ELSEVIER

December 2000

Materials Letters 46 (2000) 291–295

MATERIALS LETTERS

www.elsevier.com/locate/matlet

Makyoh-topography study of grooves scratched and etched in single-crystal semiconductors

Ferenc Riesz *

Hungarian Academy of Sciences, Research Institute for Technical Physics and Materials Science, P.O. Box 49, H-1525 Budapest, Hungary

Received 24 March 2000; accepted 10 May 2000

Abstract

A Makyoh-topography study of grooves scribed and etched in semiconductor wafers is presented. It is shown that scribing induces singular deformation of the wafer; the Makyoh image results in as an overlap or shifting aside of the images of the surface areas separated by the scratch. Etching does not induce any stress; the Makyoh image is a diffraction pattern of the etched groove. Possibilities of the use of Makyoh for detecting scratches in mirror-like surfaces are discussed. © 2000 Elsevier Science B.V. All rights reserved.

PACS: 68.35.Bs; 81.70.Fy; 07.60.Yi

Keywords: Makyoh topography; Surface morphology; Surface scratch

1. Introduction

Makyoh (or magic-mirror) topography is an optical method for the study of the flatness of mirror-like surfaces, mainly of semiconductor wafers [1,2]. The principle of the method is simple: the irregularities of the sample surface act as (local) concave or convex mirrors, therefore a collimated light beam impinging on the surface produces an image on a screen that reflects the sample morphology. The technique is mainly applied to detect the flaws induced by wafer slicing, polishing and lapping [2,3]. Makyoh-topography instruments are available commercially as well.

The image of artificial scratches (either on the front or back side of the wafer) is often used to demonstrate the high sensitivity of the Makyoh method [4]. The image of a scratch is a dark or bright line; however, the image formation mechanism of the scratches is unclear. This paper presents a systematic study of grooves scribed and etched in single-crystal semiconductor wafers. The topic of this study is further justified as follows.

(1) In high crystalline quality semiconductors, scribing and etching is a controlled and reproducible way to obtain samples that can model any line-like defect in mirror-like surfaces, such as scratches in optical surfaces, slip lines in semiconductor wafers, etc.

(2) The samples obtained represent excellent models to study the Makyoh image formation principles.

(3) The results can be relevant to the scribing and breaking technologies [5] in the semiconductor device industry.

---

[*] Tel.: +36-1-392-2222;fax: +36-1-392-2235.
E-mail address: riesz@mfa.kfki.hu (F. Riesz).

00167-577X/00/$ - see front matter © 2000 Elsevier Science B.V. All rights reserved.
PII: S0167-577X(00)00190-7

2. Experimental

Two rectangular pieces were cut from commercial double-side polished 260-μm thick (100)-oriented Si wafers for the scratched samples. Scribing was made using a diamond stylus along a $\langle 110 \rangle$ direction. The strength of the scribing was about the same as for the easy cleaving of the wafer. The width of the scratch was about 15 μm. One sample (sample A) was scribed all the way across the slice, while in the other (sample B), the scribe did not reach the edges of the sample. The sample with the etched groove is a piece of a GaAs[1] wafer in which about 10-μm wide and 10-μm deep lines were etched using e-beam lithography and wet etching.

Our Makyoh equipment [6–8] uses an 820-nm pigtailed light-emitting device (LED) as a light source collimated by a 500-mm focal length lens that is placed a few cm above the studied sample. The same lens serves as a magnifier for the 800×600 pixel resolution b/w CCD camera used for imaging. The camera is equipped with a 35-mm focal length lens. The camera video output is fed to a home-made 8-bit frame grabber card inserted into a personal computer with appropriate software for image acquisition and evaluation. This set-up is optically equivalent [6] to the traditional Makyoh arrangement, where a simple screen is used. The key parameter (L) that completely characterises the imaging is the sample-to-screen distance of the equivalent traditional Makyoh set-up [7]. In our system, L can be varied from -750 to about 500 mm using different camera lens distance settings and extensions.

3. Results and discussion

Fig. 1 shows the Makyoh images of samples A and B with the scribed face up at different L settings. For $L = 0$, the image of the scratch is a narrow line. At non-zero L settings, the images of sample A exhibit a dark (light) band at $L > 0$ ($L < 0$), whose width linearly depends on the absolute value of L. A corresponding shift of the image of the edge of the sample takes place as well. This is clearly visible in the images which were taken with a flat mirror placed beneath the samples [6] to obtain a reference (contour) image that can be used to assess the sample deformation (Fig. 2). The sum of the shifts of the two sides equals the width of the centre band. By turning the wafer with the scribed face down, we obtain an image that is equivalent to the face up image with the opposite sign L. The image intensity of the dark band is zero while that of the light band is twice that of the surrounding areas.

These observations can be explained by the following model: Scribing results in a concentrated stress that renders the two halves of the wafer to bend downwards at a small angle, while the two halves themselves remain flat. The light (dark) band in the Makyoh image comes from the overlap (shifting aside) of the images of the two halves of the wafer (Fig. 3). That is, the band is *not* the image of the scratch itself. It is the abrupt change of the surface slope that is Makyoh topography is sensitive for. The bending angle α can be calculated as $\alpha \approx (\text{width of the centre band})/L$. For sample A, we get $\alpha = 0.6°$. Using an appropriate mechanical model, the strength of the scribing can be determined from this angle. In sample B, the non-scribed parts of the wafer constrain the bending at the ends of the scratch, therefore, the bending angle, thus the width of the dark (or light) band is the smallest here: this results in an oval shape of the dark or light band (see Fig. 1c and e). The two halves of the wafer become also deformed, as evidenced by the curved shape of the image of the sample's edges.

The difference between samples A and B can be explained by St. Venant's principle [9] as well. St. Venant's principle can be summarised as follows. Consider a mechanical system in equilibrium. Now apply a set of forces and torques whose sum equals to zero. St. Venant's principle states that the system is subjected to stresses and strains only in a region whose spatial extension is in the same range as in which the forces and torques situate. The case of sample A can be regarded as a one dimensional problem, first, because of the translational symmetry, second, because the wafer thickness and the scribe

---

[1] Makyoh topography is essentially material independent. Our choice of GaAs was motivated by the availability of an established patterning technology for GaAs in our laboratory, rather than the study of material-dependent aspects.

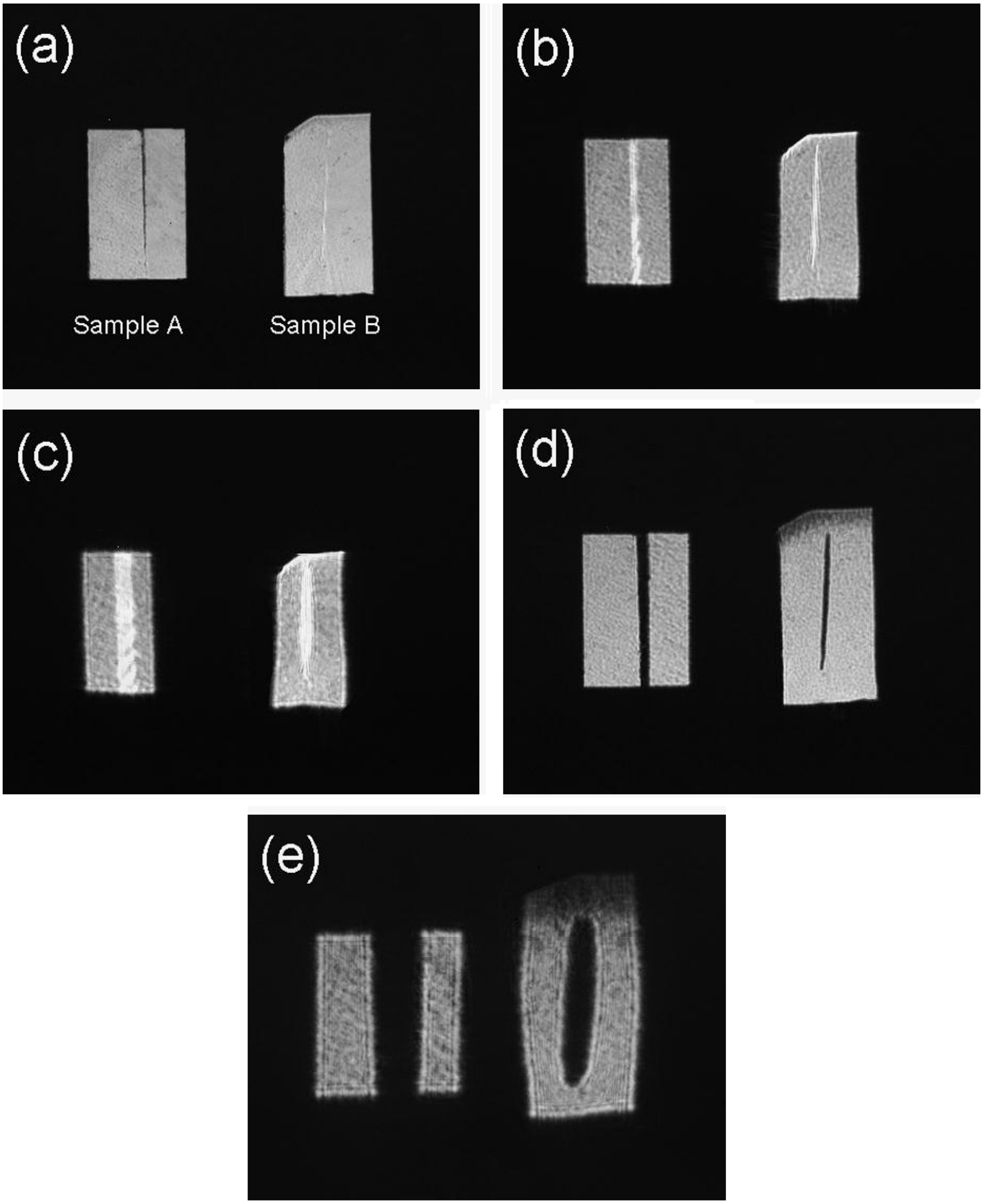

Fig. 1. Makyoh images of the scratched samples at different L settings: (a) $L = 0$, (b) $L = -65$ mm, (c) $L = -155$ mm, (d) $L = 112$ mm, (e) $L = 340$ mm. The size of sample A is 7.5×11 mm.

width are much smaller than the sample dimensions. The forces and torques due to the scratch are, therefore, localised to the small region surrounding the scratch; no deformation of the two halves takes place. The case of sample B, however, cannot be regarded as a one-dimensional problem because of the breaking of the translational symmetry: the length of the scratch is in the range of the sample size, therefore the deformation of the whole sample takes place.

Contrary to the scribed samples, the wafer with etched grooves shows no deformation as indicated by the unchanged image size at the larger values of L; the image is the well-known diffraction pattern[2] of the non-reflecting groove (Fig. 4). Indeed, it is expected that chemical etching does not introduce any stress into an originally stress-free material (surface stress effects can be neglected).

To summarise the results, in brittle materials — such as semiconductors — scribing induces a local strain field that induces an abrupt change of the surface slope, what Makyoh topography can detect. Even a small bending angle can be detected by the increase of L. Note that the image contrast is high.

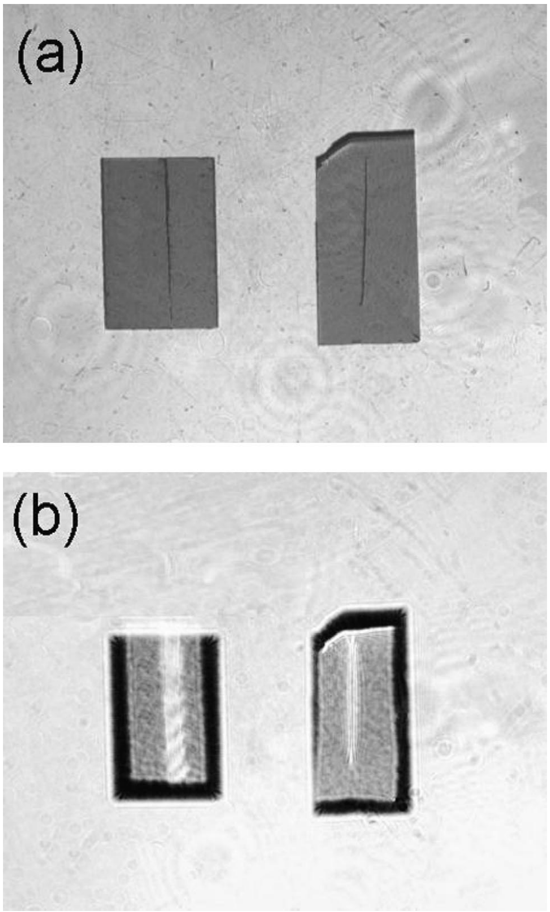

Fig. 2. Makyoh images of the scratched samples at two L settings with a flat mirror beneath the samples: (a) $L = 0$, (b) $L = -155$ mm.

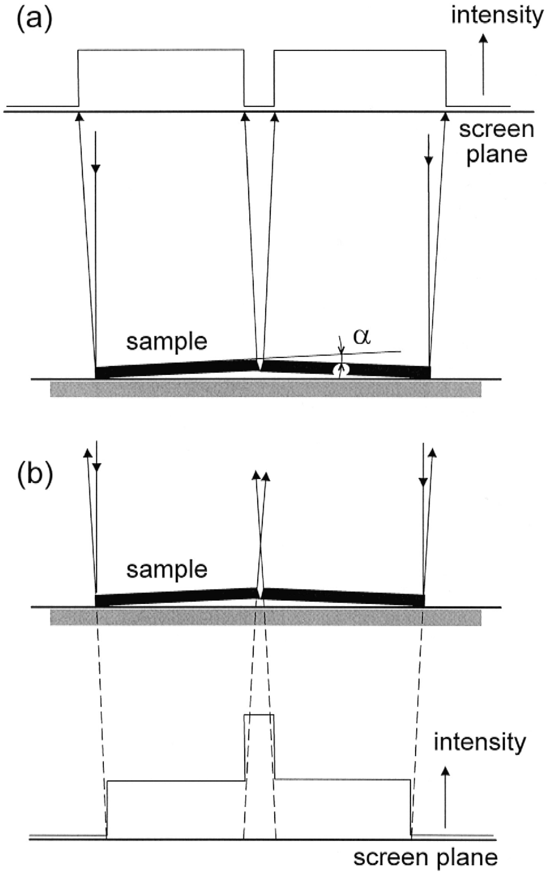

Fig. 3. Schematic model for image formation of the scribed samples for (a) positive and (b) negative L. The thin lines show the image intensities. The picture shows also the bending angle α.

---

[2] See, e.g. Ref. [10].

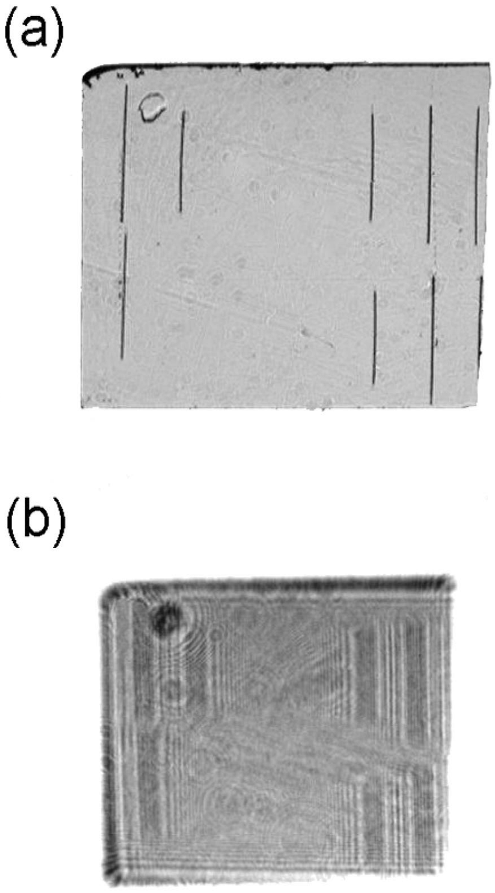

Fig. 4. Makyoh images of the wafer with etched grooves at two L settings: (a) $L = 0$, (b) $L = -225$ mm. The size of the sample is 10×12 mm.

The etched groove can model a scratch that is not associated with a stress field; this happens in ductile materials, such as metals. In this case, the Makyoh image is only a relatively weak diffraction pattern of the groove.

4. Conclusions

A Makyoh-topography study of scribed and etched grooves in single-crystal semiconductors was presented. A model for image formation was established. Our results show that Makyoh is capable to detect a groove with high sensitivity if it is associated with long-range deformation.

Acknowledgements

The author is grateful to M. Erős and J. Karányi for sample preparation, to J. Szabó and B. Szentpáli for initiating this study and for helpful discussions, and to B. Pödör for careful proofreading. This work was supported, in part, by the (Hungarian) National Scientific Research Fund (OTKA) through Grant F 25224.

References

[1] K. Kugimiya, Mater. Lett. 7 (1988) 229.
[2] P. Blaustein, S. Hahn, Solid State Technol. 32 (12) (1989) 27.
[3] Z. Laczik, G.R. Booker, A. Mowbray, J. Crystal Growth 153 (1995) 1.
[4] D. Korytár, M. Hrivnák, Jpn. J. Appl. Phys. 32 (1993) 693.
[5] J.F. Marshall, Solid State Technol. (1974) 70, (September).
[6] J. Szabó, F. Riesz, B. Szentpáli, Jpn. J. Appl. Phys. 35 (1996) L258.
[7] F. Riesz, J. Cryst. Growth, in press.
[8] F. Riesz, Phys. Status Solidi A 171 (1999) 403.
[9] S. Timoshenko, J.N. Goodier, Theory of Elasticity, McGraw-Hill, New York, 1951, Chap. 3.
[10] F.A. Jenkins, H.E. White, Fundamentals of Optics, McGraw-Hill, New York, 1981, p. 400.