ARTICLE IN PRESS

Microelectronics Reliability xxx (2014) xxx–xxx

Contents lists available at ScienceDirect

Microelectronics Reliability

journal homepage: www.elsevier.com/locate/microrel

Analytical stress characterization after different chip separation methods

M. Fuegl [a,c,*], G. Mackh [a], E. Meissner [b,c], L. Frey [b,c]

[a] Infineon Technologies AG, Wernerwerkstr. 2, 93053 Regensburg, Germany
[b] Fraunhofer Institute for Integrated Systems and Device Technology, Schottkystrasse 10, 91058 Erlangen, Germany
[c] Friedrich-Alexander-University Erlangen, Chair of Electron Devices, Cauerstr. 6, 91058 Erlangen, Germany

ARTICLE INFO

Article history:
Received 30 June 2014
Accepted 8 July 2014
Available online xxxx

Keywords:
Wafer dicing
Laser grooving
Synchrotron white beam X-ray topography
Photoelasticity
3-Point bending test
Stress characterization

ABSTRACT

Synchrotron white beam X-ray topography (SXRT) and photoelastic stress measurements were used to characterize resulting strain fields after mechanical dicing and laser grooving of bare silicon wafers. The distribution and propagation of the strain fields can be characterized by both methods. In contrast to mechanical dicing, the laser grooving process creates an inhomogeneous strain field. The influenced area is three times larger compared to mechanical dicing. The effect of the dicing procedure on the resulting mechanical fracture strength of the silicon chips was investigated by 3-point bending tests. The fracture strength of samples with an additional laser grooving process was significantly reduced under tensile load. The fracture pattern of the samples indicated that the strain field generated by the separation process causes initial points for μ-cracks propagation under mechanical load. This analysis can help to optimize dicing processes in order to attain a better reliability of chips with regard to process yields.

1. Introduction

After the semiconductor device fabrication the wafer has to be thinned and the chips have to be separated. Every separation process like mechanical dicing, laser dicing etc. has its specific application profile concerning chip size, wafer thickness, material stack, scribe line width, material stack and quality and reliability targets. Any of the dicing methods has its particular influence on the silicon bulk material, like mechanical defects, μ-cracks or strain fields. The dimension of the stressed area in the vicinity of a dicing trace is thought to be a major issue with regard to later breakage of chips or failure in future operation.

The aim of this work is to characterize the resulting stress fields along the dicing trace after the chip separation process, and correlate it to the die strength in order to optimize the separation method.

2. Experimental work

2.1. Analytical methods

The resulting stress fields along the laser grooving and mechanical dicing traces were characterized by synchrotron X-ray topography (SXRT) and photoelastic stress measurement. Both characterization methods are non-destructive and integrated methods and do not require any further preparation steps. Both separation methods were also examined by 3-point bending test.

2.1.1. Synchrotron X-ray topography

When an X-ray beam with wavelength λ hits a silicon sample, it is diffracted at the lattice plane d_{hkl} when Bragg's law (1) is fulfilled, where n is the diffraction order and θ_B is the scattering angle.

$$n\lambda = 2d_{hkl}\theta_B \quad (1)$$

At SXRT the incident X-ray beam is a polychromatic. When penetrating the sample, every diffraction vector $\vec{g}$ which fulfills Bragg's law results in a diffraction spot and a Laue diffraction pattern is created, which is recorded on a film. Any of the diffraction spots contains a full topograph of the irradiated crystal volume. Contrast variations within the topographs indicate a deviation from the diffraction condition of the original undisturbed crystal lattice e.g. a strain field [1]. The SXRT measurements were done at the Topo–Tomo beamline of the synchrotron facility ANKA in Karlsruhe [20].

2.1.2. Photoelastic stress measurement

Pure silicon is optically isotropic. Under the influence of a stress field the material becomes anisotropic and birefringent [15,16,4]. This effect is used by photoelastic stress measurement. In case of birefringence, an incident linear polarized laser beam will be split

* Corresponding author at: Infineon Technologies AG, Wernerwerkstr. 2, 93053 Regensburg, Germany.
E-mail address: michael.fuegl@fau.de (M. Fuegl).

http://dx.doi.org/10.1016/j.microrel.2014.07.086
0026-2714/

Please cite this article in press as: Fuegl M et al. Analytical stress characterization after different chip separation methods. Microelectron Reliab (2014), http://dx.doi.org/10.1016/j.microrel.2014.07.086

into an ordinary and extraordinary beam. Due to the different phase velocity, a phase shift between both beams occurs and results in a changed polarization state of the emerged laser beam.

The change of polarization state of the laser beam after penetration of the sample is a measure of the existing stress field [8]. Using the stress-optic-law (2) the phase shift δ can be used to calculate the existing shear stress,

$$\delta = \frac{2\pi h}{\lambda}(n_1 - n_2) = \frac{2\pi h}{\lambda} C_{\mathrm{Si}}(\sigma_1 - \sigma_2) \tag{2}$$

where h is the thickness of the sample, λ is the wavelength of the incident light, C_{Si} is the stress-optic coefficient of silicon, σ_1 and σ_2 are the principle stresses at a point and n_1, n_2 are the corresponding refractive indices of the different velocities of propagation of ordinary and extraordinary beam [16]. The measurements were done on a JenaWave SIREX®-C Stressimager with a lateral resolution of $2 \times 5\ \mu\mathrm{m}^2$, with two distinct orientations of the laser beam polarization relating to the dicing or grooving trace.

2.1.3. Die strength test

The investigation of the influence of the separation processes to the mechanical behaviour requires a strength test method which is especially sensitive on sidewall defects. 3-point or 4-point test methods always apply high stresses at the edges as well as on the surface of the samples, whereas a ball-ring test is only sensitive to surface defects excluding influences of the sidewall [6,13]. Since all investigated wafers had a wet chemical surface-treatment to remove the surface defects caused by the thinning process, the sidewall defects resulting from the separation process have the main influence to mechanical strength.

A 3-point bending test is used, which is standardized by SEMI standard G86-0303 [18] and has been widely used to determine the strength of silicon [17,11,3].

Fig. 1 shows the principle of the 3-point bending test. During the test, the side of the silicon die lying on the two support bars is under tensile load, whereas the other side is under compressive load. It is called 'normal bending' when the grinded backside of the silicon sample is lying on the two support bars, and 'reverse bending' vice versa, so the front side of the sample is under compressive load at 'normal bending' and under tensile load at 'reverse bending'. The bending tests were done on an INSTRON 5948 MicroTester with a 100 N load cell. The load span was $L = 3.0$ mm. The applied force at fracture is measured and converted into flexural strength σ. The maximum flexural strength is given by

$$\sigma = \frac{3FL}{2bh^2}, \tag{3}$$

where L is the distance between the support bars, h is the thickness and b the width of the sample and F is the applied force at fracture.

During bending tests of brittle materials large scattering of the resulting strength is observable. Some samples fail early while others have very high fracture strength. Most samples, however, fail at intermediate load. To describe the strength distribution of brittle materials the Weibull distribution [22] is typically used [10]. The fracture probability P is described by:

$$P(\sigma) = 1 - \exp\left(-\frac{\sigma}{\sigma_c}\right)^m, \tag{4}$$

where σ is the resulting flexural strength, σ_c is the so called scale parameter or the characteristic strength and m is the so called shape parameter or Weibull modulus. The Weibull modulus describes the scattering of strength. The higher the value of m, the less scatters the data and vice versa. The characteristic strength σ_c is the value, where 63.2% of all samples fail. 100 samples for every group were tested by means of 3-point bending test for statistical evaluation.

Using the characteristic strength σ_c, the length of the initial cracks a_c can be calculated using linear fracture mechanics [9,23,17]

$$a_c = \frac{1}{\pi * 1.1215^2}\left(\frac{K_{\mathrm{IC}}^2}{\sigma_c^2}\right) \tag{5}$$

where K_{IC} is the fracture toughness of Si. $K_{\mathrm{IC}} = 0.82\ \mathrm{MPa}\sqrt{\mathrm{m}}$ for fracture toughness of the {111} plane [2], which is the primary cleavage plane [5]. The relationship between characteristic strength σ_c and crack length a_c using Eq. (5) can be seen in Fig. 2.

2.2. Sample preparation

Within this work two separation processes were chosen for the investigation: mechanical dicing and mechanical dicing with a prior laser grooving step.

2.2.1. Mechanical dicing

Mechanical dicing is a separation process in which material is scraped away from the bulk material by a diamond grit abrasive embedded into a rotary blade [7] (Fig. 3). During the separation process, the dicing blade rotates with high speed to cut the wafer and generates a full cut or a groove.

2.2.2. Laser grooving

Laser grooving is usually used to remove metal structures and brittle materials like low-k dielectrics out of the scribe line from the wafer front side so a subsequent mechanical dicing process will only dice through bare silicon [19]. During the laser grooving a pulsed laser beam is guided along the scribe line. In the area of the laser spot, the material evaporates and forms a groove [21]. The laser grooving step is repeated several times within a scribe

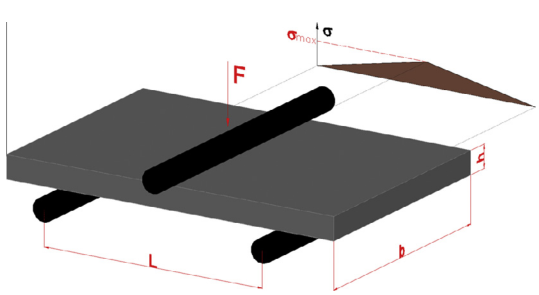

Fig. 1. Schematic of a 3-point bending test setup and initiated flexural strength distribution.

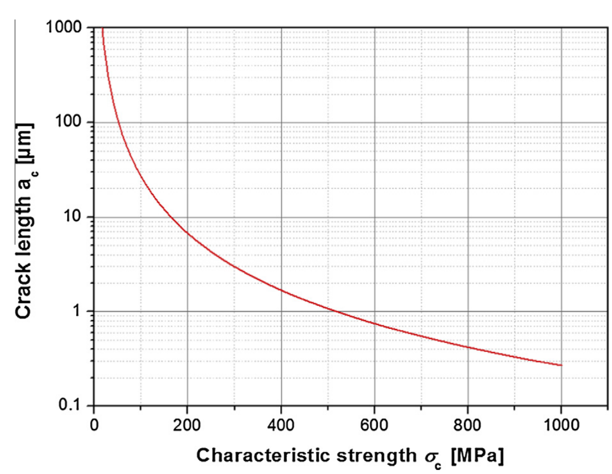

Fig. 2. Relationship between crack length a_c and characteristic strength σ_c.

Please cite this article in press as: Fuegl M et al. Analytical stress characterization after different chip separation methods. Microelectron Reliab (2014), http://dx.doi.org/10.1016/j.microrel.2014.07.086