Finite-element simulation of scratching on a coated brittle plate

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Alexey I. Ogorodnikov

Finite-Element Simulation of Scratching on a Coated Brittle Plate

Alexey I. Ogorodnikov

Ural Federal University, 19 Mira Str., Ekaterinburg, 620002 Russia.

Corresponding author: Al.Ogorodnikov@bk.ru

Abstract. This paper presents finite-element simulation of scratching on a brittle plate with functional coating under force loading by a diamond tool. To calculate stresses inside the plate and under the tool tip, a numerical experiment is set up and a parametric task is formulated. The task is solved with use of the ANSYS Programming Dynamic Language. The numerical experiment includes scratching of a silicon wafer by a diamond cutting tool, ZnS as the functional coating and force loading. As a result, internal stresses under the cone tool tip are analyzed, the APDL program is verified, and this allows us to simulate not only silicon wafers, but also any other brittle materials. Scratching is considered as a special case of common cutting.

INTRODUCTION

Scratching is a general method for studying the behavior of brittle materials [1] and for dividing silicon wafers into separate dies in the whole electronics and semiconductor industry [2]. Micro- and nanoscratch experiments provide information on the mechanism of material removal, which is helpful for choosing machining parameters [3]. Scribing, dicing, polishing and grinding are the principal treatment techniques not only for electronics, but also for optical devices and solar cells. A quality requirement after technological treatment increases for silicon wafers and defect-free components while the size of devices decreases.

There are four types of the behavior of brittle materials under force loading; they are elastic, ductile, ductile-brittle or brittle modes. Materials should be machined in the ductile mode to produce a high quality surface. Silicon, as a brittle material, is generally processed in the brittle mode due to its low fracture toughness. Mechanical cutting is a conventional method to separate a monocrystalline silicon bulk into layers or plates [4].

Various coatings are used to create functional properties of silicon wafers and optical components [5]. Coatings are used widely in concentrating solar systems to improve the performance of both reflectors and absorbers [6]. Antireflection coatings with an additional protective layer on silicon optics have a crucial importance in thermal devices. Technological advance demands to assess new techniques of careful treatment for optical and semiconductor materials (single crystals, ceramics and glasses) coated by thin functional surface coatings. A better understanding of the relationships between the mechanical properties of the surface layer and the scratch is of major importance to guarantee and to improve the reliability and lifetime of various technologies and devices that are based on layered systems of the kind [7].

Separating a brittle plate with functional coating is an important task. The separation process consists of preliminary scribing of a surface by diamond tools followed by mechanical breaking. A sharp diamond tip scratches the surface so that it creates stresses in a wafer and induces structural defects. Then crack propagation is initiated by applying pressure loading on the backside of the wafer, starting from the defect zone till total separation. However, the behavior of a surface film during such an operation is little studied. The objective of this paper is to simulate scratching of a brittle plate with functional coating under various force loadings.

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MATERIALS AND PROCESSES

Zinc sulphide (ZnS) crystal is one of the most popular materials used in infrared transmitting windows or domes for systems operating in the long wave region [8]. ZnS was taken as a coating for the simulation of internal stresses near the wafer surface under force loading, since ZnS can be coated on the silicon wafer as an anti-reflecting film to reduce the amount of sunlight lost in a solar cell or as infrared-transparent optical window.

Computer simulation of the plate samples was performed via finite element modeling under specific loading conditions to estimate the value of stresses and the depth of the defect zone under the scratch line.

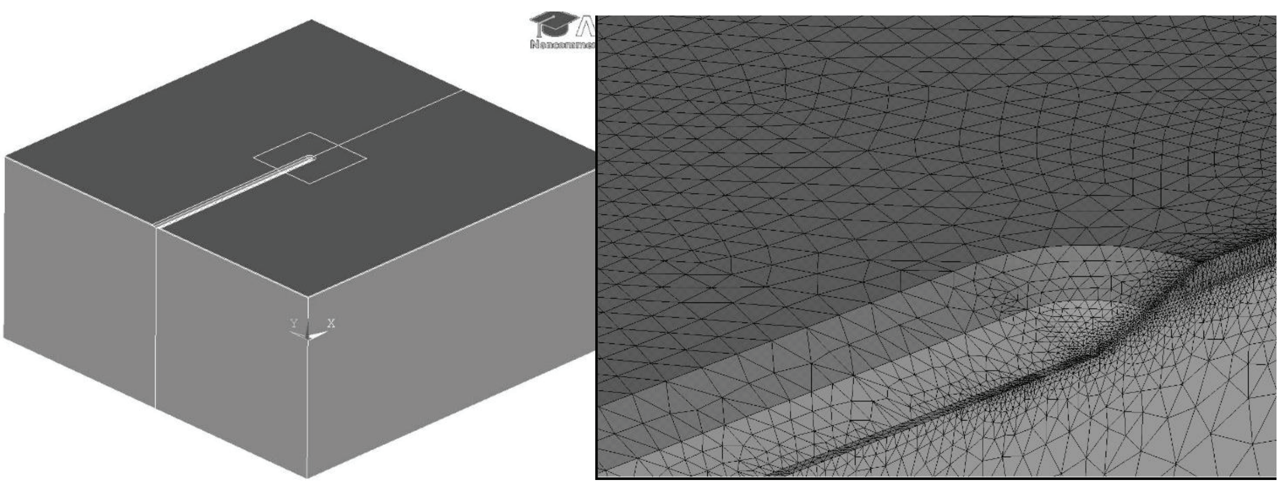
The scribing process solves two main tasks: one is to create a minimal defect zone near the scratch and the other is to provide safe separation of the crystal along the scribe lines. Chips and internal cracks are undesirable defects. The scratches were produced on the surface of a silicon wafer by the cone diamond tip with an angle of 20° to 140°. The loading force ranged from 0.01 N to 1 N. The cracks were observed in the wafer under a load of 2 N, microcracking appeared under a load of 0.1 N, and amorphous silicon covered the whole transformation zone under a load of 0.04 N.

Scribing of the silicon wafer was considered as a special case of usual cutting in our simulation. Some minor cutting differences for silicon were included in the model. Silicon is a brittle and hard material, thus we set just the normal force on the tool. The cut depth, the scratch width and the tangential component of the cutting force were derived from the predetermined normal force and also from the geometry of the tool tip and the material properties. Cutting of brittle semiconductors and optical materials is similar to the advanced theory of metal cutting.

The complexity of the cutting process, which is affected by a large number of significant factors, makes it extremely difficult to understand the mechanics of this process through full-scale tests. A detailed theory of cutting has still yet to be developed for plastically deformable metals. For optical and semiconductor materials there is no complete theory considering all the features of anisotropy, high hardness and brittleness, and also describing damage without plastic deformation and defect nucleation near coatings.

SOFTWARE AND SIMULATION RESULTS

Finite-Element (FE) software grows rapidly, and this allows us now to carry out complex computational experiments, to create and investigate complicated mesh models. FE analysis was used to simulate both the structures and technologies of crystal devices. The investigation and virtual loading of mesh models assist in search for optimal geometry of the cutting tool and the process parameters. The 3D simulation of cutting for a silicon wafer has been done via the finite element method. APDL (ANSYS Parametric Dynamic Language) programming in the ANSYS FE software package has been used to solve this simulation task. Figure 1 shows the geometry of the scratched brittle plate and the finite-element mesh around the scratch.

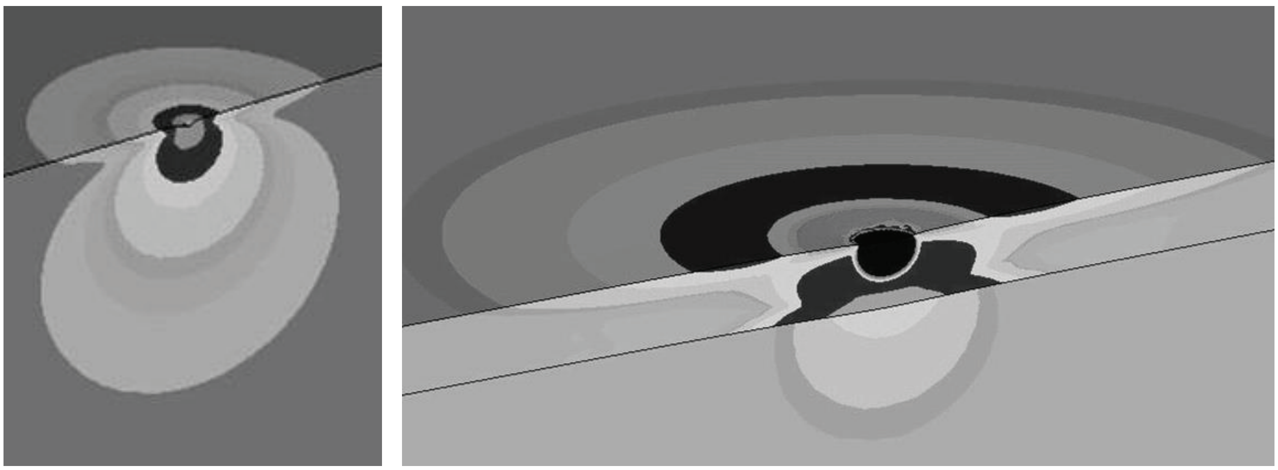


(a) (b)

FIGURE 1. Geometry (a) and finite-element mesh (b) of the coated plate with a scratch on its surface

The initial geometry consisting of a silicon plate glued to a flexible film and diamond tool was constructed by means of an ANSYS preprocessor. Loading and constraints include a Z-fixed support along the lower film surface and a Z-axis force applied to the upper surface of the tool. The Z-axis coincides with the gravity direction and normal force loading on the tool. The Y-axis coincides with the scratch line. A special top layer of the plate is intended for the analysis of the coating behavior and permits different values of contact cohesion.

A decrease in the stresses in the silicon wafer along the normal to the scratch line from the tool tip was calculated. Figure 2 and Fig. 3 shows the simulation results. The surface coating affects the stress distribution in the silicon wafer. ZnS is a soft material and, as a coating, it reduces the level of internal stresses in silicon during cutting. Compressive stresses sharply concentrated in a 5-µm-thick layer under a force load of 0.1 N, while tensile stresses were observed directly in silicon.



(a) (b)

FIGURE 2. The distribution of stress intensity in a silicon wafer without coating (a) and principal stress in a wafer with 5-µm-thick surface coating (b) under force loading

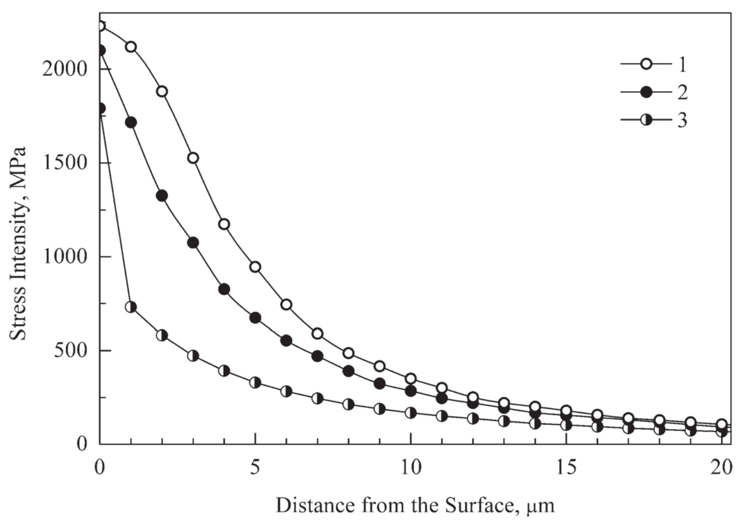


FIGURE 3. A deep profile of stress intensity in a silicon wafer for coating thicknesses of 1 µm (1), 2 µm (2) and 5 µm (3)

The developed numerical model and the verified APDL program allow us to simulate not only silicon wafers, but also any other brittle materials. Surface protection and advanced optics are two mainstream fields of application for layers of the kind. For example, silver is the most commonly used metal for coating highly transparent glasses and protecting brittle plates from corrosion.

SUMMARY

There are many functional coatings in industry nowadays; therefore, we have chosen ZnS as a simple example for our first simulation. One should not underestimate the importance of scribing and dicing of microelectronic devices with such coatings. The main task in this case is to separate microelectronic chips as clean as possible, i.e. without cracks, internal defects and other.

The best way to simulate this task and to estimate the value of stresses and the depth of the defect zone is the finite-element method, and, for that purpose, the commercial software package by ANSYS Inc. was picked as a general tool for this job. ANSYS includes a powerful dynamic parametric programming language called APDL, which provides flexibility, visualization and simplicity of use. The results obtained are predictable; namely, the level of internal stresses in silicon during cutting is reduced by means of soft ZnS coating, and compressive stresses are concentrated in a 5-µm-thick layer under the tool tip.

The next step will be extending our simulation to other coatings, being used in the microelectronic industry, with mandatory verification in real experiment. Modern simulation techniques can enhance the understanding of cutting tasks and promote further development of existing separation methods.

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