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Organic diamond disk versus brazed diamond disk for dressing a chemical–mechanical polishing pad ☆

M.Y. Tsai [a,*], P.H. Li [a], J.C. Sung [b]

[a] Department of Mechanical Engineering, National Chin-Yi University of Technology, No. 35 Lane 215 Chung-Shan Rd. Sec. 1 Taiping City, Taichung County 411, Taiwan
[b] Kinik Company, 64, Chung-San Rd., Ying-Kuo, Taipei Hsien 239, Taiwan

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ABSTRACT

Diamond pad conditioners can be used to determine the efficiency of chemical–mechanical polishing (CMP) processes and the quality of polished wafers. Conventional diamond conditioners such as brazed diamond disks (BDDs) consist of braze-bonded diamond grits. Although conventional diamond conditioners consist of regularly distributed diamond grits, the grit tips are not leveled to the same height. In this research, we 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. The ODD and the BDD were fabricated as circular dressing disks and used in the CMP of dielectric oxide films. Diamond leveling (height distribution of the diamond grits) for the BDD is found to be greater than 50 μm. The diamond tips of the ODD are leveled to less than 15 μm. The results show that the ODD-dressed pads produce fewer defects in wafers than the BDD-dressed ones. Although the pad dressing rate is lower for the ODD, the wafer removal rate for the ODD is higher than that for the BDD. Hence, the use of ODDs for the mass production of semiconductors can increase not only the lifespan of both the disks and the pads but also the throughput of wafers produced during CMP. Finally, the ODD is processed at room temperature to prevent thermal degradation of its diamond grits.
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1. Introduction

Chemical–mechanical polishing (CMP) is used in the electronics industry for the fabrication of circuits with ultra-large-scale integration to planarize an interlevel dielectric [1]. This process was employed by IBM in the 1980s; since then, it has attracted considerable attention owing to the fact that it can achieve high surface quality with high polishing efficiency. It should be noted that this process can flatten and smoothen a wafer surface for use in lithography [2]. A typical orbital-type CMP process can be divided into two main stages. The first stage involves polishing of a semiconductor using a polishing pad. During the CMP process, a silicon wafer is placed on a carrier with its face pressed against the polishing pad that is attached to a rotating polishing platen. Both the wafer carrier and the platen rotate, either in the same direction or in the opposite direction, to generate relative motion between the wafer and the pad. At the same time, slurry, which is a mixture of abrasive particles and a chemical solution, is poured between the wafer and the pad to form a liquid film. The slurry chemically attacks the wafer surface, weakening or breaking the molecular bonds on it so that the wafer molecules can be mechanically removed by the abrasives used in the polishing process. The second stage of the CMP process involves dressing of the polishing pad by a diamond disk. For the CMP process to continue and to regenerate the asperity structure of the pad, a diamond conditioner is employed periodically and continually either during in-situ dressing, in which conditioning is carried out while the wafers are being polished, or during ex-situ dressing, in which conditioning is carried out after the wafers have been polished [3,4].

A diamond conditioner is usually a circular metal substrate with multiple diamond grits electroplated or brazed on its flat surface. Although a conventional diamond conditioner has a regular distribution of diamond grits on its surface, the tips of the diamond grits are not leveled to the same height. A typical diamond disk contains over 10,000 grits; however, less than 10% of the diamond grits are engaged in cutting the polishing pad. The rest of the grits remain unused on the disk. In addition, the diamond grits are easily chipped by the impact because it is thermally damaged during its manufacturing process, as in the case of vacuum brazing or hot pressing. Moreover, the few tall diamond grits can cut 50% of the pad consumed during dressing; this shortens the pad lifespan and increases the running costs [5,6]. Thus, the consumables – diamond conditioner, polishing pad, and polishing slurry – associated with the CMP process contribute to over half of the total CMP cost [7].

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* Corresponding author. Tel.: +886 423924505 7195; fax: +886 423930681.
E-mail address: mytsai@ncut.edu.tw (M.Y. Tsai).

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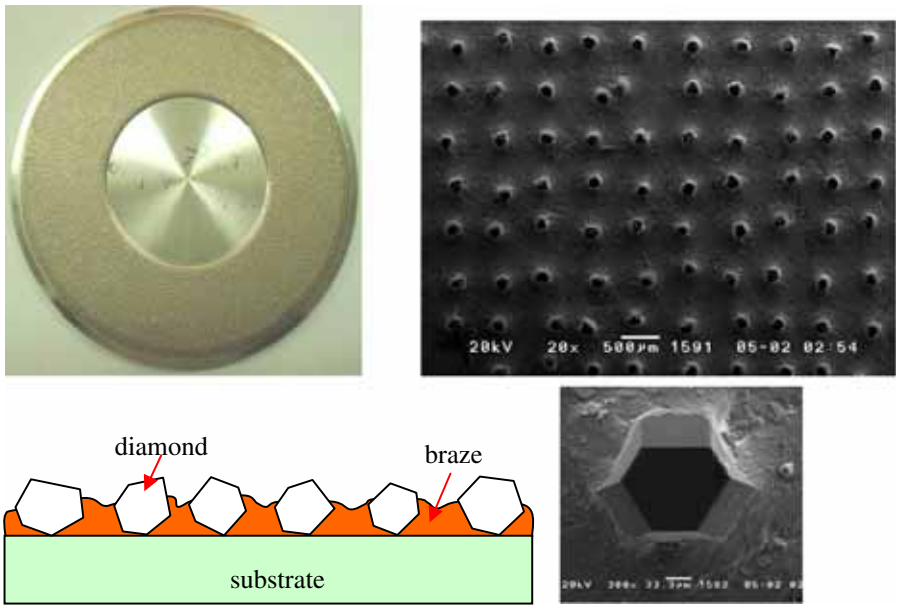

Fig. 1. Brazed diamond disk.

Tsai et al. [8] proposed a novel advanced diamond disk (ADD) that contains diamond grits with equal heights and identically shaped tips. They indicated that the dressing rate of the ADD reduced by approximately 30% and the polishing rate of the ADD was higher than that of a conventional diamond disk. However, a major disadvantage of the ADD was its manufacturing cost that increased by more than threefolds. In this paper, a novel design of a diamond conditioner, i.e., an organic diamond disk (ODD), is proposed. This design remarkably improves the leveling of diamond tips and markedly reduces the CMP cost. The ODD is manufactured by reverse casting polymers. 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. In this study, the ODD and a brazed diamond disk (BDD) were fabricated as circular dressing disks and were used in the CMP of dielectric oxide films. The pad dressing rate (PDR) was calculated to compare the new disks with the conventional diamond disks, and the effect of the dressing time on the wafer removal rate and surface roughness was studied. This basic research contributes to the understanding of conditioning techniques and further improving of the CMP process.

2. Brazed diamond disk

A conventional diamond pad conditioner is fabricated by attaching diamond grits to a metal disk. It is difficult to bond diamond with

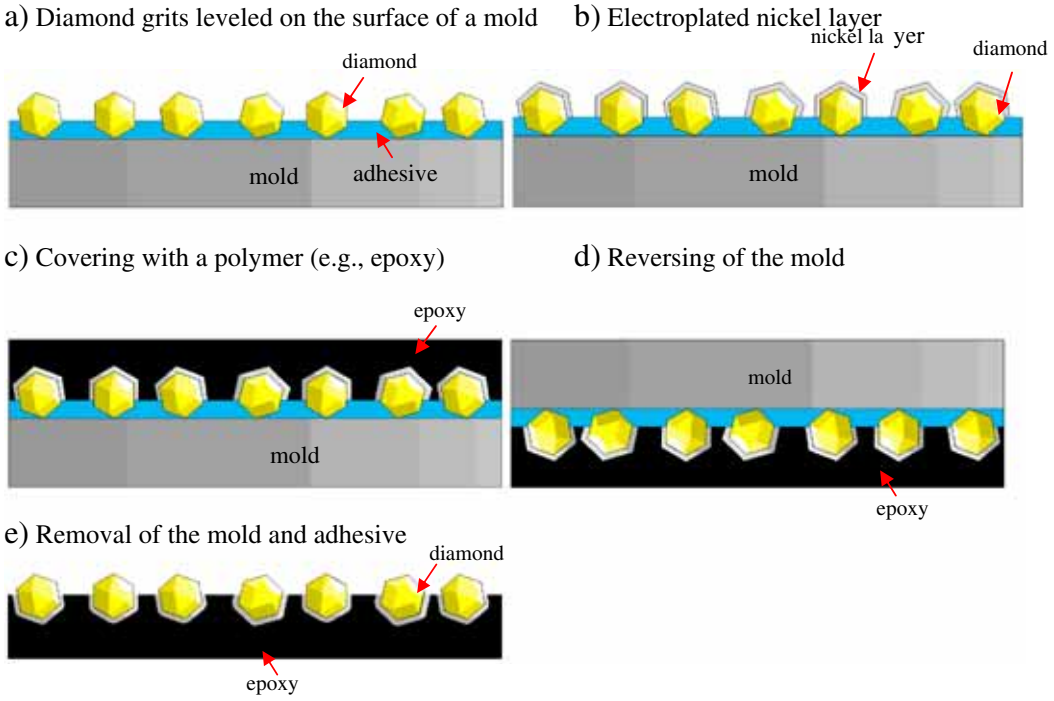

Fig. 2. Steps for manufacturing organic diamond disk.

other materials because of its natural properties. Hence, the diamond industry has developed three distinct methods to hold diamond grits in place; these methods involve (1) burying the diamond grits in electroplated nickel, (2) retaining them in sintered metal powder, and (3) brazing them with a specialty alloy [9]. The first-generation diamond pad conditioners contained randomly distributed diamond grits that were typically buried in an electroplated nickel layer. The electroplated metal held the diamonds in place only mechanically, and hence, diamonds inevitably displaced from the matrix. The loss of diamond particles during the CMP process affected the wafer performance. The second-generation pad conditioners contained clusters of diamond grits that were held in place by braze. In these clusters, the braze layer thickened. Consequently, the distribution of diamonds became random, and the diamond height varied considerably. The third-generation pad conditioners contain regularly distributed diamond grits, with each diamond strongly bonded by braze. Currently, this method of constructing pad conditioners, as shown in Fig. 1, is globally accepted for most pad conditioners.

3. Organic diamond disk

We propose a novel design of a diamond disk by reversing the process of attaching diamonds using an organic matrix (e.g. epoxy). The manufacturing steps for this diamond disk are shown in Fig. 2 and are described as follows. First, the diamond grits are leveled on the surface of a mold for their regular distribution, and then, an electroplated nickel layer is attached to the diamond grits. Each diamond grit is coated with nickel to increase its grip; this enables the polymer to bond with the uneven nickel surface. Next, the diamond grits are cast by covering with a polymer. In addition, to increase the adherence strength, each diamond grit is buried at a depth of more than twice the height of the exposed part of the grit. Then, the mold is reversed. Finally, the mold and the adhesive are removed and polymer-bonded diamond grits are obtained. This step is followed by curing and cleaning to complete the fabrication of the ODD. The ODD is fabricated at room temperature to prevent the thermal degradation of its diamond grits. In this case, the diamond tips can be leveled by compressing the disk with a flat plate to reduce the variation in the heights of the diamond tips. Another feature of the ODD is that it is very light, i.e., approximately 70 g, and it can be transparent or color-coded. This versatility of the ODD can simplify the inspections of diamond grits, for example, to check the loss of diamonds. It can also simplify the color management of CMP with different recipes, for example, red disks for copper removal and black ones for oxide polishing. In contrast, conventional pad conditioners are made of heavy metal weighing approximately 500 g, and their appearances are the same for different designs. The outer appearance of the ODD is shown in Fig. 3. The diameter and thickness of the ODD are 100 and 5 mm, respectively.

4. Experimental setup

Dressing experiments were performed using a polishing pad mounted on a commercially modified polishing machine with 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 set at

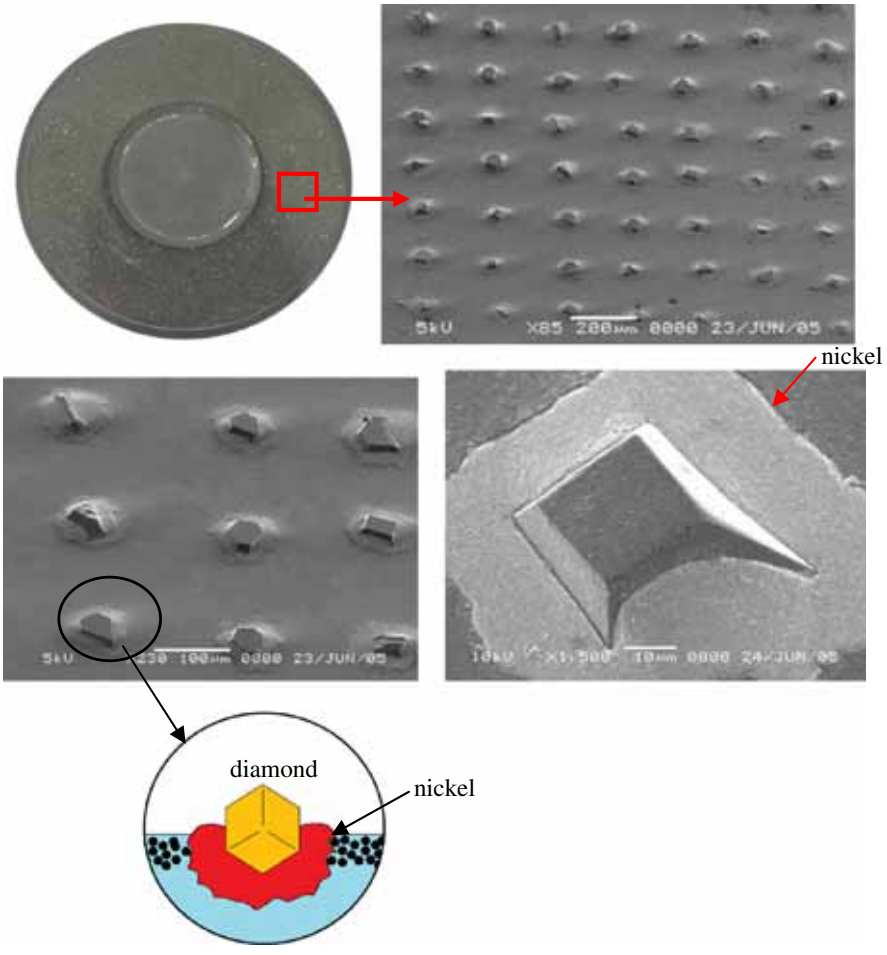

Fig. 3. Outer appearance of the organic diamond disk. Note that each diamond is covered with nickel.

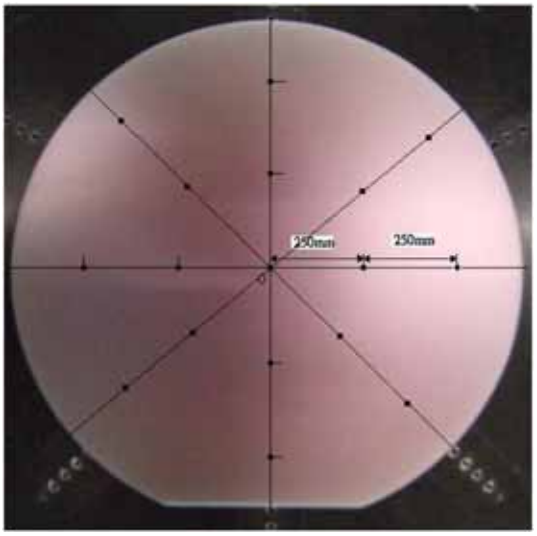

Fig. 4. Measurement positions on wafer.

approximately 5 mm/s, and the applied load was fixed at approximately 3 kg. After the pad was dressed, its surface topology was measured using a stylus-type 3D surface roughness instrument. The PDR was measured using a linear variable differential transformer (LVDT). The conventional diamond pad conditioner used herein is a DiaGrid dresser manufactured by Kinik Company, Taiwan; this dresser was bonded with metal using a brazed nickel alloy. In this work, the DiaGrid dresser is called the brazed diamond disk (BDD). The ODD used in the research is also developed and manufactured by Kinik Company, Taiwan. The diameters of both the BDD and the ODD were 100 mm.

Polishing experiments were performed using a Westech polisher (Model 372M). The speed of this polisher was adjustable and a pad was mounted on a polishing plate with a diameter of 24 in. During polishing, a power head exerted a specific load on an oxide wafer with a thickness of 8000 Å and a diameter of 6 in. A dispenser was used to supply the slurry (SS-25, Cabot Corporation) at a flow rate of 150 mL/min. 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 the back pressure were approximately 4 and 2 psi, respectively. The thickness of the oxide layer on the wafer was

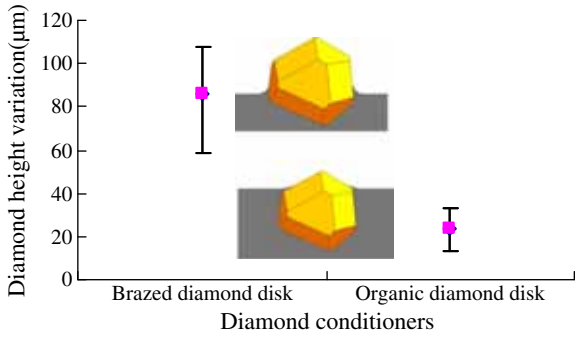

Fig. 6. Height variation in tips for diamond conditioners.

measured before and after polishing by using a technique commonly used to measure the thickness of thin films with a measurement range of 100–150,000 Å. The thickness of the oxide layer was measured at 17 different positions on the wafer, as shown in Fig. 4. A scanning electron microscope (SEM) was used to examine the morphological features of the diamond disk. An atomic force microscope (AFM) was employed to examine the morphological features of the wafer, such as its surface roughness and defects.

5. Results and discussions

Fig. 5 shows the cutter images of the BDD and the ODD produced using a stylus-type 2D surface roughness instrument. As shown in this figure, the cutter distribution of the BDD is irregular in spite of its industry-wide use in CMP. In contrast, the ODD has regular diamond cutters. In addition, the protrusion height (approximately 30 μm) of the diamonds for the ODD is smaller than that (approximately 80 μm) for the BDD. For the ODD, the burial depth of each diamond is about twice that of the exposed portion. Consequently, the risk of displacement of diamonds from the matrix while dressing the pad is minimal. The height variation in the diamond tips of the ODD is significantly smaller than that in the diamond tips of the BDD. In the case of the BDD, the diamond tips are leveled to more than 50 μm. However, as shown in Fig. 6, in the case of the ODD, the diamond tips of the ODD can be leveled to less than 15 μm because the diamond tips are already leveled. The better-leveled ODD has more cutters that can dress the pad, and thus, they share an equal dressing load.

In order to measure the BDD and the ODD lifespan, the time-dependent behavior of the material removal rate (MRR) and the

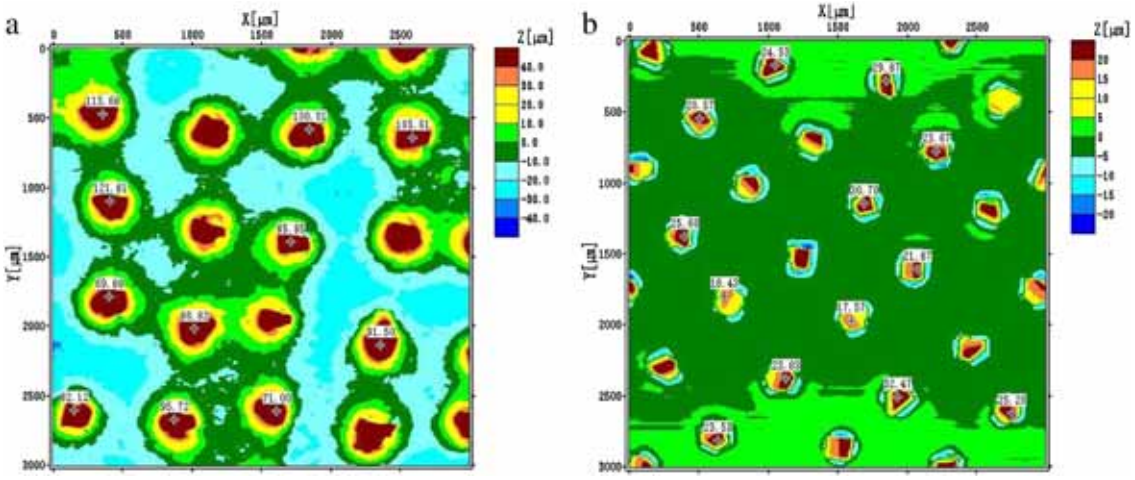

Fig. 5. Comparison of the cutting tips of (a) brazed diamond disk (b) organic diamond disk.

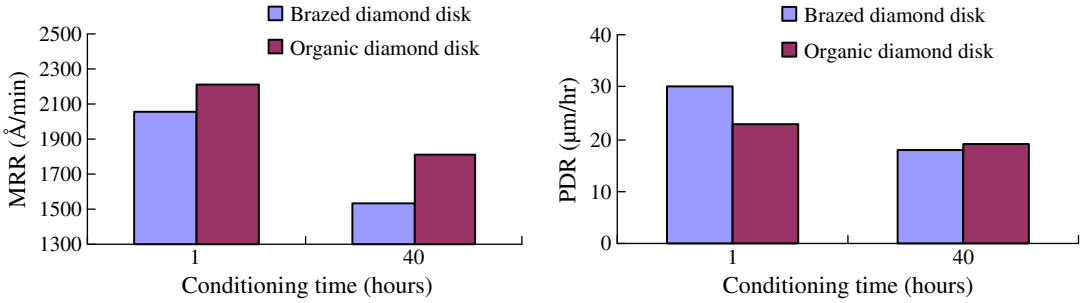

Fig. 7. Variation in the material removal rate of the wafer dressed by the brazed diamond disk and the organic diamond disk.

PDR with increasing conditioning time was investigated. The two types of conditioners were conditioned for 40 h on a groove pad under slurry SS-25 because the lifespan of a diamond disk is generally approximately 40–80 h. The graphs shown in Fig. 7 plot the variation in the MRR with the dressing time taken by the ODD and the BDD. The MRR of the ODD is higher than that of the BDD. As expected, the MRR decreases as a function of the dressing time because the wearing of the cutting edge reduces the penetration depth of the diamond grit. Consequently, the asperity height of the surface of the pad also decreases. The thinning of the slurry-permeated layer decreases the polishing rate. Sung [5] indicated that the dull diamond grits will press the polishing debris instead of scraping it off from the pad surface, thus reducing the effect of the dressing action. After 40 h, the MRR of the BDD reduced to approximately 25%, whereas the MRR of the ODD reduced to only approximately 15%. The variation in the PDR with the dressing time of the ODD and the BDD is also plotted in Fig. 7. As expected, the PDR decreases with the conditioning time, while it is consistent with the conditioning time in previous studies by Hwang et al. [10]. In this figure, the PDR of the ODD is lower than that of the BDD because more cutters share the dressing load. After 40 h, the PDR of the BDD reduced to approximately 40%. However, the MRR of the ODD reduced to only approximately 17%. On the basis of these observations, it can be inferred that the ODD can stabilize the wafer removal rate while consuming less pad material, thus resulting in a long pad lifespan.

The chemical stability of the two types of conditioners was further examined in an oxide–slurry solution for 1 and 40 h, respectively. The micrographs in Fig. 8 show that there is no apparent change in the surface morphology of the ODD and the BDD; the diamond grits are still firmly adhered to the substrate. Further, it was confirmed that no diamond grit, complete or in pieces, was displaced during the entire duration of this research, while exhibiting chemical stability and durability. The ODD was sufficiently strong in holding the diamond grits. However, the metal substrate was corroded, resulting in the formation of tiny holes on its surface in the case of the BDD, and some amount of residual slurry adhered to the ODD surface. These drawbacks should be considered while dressing in the CMP process.

The polished surfaces of the wafer after 1 and 40 h of dressing by the BDD and the ODD are shown in Fig. 9. The surface roughness values Ra of the polished oxide substrates are 0.293 and 0.243 nm obtained by the BDD and the ODD, respectively, after 1 h of dressing. The Ra of the oxide substrate polished by the ODD is lower than that of the BDD. After 40 h of dressing, the Ra of the BDD remarkably

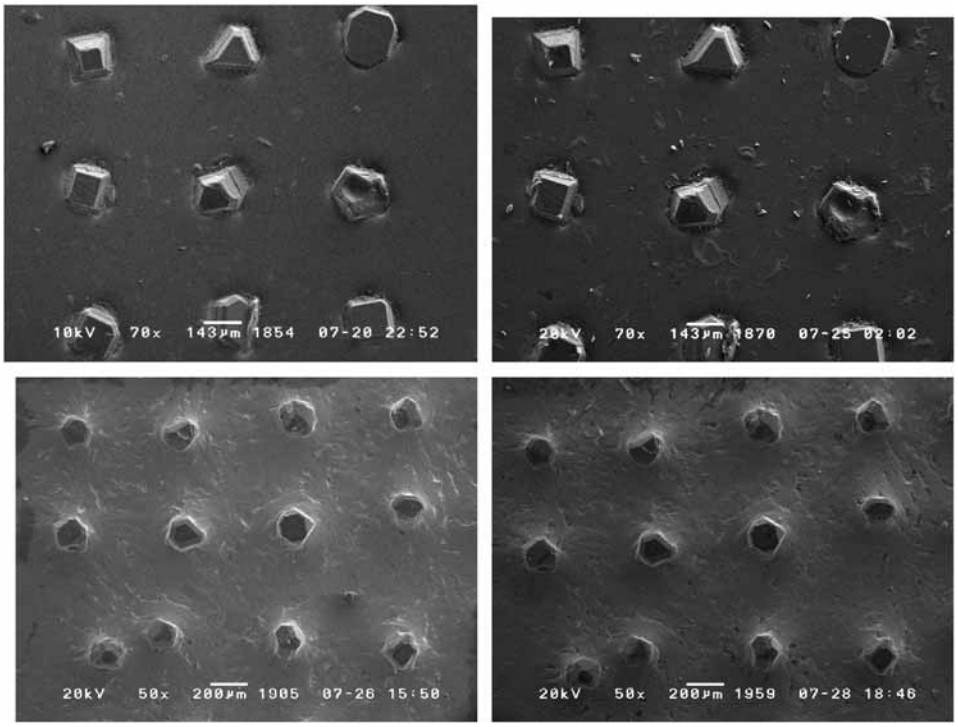

Fig. 8. SEM observation of the surface topography of the BDD after (a) 1 h and (b) 40 h and that of the surface topography of the ODD after (c) 1 h and (d) 40 h in the oxide–slurry solution.

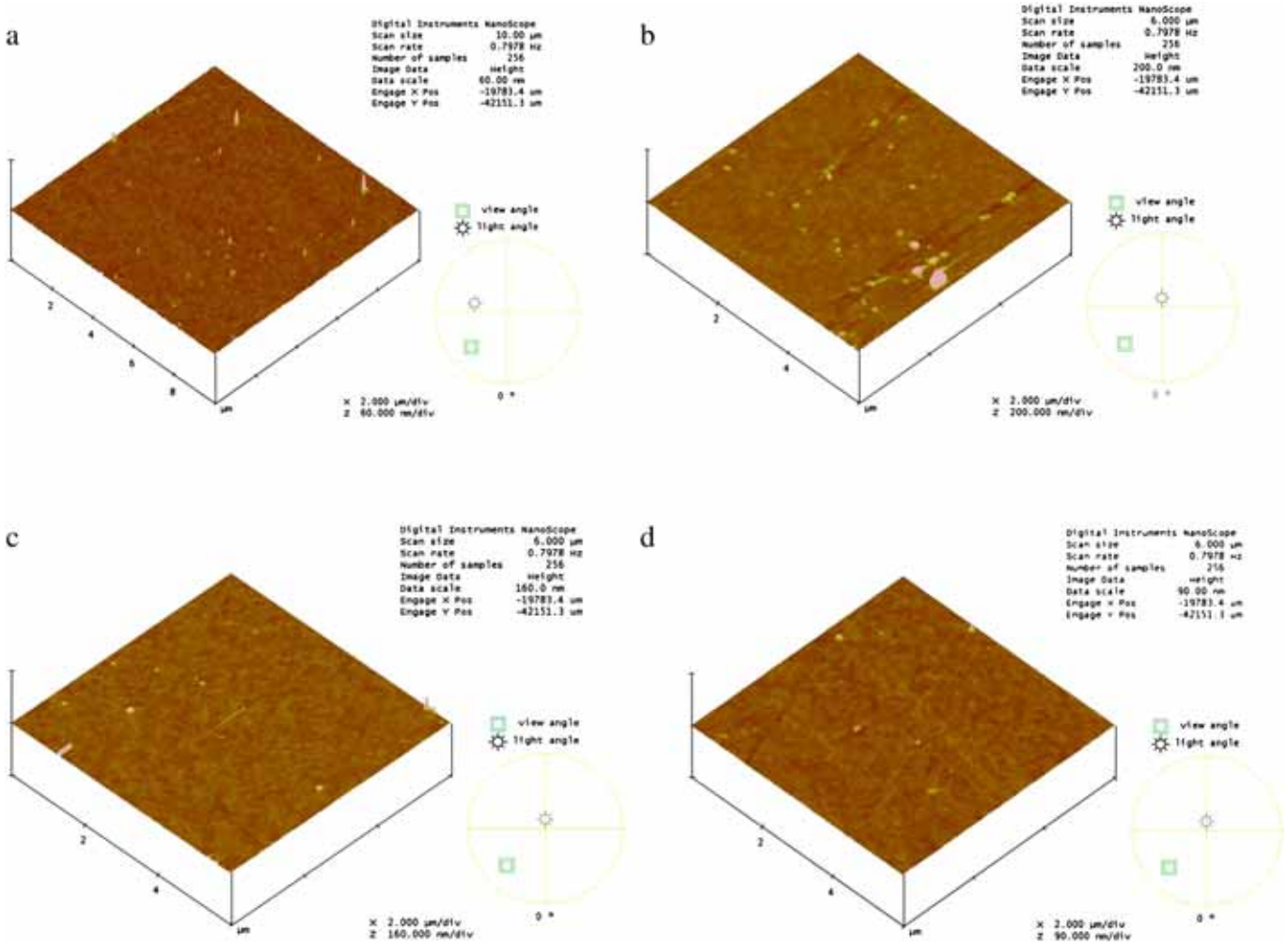

Fig. 9. AFM observation of polished surfaces of the BDD after (a) 1 h and (b) 40 h of dressing and that of the polished surfaces of the ODD after (c) 1 h and (d) 40 h of dressing.

increased to 0.492 nm. However, the Ra of the ODD increased to only 0.372 nm. Tiny scratches due to the polished surface of the wafer after 40 h of dressing by the BDD were observed, as shown in Fig. 9(b). However, the oxide film surface dressed by the ODD was without scratches, as shown in Fig. 9(d). The defect of scratch formation on the wafer surface limits the yield and reliability of the BDD in semiconductor production. Electrical shorts that occur between vias or metal lines are most likely to occur because of scratches [11].

6. Conclusion

In this paper, a novel design of a diamond disk is proposed with an organic matrix by reversing the process of attaching diamonds to improve the leveling of the diamond tips. The proposed design is in contrast to the conventional design that attaches random diamond grits to a metal by brazing. The PDR was calculated to compare the new disks with the BDDs, and the effect of the dressing times on the wafer removal rate and surface roughness was studied. The height variation in the diamond tips of the ODD is significantly smaller than that in the diamond tips of the BDD. In summary, the ODD, as compared to the BDD, can yield a higher wafer removal rate, provide better surface quality, lower the defect count, and reduce pad consumption. In addition, the manufacturing cost of the ODD reduces by approximately 40%, and the ODD exhibits chemical stability and durability while no diamond grits are displaced even after the wear–corrosion test. The results confirm that the ODD can replace conventional pad conditioners for the manufacture of semiconductors using CMP. The results obtained can help researchers to develop more efficient diamond conditioners in the future.

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