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Fabrication of micro/nanostructures as SERS substrates with the feed-back controlled normal force

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Abstract
Different from the conventional scratching method, the normal force is feed-back controlled to mechanically machine the micro grooves in the present study. During the process, the normal force is controlled to a constant value which is similar to the mechanism of the commercial Atomic Force Microscope by which to measure the nanoscale sample topography through controlling the tip-sample interaction force. A simple and low cost micro machining device which can control the normal force is established. With the controlled normal force, the effects of the edge forward and face forward machining directions on the grooves' topography is studied. Moreover, the edge forward scratching direction is more suitable for the controlled normal force scratching process than the face forward scratching direction. Finally, the machined microsquares of aluminum alloy (2A12) surface is used as the Surface-enhanced Raman Scattering (SERS) substrate with the Rhodamine 6G (R6G) probe molecule as the detecting target in the present study. Experimental results show that using this simple low cost device, the perfect microstructures can be achieved by the controlled normal force machining method.

Keyword: Micro machining, normal force, microstructures, SERS

1. Introduction

Nowadays, micro/nano machining technologies have become a hot issue attracting more and more scholars in the world [1-2]. Many kinds of micro structures including micro pits, micro gratings and three dimensional micro structures have also been machined successfully by the existing micro/nano machining methods. Among which, the micro groove plays a more and more important role in the fields of microchip cooling and chemical material transport. Thus, researchers are pursuing new ways of machining the perfect micro grooves with the depth of several microns and even several nano meters.

Since the invention of the Atomic Force Microscope (AFM), it has been applied in the nano measurement field with controlling the interaction force between the tip and the sample. Also based on the same mechanism, the tip-based nanomechanical machining method is used to fabricate nano dots, 2D nano structures, and even 3D nano structures with very high accuracy. Also the nano grooves with the depth of less than 6.8 nm were achieved successfully using a diamond tip to nano scratch the Fused Quartz surface with the normal force of less than 100 μN [3]. Works on the AFM tip-based nanomechanical machining process verify that the machining procedure by controlling the normal force is feasible.

However, restricted by the elastic constant of the cantilever, the force between the AFM tip and the sample is too small to obtain a deeper groove with the depth of larger than 1 μm. Moreover, due to the tip wear and the construction of the commercial AFM system itself, the machining scale based on AFM is small. Therefore, scholars want to use the tip-sample force control mechanism to machine the grooves with a larger depth and low cost. Some scholars used the nano indenter which can apply a larger normal force to the diamond tip to carry out the nano machining process [4]. Other scholars developed the new system based on the force control mechanism to realize the nano machining process. For example, Lee [5] et al. developed a micro machining system with a stiff cantilever which can apply several hundreds of micro Newtons to the diamond tip. By setting the normal force, the scratch depth can be achieved. However, previous studies only realized that the groove depth can be obtained through the normal force which is similar to the AFM tip-based nano machining process. The normal force applied by the tip is not feed-back controlled during the scratching process.

Therefore, in the present study, a normal force closed loop control system is established based on the basic principle of AFM. With the controlled normal force, the effects of the edge forward and face forward scratching directions on the grooves' topography and the state of the removed materials are studied on Al alloy (2A12) in detail. Finally, the machined microsquares of aluminum alloy (2A12) surface is used as the Surface-enhanced Raman Scattering (SERS) substrate with the Rhodamine 6G (R6G) probe molecule as the detecting target. The method provided is a low cost, high accuracy mechanical machining method of complex micro/nano structures which have a wide application in the fields of micro optics, MEMS, etc.

2. Experimental details

Fig. 1(a) shows the schematic of the tip-based micromachining system with a force feedback control. The system includes a coarse stage with the moving range of 200 mm and a precision stage with the moving range of 20 μm in Z axis, a force sensor (LSB-200, Futek company, USA), a diamond tip (Synton-MDP, Switzerland) as the cutting tool, an X-Y precision stage (M-714.2HD, Company, Germany) and a UMAC controller (Delta Tau Data System Company, USA). Using this kind of tip, there are two different scratching directions: One is the edge forward (edge OA) scratching direction as shown in Fig. 1(b). The other is face forward (OBC) scratching direction as shown in Fig. 1(c). In the present study, the sample used is aluminum alloy (2A12) which is machined by the ultra-precision turning method whose dimensions are 20 mm×20 mm.

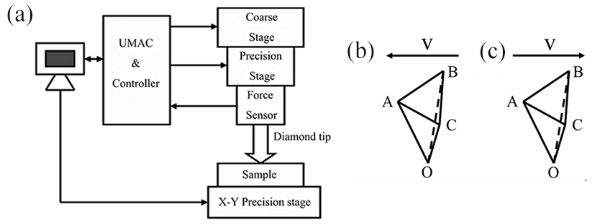

Figure 1. (a) a tip-based micromachining system with a force feedback control (b) diagram of edge forward and face forward of diamond tip

3. Results and Discussion

3.1. Effects of the edge forward and face forward scratching directions on the machined grooves

Fig. 2(a) shows the experimental response curve of the system to a step signal. When using the optimized controller parameters, the peak and setting times of this control system are 2 and 4 ms, respectively. When the normal force is controlled to be constant in scratching, the tip geometry will have a significant effect on the machined grooves. Thus, the scratching directions: the edge forward and face forward scratching directions as shown in Figs. 1 (b) and (c), are employed. The scratching speed is 0.03 mm/s. The scratching length is 1 mm. The normal forces are 10 mN, 15 mN, 20 mN, 25 mN, 30 mN and 40 mN, respectively.

Fig. 2(b) shows the SEM topographies of the grooves with the face and edge scratching directions when the normal force is feed-back controlled, respectively. Using the face forward scratching direction, the removed chip is in the style of the continuous belt, even for the normal force of 10 mN. But using the edge forward scratching direction, the chips tend to be broken into pieces with the small normal force. When the normal force is larger, the chips are in the style of the continuous belt, but they are thinner than that using the face forward scratching direction. Additionally, it can be found that burrs are formed on both sides of the grooves using the edge forward scratching direction. However, there are few burrs on both sides of the groove using the face forward scratching direction.

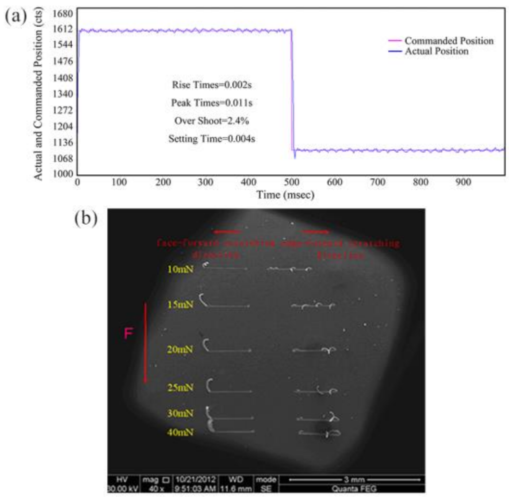

Figure 2. (a) PID control system response curves (b) SEM topography of the grooves with the face and edge scratching directions when the normal force is feed-back controlled.

3.2. Fabrication of mircosqures and SERS measurements on Al alloy

Fig. 3 shows AFM images of microsquares on the Al alloy (2A12) with a normal force of 10 mN. The feeds of 1600 and 1200 nm are used, respectively. As shown in Figure 3(a)–(b), from the morphologies of the upper and down sides of the machined squares, the pile-ups are generated by material removal when scratching Al alloy. The depth of squares are 2 μm and 2.64 μm corresponding to the feeds of 1600 nm and 1200 nm, respectively. Therefore, the depth of square is increasing with the decrease of feed. Fig. 4 shows Raman intensities of R6G for bare surface, the microsquares machined by the feeds of 1200 nm and 1600 nm. The concentration of the R6G solution was 10^{-4} mol/L. The Raman intensity of R6G is no detected on the bare surface. However, it can be observed that the SERS effects of the Raman intensity are remarkably affected by the feed f. A clear enhancement is observed in the Raman signal from R6G on machined microsquares of Al alloy, especially the feed of 1200 nm and the Raman intensity of 1362 cm-1 R6G is 700 a.u. with the feed of 1200 nm.

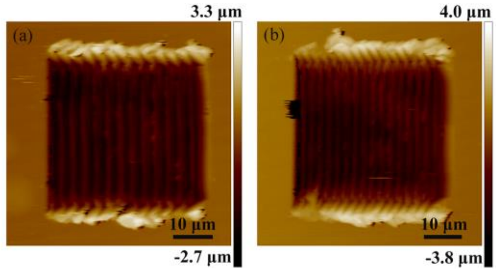

Figure 3. AFM images of microsquares fabricated with the feeds of 1600 nm and 1200 nm.

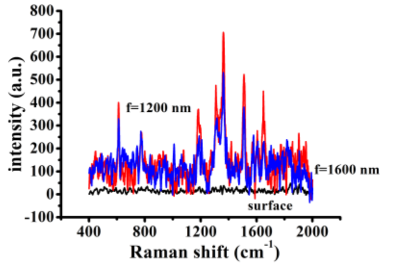

Figure 4. Raman intensities of R6G for bare surface, the microsquares machined by the feeds of 1200 nm and 1600 nm

5. Conclusion

In the present study, a tip-based machining system with the normal force controlled method is achieved. The groove and microsquares are machined with the normal force feed-back controlled on the Al alloy (2A12) using a three sided pyramidal diamond tip. Following conclusions are obtained: The scratching direction has a significant effect on the scratched groove with the controlled normal force. Using the face forward scratching direction, the belt-type chips are always achieved which induce a variation of the contact area between the tip and the sample leading to a changing groove depth. Using the edge forward scratching direction, the removed materials are mainly piled up on both sides of the groove and the formed chips tend to be broken which induces a less variation in the contact area. Thus under this condition, the groove depth and width are kept almost constant. Therefore, using the low cost device, the edge forward scratching direction and the feed-back controlled is the optimized conditions for the constant depth groove fabrication. Additionally, the machined microsquares of aluminum alloy (2A12) surface can be enhanced the Raman intensity of Rhodamine 6G (R6G) probe molecule as SERS substrate.

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