# Study on Variable Rotation Polishing Method in Chemical Mechanical Polishing Process

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***Abstract***
*Variable rotation polishing method has been studied to improve performance for the next generation wafer size of 450 mm in Chemical Mechanical Polishing (CMP) technology. This method adds the backward rotation of a polishing platen against the only forward rotation, i.e. the conventional polishing. Polishing slurry could be more efficiently supplied into the center area of the larger wafer due to the backward rotation of the platen. Material removal rate at the condition the backward rotation experimentally became 38% higher in comparison with only forward rotation. In this case, slurry film thickness of the Variable Rotation Polishing (VRP) method was slightly thinner than that of conventional rotation. Next, the asperities of polishing pad surfaces were evaluated by confocal laser scanning microscope. The higher material removal rates would also be achieved by the movement of the asperity bending back and forth direction on the polishing pad surface during the forward and backward rotation of the platen. These observed polishing pad surfaces indicated that the asperity preservation on the polishing pad is one of dominant parameters to improve the material removal rate of wafer surface in CMP process.*

***Keywords***: *Variable Rotation Polishing, CMP process, Asperity, Polishing pad, Chemical Mechanical Polishing, Slurry*

## 1 Introduction

Chemical Mechanical Polishing (CMP) is widely adopted in producing excellent local and global planarization of wafer surface for microelectronic devices and semiconductor manufacturing industry. The CMP process is required to planarize the overburden area in the interconnect process. It is a balanced polishing process, relying on chemical reaction of the slurry with the substrate, oxide, thin film and mechanical pressure on the substrate to a polishing pad to remove the passivation layer. However, the fundamental mechanisms of material removal and the interactions of the chemical and mechanical effects are not well understood [1-4].

Recently, the size of wafer used in semiconductor manufacturing industry will change from 300 mm to 450 mm, which would involve a significant investment tool and fabrication facilities. Therefore, some issues arise regarding whether the tools that are currently used for 300 mm wafers could, in some cases, simply be scaled up or whether there are any problems occurred by doing so. For example, the slurry costs would become prohibitive due to the increase in polishing pad area. Also, in the case of the conventional CMP tool the slurry might be unable to fill in the narrow gap between wafer and polishing pad around the center area when wafer size becomes larger [5,6]. We initially attempted on the slurry supply issue around the center area as mentioned above by proposing the Variable Rotation Polishing (VRP) method in CMP process.

In order to verify our proposed method, a control unit to vary platen rotation speed, rotation direction and rotation angle was developed. In this paper, we discuss on effect of the VRP method and parameter to determine the polishing Material Removal Rate (MRR) of wafer surface and its effect to the change of slurry film thickness and the different configuration of surface asperity on polishing pad. Comparatively high material removal rate was experimentally founded by changing backward rotation angle.

## 2 Chemical Mechanical Polishing

Chemical Mechanical Polishing is one of most important processes used in the semiconductor manufacturing industry to achieve the planarization of the substrate, which is necessary for constructing multilevel interconnection in Ultra Large Scale Integration (ULSI). Figure 1 illustrates the schematic of CMP process with microscopic region between a polishing pad and a wafer during polishing. A wafer is pressed and simultaneously rotated onto a polishing pad settled on a rotating platen; at the same time polishing slurry (chemical solution with nano-sized fine particles) is supplied to the polishing pad surface. The CMP mechanism is generally explained that mechanical pressure and motion in process removes the very thin material layer, which is weakened by chemical reaction of slurry substance [3,4,7]. However, the material removal mechanism in CMP process is in veil yet although some models were suggested.

Polishing pads are traditionally characterized by relatively limited historic set of parameters, not all of which are based on capable metrologies. Important parameters that determine interaction of pad with slurries, such as pad surface charge, are not widely used. The removal of material from the wafer is generally dominantly dependent upon the surface properties of the polishing pad along with other process conditions [7-9].

## 3 Concept of Variable Rotation Polishing

According to the material removal mechanism in CMP process of wafer surface for semiconductor manufacturing, the material removal of wafer surface during CMP is conducted by adhesion of the reacted silica layer of the $SiO_2$ substrate on the fine particles during attachment on the substrate surface in the microscopic level unsteady slurry flow of the narrow gap between the wafer and the polishing pad [10,11]. The VRP method is defined as bidirectional, forward and backward rotation, with variations of rotation angle and rotation speed as shown in Figure 2. It is different from the conventional polishing, in which the wafer carrier and platen rotate in only one rotational direction all the polishing time. This method could improve slurry flow distribution around center area because the method would efficiently fill the slurry by backward rotation [12]. Figure 3 shows the rotational

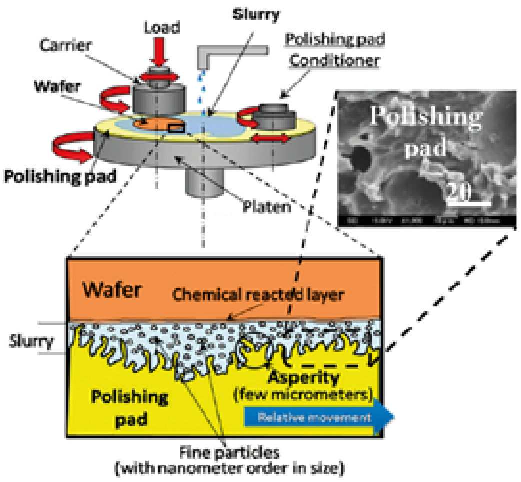


**Figure 1**: Schematic of CMP process.

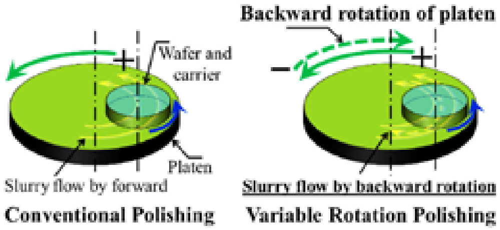


**Figure 2**: Concept of Variable Rotation Polishing method.

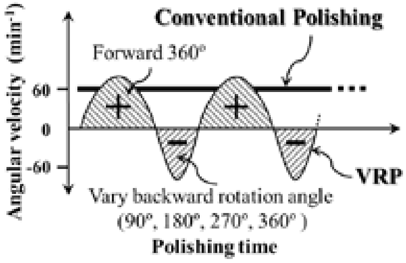


**Figure 3**: Difference of conventional polishing and VRP method.

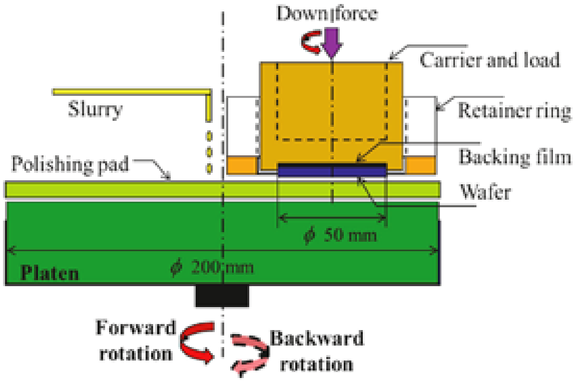


**Figure 4**: Experimental setup for verifying the VRP method.

characteristic used in VRP method represented by angular velocity (min$^{-1}$) along polishing time. As a result, slurry would return to the wafer by the backward rotation by the VRP method in accordance with our concept, thus could also save the consumption of slurry.

## 4 Experimental Setup

A polishing pad with a diameter of 200 mm was set on the experimentally developed platen of the Variable Rotation Polishing for CMP machine as shown in Figure 4. The CMP experimental conditions are shown in Table 1. Our experiment included five types of rotation. The *i* type was the conventional polishing, forward rotation only. For the *ii* to *v* types, backward rotation of 90, 180, 270, 360 degrees, were added, respectively.

**Table 1**: CMP experimental conditions

| **Work piece** | **$\phi$ 50 mm of $SiO_2$ - coated wafer (15,000 Å)** |
|---|---|
| Type of rotation (Fix forward rotation angle and vary backward rotation angle) | *i* Forward rotation (conventional)<br>*ii* Forward 360° backward 90°<br>*iii* Forward 360° backward 180°<br>*iv* Forward 360° backward 270°<br>*v* Forward 360° backward 360° |
| Conditioning time | 5 minutes before each polishing |
| Polishing time | 2.5, 5, 7.5, 10 min |
| Number of sample | 4 samples per condition |
| Polishing pad | Stacked Pad IC1000 with Suba400 |
| Pad conditioner | Blocky diamond grain #100 |
| Slurry solution | 12.5wt% of $SiO_2$ in pH 10.6 KOH |
| Flow rate of slurry | 10 ml/min |
| Pad and wafer revolution | 60 min$^{-1}$ |
| Polishing pressure | 6.89 kPa (1 psi) |

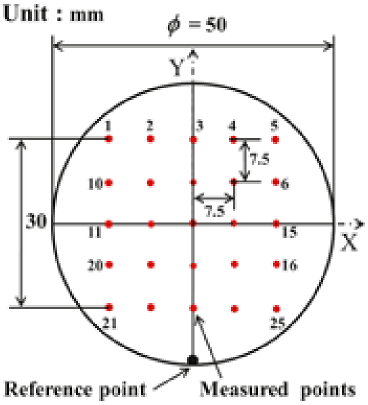


**Figure 5**: Points of measurement on each wafer.

The material removals were evaluated by the difference of the silicon dioxide film thickness before and after CMP experiments. Each material removal value was averaged from 100 points (25 points from 4 samples) as shown in Figure 5.

These were measured on by reflectometric interference spectroscope; TFW-100 Thin Film Analyzer Unit Lambda Vision Inc. Before each experimental polishing, the polishing pad (stacked pad; IC1000 with Suba 400) was conditioned by a blocky diamond (#100) conditioner for 5 minutes with 26.6 N load, rotational velocity of both platen and conditioner was 60 min$^{-1}$.

## 5 Results

The material removals in each rotation type corresponding to 2.5, 5, 7.5 and 10 minutes of polishing time were evaluated with the VRP method. The material removals of VRP method were higher than the conventional polishing by least squares method [12]. Figure 6 shows material removal in each rotation type corresponding to polishing time. Particularly, the material removal rate in the case of the 360 degree backward rotation in the VRP method was 38 percent higher than conventional rotation polishing. Figure 7 shows that, in the case of the conventional polishing, the MRR decrease along the polishing time. On the other hand, the MRR of VRP method did not much decrease as the conventional polishing until 10 minutes of polishing time. These results indicate that the VRP method could evenly keep the polishing performance even longer polishing time.

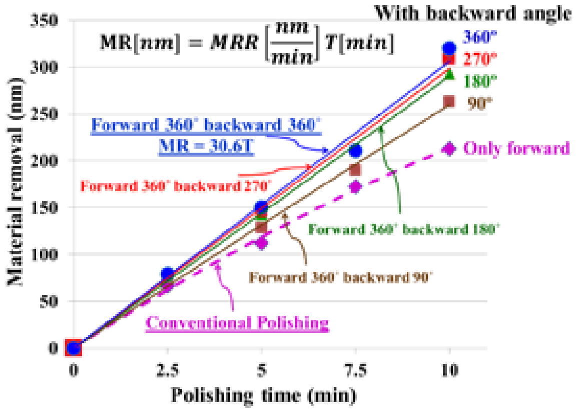


**Figure 6**: Material removal in each rotation type corresponding to polishing time.

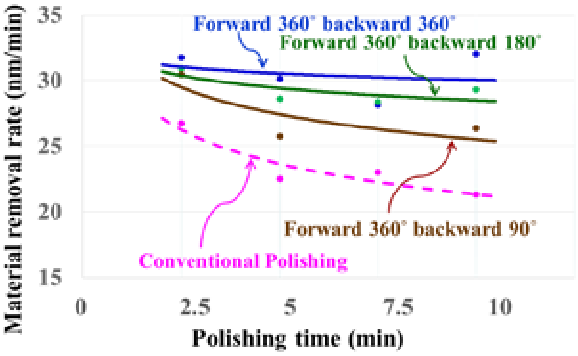
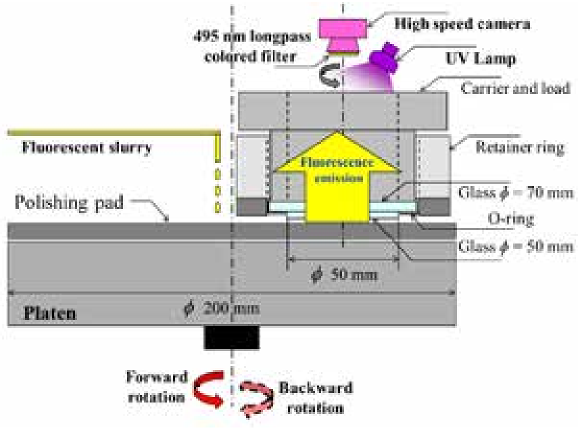


**Figure 7**: Dependence of material removal rate on each polishing time at various rotational conditions.

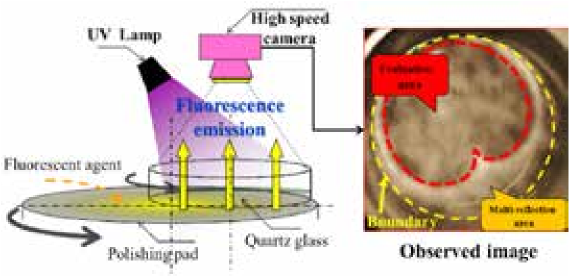
## 6 Discussions

### 6.1 *Slurry flow observation*

We obtained the behaviour of the slurry flow distribution under substrate by the intensity of the luminescence phosphor, excited by UV light, by a high speed camera as shown in Figures 8(a) and 8(b). The slurry flow under a substrate was observed through a light transparent round quartz glass for duplicating a silicon oxide film wafer [6,13]. The intensity of luminescence phosphor was calculated using image processing software. The range of intensity or grey value was set at 0 to 255 levels.

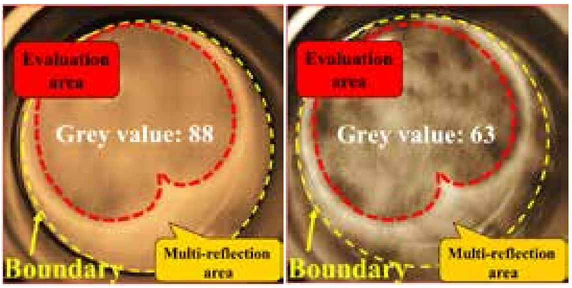


(a) Experimental setup



(b) Typical observed result

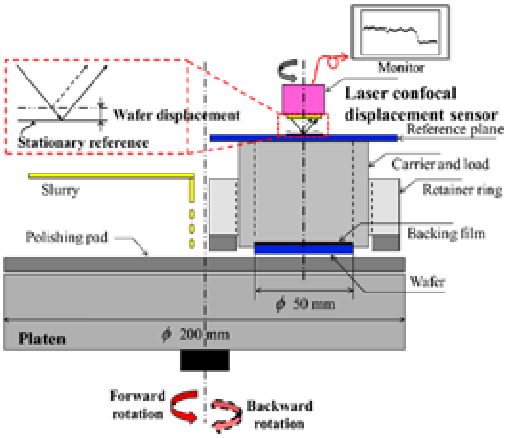
**Figure 8**: Slurry flow observation experimentation.



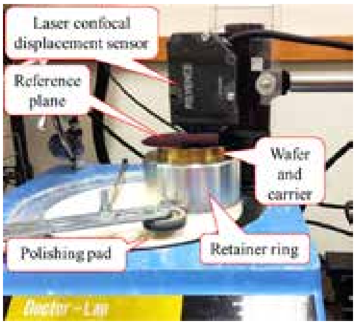
(a) Conventional polishing (b) VRP, in case of forward 360° backward 360°

**Figure 9**: Slurry flow observation between polishing pad and wafer during CMP process.

The intensity of phosphor grey value in conventional polishing was 88, evidently higher than of in the VRP method, 63 as shown in Figures 9(a) and 9(b). The results implied that the slurry thickness in the VRP method was qualitatively less than of the conventional polishing.



(a) Experimental setup



(b) Appearance of experimental setup

**Figure 10**: Experimental setup of wafer displacement measurement between the polishing pad and wafer during CMP process.

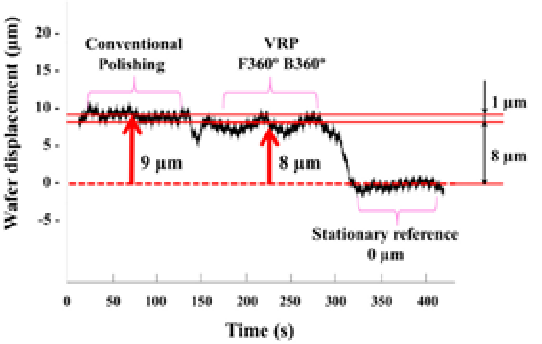


**Figure 11**: Wafer displacement result between polishing pad and wafer during CMP process.

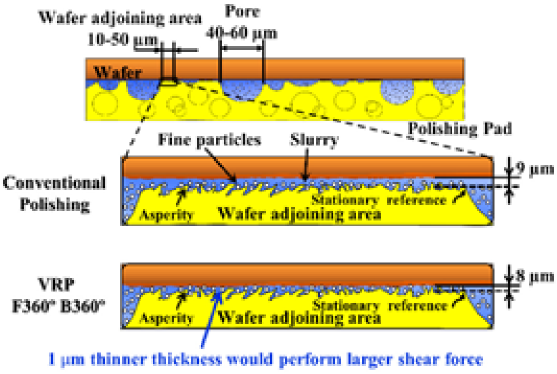


**Figure 12**: Difference of slurry film thickness displacement between conventional polishing and VRP method.

## 6.2 *Slurry film thickness*

Difference of slurry film thickness was estimated from the displacement values of wafer carrier obtained by using surface scanning laser confocal displacement meter; Keyence; LT-9010M, as shown in Figures 10(a) and 10(b). A silicon wafer that was used as a displacement reference plane, was placed on the top of wafer carrier for detecting the reflected laser from the displacement meter. Difference of slurry film thickness measurement for both the conventional polishing and the VRP method was carried out consecutively as followings; the displacement of the silicon wafer on the top of wafer carrier was measured during the conventional polishing for the first 2 minutes and subsequently followed by VRP method for another 2 minutes. After the 4.5 minutes of polishing the rotation of wafer carrier and platen was stopped. When the wafer carrier and platen were stationary, the wafer displacement was measured as the stationary reference. Experimented device had 0.3 µm of measurement repeatability at 50 ms of measurement sampling time.

The displacement results in the conventional polishing and VRP method are shown in Figure 11. The wafer displacement in the case of VRP method was estimated to be averagely 8 µm. It was revealed that the value of this method is thinner than that of conventional polishing. Based on the results obtained from the slurry flow distribution and wafer displacement measurements, the thickness of the slurry between the polishing pad and wafer during the VRP method was 1 µm thinner than that of conventional polishing as shown in Figure 12. Because shear force and MRR are estimatedly reversely proportional to slurry film thickness [14], therefore, thinner slurry film would affect larger force and MRR [15].

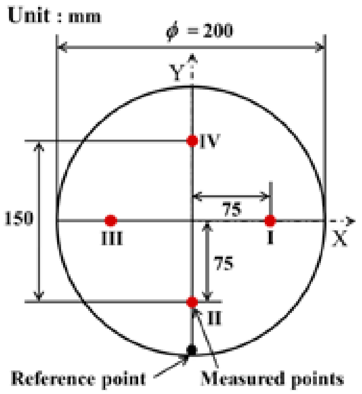


**Figure 13**: Points of measurement on polishing pad.

### 6.3 *Asperity on polishing pad surface*

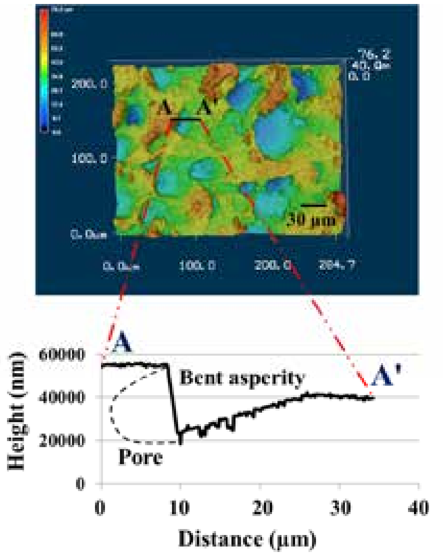
Asperities of the polishing pad in the 4 positions, each position with 3 measurements, as shown in Figure 13, were observed after drying treatment using a confocal laser scanning microscope; Keyence; VK-9710. The behaviour of the asperity on polishing pad to increase the polishing efficiency was evaluated. Figures 14(a) and 14(b) shows typical asperities around pore on the polishing pad at the case of conventional polishing and VRP method.

The conventional rotation polishing where the asperity receives one directional load, leaves the asperity bending in one direction, also conducts the slurry flow in one direction. Note that several pores on the polishing pad are covered by those angled asperity.

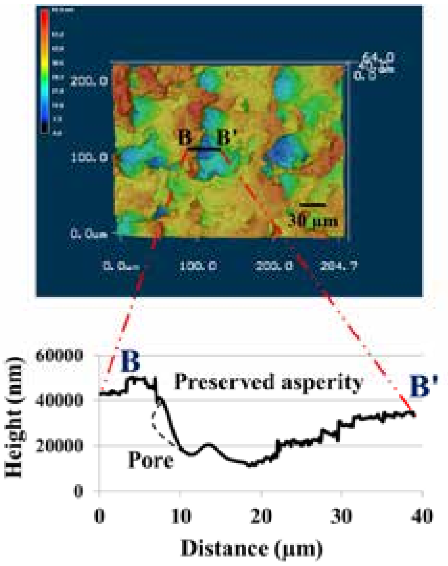
Our method appears to preserve the asperity since the bidirectional movement should maintain the asperity upright across the polishing pad. The behaviour of polishing pad asperity in the conventional CMP process would be separated into 3 stages as followings;

$t = 0$ : The entire asperities of polishing pad stand upright (after conditioning).
$t = t_F$ : After forward rotation started asperities of polishing pad is slightly bending one side.
$t >> t_F$ : Asperities are bent in one direction by forward rotation.

In the conventional polishing, the asperities on the polishing pad are bent in one direction all time. Starting from t = 0 to the asperity condition remains bent one side until the CMP process finishes as shown in Figure 15(a).



(a) Conventional polishing

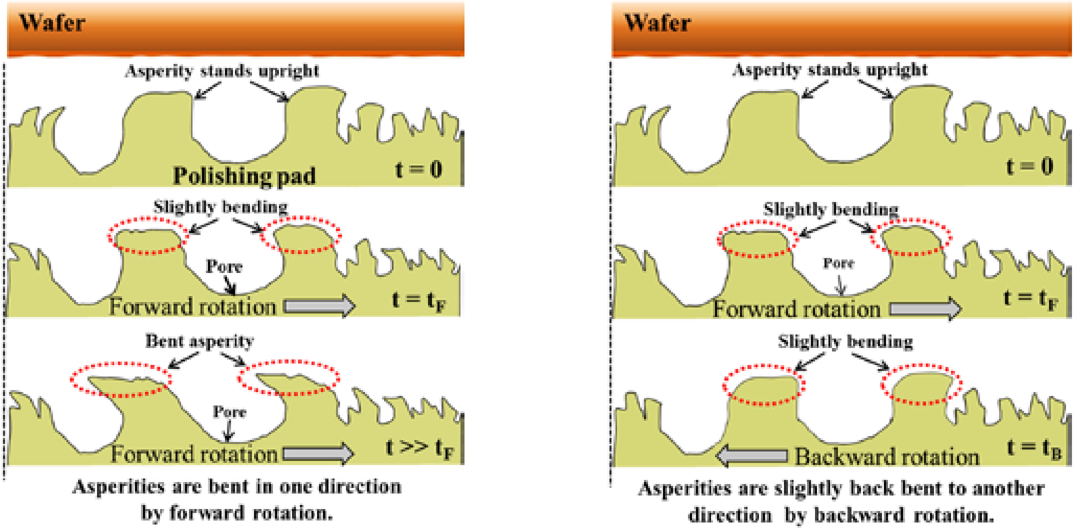


(b) VRP, in case of forward 360º backward 360º

**Figure 14**: Typical asperities around pore on the polishing pad after CMP process.

The behaviour of polishing pad asperities in the VRP method would be separated into 3 stages as followings;

$t = 0$ : The entire asperities of polishing pad stand upright (after conditioning).
$t = t_F$ : Asperities of polishing pad is slightly bending one side by forward rotation
$t = t_B$ : Asperities of polishing pad are slightly back bent to another side by backward rotation.



(a) In Conventional polishing (b) In VRP method

**Figure 15**: Behavior of asperity on polishing pad during CMP process.

In the Variable Rotation Polishing method, the asperities would be preserved because the asperities are not bent down in only one direction but the bent down asperities are slightly bent up again during backward rotation as shown in Figure 15(b). And this behaviour would make asperities stands upright at all times.

## 7 Conclusions

We proposed and then experimentally investigated the variable rotation polishing method in order to improve performance for the next generation wafer size. There are conclusions as followings;

(i) In the case of 360 degree backward rotation of the VRP method, material removal rate of the Variable Rotation Polishing 38 percent were higher than conventional polishing.

(ii) In the case of Variable Rotation Polishing, asperity of the polishing pad bend and keep to stand upright by backward rotation and remain after CMP process. This behaviour indicated that the preservation of the asperity on polishing pad would sustain the material removal rate.

(iii) Thickness of the slurry film at the case of Variable Rotation Polishing was estimated 1 µm thinner than that of forward rotation polishing and would also perform larger shear force and MRR.

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