Development of high efficiency CMG pellets for finishing mono-crystal sapphire

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Abstract. Chemo-mechanical-grinding (CMG) is a fixed abrasive process by integrating chemical reaction and mechanical grinding for sapphire wafer finishing, and shows advantages in surface integrity, geometric controllability and waste disposal. However, its material removal rate is not high enough to meet the increasing demands of sapphire wafer. As a potential solution, a new concept of CMG wheel with extremely high concentration of Cr_2O_3 abrasive has been proposed in this research. Described in this paper are development of manufacturing process with CIP (cold isostatic pressure) technique to produce CMG pellet made up to 100 wt% abrasive, and investigation on the effect of variation in abrasive concentration on CMG wheel performance.

Introduction

Mono-crystal sapphire (α-Al_2O_3) is a functional material with excellent physical and chemical properties, and has been widely applied in optical and electronical products such as light emitting diodes (LED), cover-glass for smart watch and mobile phone [1-2]. However, α-Al_2O_3 is very difficult to be machined because of its high mechanical strength and chemical stability. At present, CMP (chemical mechanical polishing) technology has been widely accepted for final finishing of sapphire due to its capabilities of providing ultra-smooth and low damage surface [3-5]. CMP generally uses a large amount of silicon oxide abrasive in slurry state, yet takes a long processing time. Such nature of free abrasive process not only increases the manufacturing cost [6], but also losses the geometric controllability on sapphire wafer [7-8]. In addition, the disposal of slurry waste could possibly cause a severe environmental pollution.

CMG (Chemo-mechanical-grinding) is a fixed abrasive process by integrating both chemical reaction and mechanical grinding into one-stop process, shows advantages over CMP in finishing efficiency, geometric controllability and waste disposal, and is applicable to subsurface damage removal for silicon, silicon nitride, quartz and other single crystal wafers so far [9-11]. In this research, CMG with Cr_2O_3 abrasives has been successfully applied into the finishing process of mono-crystal sapphire wafer [12-13]. However, the MRR (material removal rate) is still not high enough to meet our expectation. As a potential solution of

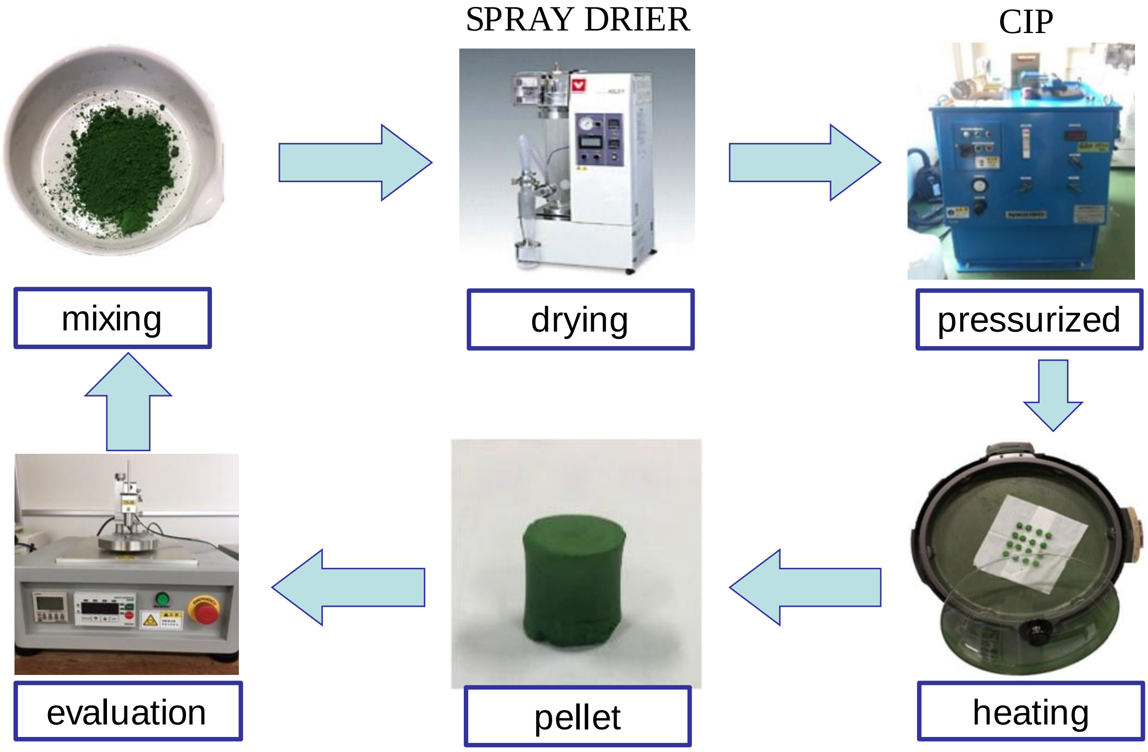


Fig.1 Production process of CMG pellet

Table 1 Conditions for CMG pellet development

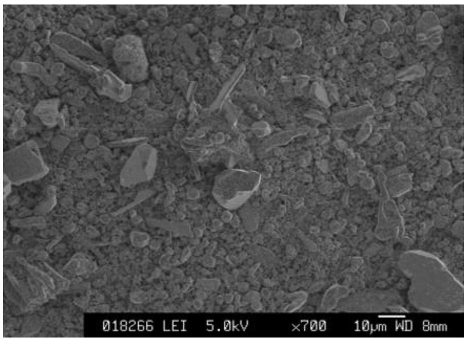
Parameter	Value
Abrasive gain	Cr_2O_3(5μm)
Binder	PVA
Molding pressure [MPa]	200, 250, 300, 350, 390
Pressurization time [min]	5, 10, 15, 20
Abrasive concentration [wt%]	99, 99.5, 99.75, 100
Heating temperature [℃]	70-80
Heating time [min]	60

improving MRR, this paper aims at developing a CMG wheel with extremely high abrasive concentration. Described in the following sections are manufacturing process with CIP (cold isostatic pressure) technique to produce CMG pellet made up to 100 wt% abrasive, friction and wear test of developed CMG pellets and discussion on the experimental results.

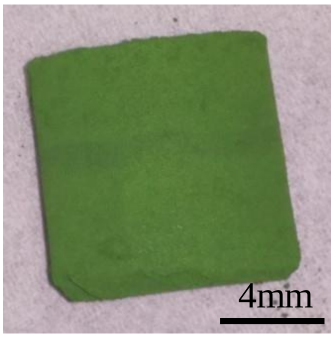
Development of highly concentrated CMG pellets

Based on the results obtained in our previous researches, the chromium oxide (Cr_2O_3) shows a better performance in terms of MRR and surface roughness than other chemically active abrasives [12-14]. Cr_2O_3 is therefore selected as the abrasive grain for the current CMG pellet development. Fig.1 shows the development and evaluation procedure of high concertation CMG pellets. Firstly, the abrasive and the PVA resin are uniformly mixed in a specified ratio, then go through a spray drier to get the dehydrated abrasives with a thin layer of PVA coating. Secondly, the PVA coated abrasives are compressed by a CIP (cold isostatic pressing) machine

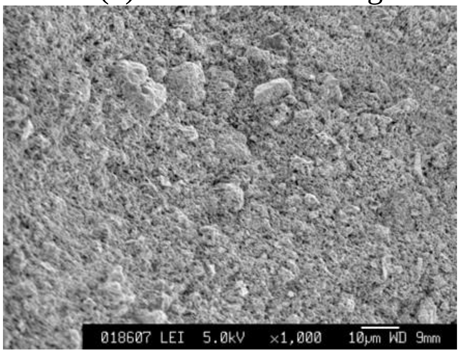
(a) Abrasive gains



(b) SEM of abrasive gains

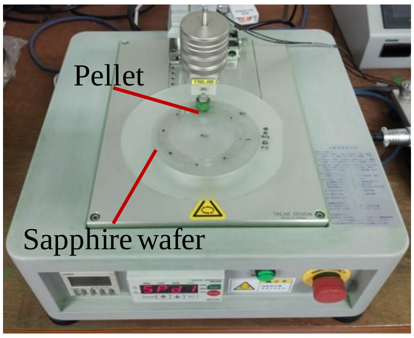


(c) Developed pellet

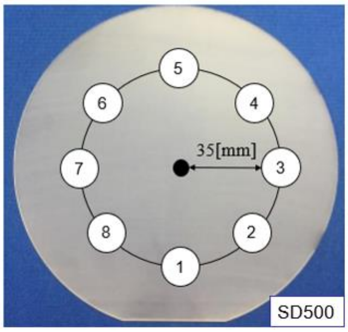


(d) SEM of pellet

Fig.2 Abrasive and pellet of 100 wt% Cr_2O_3



(a) Friction and wear tester



(b) 6inch sapphire wafer

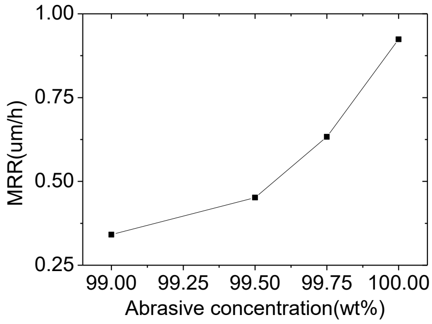
Fig.3 Friction wear tester and 6 inch sapphire wafer used for testing

Table 2 Parameters for evaluation

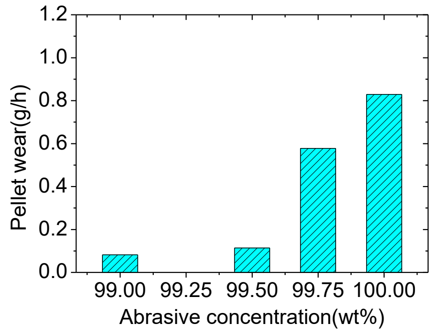
Pellet diameter [mm]	Load [g]	Pressure [KPa]	Rotational speed [rpm]	Experiment time [h]
15	400	29.5	400	3

for a specified holding time to form a pellet. Hereafter, the pellets are further heated to evaporate the moisture. Finally, the pellets are tested on a friction and wear tester to evaluate their strength and performance.

The detailed conditions for CMG pellet development are listed in Table 1. The developed CMG pellets are characterized by variation in the abrasive concentration, molding pressure and pressurization time whereas the other parameters are fixed. A typical example of Cr_2O_3 abrasive and pellet is shown in Fig.2. Shown in Fig.2 (a) is Cr_2O_3 abrasive used in this study while in Fig.2 (b) is its SEM image from which we found that both size and shape of abrasive are widely scattered. Shown in Fig.2 (c) is a pellet developed at the conditions of 100 wt%

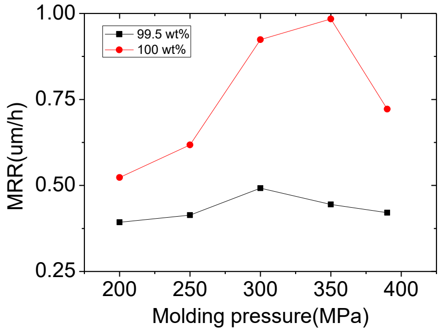


(a) on MRR

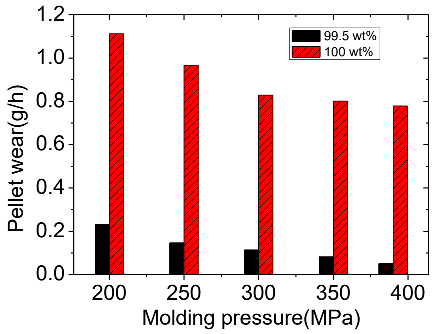


(b) on pellet wear

Fig.4 Effect of abrasive concentration

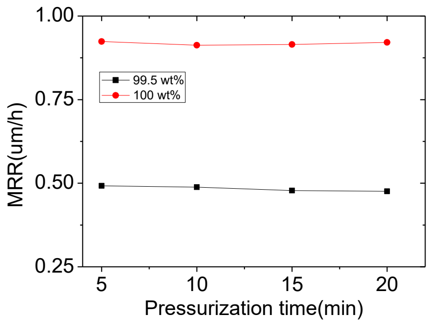


(a) on MRR

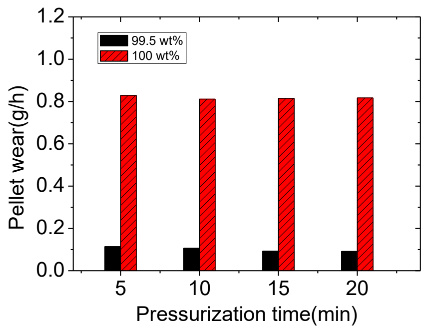


(b) on pellet wear

Fig.5 Effect of molding pressure



(a) on MRR



(b) on pellet wear

Fig.6 Effect of pressurization time

Cr_2O_3 abrasive concentration, 350 MPa pressure and 20 minutes pressurization time. Its pellet size is about $\phi 15\times 10$ mm. Fig. 2 (d) is the SEM image of the pellet cross-section. It is found that the structure of pellet consists of densified abrasive only.

Test and evaluation

All developed pellets are then tested on a pin-on-disc friction and wear tester (TL201Tt, Intelligent Tester, Trinity-lab Co.), as shown in Fig. 3, where the pellet works as a pin and the six-inch sapphire wafer (0001) as a disc. The test parameters are fixed as listed in Table 2. After each testing, the thickness variation of wafer is measured by an optical microgauge (C8125-01, Hamamatsu Co.). MRR is calculated by averaging 8 measurements uniformly distributed across the tested wafer as shown in Fig.3 (b). The pellet wear which is defined as the weight loss of pellet is measured by electronic balancer (GH-202, Max.220g, Min.1mg, e=1mg, d=0.01/0.1mg).

When the molding pressure and pressurization time are fixed at 300MPa and 5min respectively, the variation in MRR of sapphire and wear of CMG pellet are shown in Fig. 4. With an increase in abrasive concentration, the MRR increases accordingly. The higher the concetration is as we expect, the greater number of abrasives are involved in material removal in CMG process. Meanwhile, less PVA resin leads to poorer strength of pellet which causes an inceasing in wear of pellet during friction and wear test. In such circumstances, more chemically active abrasive Cr_2O_3 are relased into the interface of pellet and resulted in a higher MRR. Therefore, MRR in CMG is well correlated to the pellet wear. It is essential to maintain a certain rate of wheel wear in an actual CMG process.

Fig.5 shows the effect of molding pressure on both MRR and wear of 99.5 wt% and 100 wt% concentrated pellets, when pressurization time is fixed to 5min. With an increase in molding pressure, MRR finds its maximum at 300MPa for 99.5 wt% pellet and 350MPa for 100 wt% pellet respectively while the pellet wear keeps decreasing for both concentrations. A higher molding pressure, obviousely resulted in a higher strength of pellet, which in tun increases the resistance against the wear. As another concequence of higher molding pressure, less abrasive is worn off or released from pellet to pellet/wafer interface, which in turn decreases MRR. On the other hand, a pellet with insufficient strength is also unsustainable in CMG process to achieve desired MRR.

Fig.6 show the effect of pressurization time, when the abrasive concentration and molding pressure are kept unchanged. It is found that the effects of pressurization time on both MRR and pellet wear are negligible.

Summary

Aiming at improving MRR in CMG finishing process of sapphire wafer, this paper describes a development procedure of CMG pellet with extremely high abrasive concertation, and performance evaluation of developed CMG pellets. The results are summarized as follows;

(1) CMG pellets made of up to 100 wt% Cr_2O_3 abrasive have been successfully developed by using of CIP technique.

(2) MRR of CMG pellet increases with an increasing in the abrasive concentration.

(3) The molding pressure optimized for MRR is about 300MPa for 99.5wt% abrasive concentration, and 350MPa for 100 wt% abrasive concentration.

Acknowledgements

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