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Observation of residual stress and defects in silicon induced by scribing

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Residual stresses induced by three scribing methods, diamond point scriber, laser scriber and diamond blade saw, are studied quantitatively by infra-red photoelasticity. It is clear that diamond blade saw scribing is most desirable, for residual stress induced by it is several times smaller than the stress caused by the other methods. The stress gradient differs between the laser scribed sample and the others, probably because of the difference in stress generation mechanism. Removing the damaged layer by etching reduces residual stress. The three scribing methods are also studied by the observation of defects after annealing and the results are compared with those determined by photoelastic measurement.

1. Introduction

There are many mechanical processes in semiconductor device fabrication. However good the electrical properties of the device are, it is of no use if damage is induced in the last mechanical processes. Scribing is one of them. There are three main methods of scribing – diamond point scriber, laser scriber and diamond blade saw. In the past, productivity was the most important point in choosing scribing method and laser scribing was thought most desirable. However, it has recently become clear that laser scribing is not always best, for laser scribed pellets were liable to crack in the moulding process after scribing a wafer and separating it into pellets. One of the reasons for this was thought to be residual stress induced by scribing. These effects were studied by photoelastic measurements.

A photoelastic study of silicon crystal in mechanical processing was made by Takasu and Matsushita [1] and Lederhandler [2]. These reports were concerned with the induced stress by adhesion or grinding. Nevertheless, there are very few reports about scribing of crystal, although it is important in crystal processing technology. The purpose of this paper is to compare three scribing methods through quantitative photoelastic measurement of residual stress and defect observation after annealing and etching. The effect of removing the damaged layer by etching was also studied and is reported in this paper.

2. Sample preparation and photoelastic observation

Silicon is transparent for radiation whose wavelength is longer than 1.1 μm. Photoelastic observations were made using PbO–PbS vidicon. It is considered that the observation was made by nearly monochromatic radiation of 1.1 μm wavelength for the combination of silicon filter and PbO–PbS vidicon. Infra-red photoelastic apparatus, shown in Fig. 1, was fabricated and described by Takasu [3]. The quantitative measurement procedure is shown in Fig. 2 [5, 6]. Principal stress lines were obtained through observation by plane polariscope. Whilst the stress magnitude was determined by observation with a circular polariscope. Quantitative measurements were made using the values of piezo-optical coefficients in Table I, calculated from the values obtained by Giardini [6]. A slight approximation was made in this calculation [5].

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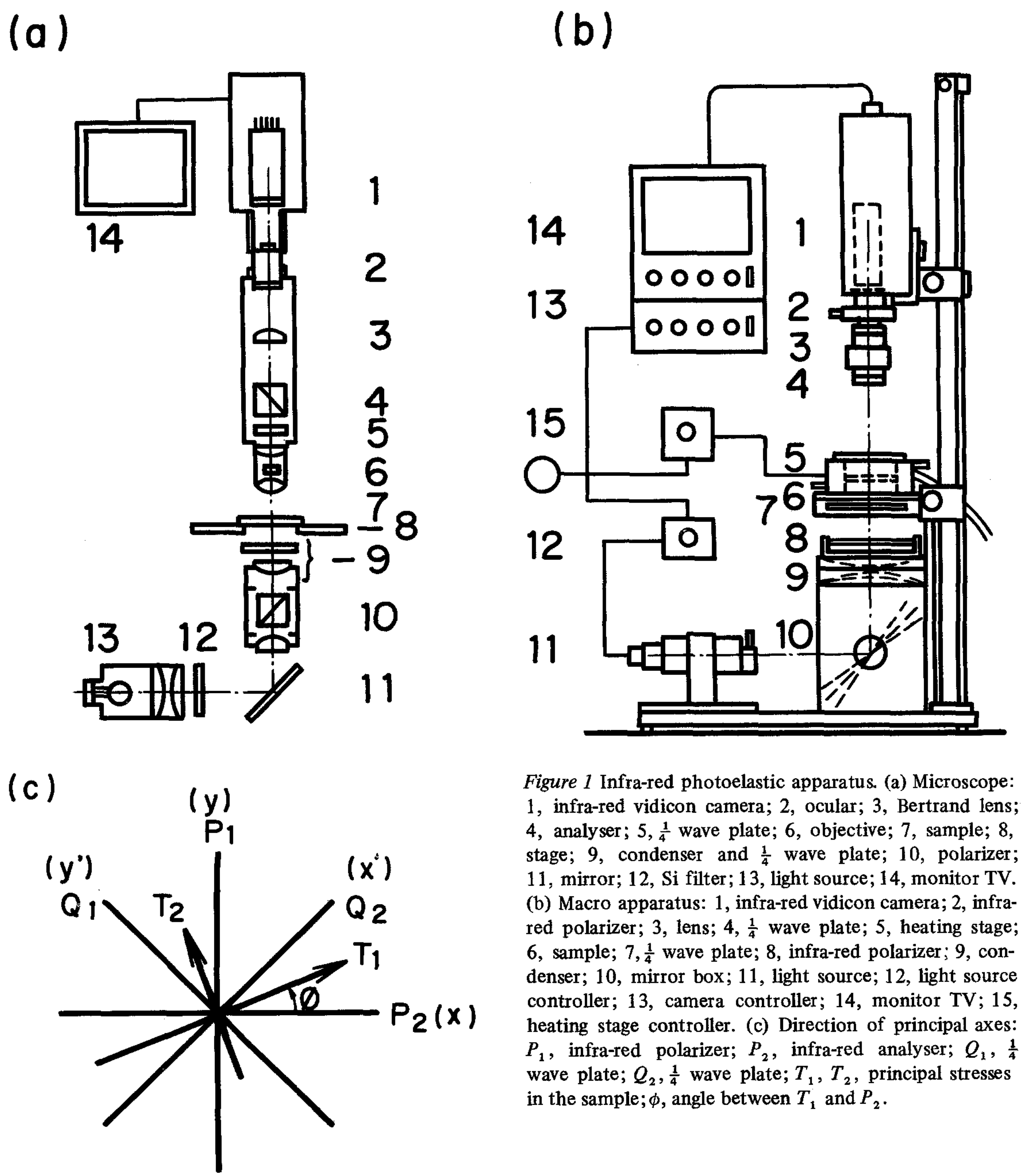

Figure 1 Infra-red photoelastic apparatus. (a) Microscope: 1, infra-red vidicon camera; 2, ocular; 3, Bertrand lens; 4, analyser; 5, $\frac{1}{4}$ wave plate; 6, objective; 7, sample; 8, stage; 9, condenser and $\frac{1}{4}$ wave plate; 10, polarizer; 11, mirror; 12, Si filter; 13, light source; 14, monitor TV. (b) Macro apparatus: 1, infra-red vidicon camera; 2, infra-red polarizer; 3, lens; 4, $\frac{1}{4}$ wave plate; 5, heating stage; 6, sample; 7, $\frac{1}{4}$ wave plate; 8, infra-red polarizer; 9, condenser; 10, mirror box; 11, light source; 12, light source controller; 13, camera controller; 14, monitor TV; 15, heating stage controller. (c) Direction of principal axes: P_1, infra-red polarizer; P_2, infra-red analyser; Q_1, $\frac{1}{4}$ wave plate; Q_2, $\frac{1}{4}$ wave plate; T_1, T_2, principal stresses in the sample; ϕ, angle between T_1 and P_2.

TABLE I Principal stress difference which causes 1λ (λ = 1.1 μm) retardation in 1 cm light path

Observation direction	Principal stress directions	Principal stress difference for 1λ retardation (kg cm^{-2})
[0 0 1]	[1 0 0] [0 1 0]	36
[0 0 1]	[1 1 0] [$\bar{1}$ 1 0]	52
[$\bar{1}$ 1 0]	[1 1 0] [0 0 1]	43
[$\bar{1}$ $\bar{1}$ 1]	[1 1 2] [$\bar{1}$ 1 0]	45
[$\bar{1}$ 1 0]	[1 1 2] [$\bar{1}$ $\bar{1}$ 1]	50
[1 1 2]	[$\bar{1}$ 1 0] [$\bar{1}$ $\bar{1}$ 1]	50

The most important factor in sample preparation for photoelastic observation is the mirror polishing of the two surfaces in the light path. In this experiment, silicon plates, with orientation and dimensions as shown in Fig. 3, were prepared for scribing characterization. All the surfaces were mirror polished for photoelastic observations and elimination of any initial stress. The scribing line was formed at the surface by three scribing methods – diamond point scriber, laser scriber and diamond blade saw. Photoelastic observations were made from the direction shown in Fig. 3.

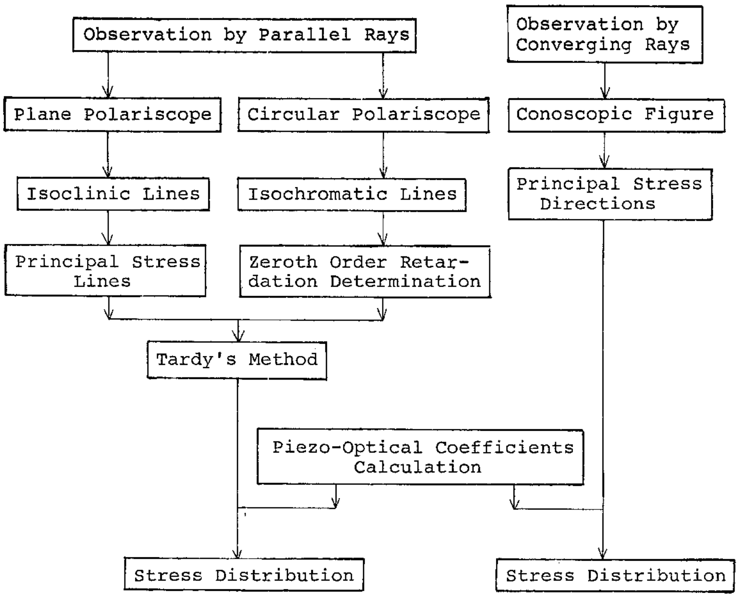

Figure 2 Quantitative measurement of stress in the crystal by photoelasticity.

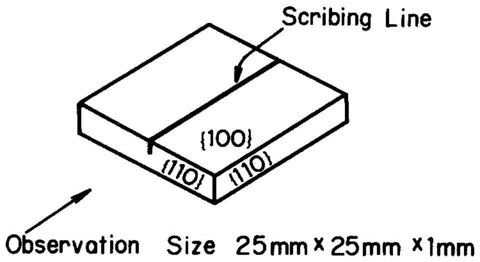

Figure 3 Sample for scribing characterization.

3. Residual stresses induced by scribing

Samples were first observed by plane polariscope, as shown in Fig. 2, and principal stress lines were obtained. Next, they were observed by circular polariscope and the stress magnitude was determined using the piezo-optical coefficients in Table I [5]. The groove shape of scribing and isochromatic lines obtained by circular polariscope are shown in Fig. 4. Fig. 5 shows the principal stress lines obtained by plane polariscope (a) and stress distribution explanation (b). Numbering the isochromatic lines was made from the standard isochromatic line of the zeroth order of retardation, which was far from the scribing line. Retardation orders for each isochromatic line and maximum retardation order near the scribing line are also shown in Fig. 4. Although the stress magnitude varied according to the scribing groove depth, so far as samples in Fig. 4 were concerned, the maximum residual stress was 60 kg cm^{-2} compression for the diamond point scribed sample, 39 kg cm^{-2} tension for the laser scribed sample (whose groove depth was 130 μm), and 4 kg cm^{-2} compression for the diamond blade saw scribed sample.

The retardation sign or stress gradient direction, determined by Tardy's method [5], for the laser scribed sample was different from that for the other samples. This result is important in solving the stress generation mechanism. Fig. 6 shows the shift in isochromatic lines for (a) the diamond point scribed sample and (b) laser scribed sample. The analyser (P_2) was rotated $\pi/4$ radians in this case. A silicon beam, bent at four points, which has a uniform stress gradient from compression to tension, was used as the standard sample to determine the stress gradient direction [5].

The effect of etching on residual stress was studied and the result is shown in Fig. 7. In this experiment, the diamond point scribed sample was etched by the etchant (HF(1), HNO_3(3), CH_3COOH(2)) at 20° C. Residual stress was rapidly reduced, according to etching time. There was no residual stress observed in the sample etched for 60 sec. Stress was also reduced by cracking at the scribing line, as shown in Fig. 8, although the effect varied according to each case.

4. Defect observation by etching

Three scribing methods were compared by defect observation after annealing and etching. Samples

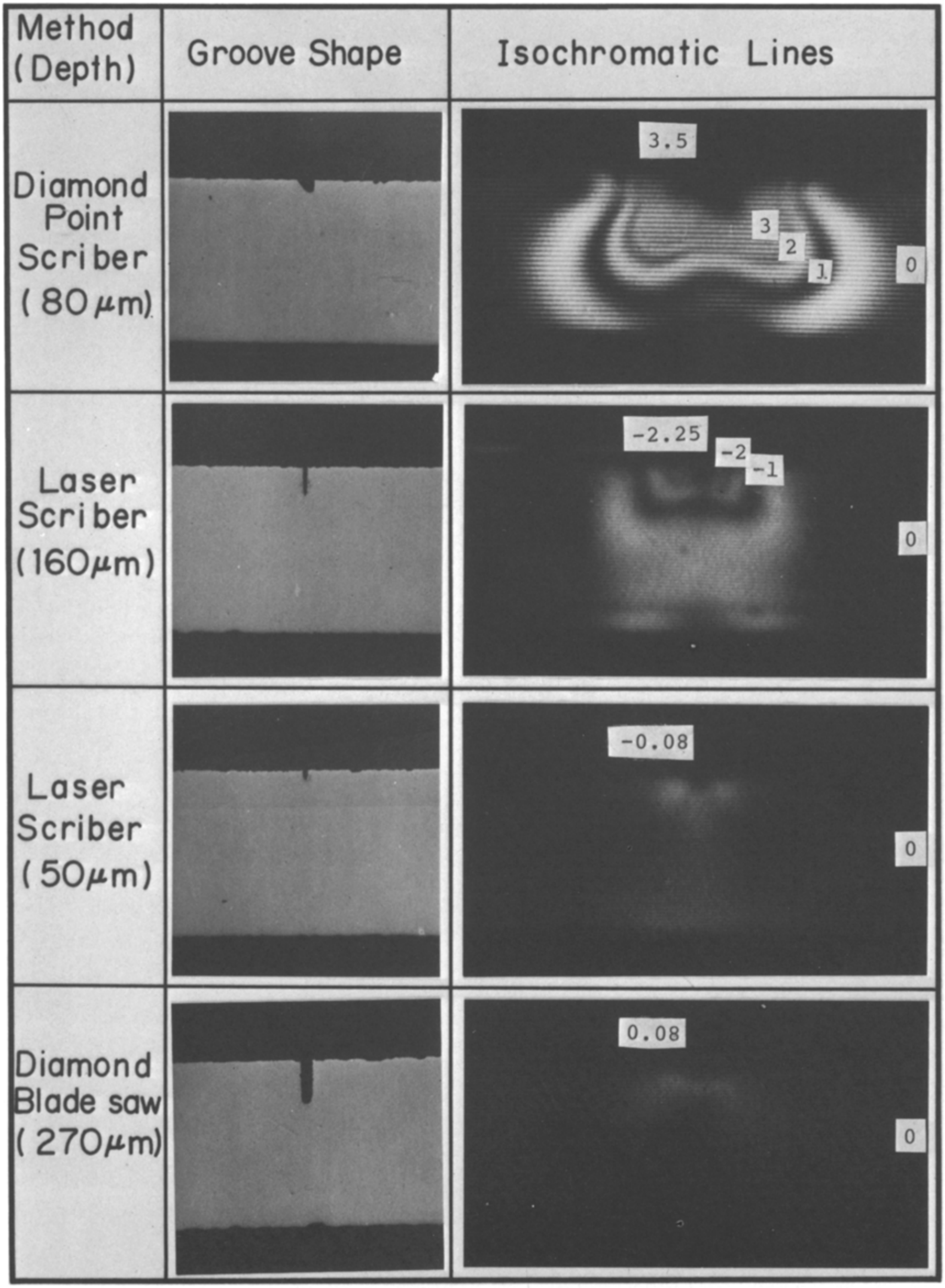

Figure 4 Scribing groove shape and isochromatic lines.

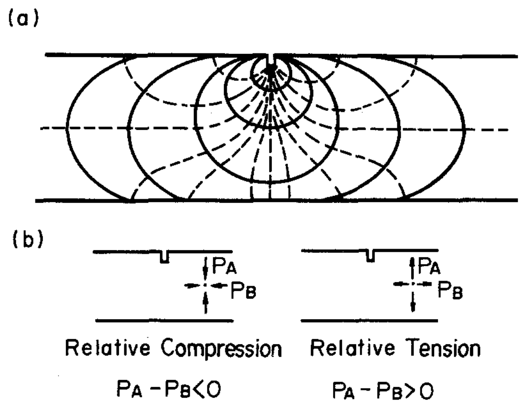

Figure 5 Principal stress lines and stress distribution explanation.

Category	Principal stress line	Principal stress
A	———	P_A
B	- - - - - - - -	P_B

were annealed in N_2 gas at 1000° C for 30 min and etched by Wright etchant (HF, 400 ml); HNO_3, 200 ml); CH_3COOH, 400 ml); $Cu(NO_3)\cdot 3H_2O$, 13 g, 5 mol CrO_3 (200 ml), H_2O 400 ml). From the results shown in Fig. 9, etch pit density was quite large in the laser scribed sample, whereas there were few etch pits observed in the diamond blade saw scribed sample.

5. Discussion

It has become clear, from this experiment, that the stress induced by the diamond point scriber was largest in magnitude and that by diamond blade saw was the smallest, although it would, of course, depend on the scribing groove depth. In the past, laser scribing was thought most desirable, from the view point of productivity and controllability because of its narrow and deep scribing line. However, this study shows that diamond blade saw scribing is most desirable, from the residual stress viewpoint. This is especially important when residual stress affects the electrical properties of a device or device fabrication reliability concerning the pellet cracking problem.

Important information about the stress generation mechanism was obtained in this experiment. From the results shown in Fig. 5, category A principal stress was relatively compressive, compared with category B stress for diamond point scribed and diamond blade saw scribed samples. The situation was the opposite for a laser scribed

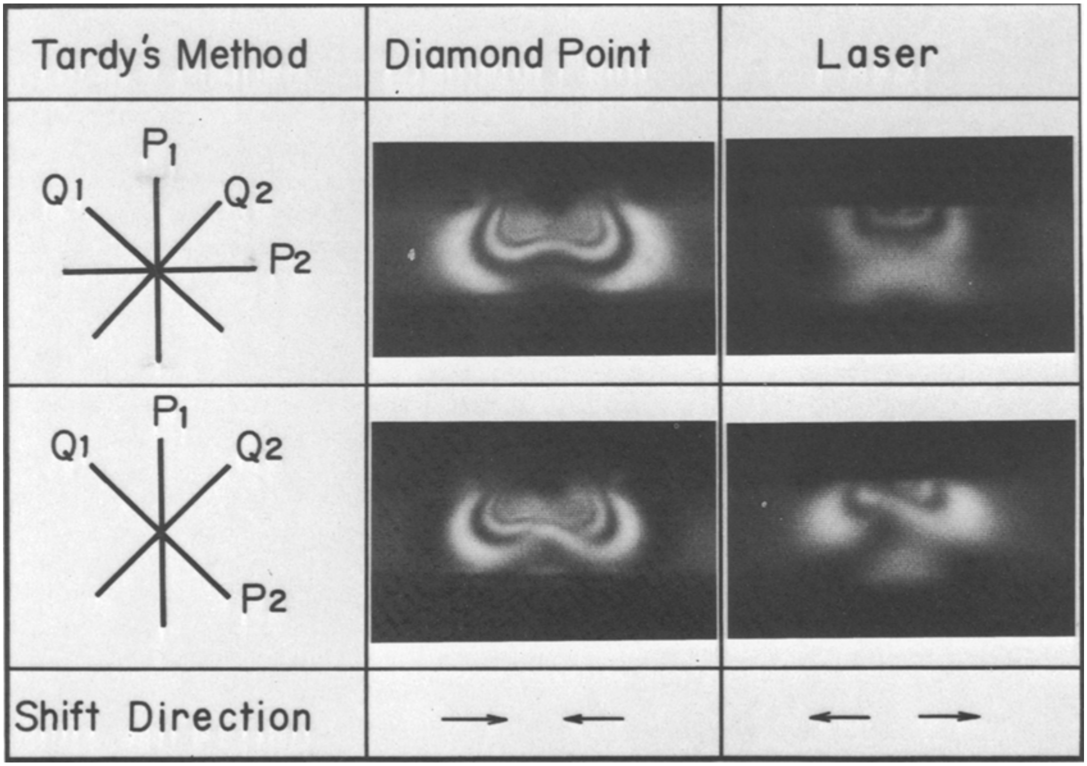

Figure 6 Shift of isochromatic lines for diamond point scribed and laser scribed samples in the observation by Tardy's method.

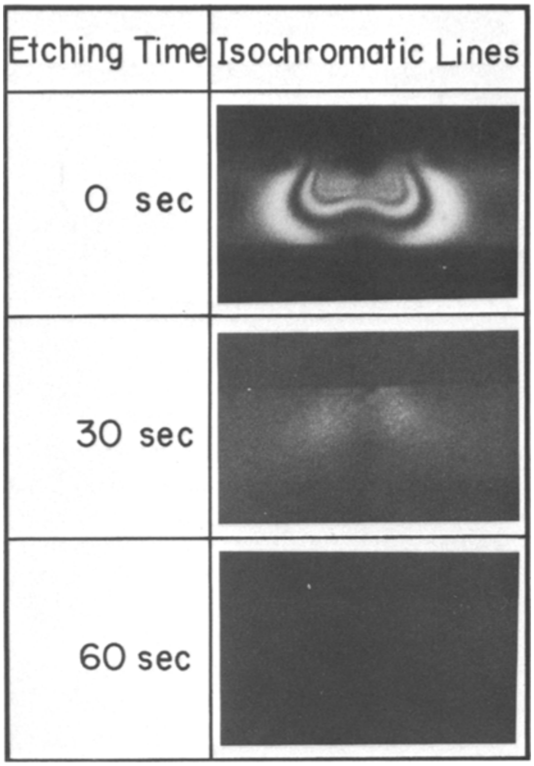

Figure 7 Etching effect on residual stress in a diamond point scribed sample.

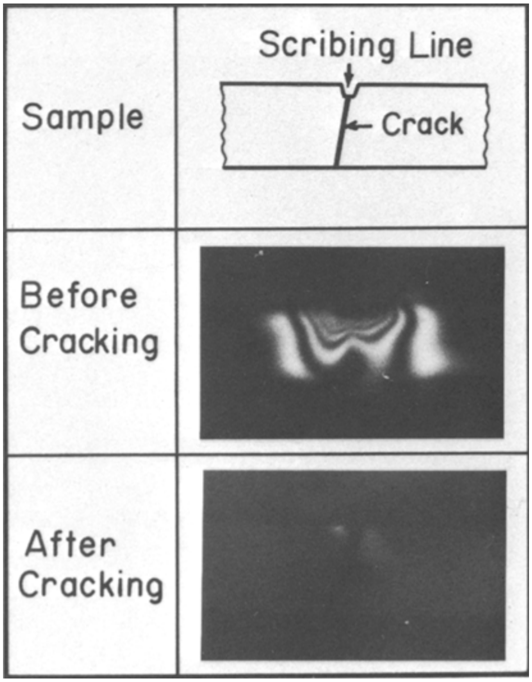

Figure 8 Cracking effect on residual stress in a diamond point scribed sample.

sample. Residual stress in silicon induced by scribing is the result of external force causing a damaged layer to form on the scribing groove wall. This brings compressive stress to silicon near the interface of the damaged layer, in the case of mechanical scribing methods (diamond point scriber and diamond blade saw), and tensile stress in the case of the thermal solution method (laser scriber). It is natural to consider that a mechanically damaged layer, which results in compressive stress, is formed by compressive force of the diamond point scriber or diamond blade saw. On the other hand, a thermally damaged layer, which results in tensile stress, is formed by solution and cooling process by laser beam. This is probably the reason for the difference in stress gradient directions between the laser scribed sample and other samples.

Removing the damaged layer by etching was effective in residual stress reduction. This shows that residual stress is mainly caused by the damaged layer. Cracking at a scribing line also reduced stress for the diamond point scribed sample. For Yasuami's result (X-ray topographic observation) for diamond blade saw scribed sample, no difference was observed by cracking [7]. Therefore, the cracking effect is thought to depend on the scribing method or stress generation mechanism.

In the etch pit distribution observation, differences between the laser scribed sample and the other samples were quite large, compared with the result of residual stress determined by photoelasticity. This is also probably because of the difference between a mechanically damaging process and a thermally damaging process. These results show that crystal characterization must be accomplished by several methods, making the best use of each one. For scribing, a diamond blade saw is most desirable from both residual stresses and defect density viewpoints.

6. Conclusions

Residual stress values, induced by three scribing methods (diamond point scriber, laser scriber and diamond blade saw), were compared by quantitative photoelastic measurement. It has become clear that the diamond blade saw is most desirable for its smallest residual stress. The stress gradient direction differed between the laser scribed sample and the other samples, because of the difference in the formation mechanism of the damaged layer. Removing the damaged layer by

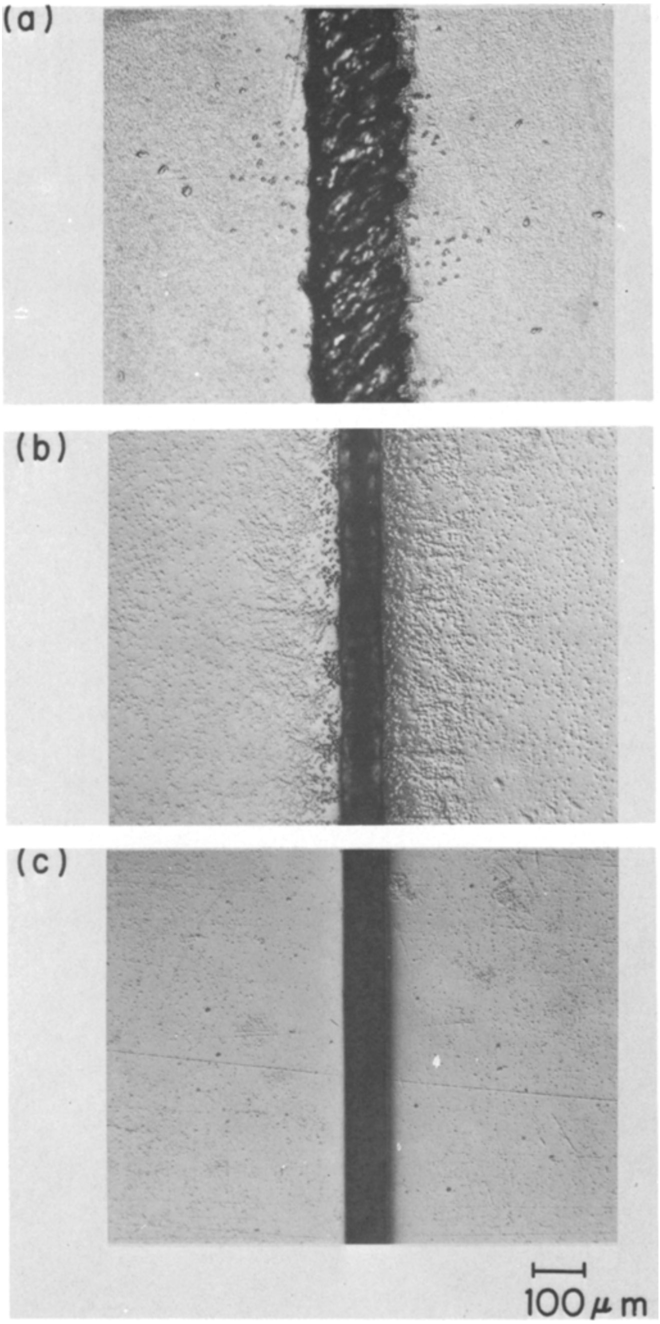

Figure 9 Etch pit observation after annealing and Wright etching. (a) Diamond point scribing, (b) laser scribing, (c) diamond blade saw scribing.

etching reduced the residual stress. The diamond blade saw scribed sample was nearly defect-free in etch pit observation after annealing, whereas laser scribing induced quite a large number of defects.

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