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Highly-efficient plasma-assisted polishing technique with auto-dressing

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Abstract
Compared to conventional free abrasive (slurry) polishing, fixed-abrasive (grinding stone) polishing is more efficient because of the higher abrasive grain density. However, as the polishing process proceeds, grinding stones get loaded and cause a decrease in material removal rate (MRR). To regain high MRR, an additional dressing process that can expose new abrasive grains to the grinding stone surface is necessary, but it also makes the polishing process discontinuous and reduces overall efficiency. Many researches have been conducted on the self-sharpening of fixed abrasive grinding stones. Nevertheless, the self-sharpening of grinding stones is not efficient with ultra-low polishing pressure, which is not large enough to break bonds so as to expose new abrasives. Hence, a polishing technique that enables auto-dressing even at ultra-low polishing pressure becomes very attractive. In this study, a highly efficient auto-dressing dry polishing process was proposed, where it combines plasma-assisted polishing and plasma-assisted dressing using Ar-based CF_4 plasma and a vitrified-bonded grinding stone. As the main component of vitrified bond materials, silica was etched using CF_4 plasma, which is equivalent to the continuous dressing of grinding stone surfaces, makes a high MRR was maintained. Thus, a highly efficient auto-dressing polishing process was realized. Moreover, the CF_4 plasma irradiation increased the MRR twice, as CF_4 plasma can not only dress a grinding stone in real time but can also modify the substrate to make it remove easily.

Ar-based CF_4 plasma, vitrified-bonded grinding stone, auto-dressing, plasma-assisted polishing

1. Introduction

AlN is an excellent candidate for heat sinks and microelectronics applications [1] owing to its high thermal conductivity, high mechanical strength, relatively low dielectric constant, and low thermal expansion coefficient. Furthermore, in recent years, research on the use of AlN substrates as an epitaxial growth substrate in the deposition of a single-crystal GaN film on AlN ceramic, has attracted considerable attention due to the small lattice mismatch between GaN and AlN ~2.4%.

Since AlN ceramic is a kind of sintered materials, when subjected to a large mechanical polishing load, many pits were formed on the surface by shedding-off grains from the sintered material surface owing to their weak intergranular interactions. Although low polishing load can effectively prevent grains shedding, it also reduces processing efficiency. High-quality polishing of sintered materials has always been a challenging in the field of precision machining. Although CMP processes are now widely used to polish difficult-to-machine materials including sintered materials, the low material removal rate (MRR) of CMP makes such processes very time-consuming. Large particles can easily be formed by the agglomeration of the abrasive particles in slurry when it is placed for a long time. The management and disposal of the used slurry in CMP are also considered as very expensive for actual industrial applications. Thus, a dry polishing technique without using slurry is desired. Generally, a fixed abrasive is used in dry polishing processes. No matter which kind of fixed abrasive grinding stone been used, over a certain period after polishing, the abrasives will undergo wear, and the grinding stones will be overloaded and will lose their polishing ability. Therefore, to solve these problems, a dry dress-free polishing technique, which can also be applied to polishing sintered ceramics materials, is desired.

Plasma-assisted polishing (PAP), a dry polishing technique that combines surface modification by plasma irradiation and removal of the modified layer by utra-low pressure or using soft abrasive, has been successfully applied to polish difficult-to-machine materials such as SiC, GaN, and diamond [2-4]. However, grinding stone overload also limited the efficiency of PAP. In this study, vacuum PAP using Ar-based CF_4 plasma, and a vitrified-bonded diamond grinding stone was applied to polish an AlN ceramic wafer. Since CF_4 plasma can not only modify the AlN surface, but also etch the bonding material of the grinding stone simultaneously to prevent the overloading, a highly-efficient PAP process for AlN ceramic wafer with auto-dressing was achieved.

2. Experimental setup

Figure 1 shows a schematic of the vacuum PAP setup used in this study. The setup comprises upper and lower metal electrodes made of aluminum alloy, and the area between them was separated from the atmosphere using a cylindrical quartz glass cover. The rotary pump was used to reduce the requiredpressure for plasma generation in this space. A ϕ 50 mm × 1.0 mm^t sintered AlN wafer was installed on the lower rotary table, and a vitrified-bonded diamond grinding stone was set on the upper rotary head, whose center of rotation was offset by 15 mm from the center of rotation of the lower rotary table. Therefore, the area to be polished was ring-shaped, as shown in Fig. 1. The gap distance between the upper electrode and AlN wafer surface was 14 mm, and the Ar and CF_4 mixture was controlled using MFCs. By applying RF (f = 13.56 MHz) power on the upper electrode, plasma was generated in the space between the upper electrode and AlN wafer, and the grinding stone was pressed against the AlN wafer with a constant load. Through the rotation of the lower rotary table and upper rotary

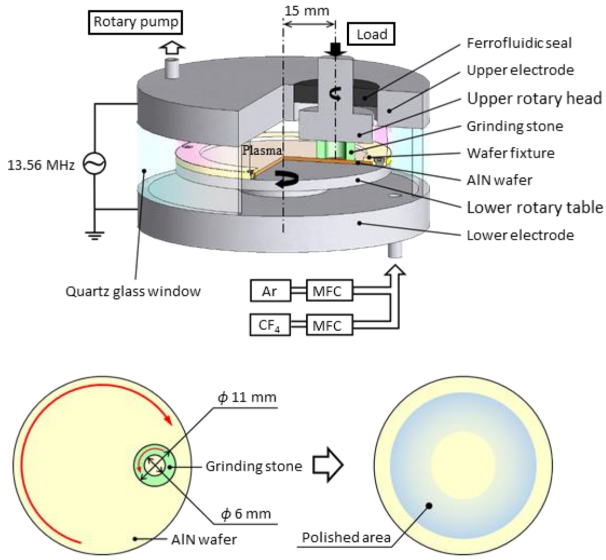

Figure 1. Schematic diagram of the vacuum PAP setup.

head, plasma irradiation and polishing were alternately conducted on the AlN wafer. Conventional mechanical polishing can also be carried out using this setup without applying RF power.

3. Results and discussion

In this study, mechanical dry polishing experiments without dressing, mechanical dry polishing experiments with frequent dressing (every 30 min), and PAP experiments without dressing were conducted on AlN wafer using a vitrified-bonded diamond grinding stone under ultralow polishing pressure (800 Pa), and the MRRs under different conditions were compared by the variation of the removal depth in polished area. To confirm the wear condition of the grinding stone surface, the surface morphology of the grinding stone was observed every 30 min using SWLI and SEM, and the representative data are shown in Fig. 2. *S*dr (developed interfacial area ratio) value was used to evaluate the surface condition of the grinding stone and is expressed as the percentage of a defined area's additional surface area contributed by its texture in comparison with the planar definition area. In another word, the *S*dr of a completely flat surface is 0. If many abrasive particles are exposed on the grinding stone surface, the *S*dr value will be large.

As shown in Fig. 2(a), just after dressing using a diamond dress plate, many pores can be observed on the initial surface of the grinding stone, and the *S*dr value of the grinding stone surface was approximately 0.6. However, during the mechanical dry polishing experiments without dressing, since only an ultralow polishing pressure was applied in order to prevent AlN grains shedding off from surface, self-sharpening of grinding stone did not occur. With the increase in the polishing time, a part of the surface of the grinding stone became smooth because the pores were filled with the falling abrasive particles, bond materials, and removed AlN chips, as shown in the area surrounded by the red frame of Fig. 2(b), and the *S*dr of the grinding stone surfacesignificantly decreased to 0.02 after 3 h of conventional mechanical dry polishing. The grinding stone quickly lost its polishing ability due to the loading of its surface, the MRR was very low, and the removal depth was only 500 nm. In contrast to the results without plasma irradiation, no loading of the grinding stone surface was observed after 3 h PAP as shown in Fig. 2(c). Many pores and diamond abrasives with cutting edges were exposed on the surface, which was similar to the initial surface just after dressing, and the *S*dr value was kept at approximately 0.6. During PAP process using CF_4 plasma, it was confirmed that

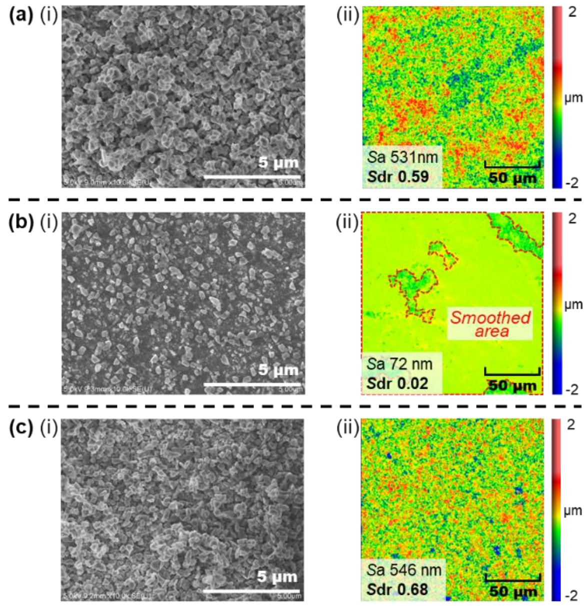

Figure 2. (i) SEM and (ii) SWLI images of the diamond grinding stone surface (a) just after dressing using a diamond dress plate (b) after 3h of dry polishing (c) after 3 h of PAP.

SiO_2, which is the main component material of the binder in the vitrified-bonded diamond grinding stone, was etched by the CF_4 plasma, which is equivalent to the continuous dressing of the grinding stone surface. The grinding stone was kept from being loaded and high MRR can be maintained [5]. Furthermore, in the case of PAP, after the CF_4 plasma irradiation, the AlN can be modified to AlF_3, and its modified layer could be easily removed by abrasives. Thus, a much deeper removal depth (1000 nm) was realized.

4. Conclusions

In the case of PAP using CF_4 plasma and a vitrified-bonded grinding stone, the CF_4 plasma irradiation not only generated an easily removable and modified AlF_3 layer on the AlN surface but also dressed the grinding stone surface simultaneously by etching the main components of the bond materials. Owing to the auto-dressing simultaneously occurring in the PAP process, a novel highly-efficient dress-free polishing process was realized. And the combined contribution resulted in twice the MRR compared with mechanical dry polishing processes without dressing.

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