Ultrasonic Vibration-Assisted Diamond Disk Dressing of CMP Polishing Pad

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Abstract - This paper introduces an ultrasonic, vibration-assisted, traditional diamond disk (UV-TDD) dressing method. The polishing pad is dressed by traditional diamond disk (TDD) and UV-TDD. The pad cut rate, torque force, and pad surface profiles of TDD and UV-TDD are investigated in experiments. Experimental results reveal that UV-TDD can produce twice the pad cut rate and reduce torque force compared to TDD. Consequently, a dressing time reduction by half is expected, and hence, the diamond life is extended. This result suggests that the combination processes of TDD/USM are feasible methods for improving dressing efficiency.

Keywords - Chemical mechanical polishing, Ultrasonic vibration, Diamond disk.

I. INTRODUCTION

Chemical mechanical polishing (CMP) has become a primary method for the planarization of semiconductor wafers. The CMP process involves simultaneous interactions among a polishing slurry, semiconductor wafer, polishing pad, and diamond disk. CMP is achieved by polishing wafers using a rotating polyurethane pad. The slurry that permeates the pad top contains submicron-sized abrasives. Reaction chemicals will gradually consume the wafer surface. The main requirements for the CMP process are the slurry, pad, diamond conditioner, clean equipment, and end-point detector. Among these components, the slurry plays a vital role in terms of removing material and ensuring high surface quality in the polished wafers. The polishing pad considerably affects the polishing results, which include aspects such as wafer material removal and uniformity. The diamond conditioner is employed periodically (and continually) to the dressing pad to regenerate the asperity structure of the pad [1-2]. CMP processing is a major factor that determines semiconductor manufacturing costs. One disadvantage of the CMP process is the high cost of its consumables. The consumables (slurry, pad, and diamond disk) used in CMP processing account for over 60% of the total CMP cost. Up to 30% of supplied slurry is wasted owing to the centrifugal force of the platen; wasted slurry is also one of the reasons for the high cost of consumables [3-4]. Therefore, consumable cost reduction has become a prime focus of researchers. In addition, it is known that CMP can produce fine surfaces but with low machining efficiency. In order to overcome this problem, many researchers have been working toward developing new methods, including abrasive-free CMP [5], fixed-abrasive CMP [6], electrochemical mechanical polishing (ECMP) [7], and chemical mechanical grinding (CMG) [8], as well as new consumables such as pads, slurries, and dressers to achieve higher polishing efficiency [9-11].

Ultrasonic machining (USM) is of particular interest for the machining of non-conductive, brittle workpiece materials such as engineering ceramics. As the process is non-chemical and non-thermal, materials are not altered either chemically or metallurgically [12]. USM has been variously termed ultrasonic drilling, ultrasonic cutting, ultrasonic abrasive machining, and rotary ultrasonic machining. The benefits of USM include considerably increased material removal rate, decreased cutting force, reduced tool wear, and improved surface finish [13]. Currently, ultrasonic vibrations are used successfully to enhance the machining capability of micro-electrical discharged machining (EDM) to allow it to be used on titanium alloys [14]. It has been found that in micro-hole machining of a titanium plate, micro-ultrasonic vibration lapping enhances the precision of micro-holes drilled by micro-EDM [15]. The positive effects of ultrasonic vibration have been confirmed by many researchers [16-19]. In recent years, many studies have focused on ultrasonically assisted polishing. For example, Suzuki et al. [20-21] studied ultrasonic, two-axis, vibration-assisted polishing with five-axis, piezoelectric actuators developed in order to finish molds used to fabricate lenses with high numerical aperture. Kobayashi et al. [22] introduced an ultrasonically assisted polishing technique for silicon wafer edge treatment and developed a corresponding experimental apparatus with an ultrasonic, elliptic vibration pad holder. The surface roughness of wafer edges polished by the presented method improved by over 31.7% relative to a wafer without ultrasonically assisted polishing.

In this study, the polishing pad is dressed by traditional TDD and UV-TDD. The polishing pad cut rate, torque force, and pad surface profiles of TDD and UV-TDD methods are described by experiments. The combined USM and TDD process is expected to improve the machining efficiency.

II. EXPERIMENTAL

A. UV-TDD System Setup

The UV-TDD system and process used in the dressing experiments are shown in Fig. 1 (schematically). The system includes a USM set, moving and rotating polishing head, rotating table, slurry supply, torque dynamometer, and PC-based controller. Its operating principle is that the exciting current created by the ultrasonic generator (power supply) in the control box is transported to a piezoelectric transducer (PZT) located in the polishing head to create a high frequency vibration. The power supply for the USM is more accurately described as a high power generator that offers the user control over both the frequency and the power of the generated signal. This electrical signal is supplied to the transducer for conversion into mechanical motion. The PZT changes the electrical signal into a mechanical vibration due to the piezoelectric effect. The mechanical vibration is amplified and transported to the polishing head by an ultrasonic technique; therefore, the rotating polishing head with the copper substrate can vibrate in the vertical direction. The polishing head is vibrated ultrasonically and rotated at the same time while being pressed against the rotating polishing pad surface at a constant pressure. Simultaneously, the slurry is provided to the interface of the copper substrate and polishing pad. Thereafter, the copper surface material is removed by the combined action of the ultrasonic vibration and traditional CMP.

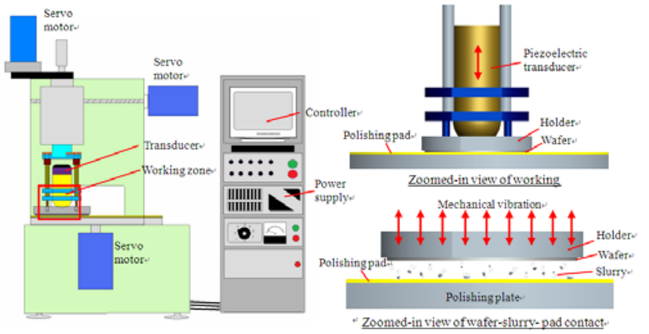

Fig. 1 Detailed schematic diagram of the ultrasonic-assisted chemical mechanical polishing test setup

B. *Dressing Conditions*

In this experiment, the power supply converts the low frequency (approximately 50 Hz) electrical supply into a high frequency (approximately 20 kHz) AC output. This electrical signal is supplied to the transducer for conversion into mechanical motion. The amplitude of the ultrasonic vibration can be adjusted in the range of 5 µm to 15 µm. During polishing, a power head applied a specific load to a copper substrate having dimensions of Φ100 mm × 0.5 mm and 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 with a diameter of 300 mm that rotated at 42 rpm. The applied pressure was approximately 27.5 kpa. The polishing slurry used in the experiments was C7092, produced by the Cabot Company. The slurry flow rate was 150 mL/min. During conditioning, the diamond pad conditioner was attached to a rotating head (spinning at 40 rpm) via a connecting holder. A polyurethane pad was mounted on a table disk that rotated at a speed of 50 rpm. The oscillation speed of the conditioner was fixed at approximately 5 mm/s. The applied load was fixed at approximately 3 kg

C. *Measurement apparatus*

After the pad was dressed, its surface topology was measured using a stylus-type instrument for three-dimensional surface roughness measurement. The radius of the diamond tip probe, nose angle, and measuring force were 5 µm, 90°, and 4 mN, respectively. Each image was captured with over 50 scan curves and 20000 points over a 0.5 mm × 1.5 mm area of the pad. The roughness values used in the next section are the averages of three measured values. The measured roughness data have approximately the same reliability as the statistically averaged value of 50 measurements. A scanning electron microscope (SEM) was employed to examine the morphological features of the pad, such as pores and grooves. The pad cut was measured using a linear variable differential transformer (LVDT) instrument. The material removal rate was determined on the basis of weight loss before and after polishing. The oxide wafers were weighed on a balance with 0.1 mg precision and their surfaces were characterized by atomic force microscopy with 0.01 nm resolution. In addition, a Laser Doppler vibration meter system was used to measure the tiny amplitude of the ultrasonic vibration.

III. *RESULTS AND DISCUSSION*

A. *Pad Cut Rates of TDD and UV-TDD during Dressing*

In the CMP process, the dressing action occurs between the diamond disk and the polishing pad. During polishing, the reaction product gradually accumulates on the pores and asperities of the pad surface, leading to so-called pad glazing [23]. Glazing is undesirable as it often leads to a decreased wafer removal rate over time when there is no pad conditioning, and increases the risk of inducing micro-scratches. Therefore, the functions of the diamond disk during dressing are to clean the debris from the pores and grooves of the pad surface, to remove slurry residues and polish by-products of the pad surface, and to regenerate the asperity structure of the pad. The wear mechanism of a pad dressed using a diamond during conditioning mainly involves the abrasive wear process and can be caused as follows (and as shown in Fig. 3 and Fig. 4) [23]. Where D is the penetrating depth, E is the amount of elastic deformation and V is the relative velocity. When the dressing pressure of the diamond grit exceeds the pressure required for the elastic deformation of the pad, the diamond grit can penetrate into the pad surface. The pad material begins to wear and generates a groove with ridges on both sides because of the relative motion between the diamond grit and the pad

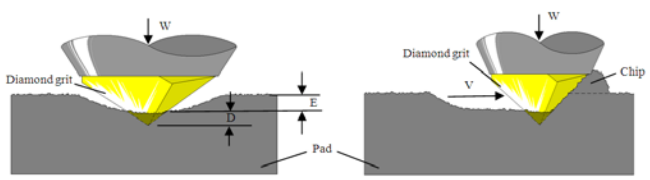

Fig. 3 Schematics of pad dressing mechanism, D: penetrating depth and E: amount of elastic deformation

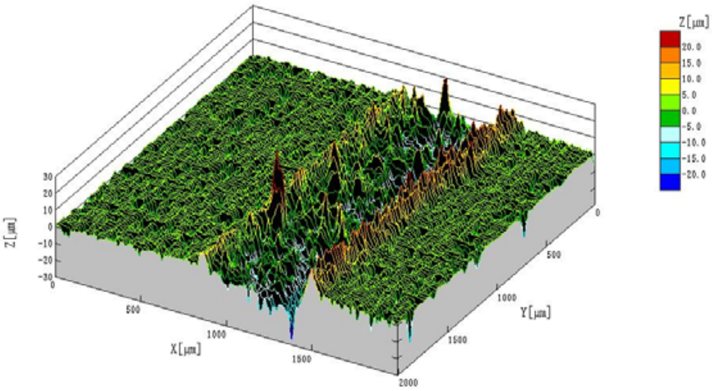

Fig. 4 Three-dimensional (3D) profile of the pad created by the penetration of the diamond grit into the pad

Figure 5 shows the variation in the pad cut rate when the pad is dressed by TDD and UV-TDD. During the dressing process, the pad cut rate was one of the most important factors that influenced the surface condition of the pad. The amount of the pad surface that is removed per unit time is the pad cut rate. The pad cut rate is measured in micrometer per hour in this study, and it is given by the pad thickness removed divided by the dressing time. In the figure, the average pad cut rate of the UV-TDD is approximately 113 μm/h, which is markedly higher than that of the TDD, which has an average pad cut rate of approximately 54 μm/h. UV-TDD leads to a better overall dressing ability in the CMP process. This may be because UV-TDD contributes to the impact force on the soft polishing pad surface to increase the penetrating depth of the diamond grit into the pad. In addition, a representative image of the torque force signal between the diamond disk and the pad generated by TDD and UV-TDD is shown in Fig. 6. A careful analysis of the torque profile indicates that the average torque force of UV-TDD, which is approximately 156 kg-mm, was lower than that of TDD, which is approximately 180 kg-mm, as shown in Fig. 7. This is probably because of the high frequency impact between the diamond grit and the polishing pad surface, which causes the cutting process in UV-TDD to become discontinuous and creates an ultrasonic impact action. This process causes the material to be penetrated by the diamond grit more easily and increases the effectiveness of the interaction between grits and the workpiece surface. Therefore, the torque force effects are decreased because less plastic deformation occurs in the cutting zone [24]. Chang and Bone [25] studied ultrasonically assisted drilling of an aluminum workpiece; they recorded an average of 20% reduction in thrust force when using ultrasonically assisted drilling. This result implies that when the UV-TDD is used, it can double the pad cut rate and reduce torque force; consequently, a reduction in the dressing time of half is expected, and hence, the diamond life is extended

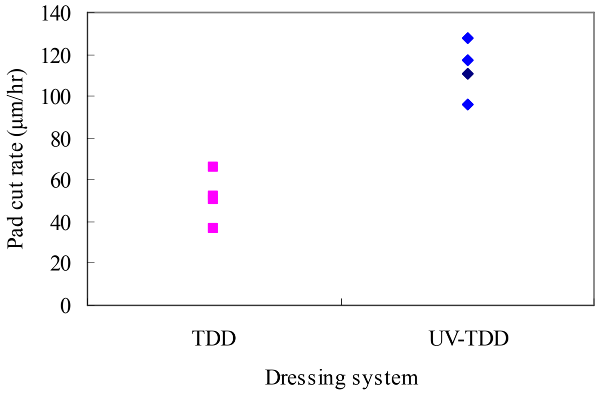

Fig. 5 Variation in pad cut rate between the disk and the pad when the pad is dressed by TDD and UV-TDD

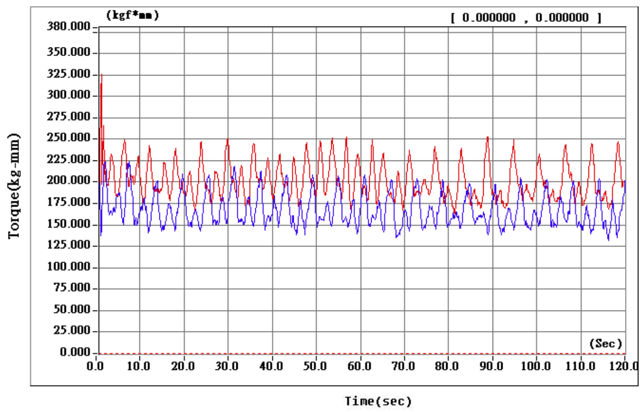

Fig. 6 Torque signals between diamond disk and pad as a function of dressing time when the pad is dressed by TDD and UV-TDD

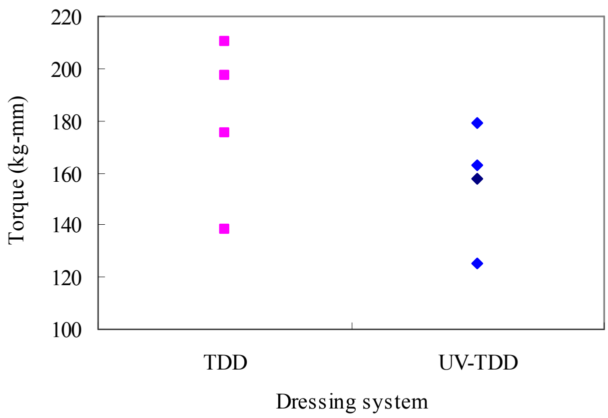

Fig. 7 Variation in torque force between diamond disk and pad when the pad is dressed by TDD and UV-TDD

B. Pad Surface Topography of DD and UV-TDD during Dressing

Figure 8 displays representative images of the pad surface measured using the stylus-type instrument after 20 minutes of dressing by TDD or UV-TDD. In the figure, comparisons of asperities in the pad, R_a of approximately 5.05 μm for UV-TDD is less than R_a of approximately 5.42 μm for TDD as shown in Fig. 9. It is found that UV-TDD can dress the pad more uniformly, substantially reducing the amount of slurry that is required for the CMP process. Usage of the TDD forms an uneven texture with variable asperities. The cross-sectional SEM images of the pores on the polishing pad after 20 min of dressing formed by TDD and UV-TDD are shown in Fig. 10. It is observed that some residual chips of pad material are trapped in the pores dressed by TDD. On the contrary, in the UV-TDD case, the pore is shown to have no residual chips. This may be because ultrasonic vibration increases the ability of the slurry to remove chips from the pores. Lin [26] described that the cavitation phenomena occurring during the USM process can separate debris or chips from the workpiece. During cavitation, innumerable small bubbles are produced in a liquid when it is subjected to a high frequency (low wavelength) ultrasonic vibration [26-27]. Thereafter, the bubbles explode rapidly to increase the flow on the slurry interface between the pad and diamond grit. The residual chips trapped in the pores decreased the area for slurry transport, and this should be taken into account during dressing in the CMP process

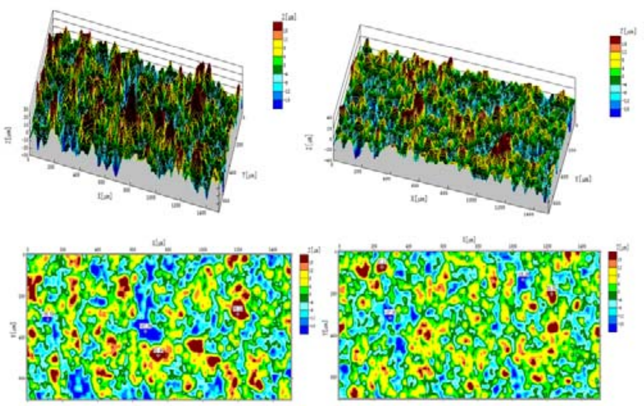

Fig. 8 Three-dimensional (3D) and two-dimensional (2D) profiles of the pad formed by (a) TDD and (b) UV-TDD

IV. CONCLUSIONS

An experimental investigation of the dressing characteristics of the polishing pad was studied when dressed by TDD or UV-TDD. A series of dressing experiments for a polyurethane pad were performed. Some interesting research results were obtained as follows. During conditioning, comparative experiments of the torque force demonstrated up to 15% reduction for the polishing pad dressed by UV-TDD. The pad cut rate of UV-TDD is twice that of TDD. The surface roughness of the dressed polishing pad obtained using UV-TDD is 5.05 μm, which is better than that obtained using TDD (5.42 μm). This result indicates UV-TDD have the potential to be effectively used as pad conditioning methods in the future.

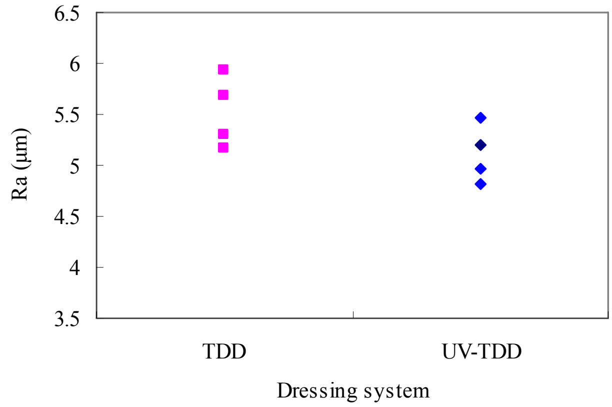

Fig. 9 Variation in surface roughness when the pad is dressed by TDD and UV-TDD

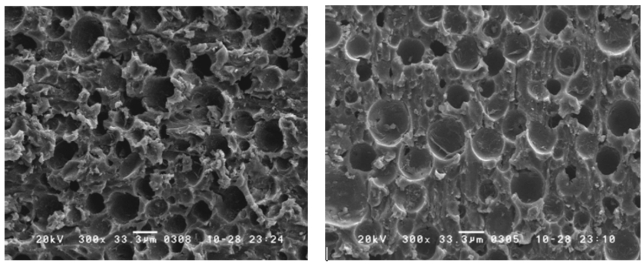

Fig. 10 SEM images of an IC1000 pad formed by TDD and UV-TDD

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REFERENCES

[1] M.Y. Tsai, Polycrystalline Diamond Shaving Conditioner for CMP Pad Conditioning, Journal of Material Process Technology, 210 (2010)

[2] M.Y. Tsai, Y. S. Liao and J. C. Sung, Novel Diamond Conditioner Dressing Characteristics of CMP Polishing Pad, International Journal of Machine Tools & Manufacture, 49 pp. 922-729 (2009)

[3] Y. J. Seo, W. S. Lee and P. Yeh, improvements of oxide-chemical mechanical polishing performances and aging effect of alumina and silica mixed abrasive slurries, Microelectronic Engineering, 75 (2004) 361-366

[4] T. F. Bibby, J. A. Adams, K. Holland, G. A. Krulik, P. Parikh, CMP CoO reduction: slurry reprocessing, thin solid films, 308-309 (1997) 538.

[5] V. H. Nguyen, A. J. Hof, H. V. Kraneburg, P. H. Woerlee, F. Weimar, Copper Chemical Mechanical Polishing using a Slurry-Free Technique, Microelectronic Engineering, 55 (2001) 305-312.

[6] P. van der Velden, Chemical mechanical polishing with fixed abrasive using different subpads to optimize wafer uniformity, Microelectronic Engineering, 20 (2000) 41-46.

[7] S. Jeong, S. Lee, H. Jeong, 2008, Effect of polishing pad with holes in electro-chemical mechanical planarization, Microelectronic engineering, 85 2236-2243

[8] S. Kamiya, H. Iwase, T. Nagaike, L. Zhou, H. Eda, and S. Kimura, Microstructural analysis for Si wafer after CMG

process, Key Engineering materials, 329, 2007, 361-366.
[9] H. Kim, H. Kim, H. Jeong, H. Seo, S. Lee, Self-conditioning of Encapsulated Abrasive Pad in Chemical Mechanical Polishing, Journal of Material Processing Technology 142 (2003) 614-618.
[10] V. H. Nguyen, A. J. Hof, H. V. Kraneburg, P. H. Woerlee, F. Weimar, Copper Chemical Mechanical Polishing using a Slurry-Free Technique, Microelectronic Engineering, 55 (2001) 305-312.
[11] M. Y. Tsai, L. W. Yan, Characteristics of Chemical mechanical Polishing using Graphite Impregnated Pad, International Journal of Machine Tools & Manufacture 50 (2010) 1031-1037.
[12] R. Singh, J. S. Khamba, Ultrasonic machining of titanium and its alloys: A review, Journal of material processing technology, 173 (2006) 125-135.
[13] E. J. Weller, Nontraditional Machining Processes, Published by society of manufacturing engineering, Dearborn, Michigan, USA, 1983.
[14] A. C. Wang, B. H. Yan, X. T. Li, F. Y. Huang, Use of micro ultrasonic vibration lapping to enhance the precision of microholes drilled by micro electro-discharge machining, International Journal Machine Tool and Manufacture, 42 (8) (2002) 915-923
[15] Z. C. Li, Y. Jiao, T. W. Deines, Z. J. Pei, C. Treadwell, Rotary ultrasonic machining of ceramic matrix composities: feasibility syudy and designed experiments, International Journal Machine Tool and Manufacture, 45 (1-13) (2005) 1402-1411
[16] H. Hocheng, K. L. Kuo, fundamental study of ultrasonic polishing of mold steel, International Journal Machine Tool and Manufacture, 42 (2002) 7-13
[17] T. B. Thoe, D. K. Aspinwall, N. Killey, combined ultrasonic and electrical discharge machining of ceramic coated nickel alloy, Journal of material processing technology, 92-93 (1999) 323-328.
[18] C. Zhang, R. Rentsch, E. Brinksmeier, Advances in micro ultraonic assisted lapping of microstructures in hard-brittle materials: a brief review and out look, International Journal Machine Tool and Manufacture, 45 (2005) 881-890
[19] K. Suzuki, T. Uematsu, M. Lwai, S. Ninomiya, S. Sano, T. Nakagawa, A New Complex Grinding method for ceramic materials combined with ultrasonic vibration and electrodischarge machining, Key Engineering materials, 329, 2007, 439-444.
[20] H. Suzuki, S. Hamada, T. Oondo, Y. Yamagata, T. Higuchi, ultraprecision finishing of micro-aspheric surface by ultrasonic two-axis vibration assisted polishing, CIRP Annals-manufacturing technology, 59 2010 347-350
[21] H. Suzuki, T. Moriwaki, T. Okino, Y. Ando, development of ultrasonic vibration assisted polishing machine for micro aspheric die and mold, CIRP Annals-manufacturing technology, 55 2006 385-388
[22] N. Kobayashi, Y. Wu, M. Nomura, T. Sato, precision treatment of silicon wafer edge utilizing ultrasonically assisted polishing technique, Journal of material processing technology, 201 (2008) 531-535.
[23] M.Y. Tsai, and Y. S. Liao, Dressing Characteristics of Oriented Single Diamond on CMP Polyurethane Pad, Machining Science and Technology, Vols. 13 pp. 92-105, (2009)
[24] T. Tawakoli, B. Azarhoushang, M. Rabiey, Ultrasonic assisted dry grinding of 42CrMo4, International Journal Advance Manufacture Technology, 42 (2009) 883-891.
[25] S. F. Chang, G. M. Bone, Burr size reduction in drilling by ultrasonic assistance, Robotics and computer-integrated manufacturing 21 (2005) 442-450.
[26] Y. C. Lin, B. H. Y an, Y. S. Chang, Machining characteristics of titanium alloy (Ti-6Al-4V) using a combination process of EDM with USM, Journal of Material Processing Technology 104 (2000) 171-177.
[27] Z. Liang, G. Zhou, S. Lin, Y. Zhang, H. Yang, Study of low-frequency ultrasonic cavitation fields based on spectral analysis technique, Ultrasonic, 44 (2006) 115-120.