IOP Conf. Series: Materials Science and Engineering **250** (2017) 012016 doi:10.1088/1757-899X/250/1/012016

Simulation Research on Micro Contact Based on Force in Silicon Wafer Rotation Grinding

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Abstract. Silicon wafer rotation grinding with cup type diamond wheel is a typical ultra precision grinding process. In this paper, a simulation model based on force for micro contact between wheel micro unit and silicon wafer is established from the stable ductile grinding process. Micro contact process in grinding is simulated using the nonlinear explicit finite element analysis software LS-DYNA. The stress-strain results on silicon wafer and wheel micro unit are analyzed by finite element method. The results show that the critical displacement and load corresponding elastic to plastic - plastic to brittle exist on silicon wafer. In silicon plastic zone tangential sliding can produce plastic groove and uplift. Wear of wheel micro unit can be based on the simulation data to judge. The research provides support for wafer grinding and wheel wear mechanism.

1. Introduction

Semiconductor devices are the foundation of electronics industry-the largest industry in the world [1]. Silicon wafers are used as the substrates to build the vast majority of semiconductor devices [2]. Manufacturing of high-quality silicon wafers is the key to the initial fabrication of semiconductor devices [3]. Especially for large diameter silicon wafers ($\phi \geqslant$300mm) flattening and back thinning processing, using ultra precision grinding than the traditional lapping process is more effective, and the application of cup type diamond grinding wheel to silicon wafer rotation grinding is a typical form of silicon wafer ultra precision grinding [4].

Silicon wafer rotation grinding method was first proposed by Matsui [5] in 1988, and its principle is shown in Figure 1. The diameter of the rotary table is slightly larger than that of the silicon wafer, and the center line of the rotary table is coincident with that of the silicon wafer. The silicon wafer is adsorbed on the working table through a vacuum. The working surface center line of the grinding wheel is adjusted to align with the center of the silicon wafer. During grinding, the grinding wheel and the silicon wafer are rotated around the respective axis, and the grinding wheel is only axial feed. The grinding depth can be controlled by adjusting the axial feed rate of the grinding wheel and the rotation speed of the silicon wafer. Ductile grinding with plastic removal mode can be realized.

Research on silicon wafer rotation grinding has attracted much attention, and its grinding mechanism is the key point of the research [6]. Representative studies have been reported. Pei Z J et al. [7] have made a series of grinding experiments, and systematically studied the influence of grinding process on the surface quality of silicon wafers. These studies focus on the process of experimental and macroscopic in order to obtain the high quality silicon wafer. However, it is difficult to analyze the micro dynamic mechanism during the grinding process, and the experimental results have high cost, but the research on the finite element simulation analysis method is more time saving and labor saving.

At present, there is no report on the micro finite element simulation of silicon wafer rotation grinding. LS-DYNA is a general-purpose finite element program capable of simulating complex real world problems [8]. It is used by the automobile, aerospace, construction, military, manufacturing, and bioengineering industries. It is especially suitable for solving nonlinear dynamic impact problems for a variety of 2D and 3D nonlinear structures.

This paper is organized into four sections. Following this introduction section, Section 2 describes that the micro contact model of grinding wheel micro unit and silicon wafer is established, including the mechanical model and the simulation model. In Section 3, simulation results are presented and analyzed. Finally, conclusions are drawn in section 4.

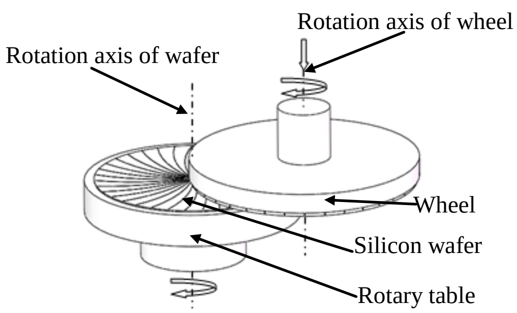


Figure 1. Illustration of silicon wafer rotation grinding.

2. Establishment of Micro Contact Model Of Grinding Wheel Micro Unit and Silicon Wafer

2.1. Micro Contact Mechanics Model

The ideal mechanical model of the micro contact between the grinding wheel micro unit and the silicon wafer is shown in Figure 2. The grinding wheel micro unit is extracted from the macro grinding wheel, which is in contact with the silicon wafer, and is composed of a unit volume of the bond holding a single diamond abrasive grain.

The actual grinding is a complex process, here to make simplifying assumptions: During grinding, the silicon wafer relative to the grinding wheel is stationary and homogeneous isotropic; bond surface of the grinding wheel end face is smooth; the diamond abrasive particle size distribution is uniform in the grinding wheel, and the height of the cutting edge of the abrasive grain is 1/3 of the average diameter of the spherical particle. The unit volume of the bond is determined by the concentration of the grinding wheel, the radius of the abrasive grain $\boldsymbol{R}$ and the density of the diamond.

In the mechanical model, the grinding wheel micro unit is the contact action on the silicon wafer with the synthesis speed $\boldsymbol{V}$ and the cutting depth $\boldsymbol{t}_{\mathrm{w}}$. The decomposition analysis of the contact process is carried out. Normal $\boldsymbol{z}$, the wheel micro unit is pressed into the silicon wafer, and the distance to be pressed is the cutting depth $\boldsymbol{t}_{\mathrm{w}}$. Normal interaction force can be formed between the wheel micro unit and the silicon wafer. Stress field can be generated in the silicon wafer by normal load $\boldsymbol{F}_{\mathrm{n}}$. With the increase of cutting depth, the stress field will be expanded, and the silicon wafer will be depressed. When the deformation exceeds the elastic yield limit and the fracture strength, the plastic and brittle deformation can occur respectively. In the same way, the normal reaction load F_n' is also applied to the wheel micro unit, and the stress field is generated. The wheel micro unit can be compressed to lead to deformation. Tangential ***x***, the wheel micro unit slides on the silicon wafer with the speed ***V***, along with the grinding motion trace. With the normal load, the sliding friction force ***f*** and ***f*** 'are formed between the wheel micro unit and the silicon wafer, and the stress field is formed on them. In this way, the silicon wafer will be crushed and produce plastic flow along the moving direction of the grinding wheel micro unit, and wear will be produced on the wheel micro unit.

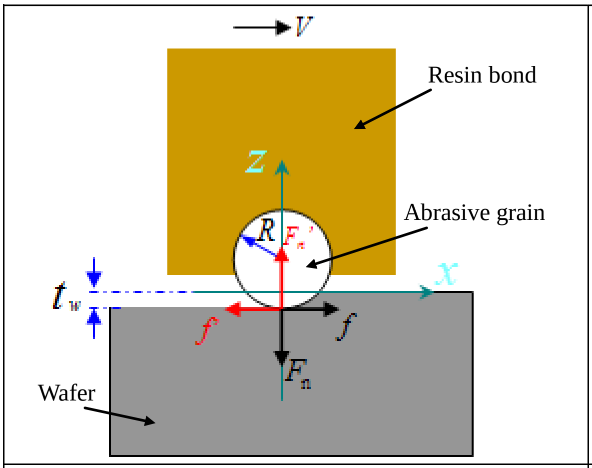


Figure 2. Micro contact mechanics model.

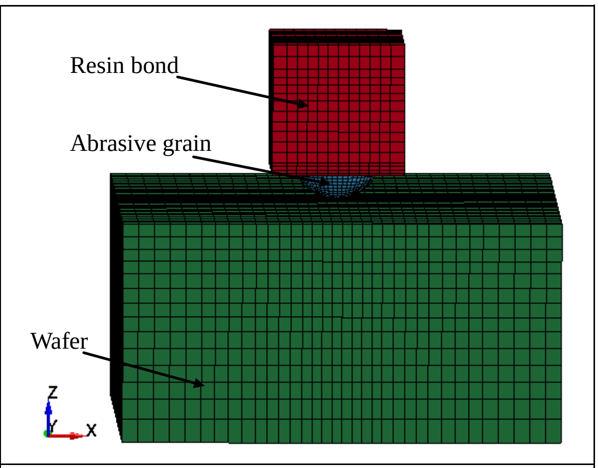


Figure 3. Micro contact simulation model.

2.2. Micro Contact Simulation Model

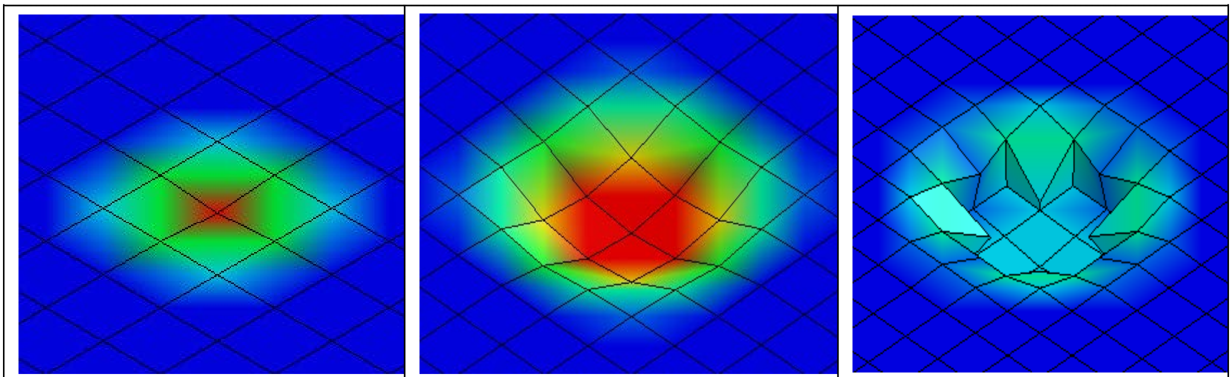
According to the analysis of the mechanical model, the three-dimensional simulation model of the micro contact between the grinding wheel micro unit and the silicon wafer is established, as shown in Figure 3. The geometric parameters of the simulation model are as follows. The size of resin bonded cube is 6μm. The diameter of the ball diamond abrasive grain is 4μm. The height of the resin embedded in the resin is 2.6μm. The size of the silicon wafer is 20*20*10μm.

In order to facilitate the calculation, the simulation model is simplified and assumed. As the elastic modulus of the diamond abrasive grain is much larger than that of silicon wafer, the material model of the diamond abrasive grain is considered as a rigid body. For the resin bond, only the factor of the force is considered, and other factors such as the thermal effect are not considered. The material model of the resin bond is considered as elastic plastic material. The silicon wafer is defined as *MAT_JOHNSON_HOLMQUIST_CERAMICS ceramic material model. The element types are all used in 3D explicit structure solid element Solid164. At the bottom of the silicon wafer, the full constraint is applied. The normal ***z*** negative and tangential ***x*** positive displacement loads are respectively applied to the bond, to realize the simulation of the grinding process of normal pressing and tangential sliding. In the simulation test, the mesh division and calibration of the model is based on the experimental data of micro scratch in silicon wafer [9].

3. Simulation Results and Analysis

3.1. Simulation Results and Analysis of Normal Pressing

In the process of simulating the grinding wheel micro unit pressing into the silicon wafer, the deformation strain of the silicon wafer is shown in Figure 4. Figure 4(a) shows the silicon wafer is starting to produce plastic strain when indentation displacement is about 45 nm, which indicates that the silicon wafer is in elastic phase before pressing to 45 nm. Figure 4(b) shows the plastic strain on the silicon wafer when pressed into about 330 nm, and the plastic strain has reached its limit. Figure 4(c) shows the strain on the silicon wafer when pressed into about 350 nm, and some elements have failure removal in the silicon wafer, which indicates that the silicon wafer begins to enter the stage of brittle fracture and deformation after pressing to 330 nm.



(a) Indentation displacement about 45 nm	(b) Indentation displacement about 330 nm	(c) Indentation displacement about 350 nm

Figure 4. Deformation strain of silicon wafer in normal pressing simulation.

During the simulation, the load curve on the silicon wafer with indentation displacement is shown in Figure 5. The figure shows that the contact force on the silicon wafer is about 2 mN when indentation displacement is about 45 nm, and the contact force on the silicon wafer is about 32 mN when indentation displacement is about 330 nm.

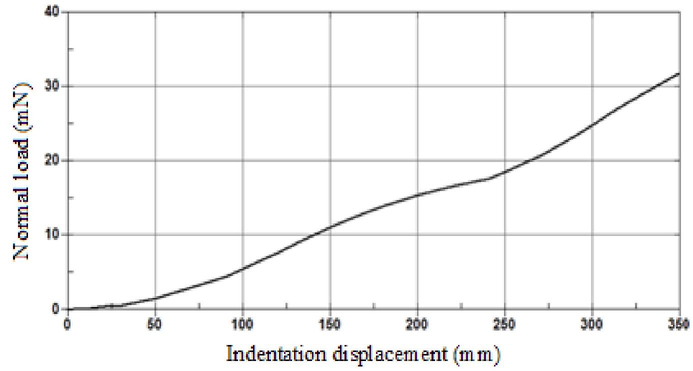


Figure 5. Load curve on silicon wafer with indentation displacement.

Simulation results of normal pressing show that under the external force, the critical values of load (2 mN) and displacement (45 nm) from elastic to plastic strain exist on the silicon wafer and the

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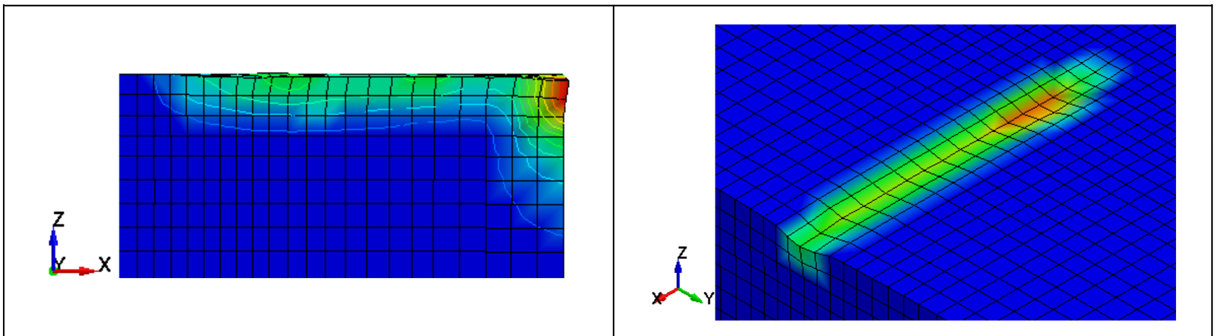
critical values of load (32 mN) and displacement (330 nm) from plastic to brittle deformation also exist on the silicon wafer.

3.2. Simulation Results and Analysis of Tangential Sliding

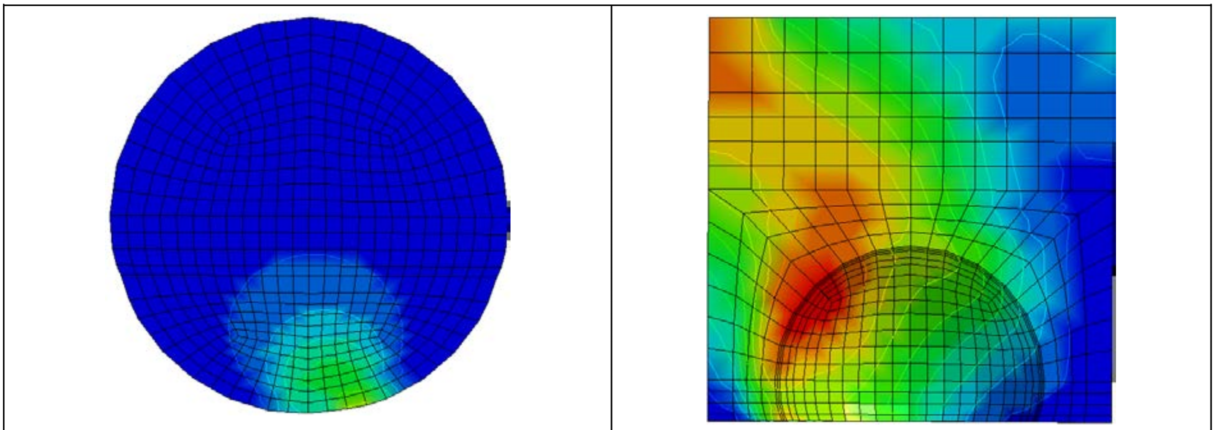
In the precision grinding of silicon wafer, the surface quality of the silicon wafer is high, so the grinding should be controlled in the ductile region, that is, the plastic stage of the silicon wafer. For the simulation of tangential sliding, the indentation displacement (i.e. the cutting depth of the abrasive grain) should be controlled in the plastic stage of the silicon wafer. The range of plastic stage has been obtained through the simulation of normal pressing, that is, the indentation displacement is between 45 nm and 330 nm.

The stress and strain simulation diagrams of the silicon wafer in tangential sliding are shown in Figure 6 (corresponding to the indentation displacement of 100 nm). The figures show that in the plastic deformation stage of the silicon wafer, the sliding stress is produced under the action of tangential sliding friction force. At the same time, the plastic flow deformation is formed under the stress in the silicon wafer, which creates the surface of a silicon wafer with plastic sliding groove and uplift.



(a) Stress diagram of silicon wafer | (b) Strain diagram of silicon wafer

Figure 6. Stress and strain simulation diagrams of the silicon wafer in tangential sliding.



(a) Stress diagram of abrasive grain | (b) Stress diagram of resin bond

Figure 7. Stress diagrams on the grinding wheel micro unit during the tangential sliding simulation.

The stress diagrams on the grinding wheel micro unit during the tangential sliding simulation are shown in Figure 7. The stress distribution on the grinding wheel micro unit in the ductile region grinding process can be intuitively understood. Figure 7(a) shows the stress diagram of the abrasive grain in the grinding wheel micro unit. It is easy to find the location of the stress concentration point from the figure. The diamond abrasive grain has high fracture strength, which makes it difficult to produce fracture at the stress concentration point. Therefore, only attrition wear occurs on the grinding wheel abrasive grain. Figure 7(b) shows the stress diagram of the resin bond in the grinding wheel micro unit. If the stress value of the stress concentration point reaches the fracture strength of the grinding wheel bond, the bond fracture wear could occur, which could lead to pull-out of the abrasive grain.

4. Conclusions

Three dimensional three body simulation model based on force is established for micro contact between wheel and silicon wafer from grinding process. The following conclusions can be drawn from simulation analysis of the model:

(1) The critical load and displacement from elastic to plastic and plastic to brittle exist on the silicon wafer under the external force, and the critical values are obtained by normal pressing simulation.

(2) The stress and strain of the silicon wafer and the grinding wheel micro unit are obtained by tangential sliding simulation. The tangential sliding force can produce plastic groove and uplift in silicon plastic zone. Wear of wheel micro unit can be based on the simulation data to judge. The results of this paper can provide support for the research of silicon precision grinding and wheel wear mechanism.

5.Acknowledgements

This study was supported by the National Natural Science Foundation of China (Grant No.U0734008), the Natural Science Foundation of Guangdong Province of China (Grant No.8151009001000048) and the Youth Foundation of Guangdong University of Technology (Grant No. 082042).

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