Mechanical Strength of Silicon wafers

Tsunefumi Mizuno and Tuneyoshi Kamae(*)
Department of Physics, Hiroshima University, (*) Also with SLAC
mizuno@hirax6.hepl.hiroshima-u.ac.jp

May 18, 2000

Introduction

A Si wafer in (1 0 0) orientation exhibits better performance (e.g., a lower value of capacitance) than that in (1 1 1) does, as shown by Yamamura (HPK) at 4^{th} STD symposium in Hiroshima. However, it was also reported that (1 0 0) wafer may break at lower stress. Having been assisted by Shin'Etsu Silicon Co., we studied references where the fracture stress and its dependence on the surface orientations have been measured. Their results are summarized here.

Formulae describing the fracture stress of material

The fracture stress of an ideal material is theoretically expressed as
$\bullet_m = (\mathbf{E}\bullet_0/\mathbf{a})^{0.5} \sim \mathbf{E}/10$ (eq. Ideal case)
where **E** denotes the Young's modulus, **a** the inter-atomic distance, and $\bullet_0$ the surface energy of the material.

For a (1 1 1) cleavage surface, the above equation for the ideal case gives $\bullet_m$ = 32 Gpa. The real material, however, is known to be much more fragile, typically by almost two orders of magnitude. This is mainly due to micro-defects in the specimens. Griffith [1] showed that the measured value of fracture stress, $\bullet_f$, can be calculated as
$\bullet_f = (2\,\mathbf{E}\bullet_0 / (\bullet\mathbf{c}))^{0.5}$ (eq. Mod1)
where **c** is the crack length. Since **a** $\bullet$ 10^{-10}m and **c** $\bullet\bullet$m,
$\bullet_f = 10^{-2}\bullet_m$.
Hence the above equation can give a good estimation of the material strength.

Although eq. Mod1 serves as a tool to estimate the strength of the material, its precision is poor. For example the plastic deformation at the edge of the crack would relieve the stress, hence modify the surface energy. To cope with this issue, an additional parameter K_{IC} is introduced as,
$\bullet_f = K_{IC}\,(\bullet\mathbf{c})^{0.5}$ (eq. Mod2)
K_{IC} is called critical stress intensity factor or fracture toughness.
Stronger material is, larger is the value of K_{IC}.

Measurements on Silicon Wafers

Strength of Si wafers has been measured by several authors and the reported values of K_{IC} are summarized in Table 1. These data seems to indicate that K_{IC} is determined within +/-10% uncertainty.

The values of fracture stress $\bullet_f$ obtained by bending specimens are shown in Figure 1. First two data in the figure are measured by loading stress perpendicular to the wafer surface [Hu ([8]). Wafers with (1 0 0) orientation seem to be slightly stronger than those with (1 1 1) orientation but not conclusive. This figure also include the results by Johnsson et al. [9], who measured $\bullet_f$ for (1 0 0) wafers treated with various coatings by bending the cantilever beams. The beam orientation is denoted as <1 0 0> or <1 1 0>. Again the data scatter over a wide range and do not allow us to draw any reliable conclusion. The scatter of data is thought to be due to unknown distribution of submicron defects in the specimens.

Summary

It is safe to conclude that the mechanical strength of Si wafers depends more on the surface condition or the length and number of micro cracks than on the surface orientation. It will also depend on the way they are supported. Thus, vibration tests in the real configuration will be essential.

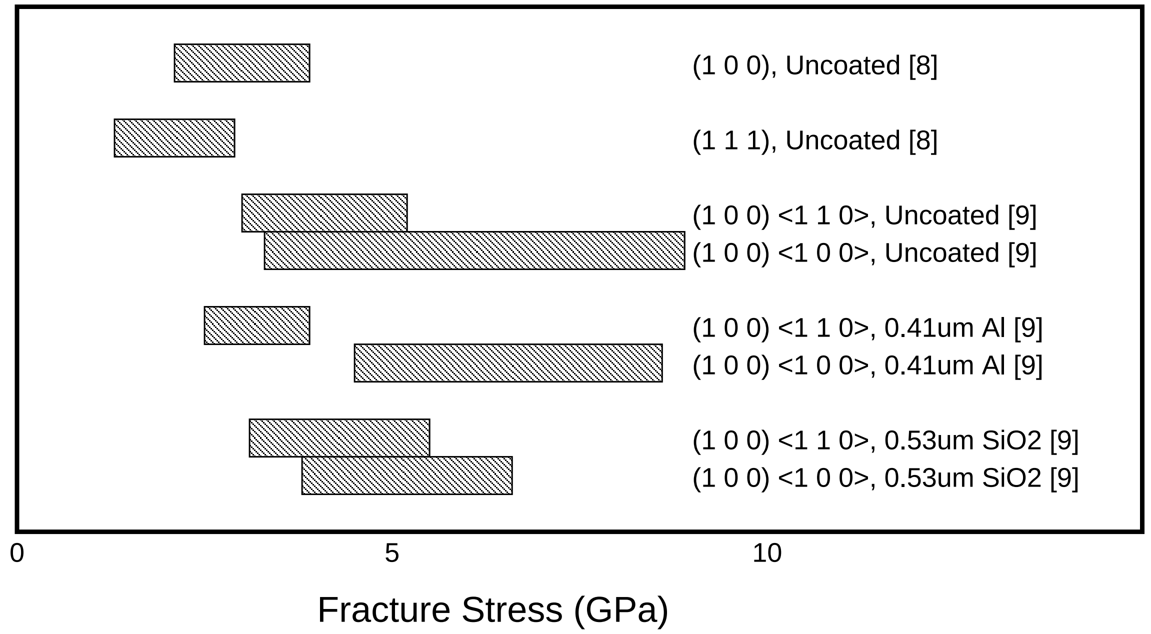
Table: K_{IC} of Si, extracting from [2]

cleavage surface	K_{IC} (Mpa $m^{0.5}$)	reference
(1 1 1)	0.96	John
(1 1 1)	0.82	Chen
(1 1 1)	0.76	Lawn
(1 1 1)	0.96	Michot
(1 1 0)	0.90	Chen
(1 1 0)	0.79	Bhaduri
(1 1 0)	0.89	Michot
(1 0 0)	0.95	Chen

Figure: Distribution of measured fracture stress for different Si surface orientations, beam orientations, and coatings. Surface orientations are denoted as (1 0 0) or (1 1 1), and beam orientations as <1 1 0> or <1 0 0>. Bars indicate standard deviation. (See attached the pdf file “stress.pdf”)

References

[1] A. A. Griffith: Phil. Trans. Roy. Soc., 221A (1920), 163
[2] I. Yonenaga: Materia Japan, 37 (1998), 1018
[3] C. St. John: Phil. Mag., 32 (1975), 1193
[4] C. P. Chen and M. M. Leipold: Bull. Am. Ceram. Soc., 59 (1980), 469
[5] B. R. Lawn, D. B. Marshall and P. Chantikul: J. Mat. Sci., 16 (1981), 1769
[6] G. Michot: *Crystal Properties and Preparation* 17--18,
Trans. Tech. Publ. Zuerich, (1988), 15
[7] S. A. Bhaduri and F. F. Y. Whang: J. Mat. Sci., 21 (1986), 2489
[8] S. M. Hu: J. Appl. Phys., 53 (1989), 3576
[9] S. Johnsson, F. Ericson and J. -A. Schweitz: J. Appl. Phys., 65 (1989), 122


(1 0 0), Uncoated [8]
(1 1 1), Uncoated [8]
(1 0 0) <1 1 0>, Uncoated [9]
(1 0 0) <1 0 0>, Uncoated [9]
(1 0 0) <1 1 0>, 0.41um Al [9]
(1 0 0) <1 0 0>, 0.41um Al [9]
(1 0 0) <1 1 0>, 0.53um SiO2 [9]
(1 0 0) <1 0 0>, 0.53um SiO2 [9]
0
5
10
Fracture Stress (GPa)