Highly efficient plasma etching to achieve atomically smooth and damage-free β-Ga_2O_3 surface

Yongjie Zhang[1,2], Yuxi Xiao[1], and Hui Deng[1,#]

1 Department of Mechanical and Energy Engineering, Southern University of Science and Technology, Shenzhen, Guangdong, 518055, China
2 Department of Physics, National University of Singapore, 2 Science Drive 3, Singapore, 117551, Singapore
Corresponding Author / Email: dengh@sustech.edu.cn

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Single crystal β-Ga_2O_3 is widely considered as a four-generation semiconductor material with an ultra-wide bandgap of about 4.85 eV, showing extensive applications in developing ultra-high-power and high-temperature electronic devices. The ultra-precision polishing of β-Ga_2O_3 is a significant step in the flow of device fabrication, as both surface roughness and processing damage would greatly affect the performance of devices. However, β-Ga_2O_3 is a typical difficult-to-machine material with strong chemical inertness and natural hard-brittle feature, making it extremely challenging to fabricate atomic-scale smooth and damage-free surfaces. To address this issue, the novel plasma-based atom-selective etching (PASE) technique is applied to polish β-Ga_2O_3. In this method, an atmospheric inductively coupled plasma is activated with Ar gas as both the ignition and cooling gases, and O_2 and CF_4 gases are introduced into the plasma to generate etching radicals. This Ar-O_2-CF_4 plasma is found to present high temperature and high radical density features, and the etching reaction between plasma and β-Ga_2O_3 can remove Ga and O atoms in the form of gaseous GaF_3 and CO (and/or CO_2) molecules, respectively. The polishing mechanism of PASE towards β-Ga_2O_3 lies in the remarkable lateral etching effect, where the etching rate of atoms at the step edge is much larger than that of atoms in the terrace plane. With the lapped β-Ga_2O_3 as the substrate, the experimental etching results indicate that all mechanical scratches can be completely removed and the Sa roughness is decreased to below 0.1 nm within 120 s. Significantly, the material remove rate of the etching process can be as high as 20.96 μm/min, which is around 1500 times larger than that of conventional chemical mechanical polishing (CMP). In addition, the polished β-Ga_2O_3 exhibits excellent surface and subsurface quality, demonstrating the damage-free processing characteristic of PASE. Therefore, PASE should be a superior atomic-level manufacturing technique, which is expected to not only guide future plasma-based surface manufacturing of semiconductor materials but also enrich both theoretical and technical contents of atomic and close-to-atomic scale manufacturing (ACSM).

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