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*Research Article*

# Development and Analysis of Double-Faced Radial and Cluster-Arranged CMP Diamond Disk

**M. Y. Tsai,[1] C. H. Chen,[1] J. H. Chiang,[2] and T. S. Yeh[2]**

[1] *Department of Mechanical Engineering, National Chin-Yi University of Technology, No. 57, Section 2, Zhongshan Road, Taiping District, Taichung 41170, Taiwan*
[2] *Chung-Shan Institute of Science and Technology, No. 481, Section Chia an, Zhongzheng Road, Longtan Shiang, Taoyuan County 325, Taiwan*

Correspondence should be addressed to M. Y. Tsai; mytsai@ncut.edu.tw

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In semiconductor manufacturing, diamond disks are indispensable for dressing chemical mechanical polishing (CMP) pads. Recently, 450 mm (18 inch) diameter wafers have been used to improve output and reduce wafer production cost. To polish 450 mm diameter wafers, the diameter of polishing pads must be increased to 1050 mm. In particular, because diamond disks are limited to 100 mm diameters, a much greater number of working crystals will be required for dressing a 1050 mm diameter pad. Consequently, new diamond disks must be developed. In this study, novel arrangements are made using a braze in diamond patterns, which are radial with a cluster arrangement of 3-4 grits per cluster. Furthermore, a double-faced combined diamond disk is developed. The polishing pad surface was characterized, and the effect of different diamond conditioners on wafer removal rate was studied. This research aims to develop a more suitable diamond disk for dressing 1050 mm diameter polishing pads.

## 1. Introduction

Chemical mechanical polishing (CMP) is a process used in the ultra-large-scale integration fabrication industry to planarize interlevel dielectric [1]. This technology employed by IBM in the 1980s is the most attractive one as it can achieve high surface quality with high polishing efficiency and it can provide a flat and smooth surface on the wafer for lithography needs [2]. In the CMP process, pad dressing is essential for achieving stable polishing performance. During polishing, the reaction product gradually accumulates in holes and grooves in the pad surface, leading to "glazing" of the pad [3–5]. Consequently, the wafer removal rate decreases because slurry can no longer be distributed uniformly on the pad surface [6–8]. Therefore, to address pad glazing and enable chemical mechanical polishing (CMP), a diamond disk is used to regenerate the pad's asperity structure, enabling it to play its designated role in polishing [9, 10].

Many studies have designed pad conditioners. Several important studies have been carried out on the design of the pad conditioner. Zimmer and Stubbmann [11] stated that the ideal conditioner should have exactly the same size, shape, and orientation as the diamond grit and that the spacing between the diamond grits should be the same. Sung et al. [12] pointed out that the number of working diamonds is markedly influenced by the level of the diamond grits. They also mentioned that the tip height distribution in conventional CMP pad conditioners is intrinsically large because of the variation in the grit size and diamond orientation. Garretson et al. [13] investigated the optimal design parameters of the pad conditioner from the viewpoint of the wafer removal rate and uniformity. They proposed that a conditioner with a flatter substrate would result in a better dressing rate. Rikita et al. [14] pointed out that the diamond grit size, crystalline orientation, distribution density, degree of diamond protrusion, and substrate planarity all affect the dressing rate of the conditioner. Tsai et al. [15] studied a revolutionary design for pad conditioners, called an advanced diamond dresser (ADD); it was fabricated by carving out a structure from a sintered polycrystalline diamond matrix to form identically shaped tips. The proposed dresser can create a more uniform pad asperity than traditional diamond conditioners. In addition, the

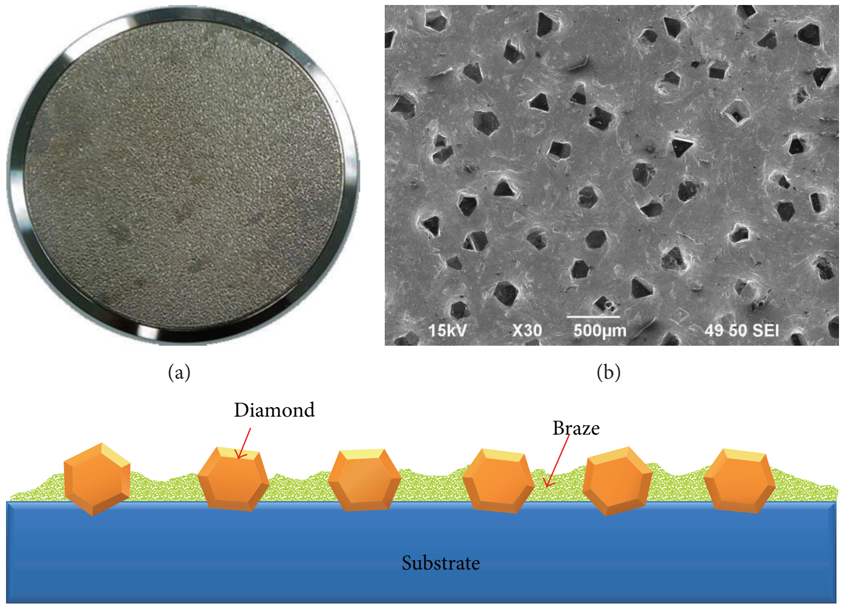



Figure 1: Conventional diamond disk.

polishing rate of the ADD exceeds that of traditional diamond conditioners. However, a major disadvantage of the ADD was its manufacturing cost, which was more than three times that of the traditional dresser. Kim and Kang [8] developed a CMP diamond conditioner on the basis of a new concept and hence improved the conditioning performance. Their novel diamond conditioner was fabricated by applying a diamond film coating to a $Si_3N_4$ substrate with regularly patterned protrusions. Shih et al. [10] investigated diamond grits that were embedded in a microcolumn array formed by nickel deposits on a substrate by using a resist mold. By employing this technique, the distribution density of the working diamond grits in the diamond conditioner could be increased. Moreover, an extra layer of strike nickel plating was used to functionalize the surface of the nickel deposit and increase its polarization, which eliminated the edge effect in the enhancement electroplating process. Li et al. [16] proposed a surface element method to develop a mathematical model to predict the pad surface shape that resulted from diamond disc conditioning. Tsai and Chen [17] evaluated diamond conditioners manufactured using polymer-bonded diamond grits for use in CMP; these conditioners are known as organic diamond disks (ODDs). ODDs are fabricated by reverse casting the substrate. Instead of using a flat substrate as the backing for attaching diamond grits, the substrate is prepared after the diamond grits are leveled on the surface of a mold. It was found that if the diamond tips of the ODD were leveled to less than 15 $\mu$m, the performance was better than that of a conventional diamond disk.

In 2012, the semiconductor industry collaboratively developed 450 mm (18 inch) diameter wafers to improve output and reduce wafer production cost. To polish these wafers, the diameter of the polishing pad was increased from 700 to 1050 mm. The dressing area increases by ~2.25 times, but the diameter of the diamond disk remains 100 mm. An improved, efficient diamond disk is required as larger polishing pads and wafers are desired. In this study, a novel arrangement is formed using brazes in diamond patterns, which are radial with a cluster arrangement of 3-4 grits per cluster. Furthermore, a double-faced combined diamond disk is developed to reduce the cost of the diamond disk. The polishing pad surface was characterized and the effects of different diamond conditioners on wafer removal rate were studied.

## 2. Double-Faced Radial and Cluster-Arranged Diamond Disk

A conventional diamond disk (CDD) is manufactured by attaching multiple diamond grits to a metal disk. Such conditioners contain either a chaotic or regular distribution of diamond grits with each diamond massively bonded by a braze (Figure 1). Although the conventional diamond conditioner has regular distribution diamond grits, tips of diamond grits are not leveled to the same height. A typical diamond disk contains over 25,000 grits, but less than 10% of diamond grits are engaged in cutting the polishing pad. The rest remains unused on the disk.

In this study, a novel arrangement is formed using brazes with a special alloy in diamond patterns, which are radial with a cluster arrangement. In the radial arrangement, diamond grits are arranged from center to periphery. In the cluster arrangement, each cluster contains 3-4 diamond grits. Diamond disks are manufactured using a three-part process (Figure 2). Part 1: a small brazed diamond disk was manufactured. Diamond grits were radial with a cluster arrangement on a flat stainless steel substrate (diameter: 20 mm, thickness: 5 mm; Figures 2(a), 2(b), and 2(c)). (a) Viscose and braze

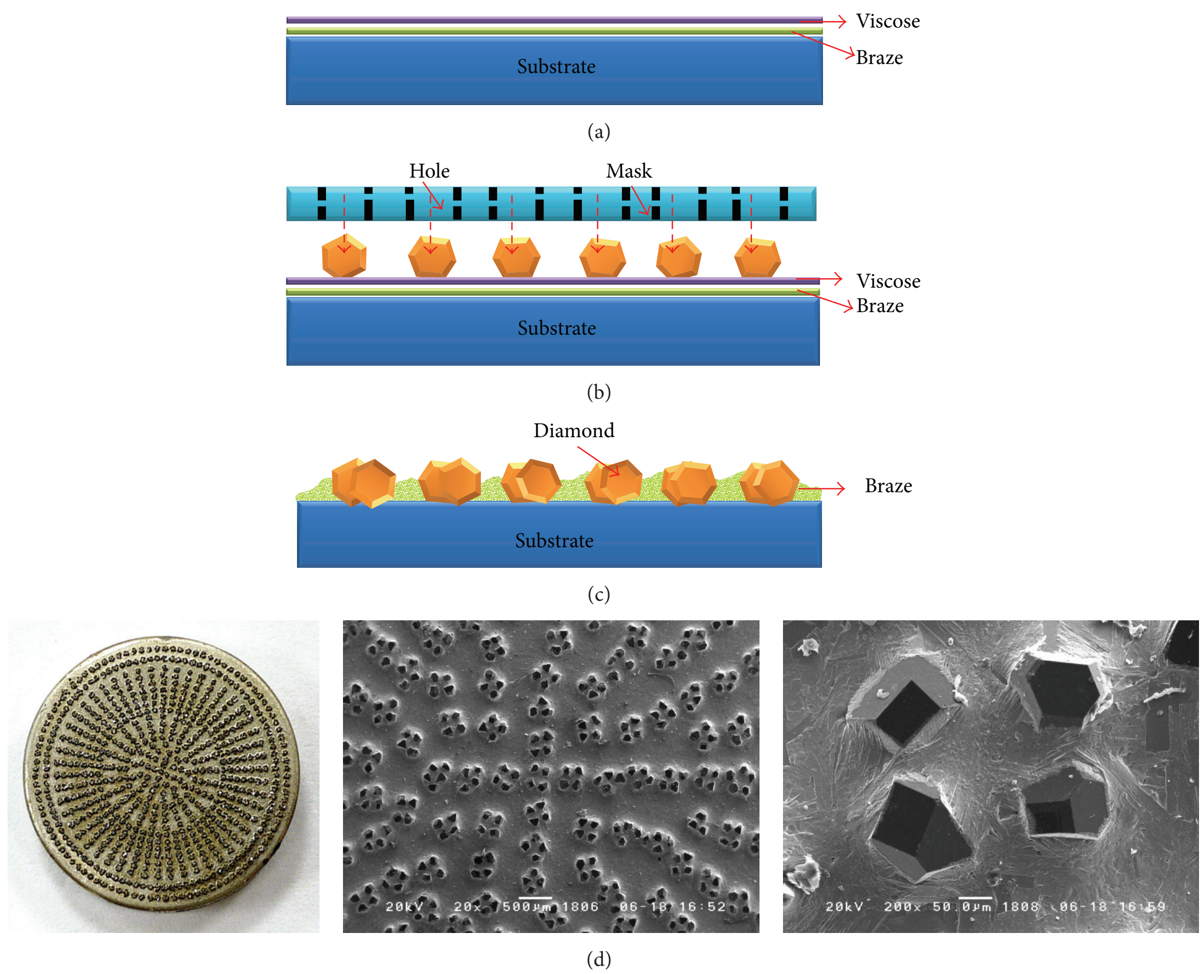



Figure 2: (a, b, and c) Manufacture of small RCADD. (d) Photograph of disk.

were placed on a diamond substrate. (b) Diamond grits were uniformly sprinkled and adhered on a substrate using a special mold. (c) Viscose and braze were melted using a tall-temperature furnace; the braze coating can hold diamond grits; owing to surface tension, the liquid climbs the diamond surface and forms a gentle slope. Thus, the diamond can be widely supported on the substrate, giving a small radial and cluster-arranged diamond disk (RCADD). Figure 2(d) shows the new diamond conditioner, SEM images of diamond groups, and single cluster-arranged diamond grits. Part 2: amounting substrate with a double-faced annulus groove was manufactured using a computer numerical control (CNC) machine. A cylindrical stainless steel substrate was prepared (diameter: 108 mm, thickness: 5 mm; Figure 3). Part 3: 24 brazed diamond disks were arranged in a predetermined location and leveled to a mold surface. The manufacturing steps are as follows (Figures 4(a), 4(b), 4(c), and 4(d)): (a) cylindrical substrate was placed on granite platen; (b) by using a special adhesive (epoxy resin) on annulus groove for thickness control and then placing 12 small diamond disks on the substrate, diamond grits can adhere to the substrate; (c) a metal platen is used to level the 12 small diamond disks, followed by curing and cleaning; (d) cylindrical substrate was reversed and steps (a)–(c) are repeated to manufacture a double-faced RCADD (Figure 4(e)).

## 3. Experimental Procedures

The dressing experiments were conducted using a polishing pad mounted on a commercially modified polishing machine that had variable speed control. The diamond pad conditioner was attached via a connecting holder to a rotating head spinning at 10 rpm. A polyurethane pad was mounted on a table disk that rotated at a speed of 40 rpm. The oscillation speed of the conditioner was fixed at about 5 mm/s. The applied load was fixed at approximately 3 kg. After the pad had been dressed, its surface topology was measured using a stylus-type 3D surface roughness instrument. The pad dressing rate was measured using a linear variable differential transformer (LVDT).

A scratch mechanism was used to form a scratch line on a soft plastic pad for different diamond disk to understand the number of working grits. The steps of the scratch experiment are as follows (Figure 5): (a) place an acrylic on the platform; use a marker pen to mark the starting point and the diamond conditioner; (b) place a weight load (10 kg) on the diamond

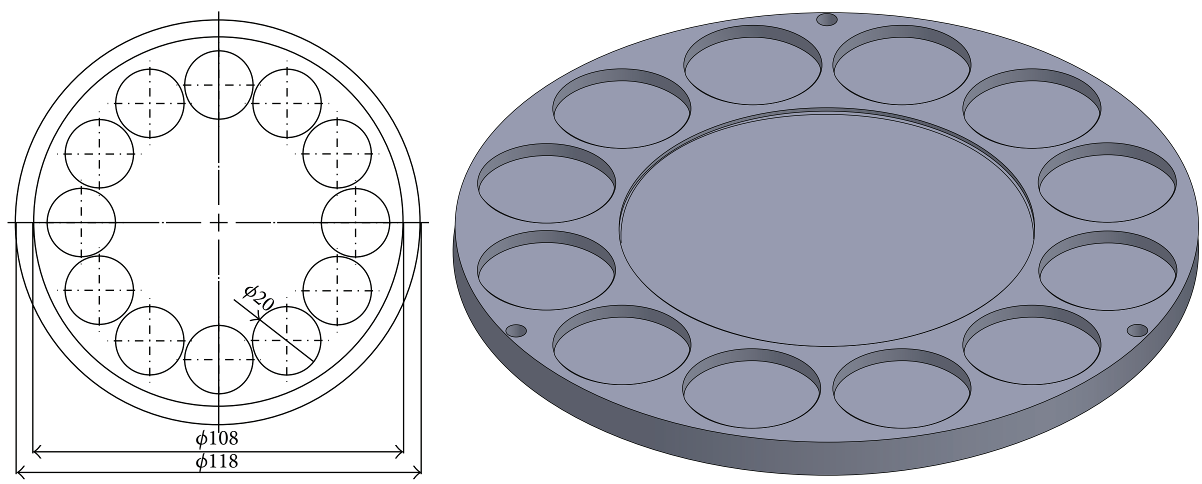



Figure 3: Cylindrical stainless steel substrate.

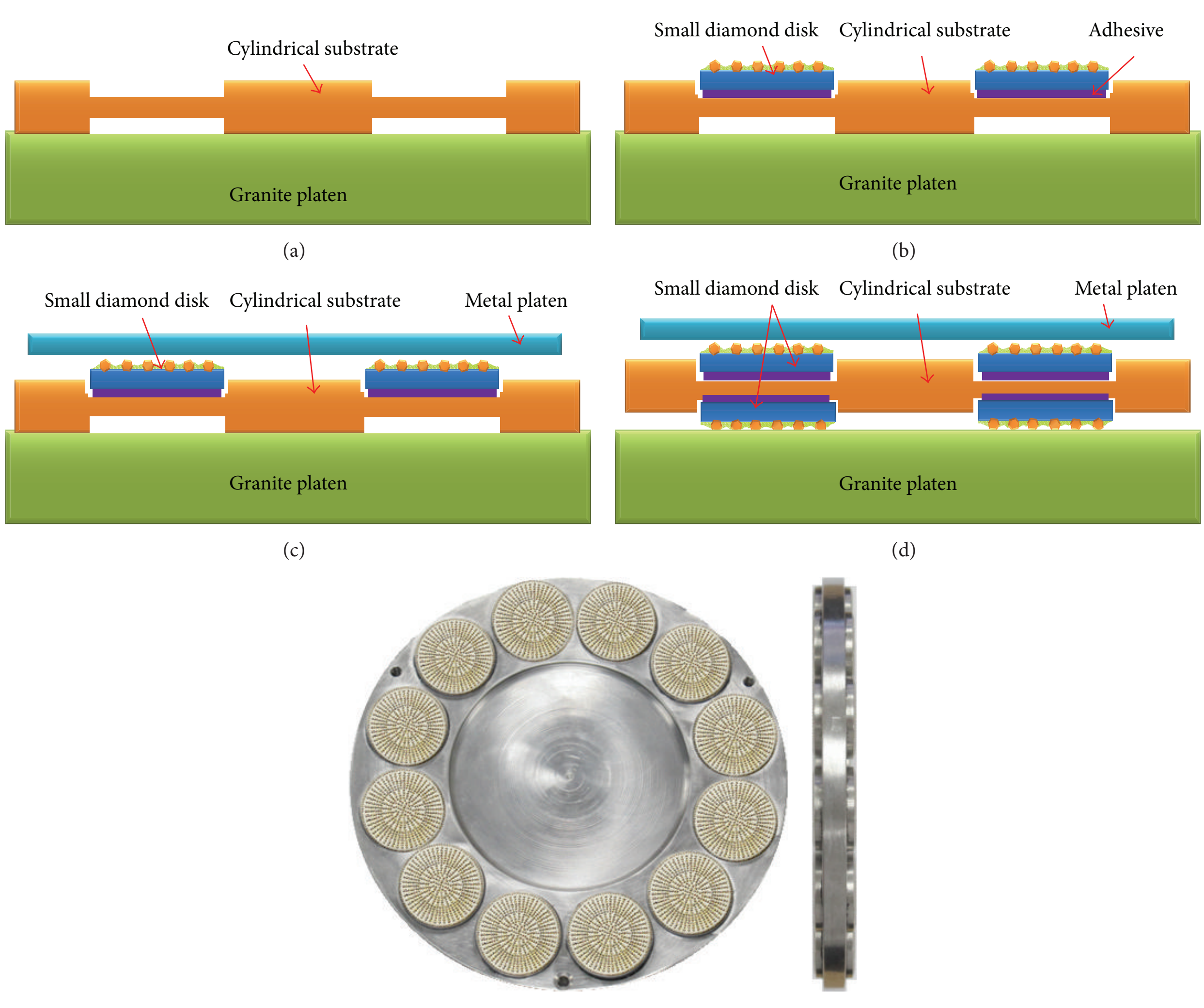



Figure 4: (a, b, c, and d) Manufacture of both combined brazed diamond disk and substrate. (e) Photograph of double-faced diamond disk.

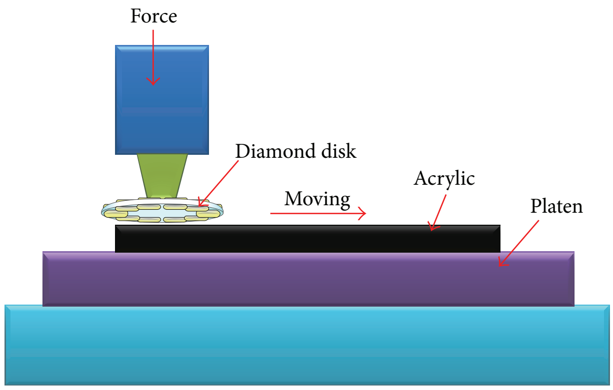



Figure 5: Schematic illustration of scratch mechanism.

conditioner and move the diamond conditioner forward; (c) observe the number of the scratch lines on the projection film or soft pad and record the number of scratch lines. Figure 6 shows a representative example of the 2D and 3D scratch line profiles of projection film after scratch experiment using a stylus-type three-dimensional (3D) surface roughness instrument.

Polishing experiments were conducted using a Westech polisher (Model 372M). Its speed was adjustable and the pad was mounted on a polishing plate with a diameter of 24 in. During polishing, a power head applied a specific load to an oxide wafer (with a thickness of 8,000 Å and a diameter of 6 in.); a dispenser was used to supply the slurry. The wafer was attached to a holder that was connected to a wafer carrier head that rotated at 40 rpm. A polyurethane pad was mounted on a table disk that rotated at 41 rpm. The applied pressure and back pressure were about 4 and 2 psi, respectively. The polishing slurry used in the experiments was SS-25, produced by the Cabot Company. The slurry flow rate was 150 mL/min. The thickness of the oxide layer on the wafers was measured before and after polishing using a system that is commonly applied to measure the thickness of thin films, with a measurement range of 100 to 150,000 Å. The data reported herein were measured at 17 positions, as shown in Figure 8. A scanning electron microscope (SEM) was used to examine the morphological features of the polishing pad.

## 4. Results and Discussion

Pad cut rate (PCR; thickness of material removed/dressing time) is one of the most important factors affecting surface conditions and pad cost. Figure 7(a) shows the variation of PCR for a CDD and RCADD. After 1 h of dressing, that of the latter (47 $\mu$m/hr) is around two times that of the former (24 $\mu$m/hr). RCADD is thus better for dressing a 1050 mm diameter polishing pad. After 20 h of dressing, the PCR of the latter and former reduced by only 6% and over 16%, respectively. Figure 7 shows the pad surfaces after 1 and 40 h of dressing by RCADD and CDD. Ra of the pad dressed by RCADD is relatively higher; this may affect wafer material removal rate (MRR), as discussed later. Figure 8 also shows the variation in the scratch lines dressed by RCADD and CDD. The number of scratch lines (approximately 432) when using the conventional diamond dresser was lower than the number (approximately 484) obtained by RCADD. In addition, RCADD, having only 10,000 diamond grits bonded to the substrate, has more effective cutting tips than CDD, having 25,000 diamond grits to benefit reduction in costs. Again confirmed using pressure-sensitive paper as shown in Figure 9, it is found that the efficiency of RCADD cutting tips is more than CDD cutting tips. The result also was in agreement with a later studied proposed wear rate model of the polishing pad, like that of Tso and Ho [18], who pointed out the empirical equation as follows:

$$\mathrm{PWR} = K_D \frac{V_D}{RA} \lambda d_0 \left( \frac{P}{H_p} \right)^{1.5}. \quad (1)$$

Here, $K_D$ is a wear rate constant; $P$ is the dressing pressure; $V_D$ is the dressing relative velocity; $A$ and $R$ are the dressing area and the effective radius of the diamond grit; $\lambda$ and $d_0$ are the effective diamond working grits and the size of diamond grit.

Wafer removal rate is one of the most important factors affecting wafer performance and cost. The performance index MRR is a function of the polishing pressure $P$ and the polishing velocity $V$. Many models have been proposed based on different assumptions. For example, the experience-based Preston's equation, shown in (2), has been widely used in semiconductor CMP process. Consider

$$\mathrm{RR} = k_p \times P \times V. \quad (2)$$

Other similar models can be also found in Wang et al. [19] and Tseng and Yi [20]. Several other models also take material properties, such as elastic properties, into account to formulate the polishing constant $K_p$ is (2). For example, the model by Liu et al. [21] derived the following relationship:

$$\mathrm{RR} = C'' \left[ \frac{\mathrm{HV}_w}{\mathrm{HV}_P + \mathrm{HV}_w} \right] \left[ \frac{E_p + E_w}{E_p E_w} \right] \times P \times V, \quad (3)$$

where $\mathrm{HV}_w$, $\mathrm{HV}_p$, $E_p$, and $E_w$ represent the hardness of the wafer, the hardness of the pad, Young's modulus of elasticity for the pad, and Young's modulus of elasticity for the wafer. The relationship can be further simplified to the following equation as the hardness of polishing pad HVP is far less than that of the wafer $\mathrm{HV}_w$:

$$\mathrm{RR} = C'' \left[ \frac{1}{E_p} + \frac{1}{E_w} \right] \times P \times V. \quad (4)$$

The foundation for these models, nevertheless, is the abrasive wear model though different assumptions have been made and ignored the effect of diamond disk. Figure 10 shows the measured wafer removal rates in oxide-CMP for different diamond disks. The MRR is defined as the thickness removed over a unit of time, as shown in (1):

$$\mathrm{MRR} = \frac{T_{\mathrm{pre}} - T_{\mathrm{post}}}{t}, \quad (5)$$

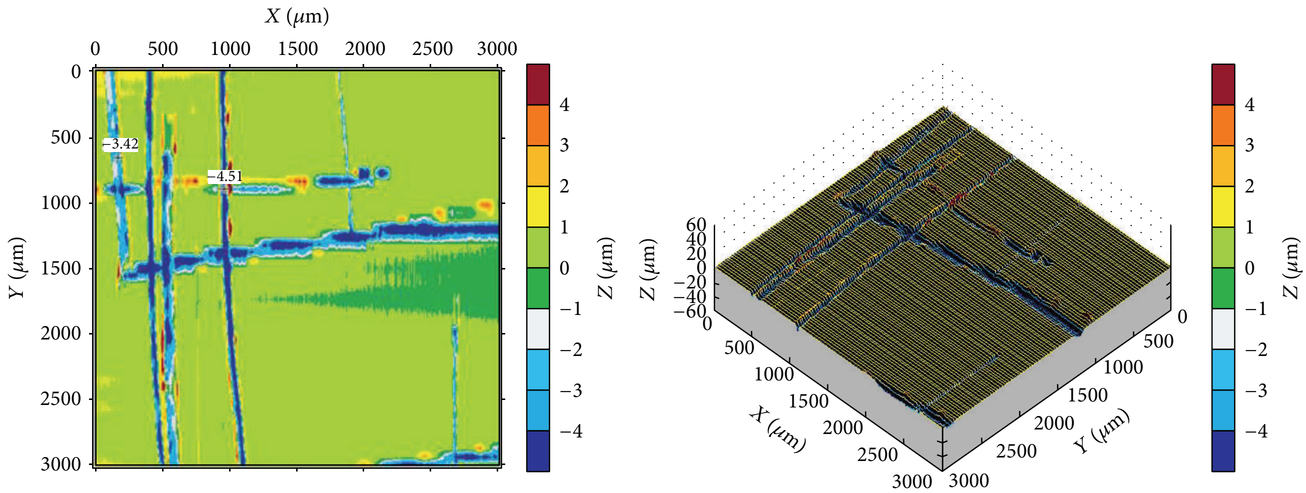
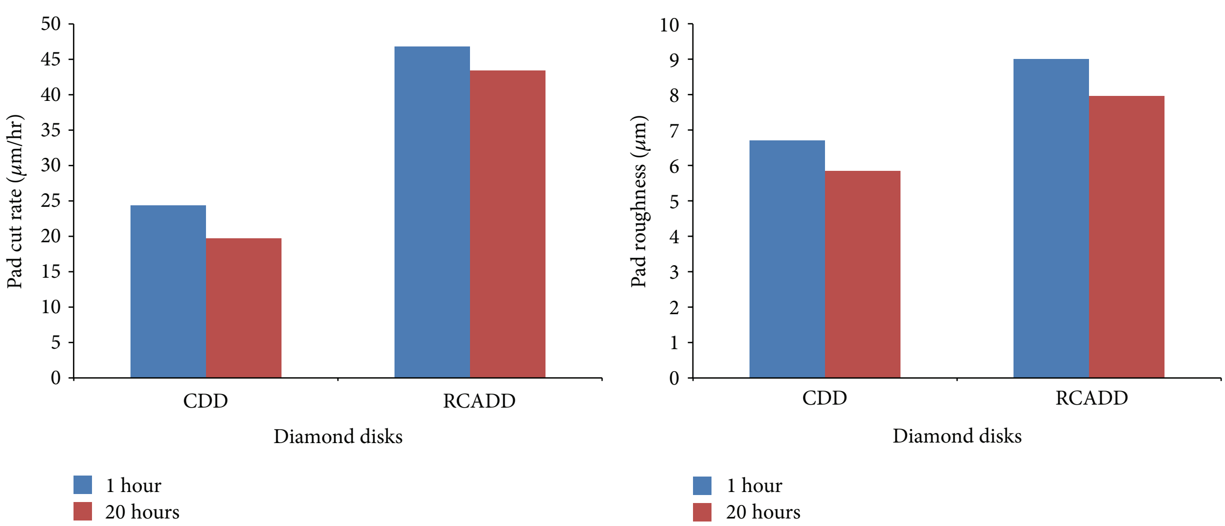



FIGURE 6: Representation example of 2D and 3D profile of pad after scratch experiment.




(a) (b)

FIGURE 7: Variation in (a) PCR and (b) Ra of pad dressed by CDD and RCADD.

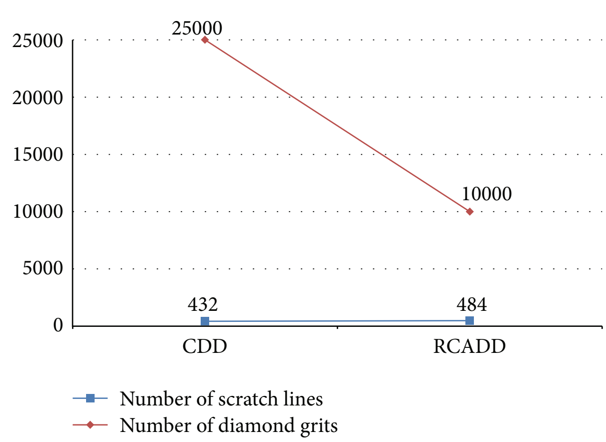
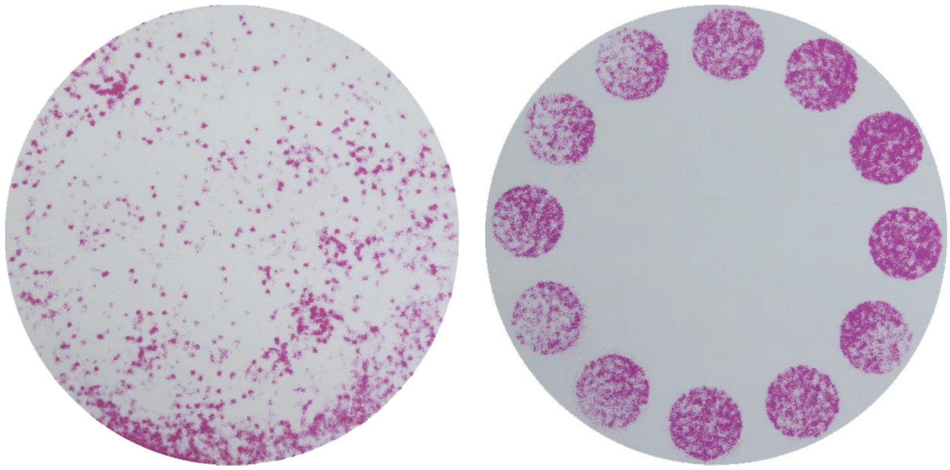



FIGURE 8: Variation in scratch lines and diamond grits for CDD and RCADD.



(a) (b)

Figure 9: Efficacy of (a) CDD and (b) RCADD cutting tips.

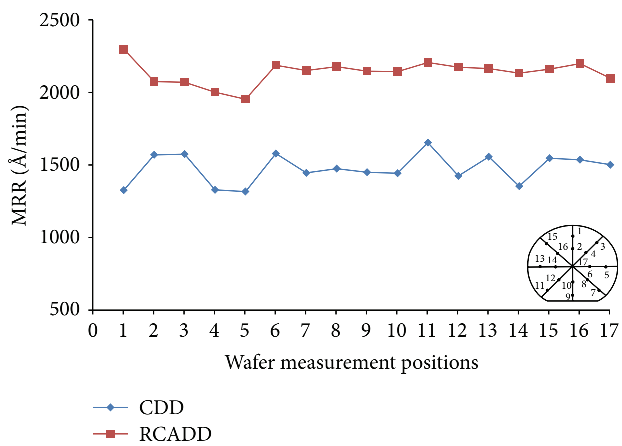
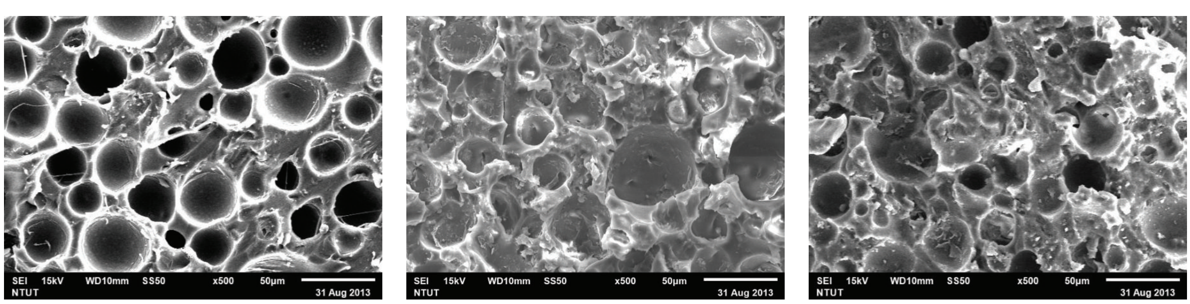



Figure 10: Measured wafer removal rates for different diamond disks.




(a) (b) (c)

Figure 11: Images of SEM for (a) unused, (b) RCADD, (c) and CDD.

where $T_{pre}$ and $T_{post}$ denote the thickness, in Å (10-10 m), before and after polishing, respectively. The MRR for dressing using RCADD (~2100 Å/min) was markedly higher than that for dressing using CDD (~1506 Å/min), possibly because the pad surface roughness of RCADD is higher than that of CDD (Figure 3).This result is identical to that of Oliver et al. [22], who proposed that the wafer removal rate was sensitive to the surface roughness (Ra). Li et al. [7] found that rougher pad surfaces removed more material than smoother ones.

The cross-sectional SEM images of the pores on the polishing pad formed by CDD and RCADD are shown in Figure 11. It was observed that most pores still remain round, similar to unused polishing pads (Figure 11(a)) dressed by RCADD, as shown in Figure 11(b). On the other hand, for CDD the shape of various pores was unclear and some chip residues remained on the pad surface, as shown in Figure 11(c). These trapped residual chips decreased the area available for slurry transport, a dynamic that must be taken into account during dressing in the CMP process. These results may be another reason why the polishing rate of CDD was low.

## 5. Conclusion

This study developed a novel technique for forming brazes in diamond patterns, which are radial with cluster arrangement with 3-4 grits per cluster. A double-faced combined diamond disk is designed and manufactured. We evaluated the surface characteristics, PCR, and removal rate of a dielectric oxide film dressed using these diamond disks. Experimental results showed that the proposed diamond disk has around two times higher PCR and about 28% higher wafer removal rate. The novel conditioner can also reduce diamond disk cost. The proposed pad's area increases by around 2.25 times from 0.385 to 0.866 $m^2$, making it suitable for dressing 1050 mm diameter polishing pads.

## Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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