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Simulation and experiments for micro/nano channel scratching

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Abstract
Micro/nano channel has been widely used in many fields, such as microfluidics, electronic devices system, and biology. Atomic Force Microscope (AFM) is considered as one of the best choices for the tip-based nanofabrication, however, the stiffness anisotropic of the probe cantilever in xy plane leads to manufacturing errors for the 3-D nano-structure fabrication. Thus, we proposed a novel design and attached the probe onto a cross shaped suspension with isotropic stiffness. To further insight into the micro/nano channel scratching of regular three-side pyramidal tip, both computational and experimental testing has been conducted to investigate the tip-based nano-fabrication. The computational simulations are based on the Smoothed Particles Hydrodynamics (SPH) method and implemented in LSdyna software. The effects of tip geometry, sample property and processing parameters on scratching process have been investigated. According to the computational and experimental results, it is noted that the scratching speed has little influence on the scratching quality. The depth of the scratching channel is related to the normal load, the larger normal load will increase the channel depth. It can be seen that the chips are harder to form on the copper surface scratching than that on the silicon surface. This is mainly due to the plasticity of copper and the larger face angle of the pyramidal diamond tip. Therefore, a sharper tip with small face angle should be used to facilitate the remove of the material in tip-based scratching for micro/nano channels.

Keywords : micro/nano channel, scratching, simulation and experiments

1. Introduction

Nanochannels have been widely used in microfluidics technology, such as rapid DNA sequencing, drug delivery, battery and nanofluidic transistor [1]. Among various methods, tip based micro/nano scratching is simple and efficient to fabricate the nanochannel [2-4].

The numerical simulation usually acts as the role of guiding the experiments, and shows the possible phenomenon in the actual experiment. Molecular dynamics (MD) is an efficient method for the investigation of the micro/nano scratching, but the scratching depth was usually less than 10 nanometers, since a larger scratching depth will result in a very long simulation time. Smooth particle hydrodynamic (SPH) is a mesh-less method based on Lagrangian method, and with the development of the method, it has been successfully applied in micro machining simulation in recent years [5-7]. Although the SPH is a kind of finite element method, the scratching depth has reached 50nm [6].

AFM has been the most popular equipment for the tip based scratching although it is invented for morphology characterization. However, it is easy to be disturbed by the environment due to the small stiffness in the *z* direction, and the AFM cantilever is single-axis probe suspension, leading to different stiffness in different scratching direction [8]. The experiments in this paper are implemented in a self-developed machine, the probe suspension mechanism of which is cross-shaped with high stiffness and good isotropic stiffness in xy plane [9].

The simulation with SPH method and the scratching experiments are presented in this paper. Firstly, the SPH scratching model is constructed, and then the influence of face angle, sample property, scratching speed and normal load on the scratching property are investigated through simulation and experiments, respectively.

2. SPH simulation

2.1. The construction of SPH scratching model

In the SPH scratching model construction, the sample of cooper is discretized with a set of SPH particles and is described by Johson-Cook model [5, 6]. The particle diameter is 40nm, and the particle number is 60×50×25 in scratching direction, lateral direction and depth direction, respectively. The probe tip is modelled as spherical capped regular three side pyramidal tip model with density 3520kg/m^3, young's modules 1100Gpa and poison's ratio 0.29, which is seen as rigid in the simulation.

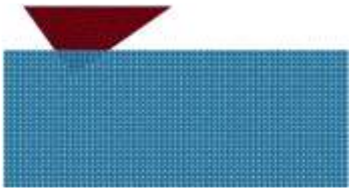
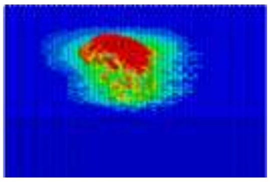
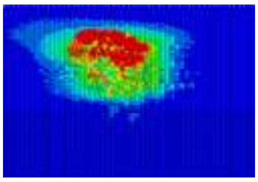


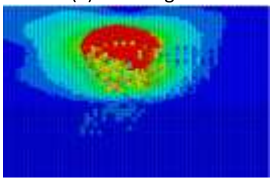
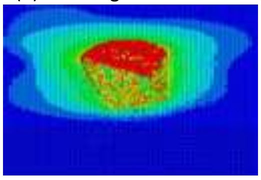
Figure 1. SPH scratching model

2.2. SPH scratching

In the spherical capped regular three side pyramidal tip scratching, the face angle has significant influence on the tip-sample interface area, and thus a series of simulation with different face angle (25˚, 35˚, 45˚, 55˚) are implemented. The simulation is performed in the sideface-forward direction [10] with scratching depth 160nm. The simulation results of the generated chips and the von mises stress are shown in Fig. 2, which indicates the separated chips are formed in small face angle of 25˚ and 35˚, but when the face angle reaches up to 45˚or larger, the separated chips cannot break away from the sample and even be replaced by ridge on left side of the groove. Moreover, the pyramidal model with bigger face angle results in larger groove width and residual stress area during the scratching. It may be caused by the fact that the pyramidal surface is becoming more and more parallel with the sample surface with the increase of face angle, the formed chips have less space to flow away, as a result, the chips cannot break away from the sample effectively and even become ridge on the sample surface, which can be seen in Figs. 2 (c) and (d).

(a) Face angle of 25˚ (b) Face angle of 35˚

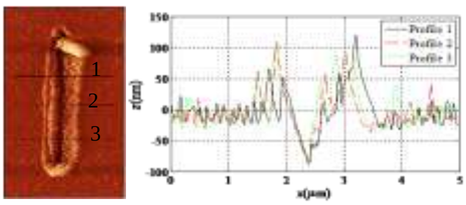



(c) Face angle of 45˚ (d) Face angle of 55˚

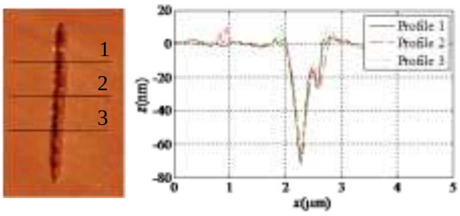
Figure 2. Scratching depth

3. Experiments

Based on the developed micro/nano scratching system in reference [9], a Berkovich probe with face angle 65.3˚ is used for the scratching experiments. The scratching results of cooper and silicon are shown in Figure 3. In the cooper scratching of Figure 3(a), it is obvious that the ridge is generated in the two sides of the groove, and the same phenomenon has been shown in the SPH simulation. While in the silicon scratching, the ridge phenomenon is significantly weaken, this is because the silicon is harder and more fragile than cooper, so the removed material is easier to be separated from the base.



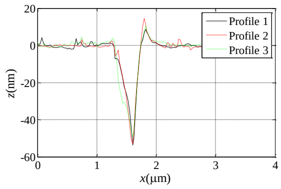
(a) The scratch of cooper



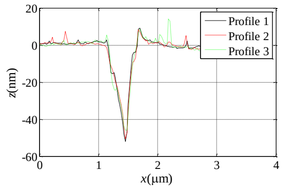
(b) The scratch of silicon

Figure 3. The scratch of different material

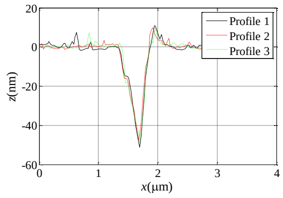
According to the material removal results, the silicon has better scratching property, so the scratching on silicon surface with three different scratching speeds of 2μm/s, 5μm/s and 10μm/s are carried out, and the cross-sections of the groove in three positions are shown in Fig. 4. The results indicate the scratching depth is always nearly 50nm for all three scratching speed, which mean the scratching speed has little influence on the scratching process.



(a) 2μm/s



(b) 5μm/s



(c) 10μm/s

Figure 4. The scratch of different scratching speed

The scratching depth with different normal load are shown in Figure 5, indicating the scratching depth is increased as the normal load increase, but the rise speed is becoming smaller in larger normal load. This is because with same increase of scratching depth, the tip-sample contact area in large scratching depth increases much more than it in small depth, so an additional normal load is required in large scratching depth.

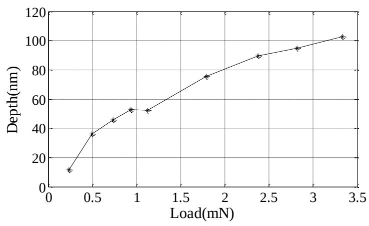


Figure 5. The scratch of different scratching speed

4. Conclusion

The influences of face angle, sample property, scratching speed and normal load on the scratching process are investigated through simulation and experiments. The results show a sharper probe tip and harder sample is helpful to remove the material, the scratching speed has little on the scratching process, and the scratching depth increase with the increase of the normal load.

In the future work, more machining parameter, such as the scratching direction, scratching number and feed speed will be considered in the scratching process. And then three dimensional micro/nano structures will be fabricated with the selected machining parameters.

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