Progress toward the Processability of GaN-on-Diamond Wafers

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High-electron-mobility transistors (HEMT) fabricated on GaN-on-diamond wafers have recently demonstrated greatly improved thermal-management properties relative to devices fabricated on silicon carbide [1]. Furthermore, modeling results show the potential to dramatically improve RF performance [2]. Freestanding GaN-on-Diamond wafers up to 2” in diameter have been fabricated with diamond thicknesses < 100 µm [3]. To date, however, processing of freestanding wafers has been accomplished via various techniques of temporary bonding (e.g. via crystal bond wax) to a carrier wafer. While this approach has led to successful fabrication of initial demonstration devices, its adequacy for volume manufacturing is still unclear due to the labor and material cost involved. For high-volume manufacturing implementation, a more robust (and lower cost) wafer handling solution is required.

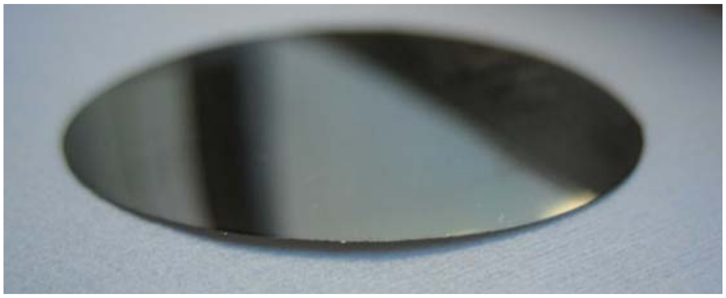

Figure 1. 2” diameter diamond wafer with 1 mm bow prior to mounting.

GaN-on-diamond wafers present unique challenges for device fabrication arising from the fact that CVD-diamond is a very hard material and CVD-diamond wafers generally exhibit a bow. An image of a 2” diamond wafer with a thickness of 100 µm is displayed in Figure 1. As a result of material hardness, diamond wafers are extremely difficult to thin down, especially after devices have been built on it. Therefore, the initial thickness of the diamond wafer must equal the final desired diamond wafer thickness. For most applications diamond thicknesses of less than 100 µm are sufficient to observe substantive thermal and performance benefits. However, diamond wafers with thicknesses below 150 micrometers are too fragile for production environment machine handling, even though handling with tweezers is acceptable. The typical bow of freestanding, 2 inch diameter diamond wafers is at least several hundred micrometers. This amount is difficult to manage in standard photolithography processes. Although thin diamond wafers are flexible enough to be pulled flat on a vacuum chuck, there remains a significant risk of diamond breakage. For stepper lithography, the bow should be less than 30 micrometers over a 2 inch diameter wafer.

Another challenge occurs at the wafer dicing stage, after planar device fabrication is complete. Due to its extreme hardness, mechanical cutting of diamond is very difficult and costly. For this reason, diamond wafers must be laser-scribed rather than sawed, a step which also requires good wafer flatness.

Rather than implementing tight controls on the diamond wafer growth process to manage flatness, a significantly simpler approach is to process diamond wafers while they are mounted on a carrier wafer that provides necessary flatness and mechanical robustness.

In this paper we present recent progress toward the processability of GaN-on-diamond wafers. We first demonstrate a temporary bonding-to-carrier technique using materials supplied by Brewer Science [4]. This bond to carrier is suitable for thermal processing steps up to 220°C and has been used in the initial demonstration devices of GaN-on-diamond. In addition, we discuss a semi-permanent bonding-to-carrier technique that produces excellent flatness for standard or advanced lithography processing. Tweezers handling of a 100 µm diamond wafer bonded to a 300 µm Si carrier is demonstrated in Figure 2. Figure 3 gives a surface plot showing the thickness variation of the diamond on carrier stack as measured by a micrometer. The variation in wafer thickness is less than 100 µm. This latter bond is suitable for high-temperature processing (up to 850 °C), including the deposition of thermal dielectric layers or contact anneals. Figure 4 shows the temperature cycling profile used to test the integrity of the semi-permanent bond. The bond survives 10 cycles from room temperature to 850 °C. Finally, the carrier may be one-time dismounted to produce fabricated, free-standing wafers.

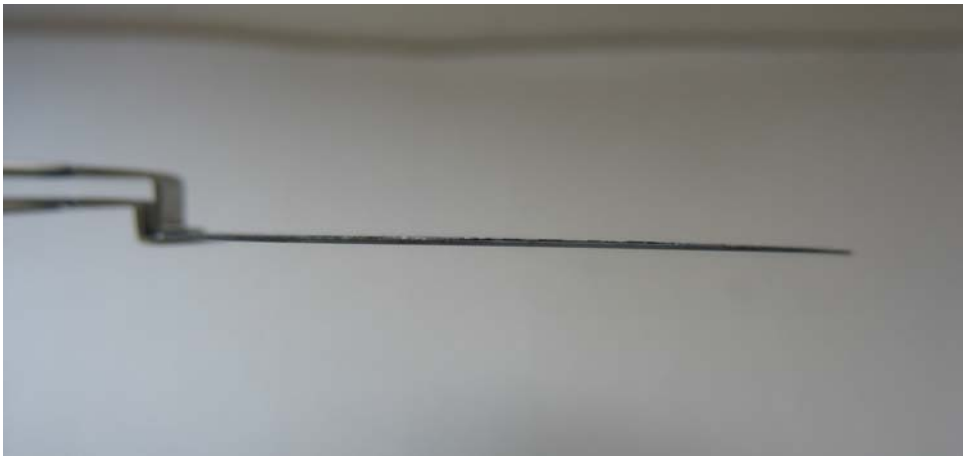

Figure 2. 2” diameter GaN-on-diamond wafer after mounting with semi-permanent bond (side view).

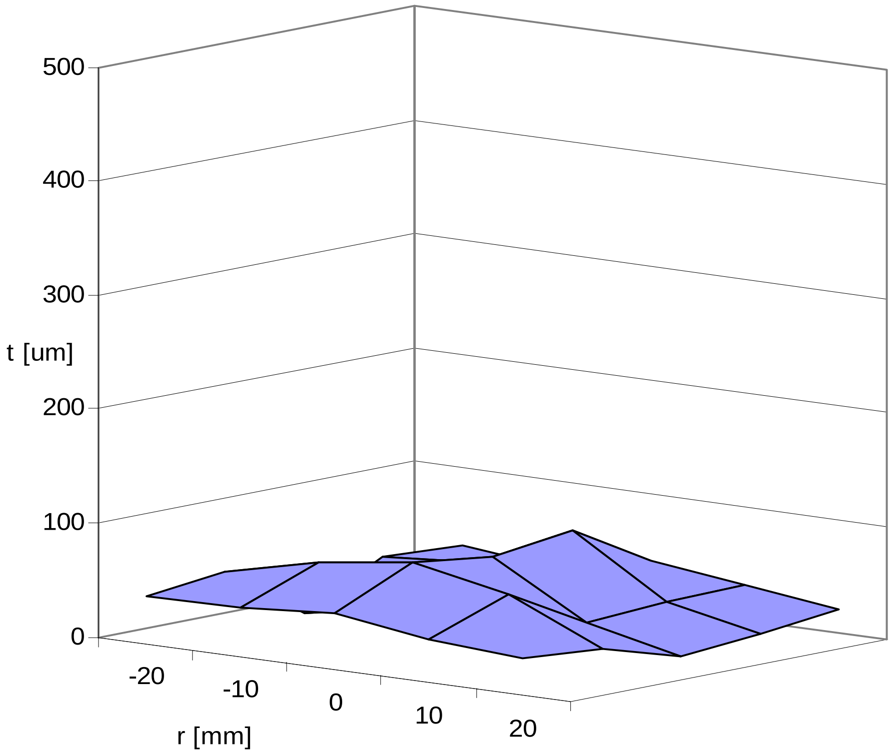

Figure 3. Surface profile of 2” diameter diamond wafer after mounting with semi-permanent bond.

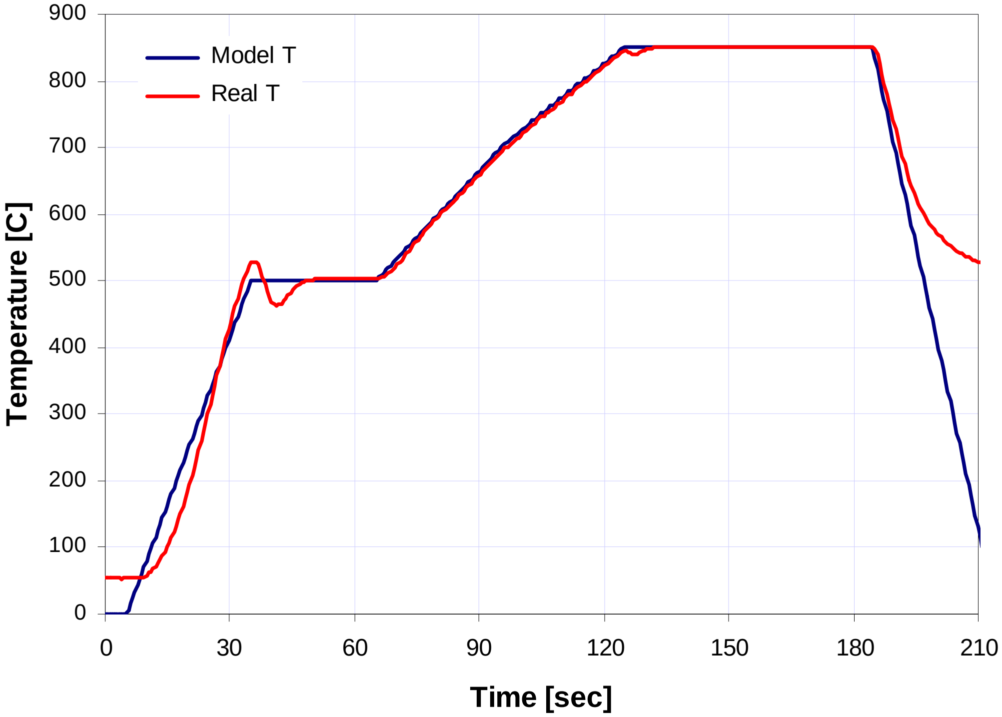

Figure 4. Rapid thermal anneal profile for temperature cycling of a semi-permanent bond.

References:

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