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Study on the finishing capability and abrasives-sapphire interaction in dry chemo-mechanical-grinding (CMG) process

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ABSTRACT

Chemo-mechanical-grinding (CMG) is a fixed abrasive process by integrating both chemical reaction and mechanical grinding. This paper targets on studying the finishing ability of dry CMG processes for mono-crystal sapphire and understanding the underlying abrasives-sapphire interaction. The experiment results suggest that dry CMG processes by applying either Cr_2O_3 or SiO_2 are able to produce sapphire substrate with an excellent surface quality and subsurface integrity, meanwhile, maintain the geometric accuracy. The underlying abrasives-sapphire interaction termed as solid phase reaction is demonstrated by X-ray photoelectron spectroscope (XPS) analysis. It is suggested that Cr_2O_3 abrasives is more chemically active against sapphire (Al_2O_3) when compared with SiO_2 abrasives. Combined with a higher mechanical effect provided by Cr_2O_3 abrasives, the finishing efficiency of Cr_2O_3 abrasives is almost 2 times higher than traditional SiO_2 abrasives. The subsurface integrity characterization by using Raman microscope and transmission electron microscope reveals that Cr_2O_3 abrasives introduces a shallow damage layer (about 100 nm) on the top surface of sapphire substrate since the chemical effect is not sufficient enough to meet the balance with mechanical effect. With a better mechanical-chemical balance achieved by SiO_2 abrasives, a damage free subsurface is obtained. Therefore, besides of traditional SiO_2 abrasives, Cr_2O_3 abrasives is suggested to be another potential candidate for finishing sapphire substrate.

1. Introduction

Sapphire (mono-crystal aluminum oxide) is gifted with extraordinary mechanical, chemical, thermal, and optical properties and thus has become a key component in a variety of high-technology products such as visible-infrared optical windows, gain medium for Laser systems, and light emitting diodes (LEDs) [1,2]. Practically, sapphire substrate shoulders the responsibility for growing group III–V elements based epitaxy layers for LEDs which show huge advantages against traditional incandescent and fluorescent lamps in energy consumption and service lifetime [3–6]. The quality of epitaxy layers is largely determined by the surface quality and subsurface integrity of sapphire substrate [7]. The chemical mechanical polishing (CMP) technology combined with industrial colloidal silica (SiO_2) stands out as the preferable process to produce sapphire substrate with desired surface quality and subsurface integrity [8]. In last several years, many papers have investigated the performance of industrial colloidal silica based CMP process on the final polishing of sapphire substrate [8–15]. Although the polished sapphire substrate is given an ultra-smooth surface, the material removal rate (MRR) still fails to meet the requirement of mass production. It is also difficult for the CMP process to maintain the geometric accuracy of sapphire substrate, especially when the sapphire substrate becomes larger [16]. Meanwhile, recently developed abrasive (SiO_2) syntheses or catalysts show a better performance in terms of surface quality and polishing efficiency on the CMP process for sapphire substrate [17–22]. However, these advancements are too costly and complicated to be put into practical application and unable to overcome the intrinsic shortages from CMP process. On the other hand, all these accessible publications only pay attention to the surface quality of sapphire substrate rather than the subsurface integrity. It should be noted that the abrasive applied to polish sapphire substrate is still based on SiO_2. Few papers show the performance of other abrasive candidates and finishing processes which are potential to polish/finish sapphire substrate [9,10,16,23–31].

Therefore, this paper will present a new finishing process termed as chemo-mechanical grinding (CMG) for sapphire substrate. CMG is a fixed abrasive process by integrating chemical reaction and mechanical grinding into one-stop process and shows advantages against CMP in finishing efficiency, geometric controllability, and waste disposal [25]. The chemical aspect of CMG is based on a solid-phase reaction between

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the abrasive and workpiece and resulted in a soft product which can be mechanically removed by subsequent soft abrasive [28]. The application of CMG process in crystal materials such as silicon, silicon nitride, and silicon carbide has already been revealed in publication [25–30]. The previously published paper has also revealed that CMG process by applying chromium oxide (Cr_2O_3) is potential to produce sapphire substrate with an excellent surface and subsurface quality, and the dry CMG seems to perform better than wet CMG [16,31]. In this paper, a deeper study concerning with finishing capability and abrasives-sapphire interaction in dry CMG process will be addressed. Besides of surface quality, the characterization of subsurface integrity will also be highlighted.

2. Wheel development and experiment set-up

In this paper, a new Cr_2O_3 based grinding wheel was developed to study the finishing ability and abrasive-sapphire interaction in dry CMG process as well as the experimental repeatability referring to the previous publication [16,31]. Since SiO_2 was the most common abrasive applied for final finishing/polishing of sapphire substrate, an almost identical SiO_2 based grinding wheel was also developed as a comparison. The specifications of CMG wheels are listed in Table 1. The abrasive size of both CMG wheels is about 5 μm and much larger than that of traditional CMP process. The experiment was carried out on a grinding platform (UPG-150) which is able to perform grinding process under either constant in-feed rate or constant pressure as shown in Fig. 1. In current study, the diamond wheel moves towards sapphire substrate by a constant in-feed rate while the CMG wheel is pressed on the sapphire substrate by a constant pressure.

The sapphire substrates used for experiment were commercially purchased C-plane (0001) with two inches size. Its hardness is around 22.5 GPa (HV1, Load = 9.807 N). All sapphire substrates were at first ground by a diamond wheel (SD1000N40 V) to guarantee the initial surface consistency and alignment between sapphire substrates and grinding wheels. The parameters of diamond grinding process are listed in Table 2. The surface profile of sapphire substrate after being ground by SD1000N40 V is shown in Fig. 2, and the surface roughness (Ra) is about 50 nm. The sapphire substrate is characterized with scratches and pits distributing across its surface.

Those pre-ground sapphire substrates were subsequently finished by CMG process at the same set-up. The parameters of CMG process are listed in Table 3. Prior to CMG, the wheel was conditioned (truing and dressing) by use of an electroplated #120 diamond wheel. Instead of constant in-feed rates (10, 2 μm/min) in diamond grinding process, a constant pressure (62.5 kPa) was applied in CMG process. It should be noticed that all the CMG processes were conducted under dry condition. Every round of CMG process was lasting for one hour. After the CMG process, the sapphire substrate was cleaned by an ultrasonic cleaning

Table 1
Specifications of CMG wheels.

Prototype of CMG wheel		
Abrasive	Cr_2O_3	SiO_2
Abrasive size [μm]	5	
Abrasive hardness (Vickers) [GPa]	14–18	11–14
Abrasive concentration [vol%]	42	52
Wheel diameter [mm]	300	300
Bond material	Phenol resin	
Bending strength [kg/mm^2]	0.84	1.15
Elastic modulus [kg/mm^2]	509	711
Density [g/cm^3]	2.49	1.66

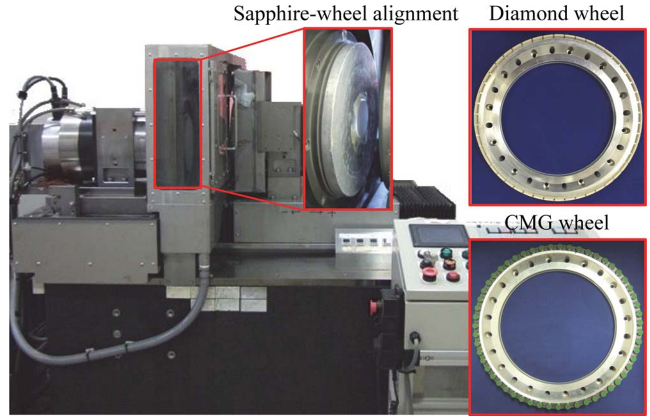

Fig. 1. Experiment tool (UPG-150) and set-up.

Table 2
Parameters of diamond grinding.

Diamond wheels	SD1000N40V
Wheel revolution [rpm]	1200
Wafer revolution [rpm]	200
Down-feed rate [μm/min]	10
	2
Down-feed [μm]	30
	2
Spark-out time [s]	60
Coolant [l/min]	2 (water)

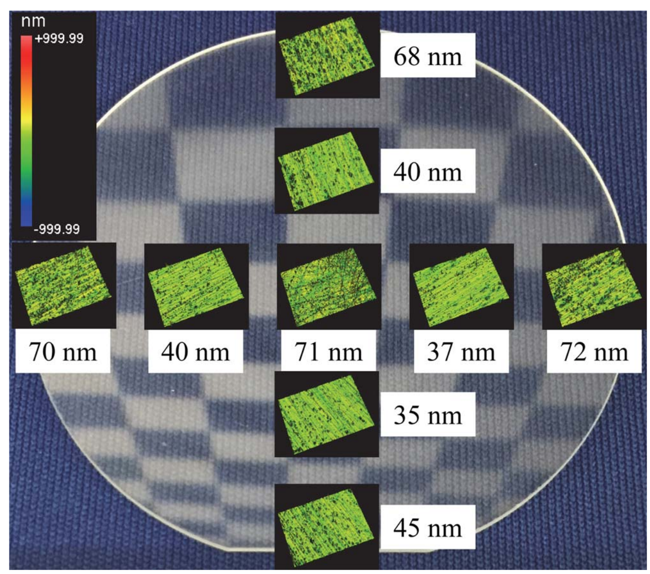

Fig. 2. Sapphire surface before CMG process (Ra = 53 nm after diamond grinding).

Table 3
Parameters of CMG process.

CMG wheels	Cr_2O_3 and SiO_2
Grinding condition	Dry
Wheel revolution [rpm]	600
Wafer revolution [rpm]	100
Grinding force [N]	10
Grinding pressure [kPa]	62.5