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Analysis of Pressure Distribution and Verification of Pressure Signal by Changes Load and Velocity in Chemical Mechanical Polishing

Changsuk Lee[1], Jaehong Park[2], Masaharu Kinoshita[2], and Haedo Jeong[1,#]

1 Graduate School of Mechanical Engineering, Pusan National University, 2, Busandaehak-ro 63beon-gil, Geumjeong-gu, Busan, 609-735, South Korea
2 Research and Development of Solution Center, Nitta Haas Incorporated, 3-17-1, Kannabidai, Kyotanabe-shi, Kyoto, 610-0333, Japan
Corresponding Author / E-mail: hdjeong@pusan.ac.kr, TEL: +82-51-510-3210, FAX: +82-51-510-8442

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The Preston's equation which was known as the governing equation of the polishing results in CMP process is caused by the wafer pressure and velocity. It is very important for the pressure and velocity to examine the fundamental characteristics which have effects on the polishing results. In this study, the intelligent pad which can measure the pressure distribution delivered to the wafer by the independent change of the pressure and velocity in real-time was used. The intelligent pad has sheet shape of embedded pressure sensor and functions of pressure signal processing, saving and transmitting in real-time. The average and the deviation of pressure signals were calculated by extracting the signal value from the measured pressure distribution, and the quantitative analysis was conducted by using the full width at half maximum (FWHM) value of the probability density function. The suitability of pressure signal was confirmed by polishing the oxide wafer in the same experiment conditions. So, the average and deviation of the pressure signal value correspond with the material removal rate (MRR) and non-uniformity of the polishing result. In conclusion, the intelligent pad system will be a good monitoring tool to understand various phenomena in CMP process.

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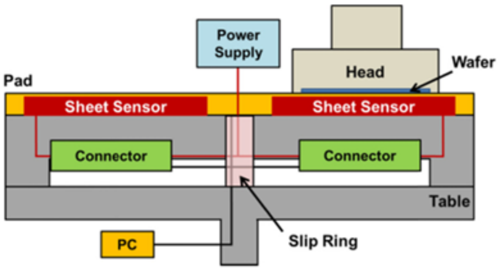
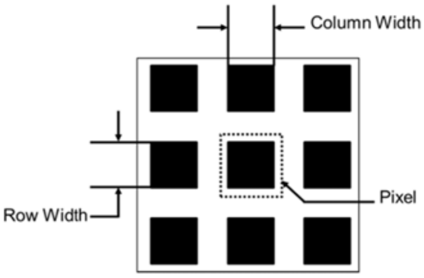
1. Introduction

The wafer is attached to the polishing head, suppressed to the surface of the polishing pad by the pressure, and in this state, the wafer and polishing pad rotate in the same direction and removal the wafer surface at a constant relative velocity.[1] The factors affecting the polishing results can be divided into process factors (pressure, relative velocity and polishing temperature) occurring in each process and the factors by the properties of the materials used for polishing (chemical factors of slurry, particle scale and contents, fluid mechanics of slurry thickness film, modulus of elasticity of polishing pad and types of wafer thin-film).[2] The Preston's equation most widely known as the governing equation of the CMP results includes pressure and velocity only, which are in a proportionate relation with this.[3] Previous studies have proven only investigated the polishing results such as material removal rate and non-uniformity. Also, there was no formal research to check the polishing progress in CMP.[4,5] So, the CMP monitoring technology is becoming the main issue of CMP. The monitoring system for CMP equipment, which uses friction force and temperature measurement, has been widely used as monitoring tool. The correlation between friction force and temperature were investigated in terms of the tribology aspects by using the monitoring system. Various friction signals (1-dimensional) were monitored and analyzed the different parameters like as pressure, velocity and slurry flow rate.[6-8] But, these signals cannot explain exactly what is happening at wafer whole area. We focused on the pressure and velocity forming Preston's equation and measured the pressure distribution delivered to the wafer surface according to their changes using intelligent pad system. Attaching a pressure sensor under the commercial polishing pad, a system that can monitor the pressure that the wafer receives during the process in real-time was produced. The image of pressure distribution was obtained, and for the quantification of the analysis, it was converted to pressure signal value. Also, full width at half maximum (FWHM) of the histogram and probability density function was calculated using the mean and deviation of the pressure signal value. FWHM is expression of the extent of a function, given by the difference between two extreme values of the independent variable at which the dependent variable is equal to half of its maximum value.[9] And next, the thin-film



(a) Diagram of intelligent pad system



(b) Structure of pressure sensor

Fig. 1 Schematic of intelligent pad system and structure of pressure sensor

thickness of oxide wafer before and after polishing was measured to calculate material removal rate and uniformity and compare the correlation for the verification of the measured pressure signal value by the intelligent pad system.

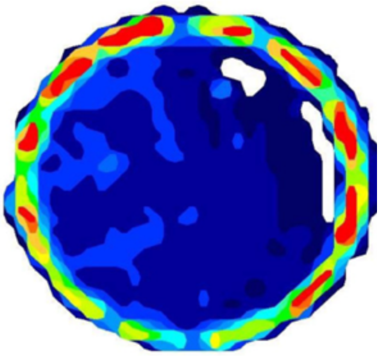
2. Experiment

2.1 Experiment equipment and method

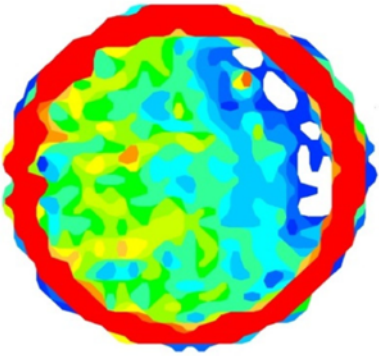
Fig. 1 shows the schematic diagram of the intelligent pad system, which primary consists of power supply, sheet sensor and connector. Especially, the connection between pressure sensor and computer is important because CMP polisher has a structure of rotation body. So, we used slip ring to overcome the problem of electric wire twist. The pressure sensor which can confirm the 6inch oxide wafer and retainer ring was used for the basic test of the intelligent pad. The pressure sensor is depending on the principle of piezoelectric using polymer material. The vertical and horizontal scale of the pressure sensor used in the experiment was 236 mm, 218 mm and number of pixels was composed as 48 and 44, respectively. The each pixel size (column and row width) was about 4.99 mm. The polisher, GnP Tech POLI-762 was used, IC-1000 polishing pad of Nitta Hass and 6 inch oxide wafer were used. First, when the velocity was 60 rpm, the pressure of the wafer and retainer ring was 100-200 g/cm^2, 200-300 g/cm^2 and 300-400 g/cm^2, so the pressure gap between the wafer and retainer ring was maintained as 100 g/cm^2. Second, the pressure distribution which is delivered to the wafer was measured by fixing the pressure of wafer and retainer ring at 200 g/cm^2 and 300 g/cm^2, and setting the velocity of the polishing head and wafer as 30 rpm, 60 rpm, 90 rpm and 120 rpm.

Table 1 Pressure signal at each pressure sensor pixel

Retainer ring			Wafer edge			Wafer	
255	220	177	110	77	59	51	57
242	226	196	123	69	45	51	41
221	218	169	121	65	41	55	0
229	207	159	114	70	35	44	47



(a) Retainer ring focusing



(b) Wafer focusing

Fig. 2 Two types of focusing method at retainer ring and wafer area; (a) Retainer ring focusing and (b) Wafer focusing

2.2 Digitized of pressure distribution

There is a limitation only with the image of the pressure distribution by the intelligent pad in explaining the pressure delivered to the wafer. Thus, quantification is necessary for a clear analysis of the pressure distribution. This study converted the pressure that each pixel of the pressure sensor receives to a pressure signal value. Table 1 shows the pressure signal value entered in the pixel of pressure sensor. The pressure signal value is expressed with a value between 0 and 255, and it may be shown with various colors according to the relevant value. If this scope of the pressure signal value is controlled, the pressure distribution of the area that the user wants can be checked more in detail. However, the quantified pressure signal value does not show the accurate pressure that the wafer receives during the CMP process, but means the relative pressure between neighboring pixels. Therefore, whether the pressure distribution delivered from a specific location is high or low pressure can only be compared.

2.3 Focusing method of pressure distribution

It can be divided into two methods to visualize the pressure distribution like Fig. 2, depending on the focus. Regarding the method of focusing on the retainer ring, the pressure distribution can be checked according to the width and form of the retainer ring, but detailed pressure comparison of the wafer area is difficult. However, regarding the method of focusing on the wafer, the pressure distribution of the retainer ring cannot be known exactly, but the pressure distribution of the fine area like wafers edge can be checked easily. This focusing method can be shown adjusting the maximum pressure signal value divided into 0 to 255.

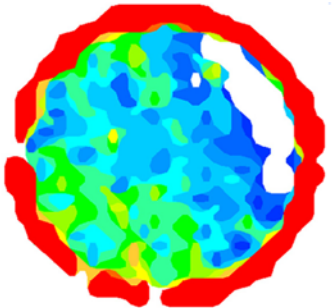
3. Results and Discussion

3.1 Pressure distribution according to the change of load

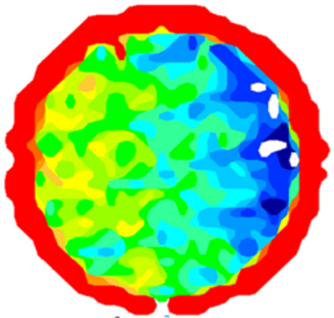
The image of the pressure distribution by the pressure of the wafer and retainer ring in each condition was shown in Fig. 3. It can be seen that as the wafer pressure increases, the red areas which mean the high pressure in the pressure distribution image was increased.

The intelligent pad shows the measurement results of pressure distribution as image firstly, so it has a limitation in a quantitative analysis. So the histogram was shown in Fig. 4 by extracting the pressure signal value of each pixel of the pressure sensor in order to recover this limit. The rank scale of the pressure signal value was set 5, so the number of applicable pressure signal values was examined. The most of the pressure signal value was existed on the low pressure distribution area in 100-200 g/cm^2 pressure condition, so the tail of the graph was formed on the right way. On the other hand, the tail of graph was on left way and the pressure signal value was shown in the high pressure distribution area mainly in 300-400 g/cm^2 pressure condition.

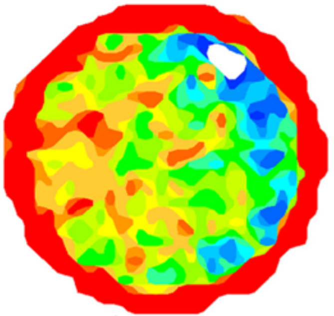
The Fig. 5 showed the probability density function (PDF) by calculating the average and deviation of the pressure signal value in the histogram. The peak value position in the probability density function means the pressure average, which delivered to the wafer, and this value can be judged that has close relations with the material removal rate. In addition, the deviation of the pressure signal value can be examined by introducing the full width at half maximum (FWHM). When the pressure condition of the wafer and retainer ring are 100-200 g/cm^2, the range of FWHM value was 12 to 18, and the difference was 6, and when it is 200-300 g/cm^2, the range of FWHM value was 16 to 33, so the difference was measured 17. The range FWHM value under a pressure condition of 300-400 g/cm^2 was 31 to 53, so the difference of the pressure signal was 21. Through this result, as the lower pressure of the wafer and retainer ring showed, the more uniform pressure can be delivered to wafer. The difference between two independent variables in the probability density function shows the range of the deviation of the pressure signal value delivered to the wafer, and it can be judged that corresponds with the uniformity of the CMP process. Therefore, the average and deviation of the quantified pressure signal value become the index for estimation of the material removal rate and uniformity in CMP process. In order to verify the measured pressure signal value using the pressure sensor of the intelligent pad, the thin-film thickness of 6inch oxide wafer before and after polishing were measured to compare the tendency with the CMP results. The polishing condition is as Table 2. The ILD-3225 of the slurry was used for removing the oxide, and the flow rate was set as 250 mL/min, polishing time was set 60 seconds.



(a) Wafer 100g/cm^2 and Retainer ring 200g/cm^2

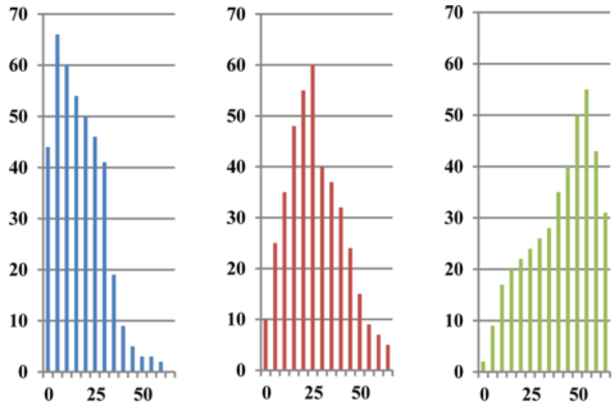


(b) Wafer 200g/cm^2 and Retainer ring 300g/cm^2



(c) Wafer 300g/cm^2 and Retainer ring 400g/cm^2

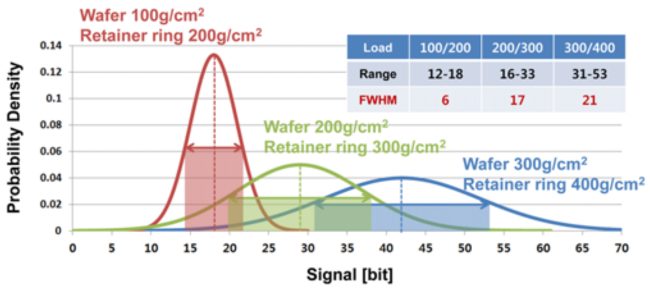
Fig. 3 Pressure distribution according to the change of load



(a) W100-R200 (b) W200-R300 (c)W300-R400

Fig. 4 Histogram according to the change of load

The result of the material removal rate and uniformity increased for the increase of the wafer and retainer ring load as Fig. 6. The material removal rate in CMP process showed the proportional relation with the pressure of the Preston's equation, and it was mentioned in the introduction. In the case of the uniformity, the best result was shown in

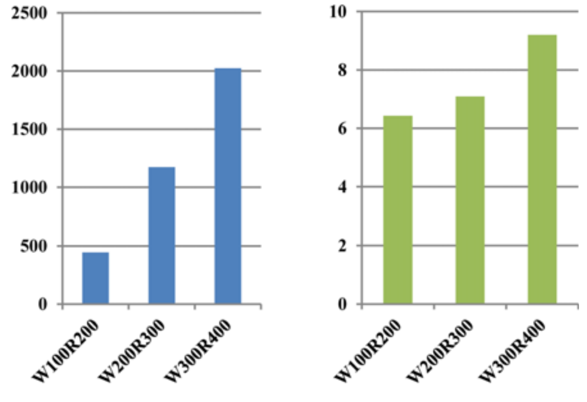


Load	100/200	200/300	300/400
Range	12-18	16-33	31-53
FWHM	6	17	21

Fig. 5 Probability density function according to the change of load

Table 2 Polishing conditions

Parameters	Conditions
Polisher	POLI-762 (GnP Technology)
Polishing pad	IC 1000 (Nitta Haas)
Wafer	6inch oxide
Slurry	ILD-3225
Velocity	Head 60rpm / Table 60rpm
Pressure	W100 g/cm^2 and R200 g/cm^2
	W200 g/cm^2 and R300 g/cm^2
	W300 g/cm^2 and R400 g/cm^2



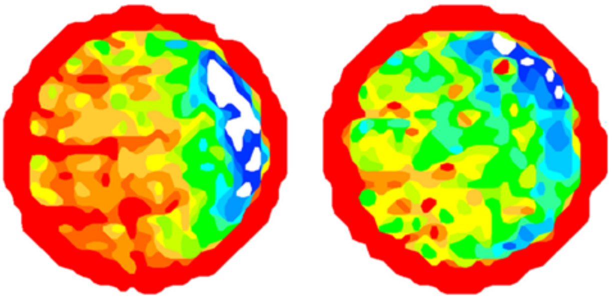
(a) Material removal rate (b) Uniformity

Fig. 6 CMP results according to the change of load

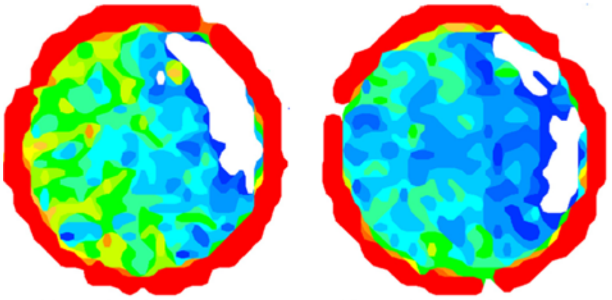
the low pressure condition, and as the pressure of the wafer and retainer ring increase, the uniformity decrease, and this result showed the tendency with the pressure signal value. Therefore, the result of the pressure distribution using the intelligent pad can assume the information about the polishing result in CMP process, and it is judged that will be very usefully used for monitoring in real-time.

3.2 Pressure distribution according to the change of velocity

Fig. 7 showed the pressure distribution image by the changes in the velocity. As the velocity, the pressure which is delivered to the wafer is decreased, so this result can be decided by the thickness change of the slurry film between the wafer and pad depending on the velocity of the polishing head. The lubrication state in the contact interfaces between the wafer and pad will change as the velocity increases, so the fluid dynamic force by the slurry will be generated. The fluid dynamic force acts as the pressure direction of the polishing head and the opposite direction, so if the velocity increases, the real pressure, which is delivered to the wafer will decrease despite the same pressure.[10,11]



(a) Head and Table 30rpm (b) Head and Table 60rpm



(c) Head and Table 90rpm (d) Head and Table 120rpm

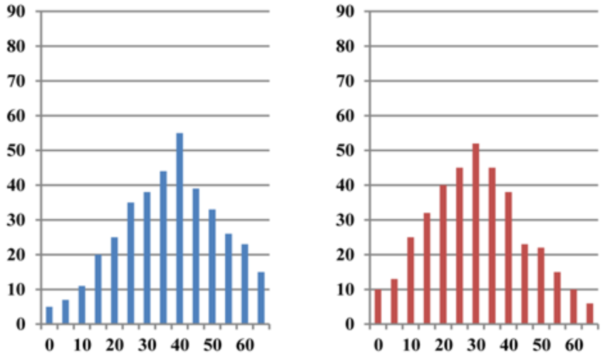
Fig. 7 Pressure distribution according to the change of velocity

The histogram about each condition was marked on Fig. 8. If the velocity is low, the pressure signal value is shown in the high pressure distributional area mainly, as the velocity increased, the peak value location of the pressure signal value moved to the left side as the low pressure distributional area band. The deviation of pressure signal value was calculated using half-maximum value of probability density function like Fig. 9. The half-maximum value of velocity and pressure signal showed an inverse proportion tendency in each other, the velocity was 30 rpm, and the scope of half-maximum value was 27~50, so the difference of pressure signal was shown 23. On the other hand, the scope of the half-maximum value in 120 rpm as the highest velocity was 11~17, so the difference was measured as 6. Therefore, it can be seen that as the higher the velocity was, the pressure which is delivered to the wafer can be more uniformed.

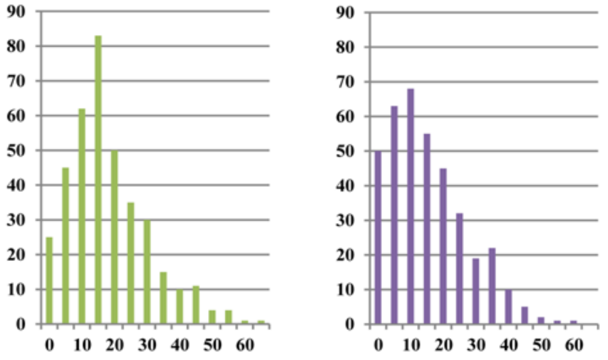
The polishing was carried out to verify this result in the same way as that in the first experiment, and the polishing result, according to the change in velocity was shown in Fig. 10. If the velocity increases, the sliding distance between the wafer and the pad increases, so it showed a high material removal rate, but polishing uniformity was low as the pressure signal value measured by the intelligent pad.

4. Conclusions

This study measured a pressure distribution image by independent changes in the pressure and velocity of the wafer and the retainer ring using an intelligent pad monitoring system. It was converted to a pressure signal value to calculate the mean and deviation under each condition for the quantification of the measured pressure distribution

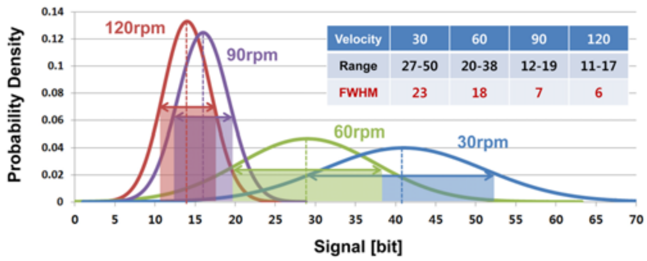


(a) Head and Table 30rpm (b) Head and Table 60rpm



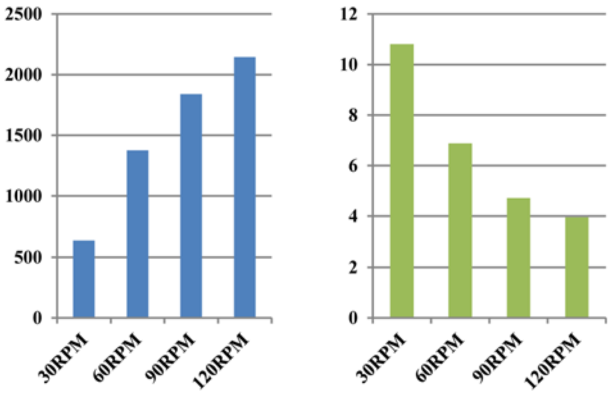
(c) Head and Table 90rpm (d) Head and Table 120rpm

Fig. 8 Histogram according to the change of velocity



Velocity	30	60	90	120
Range	27-50	20-38	12-19	11-17
FWHM	23	18	7	6

Fig. 9 PDF according to the change of velocity



(a) Material removal rate (b) uniformity

Fig. 10 CMP results according to the change of velocity

image, and analyzed using the full width at half maximum value of histogram and probability density function. The mean and deviation of the pressure signal value were respectively judged to correspond to the MRR and non-uniformity. To confirm the accuracy of pressure signal, we investigated the correlation through oxide wafer polishing. As a result, it was found that the lower the wafer and retainer ring pressure and the higher the velocity, the more uniformly the pressure delivered to the wafer became. The intelligent pad is advantageous in CMP monitoring and numerous phenomenon predictions since the wet and dynamic states and pressure distribution in the whole wafer surface are happening in real-time. And the intelligent pad system will be a good monitoring tool to understand various phenomena in CMP process.

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REFERENCES

1. Lee, H., “Empirical Modeling of Wafer-Scale Removal Profile using Spatial Parameter in Copper CMP,” Ph.D. Thesis, Graduate School of Mechanical Engineering, Pusan National University, 2010.
2. Kim, H., “A Study on the Interfacial Characteristics and Its Effect on Material Removal in CMP,” Ph.D. Thesis, Graduate School of Mechanical Engineering, Pusan National University, 2003.
3. Preston, F. W., “The Theory and Design of Plate Glass Polishing Machines,” Journal of the Society of Glass Technology, Vol. 11, No. 44, pp. 214-256, 1927.
4. Jeong, H., Park, B., Lee, H., Kim, H., Seo, H., et al., “Monitoring System in CMP Process,” Proc. of the 1st Pac-Rim International Conference on Planarization CMP and Its Application Technology, pp. 54-65, 2004.
5. Li, Y., “Microelectronic Applications of Chemical Mechanical Planarization,” John Wiley & Sons, pp. 94-95, 2008.
6. Kim, H. J., Kim, H. Y., Jeong, H. D., Lee, E. S., and Shin, Y. J., “Friction and Thermal Phenomena in Chemical Mechanical Polishing,” Journal of Materials Processing Technology, Vols. 130-131, pp. 334-338, 2002.
7. Sorooshian, J., Hetherington, D., and Philipossian, A., “Effect of Process Temperature on Coefficient of Friction during CMP,” Electrochemical and Solid-State Letters, Vol. 7, No. 10, pp. G222-G224, 2004.
8. Hocheng, H., Huang, Y. L., and Chen, L. J., “Kinematic Analysis and Measurement of Temperature Rise on a Pad in Chemical Mechanical Planarization,” Journal of the Electrochemical Society,

Vol. 146, No. 11, pp. 4236-4239, 1999.

9. Wikipedia, “Full Width at Half Maximum,” http://en.wikipedia.org/wiki/Full_width_at_half_maximum (Accessed 15 APR 2015)

10. Yu, T. K., Yu, C., and Orlowski, M., “Combined Asperity Contact and Fluid Flow Model for Chemical-Mechanical Polishing,” Proc. of IEEE International Workshop on Numerical Modeling of Processes and Devices for Integrated Circuits, pp. 29-32, 1994.

11. Lu, J., Rogers, C., Manno, V., Philipossian, A., Anjur, S., and Moinpour, M., “Measurements of Slurry Film Thickness and Wafer Drag during CMP,” Journal of the Electrochemical Society, Vol. 151, No. 4, pp. G241-G247, 2004.