A Study on Characteristics of Bamboo Charcoal for Polishing of Silicon Wafer

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Abstract - Using bamboo charcoal's features of porosity and high specific surface area, the study pours slurry to the inside of vascular bundle of bamboo charcoal. When the slurry flows to the contact surface between bamboo charcoal and sample to carry out polishing experiment, the structure of bamboo charcoal itself is disintegrated by the abrasion function of abrasives. During this time, the abrasives inside the vascular bundle of bamboo charcoal keeps on machining on the workpiece surface due to disintegration of the surface layer of bamboo charcoal. Through the process of repeated disintegration of the surface layer of bamboo charcoal and continuous supply of new abrasives, polishing effect can be enhanced. According to experimental results, under the condition that the concentration of A1 abrasive is 0.5wt%, the original surface roughness of silicon wafer can be improved from Ra 0.273μm to be around Ra 0.026μm within 30 minutes. As to diamond powder in particle size D3, its surface roughness can be improved to be Ra 0.021μm with mirror surface effect. It is proved that the study of polishing by bamboo charcoal together with different abrasives can acquire rather good effect in surface improvement.

Keywords - Bamboo charcoal, Polishing, porous, self-lubricity,

I. INTRODUCTION

Bamboo charcoal is a newly developed material with electric conductivity, high absorption and other features. Among these features, the most noteworthy one is the porous internal structure of bamboo charcoal. Its surface area can be as great as $300m^2/g$. Scholars of different domains successively made extensive studies of bamboo charcoal [1-3]. Xingzhong carried out carbothermal reduction of bamboo charcoal and SiO_2, and successfully made alpha silicon carbide (α-SiC) in an argon environment under 2100°C [4]. Using bamboo charcoal's characteristics of far-infrared ray and anion, Lou firstly added bamboo charcoal powder to fiber to make bamboo charcoal/cotton complex yarn, which were then composite woven with stainless steel wires to develop a kind of new material being water resistant and vapor permeable [5].

Lin studied the electromagnetic shielding effectiveness of the composite woven material containing bamboo charcoal powder. Research results showed that this kind of bamboo charcoal composite woven material has apparent effect [6]. K.H. Wu studied the NiZn-coated nanoparticles with different percentages of bamboo charcoal content. Research results showed that NiZn bamboo charcoal can change the magnetic properties, and possesses better microwave absorbing properties [7].

Some scholars put their research themes and focuses on the adsorption characteristics of bamboo charcoal. Wang's experiments proved that bamboo charcoal could better absorb dimethyl sulfide in water than other kinds of powdered activated carbon [8]. Wang soaked bamboo charcoal in a steam environment, and observed the absorption situation of heavy metal ions. Experimental results showed that among different heavy metals, the absorption of lead was highest [9]. Chen's experimental results showed that the ammonia absorption improvement rate of bamboo charcoal having undergone polymerization treatment by acrylic acid can reach 98% [10].

In the aspect of biological medicine, Yang used bamboo charcoal and polyoxometalate to prepare a biological protective material with antibacterial efficacy [11]. All the above has revealed that bamboo charcoal has been very extensively applied. However, according to the past literature, except the early days' study of Hokkirigawa that clearly indicated that porous material having undergone high temperature treatment had good self-lubricity effect [12], there is no other application and studies of porous bamboo charcoal polishing and machining tool found. This is extremely too bad to make no use of the peculiar features of electric conductivity and porosity in bamboo charcoal.

Chemical mechanical polishing (CMP) is an indispensable key technique in semiconductor manufacturing process. In order to let CMP process be undertaken stably and continuously, and maintain the quality of wafer, polishing pad has to be trimmed appropriately by diamond conditioner. In this way, the surface profile and characteristics of wafer can be restored, and the life of polishing pad can be extended [13]. In a study of polishing efficiency of polishing pad made by Zhang, increase in polishing time and abrasion pressure is found to have easily created wear to polishing pad [14]. A study of Hooper mentioned that wear problem would occur to polishing pad after polishing; deformation of polishing pad would further happen; and the polishing efficiency and wafer planarization may also be affected [15].

In order to improve the above shortcomings of polishing pad, the study makes use of the porous characteristic of bamboo charcoal itself, together with abrasive to make a novel bamboo charcoal polishing system. The study also conducts polishing experiment of silicon wafer surface, and explores the effects of the parameters of such technical process on the surface roughness after polishing. It is hoped that not only environmental protection and minimum machining cost are both considered, mirror surface effect can also be obtained within the shortest machining time.

II. DESCRIPTION OF EXPERIMENT

A. Experimental Equipments

The experiment uses precise single lapping machine (M-15FS) produced by Jeng Yueh Enterprise Co., Ltd. and a self-made pressure output equipment to carry out abrasion and polishing test. After the experiment is finished, ultrasonic cleaner is used to clean the sample. Then, surface topology interferometer and scanning electron microscope are used to carry out measurement and analysis. The experimental equipments are shown in Fig. 1.

Fig. 1 Experimental equipments

B. Experimental Materials

The bamboo charcoal block used in the experiment are the Moso bamboo being carbonized under temperature 1000oC. Its density is around 0.6 g/cm3, specific surface area 300 m2/g, and carbon content 75~86%. The structure of bamboo structure is shown in Fig. 2. The sample in the experiment is N type silicon wafer, with thickness 610-640μm, electric resistance 2-7Ω-cm, and Ra 0.275μm. Related parameters of machining are shown in Table 1.

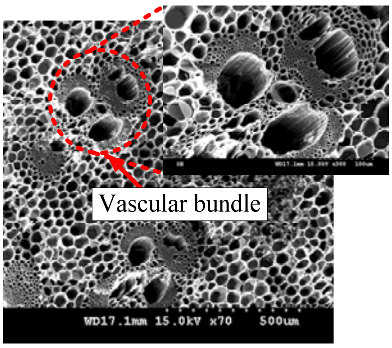

Fig. 2 Structure of bamboo charcoal

Table 1 Machining parameters

Factors	Parameters
Type of particles	0.3μm aluminum oxide powder (A1) <0.5μm Diamond powder (D1) 0.25-0.5μm Diamond powder (D2) <1μm Diamond powder (D3) 2-4μm Diamond powder (D4)
Concentration (wt%)	0.5
Loading(N)	10, 20, 30
Speed(m/min)	2.5, 5, 7.5
Time(min)	15, 30, 45

C. Experimental Methods

For the making of bamboo charcoal tool, blocks of bamboo charcoal are firstly cut into pieces in the size of 80×80×250mm. The impurities of the cut bamboo charcoal are removed by an ultrasonic cleaner. The cleaned bamboo charcoal pieces are placed in a drying box for 24 hours to keep the inside of vascular bundle dry. The bamboo charcoal being treated is placed in a fixture to carry out subsequent polishing experiments. Slurry is injected to the contact surface between vascular bundle of bamboo charcoal and wafer via pipeline, enabling slurry to carry out polishing on sample continuously. Since bamboo charcoal automatically peels off while polishing, there are not only abrasive particles brought by slurry, but also those supplemented from the peeling bamboo charcoal. Through such process of repeated polishing and disintegration of bamboo charcoal surface layer, the polishing effect of sample is improved.

III. RESULTS AND DISCUSSION

A. Exploration on Bamboo Charcoal Composite Polishing by Oxidized Aluminum Powder

1) Effects of Machining Time on Surface Roughness

Under the machining conditions of fixed concentration at 0.5wt% and fixed load at 30N, the paper explores the effects of machining time on surface roughness under different rotational speeds. Related results are shown in Fig. 3. When machining time is 30 minutes and rotational speed is 7.5m/min., an optimal surface roughness 0.022μm can be obtained. When polishing sustains up to 45 minutes, surface roughness does not have apparent change anymore. When rotational speed is 5m/min. or 7.5m/min., surface roughness decreases with the increase of machining time. And when rotational speed is 2.5m/min., owing to the low rotational speed, low cutting force can easily make abrasives accumulated on the slight crack of the sample and deepen the defect, resulting in a rise of roughness with the increase of machining time.

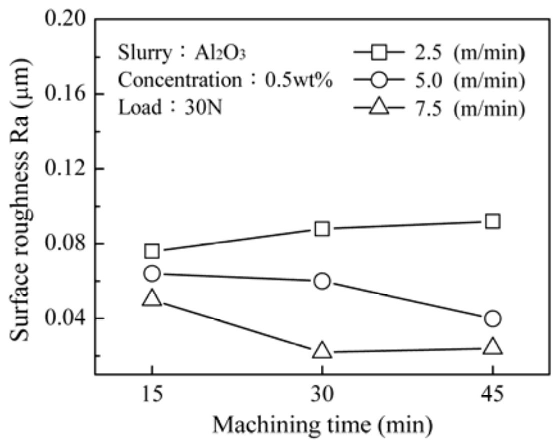

Fig. 3 Relationship between machining time and surface roughness under different speeds

With the increase of the number of times of polishing, the volume shrinkage caused by disintegration of bamboo charcoal is getting great. Therefore, in order to understand the life of bamboo charcoal under different machining parameters, it is very important to study the wear rate of bamboo charcoal via the entire experiment. Fig. 4 shows the relationship between machining time and the wear of bamboo charcoal in the experiment.

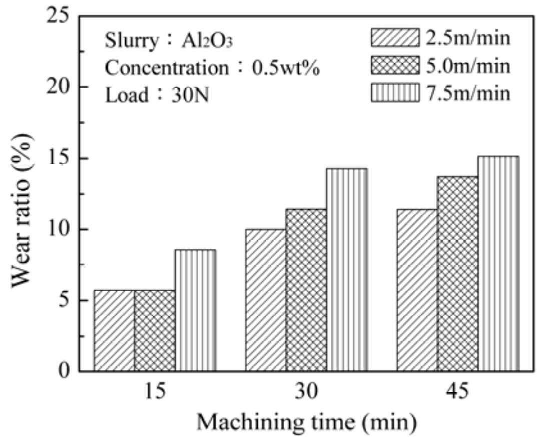

Fig. 4 Relationship between machining time and wear of bamboo charcoal

2) Effects of Speed on Surface Roughness

Under the machining conditions of fixed concentration at 0.5wt% and fixed time at 30 min., the paper explores the effects of machining time on surface roughness under different speeds. Related results are shown in Fig. 5. Under the machining conditions that speed is 7.5m/min. and the applied load is 30N, an optimal surface roughness Ra 0.022μm can be obtained. Under the machining parameter that the applied load is 20N, the improvement of surface roughness is most apparent when speed increases from 5m/min. to 7.5m/min.

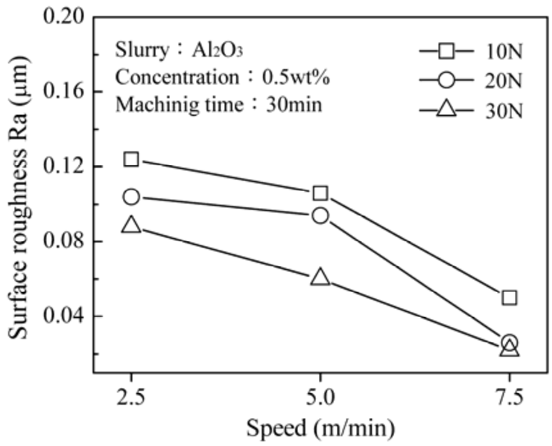

Fig. 5 Relationship between speed and surface roughness under different loads

The effects of machining speed on wear rate are shown in Fig. 6. Under the same machining time, the wear rate of bamboo charcoal increases continuously with the increase of machining speed. It can be clearly observed from the figure that at speed 7.5m/min., and when load increases from 20N to 30N, wear rate increases by above 3 times.

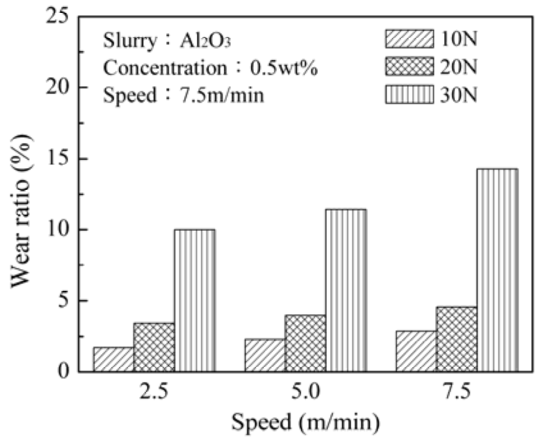

Fig. 6 Relationship between machining speed and the wear of bamboo charcoal

3) Effects of Load on Surface Roughness

Load can affect the actual contact area between bamboo charcoal and sample surface. When greater load is applied, the actual contact area will be greater, and the uniformity of sample surface will be better. The schematic diagram of applied load and actual contact area is shown in Fig. 7.

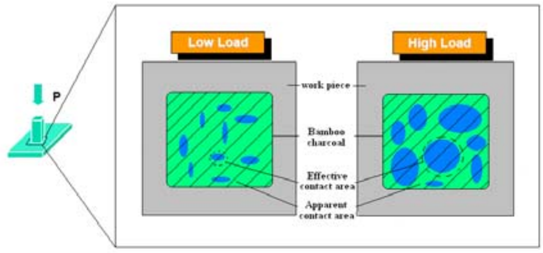

Fig. 7 Schematic diagram of applied load and actual contact area

Under the machining conditions of fixed concentration at 0.5wt% and fixed machining speed at 7.5m/min., the effects of load on surface roughness are shown in Fig. 8. When machining time is 30min. and the applied load exceeds 20N, an optimal surface roughness can be obtained.

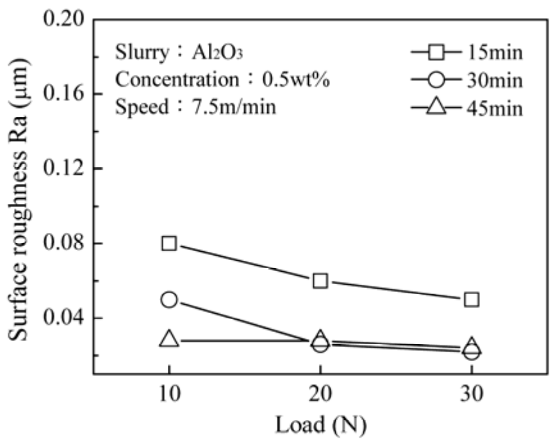

Fig. 8 Relationship between load and surface roughness under different machining time

When machining time is continuously increased to 45 min., Ra has no apparent change. When machining time is 30min. and the applied load increases from 10N to 20N, the change of surface roughness is more apparent, and Ra value reduces from 0.052μm to 0.026μm.

When polishing time is 15min., the wear of bamboo charcoal increases steadily with the increase of load. When load increases from 20N to 30N, the wear of bamboo charcoal appears to be doubled. Fig. 9 shows the relationship between the applied load and the wear of bamboo charcoal.

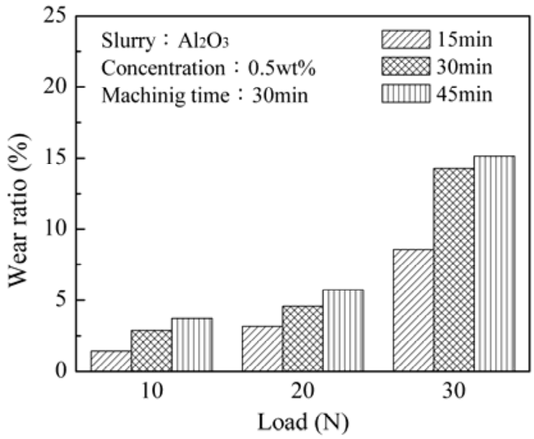

Fig. 9 Relationship between load and the wear of bamboo charcoal

4) Observation of Sample Surface

Fig. 10 shows the SEM diagrams of sample before and after polishing at machining speed 7.5m/min. under load 20N for polishing time 30min. The sample surface appears to be uniform and gentle. From the figure, it can be seen that after polishing, the sample surface appears to have clear mirror surface with reflective effects.

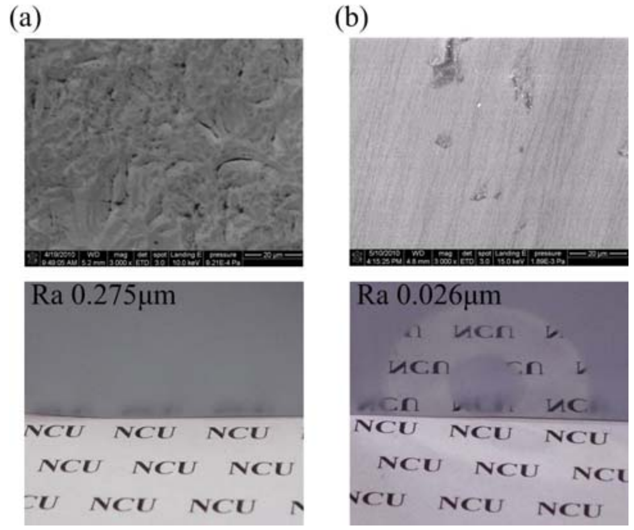

Fig. 10 Comparison of sample surfaces (a) of original sample (b) after polishing

B. Exploration of composite polishing by diamond power bamboo charcoal

1) Effects of machining time on surface roughness

Under the machining conditions of concentration 0.5wt%, speed 7.5m/min. and load 20N, the paper explores the effects of 4 kinds of diamond powder in different particle size on surface roughness under different machining time, as shown in Fig. 11. The optimal surface roughness Ra 0.015μm is achieved when the particle size of diamond powder is D4 and the machining time is 30 minutes. However, when polishing time exceeds 15 minutes, diamond abrasives D4 cannot be squeezed out due to its excessively great particle size. Therefore, although an optimal surface can be obtained in a short period of time, bamboo charcoal cannot be used repeatedly, and the wear of bamboo charcoal is also higher. Therefore, it is quite difficult to keep on using abrasive D4 to carry out machining. Fig. 12 shows the relationship between machining time and the wear of charcoal.

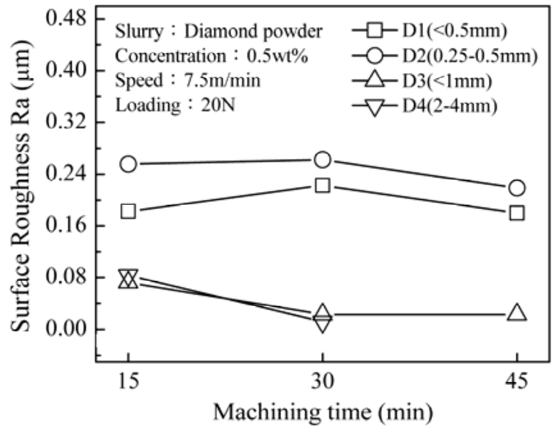

Fig. 11 Relationship between machining time and surface roughness

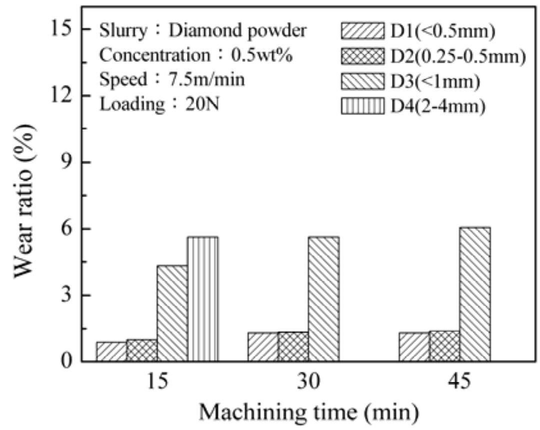

Fig. 12 Relationship between machining time and the wear of bamboo charcoal

2) Effects of speed on surface roughness

For diamond powder in different particle size, and with concentration 0.5%, machining time 30min. and load 20N, the effects of machining speed on the surface roughness of sample are shown in Fig. 13. When the particle size of abrasive is greater than 1μm, the tendency of declining surface roughness with speed increase is quite apparent. For abrasives with smaller particle size (D1 and D2), their polishing effect is still not apparent, with Ra value being 0.22μm.

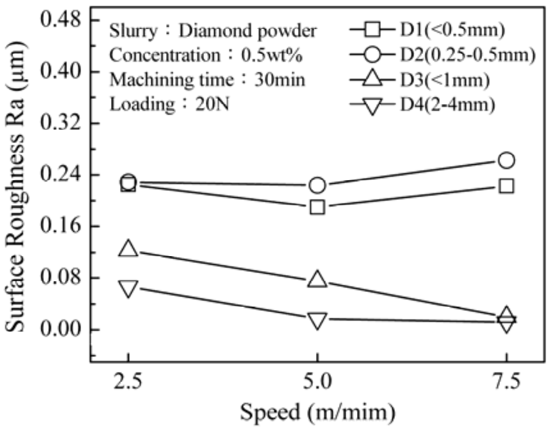

Fig. 13 Relationship between machining speed and surface roughness

Fig. 14 shows the effects on the wear rate of bamboo charcoal under different machining speeds. The diamond powder in small particle size has lower polishing effect, and also has lower wear rate of bamboo charcoal. When machining speed increases from 5m/min. to 7.5m/min., wear rate rises with the increase of surface roughness, showing that the diamond powder in small particle size not only fails to achieve an optimal surface roughness, but also shortens the life of bamboo charcoal. As to the diamond powder in large particle size, the surface roughness for diamond powder in particle size D3 and D4 is Ra 0.017μm and Ra 0.016μm respectively, without a great difference in between. However, the wear rate of diamond powder in particle size D3 is lower than that of diamond powder in particle size D4.

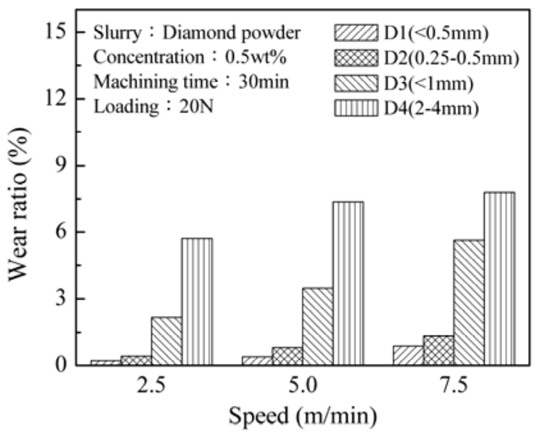

Fig. 14 Relationship between machining speed and the wear of bamboo charcoal

3) Effects of load on surface roughness

When diamond powder in different particle size is under the machining conditions of concentration 0.5wt%, speed 7.5m/min. and machining time 30min., the effects of load on surface roughness is shown in Fig. 15. When applying load 30N on diamond powder in particle size less than 1μm, Ra value reaches 0.021μm. And when applying load 20N on diamond powder in particle size D4, surface roughness reaches 0.013μm. After load is continuously applied to 30N, surface roughness does not have apparent change.

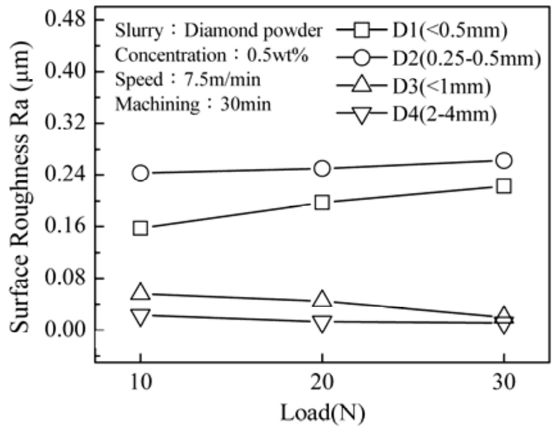

Fig. 15 Relationship between load and surface roughness

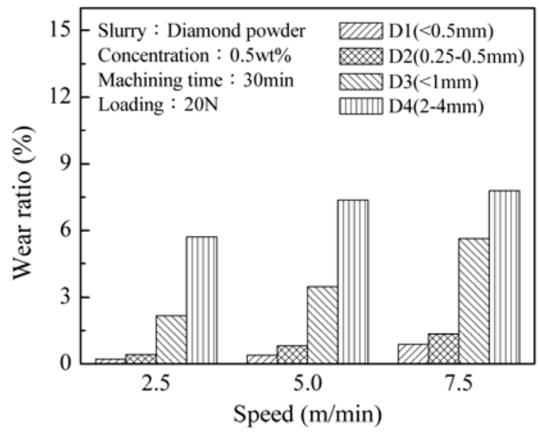

Fig. 16 Relationship between load and wear of bamboo charcoal

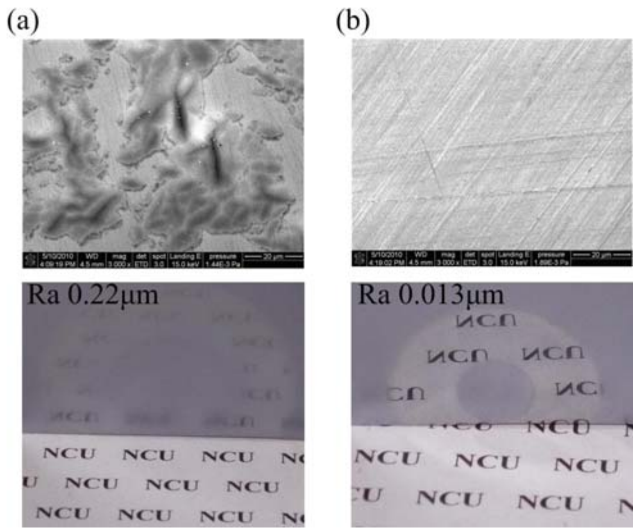

Fig. 17 Polishing by (a) D1 (b) D3 particles under conditions of machining time 30min., speed 7.5m/min. and load 30N

However, in consideration of the wear and life of bamboo charcoal, the diamond abrasive D4 cannot be used in the study's bamboo charcoal machining test for a long time. Thus, in order to acquire an optimal surface roughness, it is most suitable to use diamond powder in particle size less than 1μm and apply load 30N. Fig. 16 shows the effects of different loads on the wear rate of bamboo charcoal when diamond powder in different particle size is at concentration 0.5wt%, polishing time 30min. and machining speed 7.5m/min.

Having used SEM to observe the surface profile of sample after machining, we can clearly find that there are more apparent scratches on the surface of sample. Fig. 17 shows the SEM diagram of polishing. Comparing to the powder in smaller particle size, diamond powder D3 and D4 has better improvement effect.

IV. DUSCUSSION

Bamboo charcoal is a newly developed product stressing environmental protection and having multiple functions. The study uses the porous characteristic of bamboo charcoal to successfully produce a composite polishing system of bamboo charcoal, and explore the polishing effect of different abrasives on silicon wafer surface under different machining parameters. The research results are as follows:

1) When oxidized aluminum powder is used for polishing of silicon wafer sample by bamboo charcoal at machining speed 7.5m/min. and applied load 20N for polishing time 30min., the surface roughness of sample can be reduced to Ra 0.026μm, and improvement rate can reach 90.2%.

2) When diamond powder D3 is used for polishing of silicon wafer sample by bamboo charcoal at machining speed 7.5m/min. and applied load 30N for polishing time 30min., the surface roughness of sample can be reduced to Ra 0.017μm, and improvement rate can reach 92.3%.

3) When composite polishing is performed by bamboo charcoal, together with oxidized aluminum powder and diamond powder, an optimal surface quality can be obtained under suitable machining conditions. However, excessive machining conditions not only fail to enhance surface quality, but also increase the wear of bamboo charcoal.

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REFERENCES

[1] K. Mizuta, T. Matsumoto, Y. Hatate, K. Nishihara, T. Nakanishi, Removal of nitrate-nitrogen from drinking water using bamboo powder charcoal, Bioresource Technology, Volume 95, Issue 3, December 2004, Pages 255-257

[2] R.S. Zhao, X. Wang, J.P. Yuan, J.M. Lin, Investigation of feasibility of bamboo charcoal as solid-phase extraction adsorbent for the enrichment and determination of four phthalate esters in environmental water samples, Journal of Chromatography A 1183 (1-2), pp. 15-20, 2008

[3] P. Kandhavadivu, C. Vigneswaran, T. Ramachandran, B. Geethamanohari, Development of polyester-based bamboo charcoal and lyocell-blended union fabrics for healthcare and hygienic textiles, Journal of Industrial Textiles 41 (2), pp. 142-159, 2011

[4] G. Xingzhong, Z. Lingjie, Y. Liqing, Y. Hui, Z. Lin, Preparation of silicon carbide using bamboo charcoal as carbon source, Materials Letters, Volume 64, Issue 3, Pages 331-333, 15 February 2010

[5] C.W. Lou, , J.H. Lin, Evaluation of bamboo charcoal/stainless steel/TPU composite woven fabrics, Fibers and Polymers 12 (4), pp. 514-520, 2011

[6] J.H. Lin, A.P. Chen, C.M. Lin, C.W. Lin, C.T. Hsieh, C.W. Lou, Manufacture technique and electrical properties evaluation of bamboo charcoal polyester/stainless steel complex yarn and knitted fabrics, Fibers and Polymers 11 (6), pp. 856-860, 2010

[7] K.H. Wu, T.H. Ting, C.I. Liu, C.C. Yang, J.S. Hsu, Electromagnetic and microwave absorbing properties of Ni0.5Zn0.5Fe2O4/bamboo charcoal core–shell nanocomposites, Composites Science and Technology, Vol. 68, Issue 1, pp. 132-139, 2008

[8] M. Wang, Z.H. Huang, G. Liu, F. Kang, Adsorption of dimethyl sulfide from aqueous solution by a cost-effective bamboo charcoal, Journal of Hazardous Materials, Volume 190, Issues 1-3, Pages 1009-1015, 15 June 2011

[9] S.Y. Wang, M.H. Tsai, S.F. Lo, M.J. Tsai, Effects of manufacturing conditions on the adsorption capacity of heavy metal ions by Makino bamboo charcoal, Bioresource Technology, Volume 99, Issue 15, Pages 7027-7033, 2008

[10] K.S. Chen, W.Y. Chen, S.C. Liao, Surface graft polymerization acrylic acid onto bamboo charcoal and to improve ammonia adsorption, Desalination and Water Treatment, Volume 17 Issue 1-3, Pages 168-175, 2010

[11] Fu-Chu Yang, Kuo-Hui Wu, Wen-Po Lin, Ming-Kuan Hu, Preparation and antibacterial efficacy of bamboo charcoal/polyoxometalate biological protective material, Microporous and Mesoporous Materials, Volume 118, Issues 1-3, Pages 467-472, 1 February 2009

[12] K. Hokkirigawa, T. Okabe, K. Saito, Friction properties of new porous carbon materials: Wood ceramics, Journal of Porous Materials, 2 (3), pp. 237-243, 1995

[13] M.Y. Tsai, S.T. Chen, Y.S. Liao, J. Sung, Novel diamond conditioner dressing characteristics of CMP polishing pad, International Journal of Machine Tools and Manufacture, Volume 49, Issue 9, Pages 722-729, July 2009

[14] L.C. Zhang, A.Q. Biddut, Y.M. Ali, Dependence of pad performance on its texture in polishing mono-crystalline silicon wafers, International Journal of Mechanical Sciences, Volume 52, Issue 5, Pages 657-662, May 2010

[15] B.J Hooper, G Byrne, S Galligan, Pad conditioning in chemical mechanical polishing, Journal of Materials Processing Technology, Volume 123, Issue 1, Pages 107-113, 10 April 2002