Diamond etching for GaN-based power devices

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Introduction

Semiconductor devices are broadly divided into silicon devices and compound semiconductor devices. Optical devices and high-speed devices that utilize the characteristics of compound semiconductor materials have made remarkable progress over the years, led by many researchers, including Professor Isamu Akasaki, a tenured professor at Meijo University [1].

Gallium nitride (GaN) devices have excellent physical properties and are being researched on applications of power devices and high-speed devices. Among them, GaN HEMTs (High Electron Mobility Transistors) have advantages over Si and GaAs in terms of saturation electron velocity and dielectric breakdown field strength. In particular, GaN-on-Si HEMTs fabricated on SiC substrates are used in high-output, high-frequency communication devices.

However, GaN-on-SiC HEMT is thermally limited due to the localized high temperature generated during high-power operation, which reduces reliability. One of the potential solutions is to utilize the high thermal conductivity of the diamond substrate[2]. In fact, there are research reports[3] that GaN HEMTs formed on diamond substrates have a high thermal conductivity, and the gate electrode surface temperature significantly improved in heat dissipation compared to devices on Si substrates.

This technical report describes vertical diamond etching for GaN-based devices, the demand for which is expected to grow further in the future.

Diamond etching

Diamond is a wide-gap semiconductor that has several advantages, including low noise and high sensitivity, and is therefore used in radiation detectors and other devices that require radiation resistance. Figure 1 shows 8 um deep polycrystalline diamond etching using Ni mask (200 nm thick) for X-ray detector fabrication. Due to limitation of process gases, roughness was on sidewalls and bottom surfaces, however, high selectivity over 60 and etch rate of 250 nm/min were achieved.

Figures 2 and 3 show diamond via-hole etching results for GaN-based devices. Figure 2 is the result of 60 µm deep etching on hole patterns with diameter of 30~50 µm. Employment of SiO2 as a mask avoided metal sputtering during etching. Furthermore, selectivity of 20 was achieved between diamond and SiO2 mask. Diamond etch rate was approximately 1µm/min. In figure 3, diamond etch rate was improved to 2.4 µm/min while maintaining the selectivity ratio of 20 against SiO2 mask.

Recipe can be adjusted to prioritize diamond surface smoothness. In figure 4, while diamond etching rate was controlled to 585 nm/min, smoother surfaces were achieved. The etching process for smooth diamond surfaces are applied to fabrication of MEMS sensors to detect electromagnetic fields.

We contribute to customers' various demands on semiconductor device manufacturing. The diamond etching solution on this report is one of the process technologies we have developed.

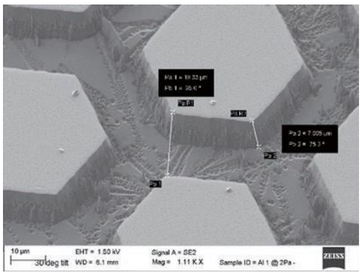

Figure 1. Diamond etching using Ni mask

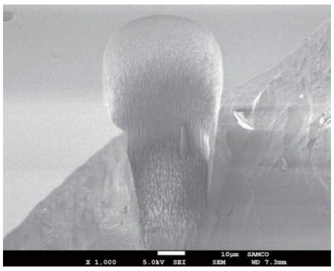

Figure 2. 60 µm deep diamond via-hole etching

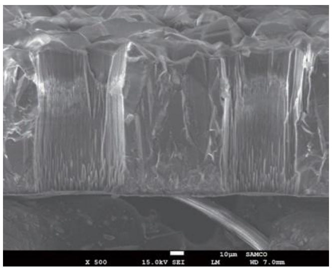

Figure 3. 100 µm deep diamond via-hole etching

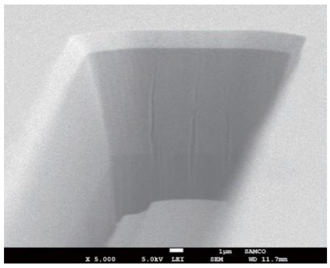

Figure 4. Diamond etching with smooth sidewalls

Reference

l) Isamu Akasaki, "III-V Compound Semiconductors," Advanced Electronics Series, Baifukan (1994)
2) Koji Yoshitsugu, Takashi Matsuda, Eiji Yagyu. 'Thermal Analysis of GaN Devices Using Diamond Substrates with Commercial Thermal Conductivity (Special Issue on Optical and High-Frequency Devices)' Mitsubishi Electric Technical Review 93, no.3 (2019): 196-200
3) Shuichi Hiza, Kunihiko Nishimura, Eiji Yagyu, Mikio Yamamuki. "Development of GaN-HEMT using diamond heat dissipation substrate." Applied Physics 90, no. 3 (2021):167-171.

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