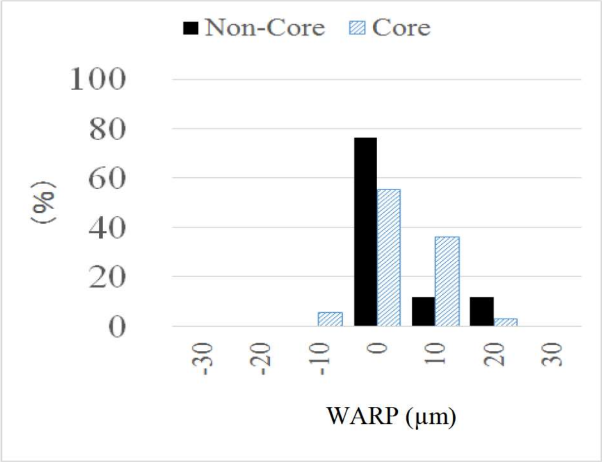


Fig. 8. WARP histogram for GaN substrate.

CONCLUSIONS

We have developed non-core 4-inch GaN substrates with small off-angle variation, less than 0.2 degree, and low dislocation density, less than 1E+6cm^{-2} over the entire surface. We have already transferred this technology to production for LED applications. And we also expect this technology to be applicable to the power device market.

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