JOURNAL OF MATERIALS SCIENCE LETTERS 15 (1996) 586–587

Subsurface damage in single-crystal silicon due to grinding and polishing

I. ZARUDI, L. ZHANG
Centre for Advanced Materials Technology, Department of Mechanical and Mechatronic Engineering, The University of Sydney, NSW 2006, Australia

Grinding and polishing are widely used surface finish operations for a variety of precision and delicate component of ceramics, such as silicon wafers and gauges. However, the formation and evaluation of the subsurface damage induced have not been investigated, although subsurface damage is extremely important to the quality of the products.

Grinding and polishing are usually carried out by a series of steps, beginning with rough grinding with coarse abrasives, followed by fine grinding with fine abrasives and then finished by a final polishing with ultra-fine abrasives. Unfortunately, it is still the manufacturing practice that the thickness of material removal at every step is determined empirically according to a rough examination of the ground/polished surface. This examination method is not reliable, as has been pointed out recently by the authors [1], and the subsurface damage of a component can be severe even though its surface may look crack-free.

The present work is to evaluate the subsurface damage in single-crystal silicon during grinding and polishing. The treated surface had (1 1 0) orientation. Rough grinding was conducted using coarse loose abrasives (silicon carbide) with a mean diameter of 50 μm and followed by grinding using abrasives of 25 μm. Fine grinding was carried out using loose abrasives (aluminium oxide) with mean diameters 15 μm, 9 μm, 5 μm and 1 μm, respectively. Polishing was arranged as a finishing procedure by ultra-fine particles (0.025 μm) using a matrix such as pitch with a suitable oxide slurry. The detailed grinding and polishing procedure can be found in [2]. It is important that at each grinding or polishing step, the depth of subsurface damage be determined such that this damaged layer can be removed in the next step. Subsurface damage was evaluated by means of transmission electron microscopy (TEM). To do this, a specimen after each grinding/polishing was sectioned perpendicular to the ground/polished surface to make cross-section view specimens for TEM. Details of the procedure can be found in [1]. This method of specimen preparation enables the subsurface damage to be investigated thoroughly in the plane perpendicular to the ground or polished surface.

It was found that the structure of the bulk material was almost dislocation free, thus any subsurface damage must be caused by grinding/polishing.

The subsurface damage after coarse grinding with abrasive particles (mean diameter 50 μm) is shown in Fig. 1a. Two definite regions can be observed. The first is a highly deformed region of depth 2–4 μm, immediately beneath the ground surface, with an

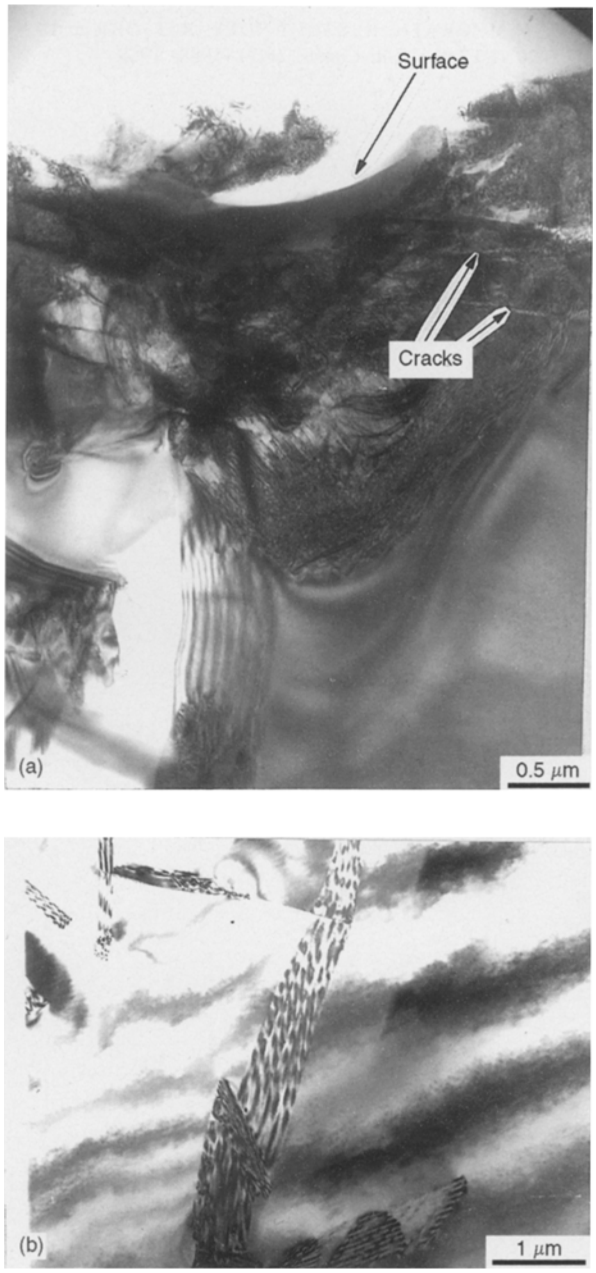
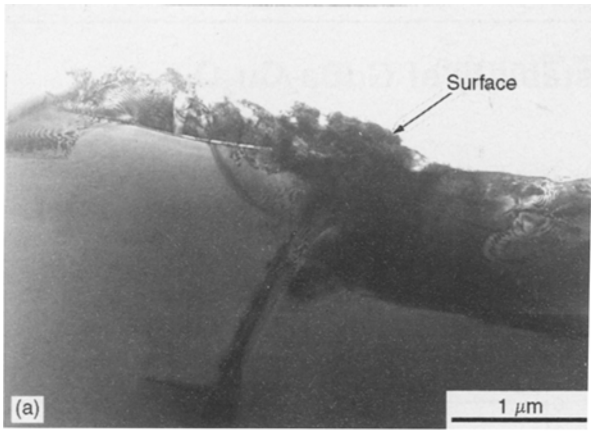
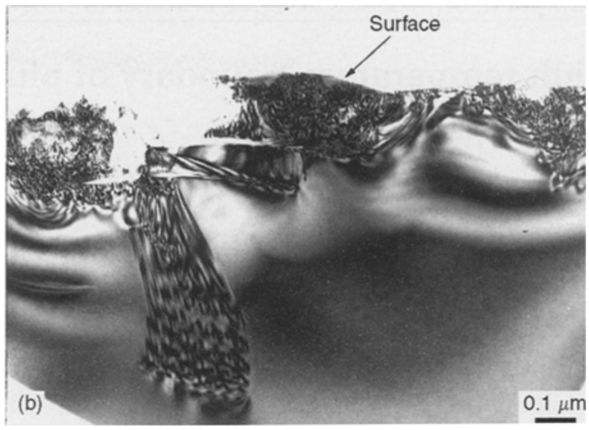


Figure 1 Subsurface damage in single-crystal silicon after grinding with 50 μm abrasive particles: (a) high density dislocations and microcracks; (b) dislocation rosette.





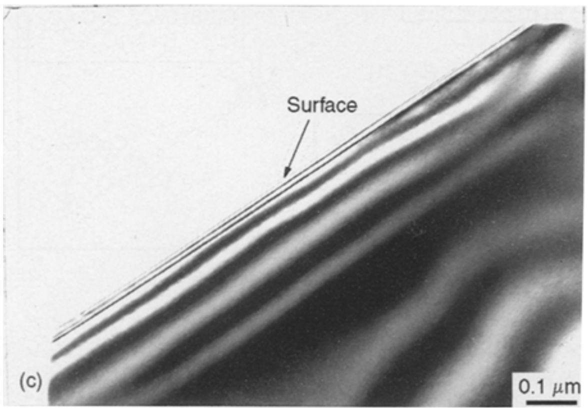


Figure 2 Variation of subsurface damage with processing conditions: (a) after grinding with 5 μm abrasive particles; (b) after grinding with 1 μm abrasive particles; (c) after polishing.

extremely high density of non-uniform dislocations and a sharp boundary. Many cracks appeared in this zone. The second region outside the above zone has very localized deformation. Only a limited number of liner arrays of dislocations can be observed there, Fig. 1b. These arrays are usually called rosettes [3], which have also been found in some indented materials. These arrays of dislocations develop further along certain easy slip directions and are stopped by pile-ups [4]. The depth of this zone is about 16–20 μm. Such plane dislocation arrays usually serve as stress concentrators [5] and therefore are extremely undesirable from the point of view of crack preventation, because cracks are often initiated along such dislocation arrays. Both of the above deformed regions must be removed in the next grinding/polishing operation in order to obtain a real damage-free surface and subsurface.

The subsurface damage after grinding with 25 μm abrasives has the same features as those described above except a smaller depth (12 μm).

After grinding with 5 μm abrasives, the depth of the first damaged zone reduces to 0.5 μm (Fig. 2a). In addition, slipping bands in the second region occur occasionally and the length of the rosettes reduces to 2 μm. Thus the total depth of subsurface damage is 1–3 μm. After fine grinding with 1 μm abrasives, the subsurface damage is still quite obvious in spite of the fact that the surface is reflecting (Fig. 2b) and the depth of the first and second damaged regions are reduced to 0.25 and 1.25 μm, respectively.

The damage was completely removed by polishing. The image of the subsurface after polishing (about 10 h) shows that dislocations and microcracks can no longer be detected, Fig. 2c.

In conclusion, to obtain a perfect component, subsurface damage must be taken into account in the design of steps and processing parameters, such as layer thickness of material removal in grinding or polishing operations.

Acknowledgements
The continuous support from the Australian Research Council Large Grant is very much appreciated. The authors would like to thank the electron microscopy unit of Sydney University for use of its facilities. Thanks also to A. J. Leistner CSIRO Australia for the preparation of ground and polished specimens.

References
1. I. ZARUDI, L. C. ZHANG and Y.-M. MAY, *J. Mater. Sci.* **30** (1995) (in press).
2. A. J. LEISTNER and W. J. GIARDINI, *Metrologia* **31** (1994) 231.
3. E. LE BOURHIS, A. ZOZIME and J. P. RIVIÊRE, in "Electron microscopy 1994", edited by B. Jouffrey and C. Colliex (Les Editions de physique, Paris, 1994) p. 13.
4. G. Y. CHIN, in "Deformation of ceramic materials", edited by R. C. Brandt and R. E. Tressler (Plenum Press, New York, 1975) p. 25.
5. B. LAWN in "Fracture of Brittle Solids", edited by E. A. Davis and I. M. Ward, (University Press, Cambridge, 1993) p. 314.

Received 5 July
and accepted 18 September 1995