

Single Diamond Dressing Characteristics of CMP Polyurethane Pad

Y.S. Liao^{1,a}, M.Y. Tsai^{1,b}, J.C. Sung^{2,c} and Y.L. Pai^{2,d}

¹Department of Mechanical Engineering, National Taiwan University
No. 1, Sec. 4, Roosevelt Rd., Taipei 106, Taiwan

²KINIK Company, 64, Chung-San Rd., Ying-Kuo, Taipei Hsien 239, Taiwan

^aliaows@ntu.edu.tw, ^bmytsai@ncit.edu.tw, ^csung@kinik.com.tw, ^dpai@kinik.com.tw

Keywords: chemical mechanical polishing; polyurethane pad; diamond conditioner

Abstract. The fundamental characteristics of dressing action on the polyurethane pad are investigated via dressing by single diamond of different orientations, dressing parameters and dressing path in this study. Experimental results show that a groove with pile-up on both side walls forms as the diamond moves over the pad with a specific dressing depth. The resulting asperities on the pad are strongly affected by the diamond orientation. Plowing is found to be the major mechanism responsible for this surface topology if dressing is conducted by the face of a diamond. On the contrary, cutting action dominates when the point of a diamond is responsible for dressing. It is also found that dressing velocity has an insignificant effect on the groove and ridges created on the pad. The depth of the groove is smaller than the dressing depth due to the spring back of the pad. When the groove created is repeatedly dressed over the same track, the ridge height and groove depth increases for each additional dressing. When two grooves cross each other, the ridges at the four corners of the intersection grow while the depth of the overlapped area decreases. These ridges will become the pressure enhancer of the abrasives to polish the wafer.

Introduction

The performance of the polishing action that takes place between a semiconductor wafer and a polyurethane pad in the chemical mechanical polishing (CMP) process is often determined by the texture of the pad surface. With the polishing of the wafer underway, the reaction product would gradually accumulate onto the pores and asperities of the pad surface leading to the so-called glazing of the pad [1]. In order to allow CMP to continue, the polyurethane pad that is used to hold slurry must be dressed periodically to maintain its surface texture that is optimized for polishing wafers efficiently.

The dressing tool most commonly used is a diamond pad conditioner having a multitude of diamond grits held on the flat surface of a metal substrate [2]. Zimmer and Stubbmann [3] pointed out that the grit size, shape, crystalline orientation, distribution density, amount of protrusion of the diamond, and the substrate planarity all would affect the dressing rate of the conditioner. Baker [4] investigated the pad surface created during conditioning and its influence on polishing performance. He claimed that pad surface topology was determined by conditioning grid rather than by conditioning parameters. Liang et al. [5] stated that the polishing pad was subjected to plastic deformation during conditioning, and abrasive wear was the main mechanism while cutting played a minor role. Although there have been many researches related to the dressing by diamond disks, there is no fundamental study of the dressing action so far. Consequently, the dressing characteristics of polyurethane pad have not been understood comprehensively.

In this paper a single diamond dresser is used. The effects of diamond orientation, dressing parameters and dressing path are investigated. This basic research on the characteristics of dressing action may contribute to further improvement of conditioning techniques and CMP process.

Experiments

The dry dressing tests are conducted on a CNC machining center with a rotary table (0~600rpm) attached on its work table. The dressing depth can be adjusted to an accuracy of 1 μm . The single diamond dresser mounted on the spindle chuck is dragged across a polyurethane pad that is trued in advance. The polyurethane pad used is Rohm&Haas IC 1000-A2 without grooves. The single diamond dresser used is the DiaGrid dresser manufactured by Kinik Company, Taiwan. The diamond is about 600 μm in size. It is made of the cubic (100) and the octahedral (111) planes, and can be oriented in various directions relative to the pad surface. A schematic diagram of dressing by a single diamond is shown in Fig.1. When it is carried out by the crest line of the diamond parallel to the pad surface and perpendicular to the cutting direction with (100) plane (referring as rake face) of the diamond orients 55° from the normal of the pad (this corresponds to the rake angle α of -55° in cutting as shown in Fig. 2(a)) it is defined as “basic dressing mode” in the paper. The term “line dressing” in the paper is coined for the dressing by the crest line of the diamond. From Fig. 1 it is noted that rotating the tool (i.e. diamond) in basic dressing mode around x-axis by an angle C_e , referring as cutting edge angle as depicted in Fig. 2(b), resulting in line dressing by an inclined crest line. When $C_e = 35^\circ$ then dressing is conducted by the apex of the diamond having the rake face inclines 55° from the normal of the pad, and it is the “point dressing” used in the paper. Similarly, rotating the tool with respect to y-axis such that the (100) plane is in contact with the surface and takes part in dressing leads to the so-called “face dressing” (in this case $\alpha = -90^\circ$). If the tool is rotated about z-axis by an inclination angle i , then oblique cutting instead of orthogonal cutting is performing as shown in Fig.2 (c). The ranges of C_e , α and i used in the experiment are $0^\circ\sim 35^\circ$, $-35^\circ\sim -90^\circ$ and $0^\circ\sim 90^\circ$, respectively. After the pad has been dressed, its surface topology is measured by a stylus type 3-dimensional surface roughness measuring instrument. The radius of the diamond tip probe, the nose angle and the measuring force are 5 μm , 90° and 4mN, respectively. The measured results allow us to determine ridge height and groove area quantitatively.

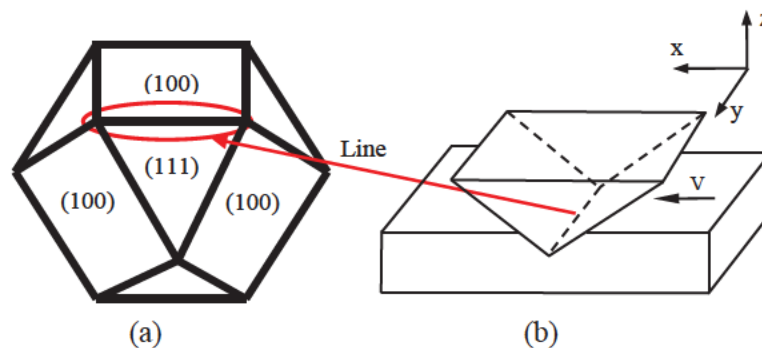


Fig.1 Schematics of dressing by a single diamond (a) geometry of single diamond, and (b) basic dressing mode

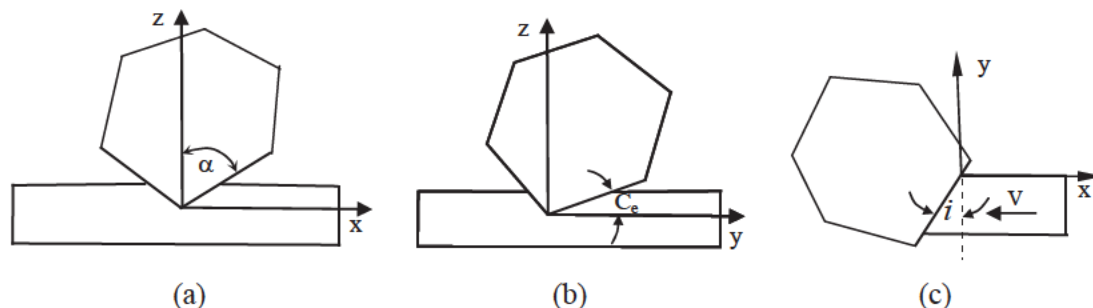


Fig.2 Definitions of (a) rake angle α , (b) cutting edge angle C_e , and (c) inclination angle i

Results and Discussions

The 3D profiles of the pad after point dressing, line dressing, and face dressing, respectively under increasing dressing depth condition are displayed in Fig. 3. In this experiment, while the diamond is traversing a distance of 10mm, it also descends 200 μm . Hence a groove with increasing depth is observed. It is found that when the dressing depth is less than about 15 μm , the pad material will recover as soon as the diamond leaves the area being dressed and no permanent deformation takes place since it is in the range of elastic behaviour. The pad material begins to wear and a groove forms when the dressing depth is larger than 15 μm . But chips are not found until a dressing depth of 30 μm and beyond. This could be owing to a dressing depth that is smaller than minimum uncut chip thickness. It can be seen from Fig. 3 that there are pile-up materials at both sides of the created groove. It is also noted that a wedge or prow develops in front of the diamond during the dressing process. The pile-up is mainly due to plowing action as will be discussed later. In addition, the long and random molecule chains of polyurethane pad may entwine and roll up each other and enhances the pile-up effect.

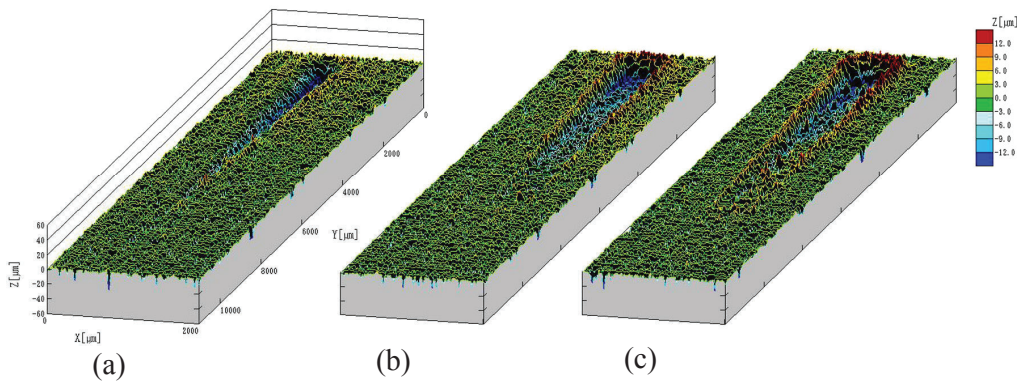


Fig. 3 Groove formed by dressing method (a) point dressing, (b) line dressing, and (c) face dressing

The cross section of a created groove is schematically drawn in Fig. 4. In the figure, the quantities R_1 and R_2 are two side ridges areas, and G is groove area. From tribology viewpoint, the dressing action on the pad by a diamond is a typical abrasive wear process. The wear of the pad could be attributed to plowing action and cutting action [6]. In order to evaluate the contribution of plowing, a plowing ratio w is defined below:

$$w = \frac{R_1 + R_2}{G} \quad (1)$$

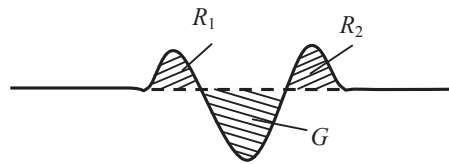


Fig. 4 Cross section of a created groove

There is no material loss and the sum of both side ridge areas equals to the groove area when $w=1$. The permanent deformation is resulted from plowing action alone in this case. Conversely, under the condition of $w=0$, there are no side ridges and the deformation is completely achieved by cutting action. The 2D profile dressed by basic dressing mode under a dressing depth of 200 μm is shown in Fig. 5. Different colours on the figure reveal different heights. Again the ridges form on both sides of the groove can be clearly seen and the observation discussed

previously is confirmed. Figs. 6-8 show the variation of w with respect to the inclination angle, cutting edge angle, and rake angle, respectively. It is noted from these figures that w are larger than 0.5 except under a larger cutting edge angle condition. This implies that plowing dominates wear of the pad. When the cutting edge angle is increased, the deformation mode tends toward cutting action. The use of a larger inclination angle or a larger negative rake angle results in more plowing action than cutting action in groove formation as expected. The ridge height is also shown in the figures because it becomes the pressure enhancer of the abrasives to polish the wafer. The orientation of the diamond that presses against the pad affects strongly the dressed asperities on the pad. The ridge height increases with the decrease of cutting edge angle and rake angle, but it does not vary significantly with the inclination angle. The largest ridge height is created by the rake angle of $\alpha = -90^\circ$. That is, the face dressing. The cutting edge angle of $C_e = 35^\circ$ (i.e. point dressing) results in the least damage to the pad because of small contact area. On the other hand, the face dressing creates a wide and shallow groove with excessive permanent deformation that results in wide and high ridges. These results imply that if consumption of the pad is the major concern then the use of point dressing is recommended.

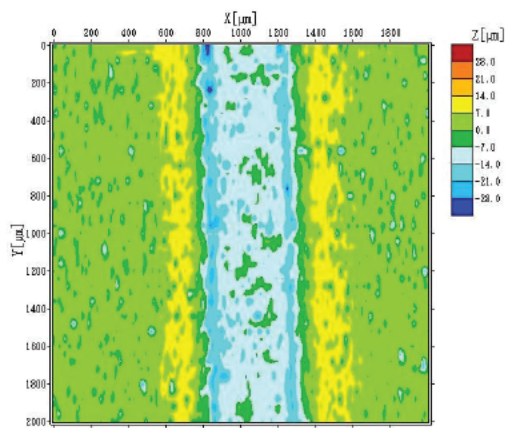


Fig. 5 Groove formed by basic dressing mode under a dressing depth of 200 μm

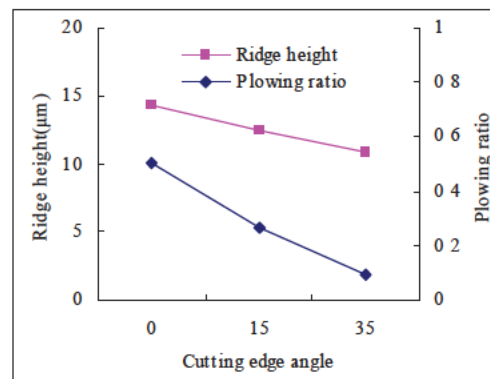


Fig. 6 Variation of ridge height and plowing ratio with cutting edge angle

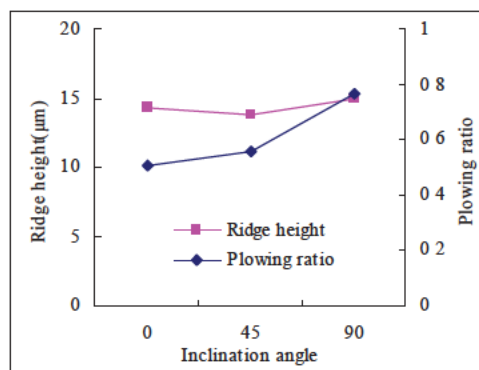


Fig. 7 Variation of ridge height and plowing ratio with inclination angle

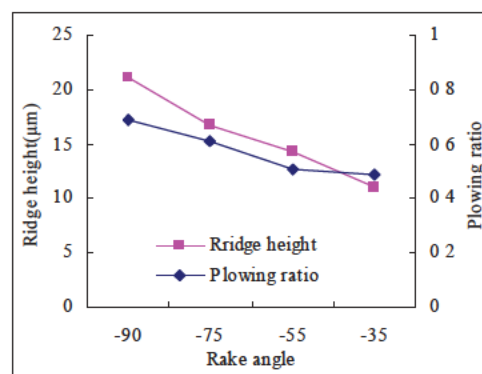


Fig. 8 Variation of ridge height and plowing ratio with rake angle

Since a pad dresser contains thousands discrete diamond grits that are bonded to a metal substrate, random scratch patterns are created when it moves on the rotating pad in practice. The 3D profile and its 2D image for surface height analysis of a representative cross groove on the pad surface created by face dressing under a dressing depth of 200 μm are displayed in Fig. 9(a) and Fig.

9(b), respectively. It is observed that the two sides of the groove are raised. At the four corners of the intersection, the ridges are higher because the ridge created in the first dressing is raised further in the second dressing. Comparing with the single path the ridge height grows more than 20% as shown in Fig. 10. In other words these ridges become the highest points on the pad. As a consequence, the ridges at the intersection will pressurize the rotating wafer and polish away the contact region of the wafer. Moreover, it is found that the groove of the intersection is deeper. This phenomenon was also observed with repeated sliding over the same track without changing the dressing depth as shown in Fig. 11. The groove depth does not increase by the same amount for the succeeding dressing action. The reason can be attributed to the viscoelastic (time-dependent) property of the polyurethane pad. The increase of groove depth also leads to an increase of ridge height as depicted in Fig. 12. Quantitatively, the ridge height increases by about 20~30% for each additional dressing. This results show that in the case of noisy dressing, the groove on the pad is not only irregular but also deeper. As a result, the amount of slurry used in the CMP process may increase substantially. One of the more interesting observations is that the groove depth is smaller than the dressing depth. A careful examination of Fig. 12 reveals that the groove depth is about $6\mu\text{m}$, but the dressing depth is controlled at $100\mu\text{m}$. Hence the spring back of the pad is about 94%. The amounts of spring back for point dressing and line dressing are 86% and 91%, respectively as given in Fig. 13. Since there is a large spring back, it should be taken into account during dressing in the CMP process.

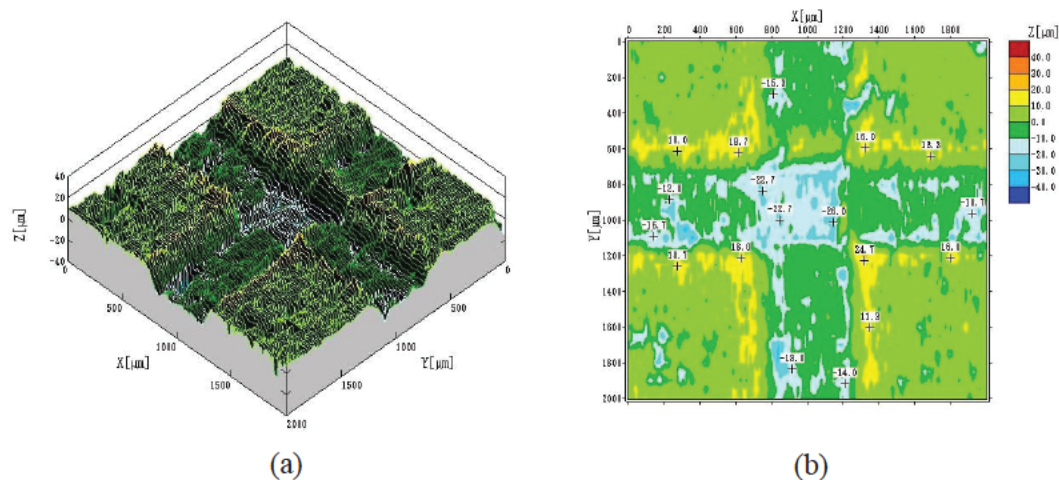


Fig. 9 Groove formed by cross dressing under a dressing depth of $200\mu\text{m}$ (a) 3D profile, and (b) 2D image for surface height analysis

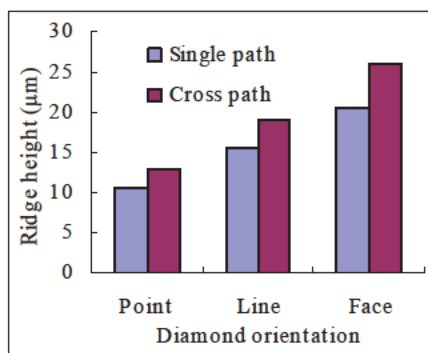


Fig. 10 Ridge height for single path and cross path dressing

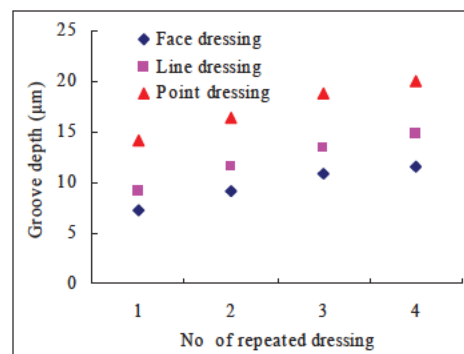


Fig. 11 Variation of groove depth for repeated dressing

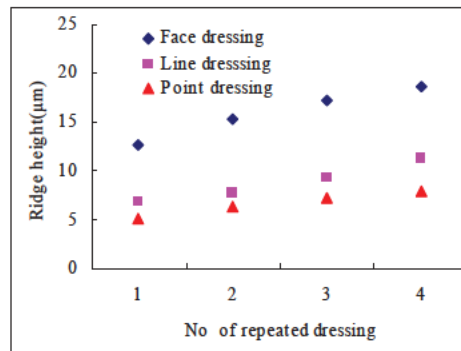


Fig. 12 Variation of ridge height for repeated dressing

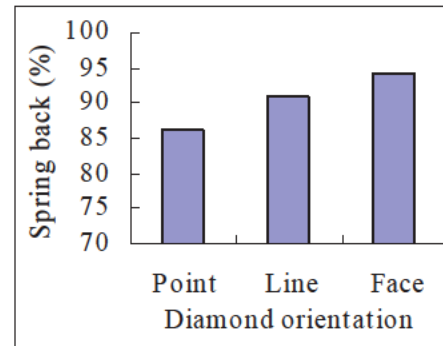


Fig. 13 Spring back under a dressing depth of 100 μm

Conclusion

In this work, dressing by single diamond with the controlled diamond orientation, dressing parameters and dressing path is presented to investigate the fundamental characteristics of dressing action. It is found that a groove with ridge on both side walls is created when the dressing depth is larger than a specific value. The diamond orientations affect strongly the resulting asperities on the pad. The wear of the pad is attributed to plowing and cutting. When the inclination angle is increased or the rake angle is decreased, wear tends to be dominated by plowing action. On the other hand, cutting action plays a major role under a larger cutting edge angle condition. In the case of cross or repeated dressing, the groove on the pad is not only irregular, but also can be unnecessarily deeper. As a result, the amount of slurry used in the CMP process may increase substantially. Moreover, the groove depth is smaller than the dressing depth, and spring back of the pad is significant in dressing during the CMP process.

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10.4028/www.scientific.net/KEM.329

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10.4028/www.scientific.net/KEM.329.151