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Shear Stresses in a Notched Circular Disk

In the dicing of a silicon disk into separate integrated circuit chips, an alignment notch is commonly used to maintain the disk in a precise and stable position throughout the process. This notch is formed in a grinding operation which causes mechanical damage to the crystal structure in the vicinity of the notch. The increase in crystal dislocation density will degrade the performance of any circuit chips located in the damaged area. Hence, it is important to learn the extent of damage in the disk so that the affected region can be avoided during the production of chips.

It is possible to determine the dislocation density in the disk by X-ray diffraction microscopy.[1] However, it is equally important to determine the distribution of the stress incurred during the grinding operation so that this distribution may be correlated with that of the dislocation density.

No previous theoretical or experimental attempts are known to have been made to determine the stresses in a loaded silicon disk during the notching operation. Frocht[2] has employed the techniques of photoelasticity to determine the stresses in a notched disk symmetrically supported by two concentrated loads on the boundary of the disk. His results are not directly applicable to the present problem, as the stresses introduced in a disk are functions of the elastic properties of the disk material; the concentrated loads used in his investigation differ from the loading condition pertinent to the notching operation.

This note presents a method of determining the stresses that exist during the notching operation in a silicon disk loaded parallel to the [111] plane (Fig. 1). At the circular notch, normal pressure is uniformly distributed, and at I and II, uniform radial pressures are distributed over small segments of the boundary of the disk. For simplicity it is assumed that the shear stress is zero on the boundaries of the notch and the disk. However, the boundary shear stresses can be taken into consideration in a manner similar to that outlined in this note. The silicon disk with a [111] orientation can be regarded as an isotropic disk in a state of plane stress.[3]

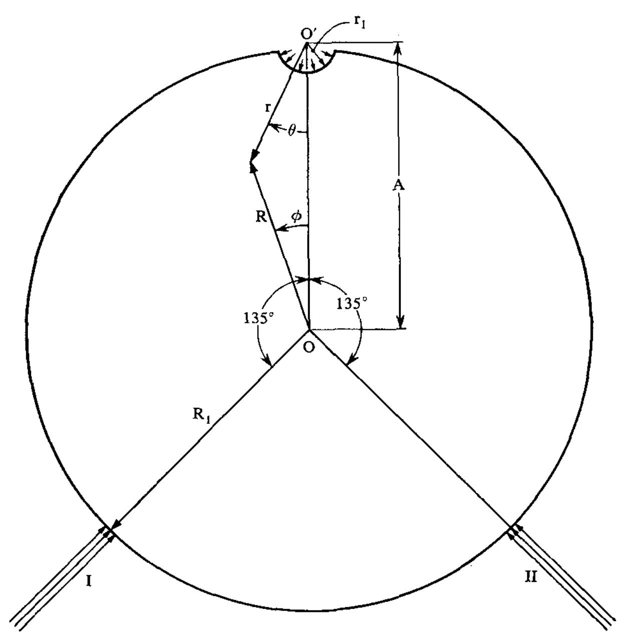


Figure 1 Geometry and loading conditions of notched circular disk. Dimensions: $r_1 = 0.0708$ in., $A = 0.6395$ in., $R_1 = 0.625$ in., thickness, $t = 0.00787$ in.

The solution to be presented is obtained by a convergent combination of stress functions; the procedure used is parallel to that adopted by Ku in solving the stress concentration problem in a rotating disk with central and noncentral holes.[3]

The Airy stress function,

$$\Phi_0 = a_0 \ln r , \tag{1}$$

is taken first. The constant a_0 is determined from the uniform pressure at the notch. Next,

$$\Phi_1 = b_0 R^2 + \sum_{i=2}^{\infty} (c_i R^i + d_i R^{i+2}) \cos (i\phi) \tag{2}$$

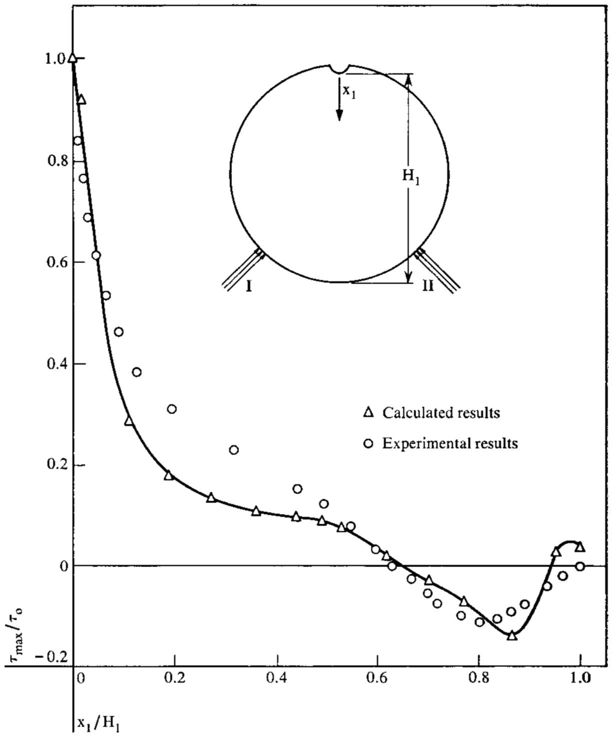


Figure 2 τ_{max}/τ_0 vs x_1/H_1.

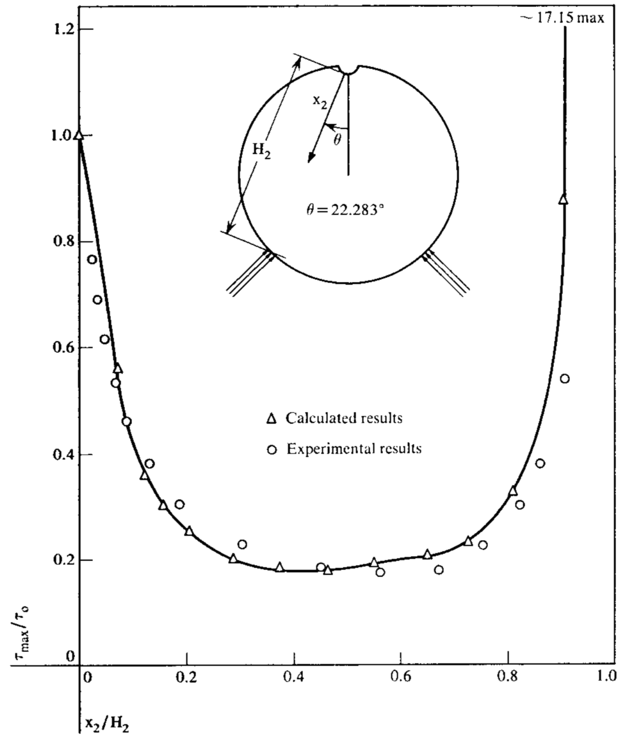


Figure 3 τ_{max}/τ_0 vs x_2/H_2.

is taken to remove the stresses on the boundary of the disk introduced by Φ_0, and to satisfy the uniformly distributed normal pressures at I and II. Then

$$\Phi_2 = a_0 \ln r + g_1 r^{-1} \cos\theta + \sum_{i=2}^{\infty} [g_i r^{-i} + h_i r^{-(i+2)}] \cos i\theta \tag{3}$$

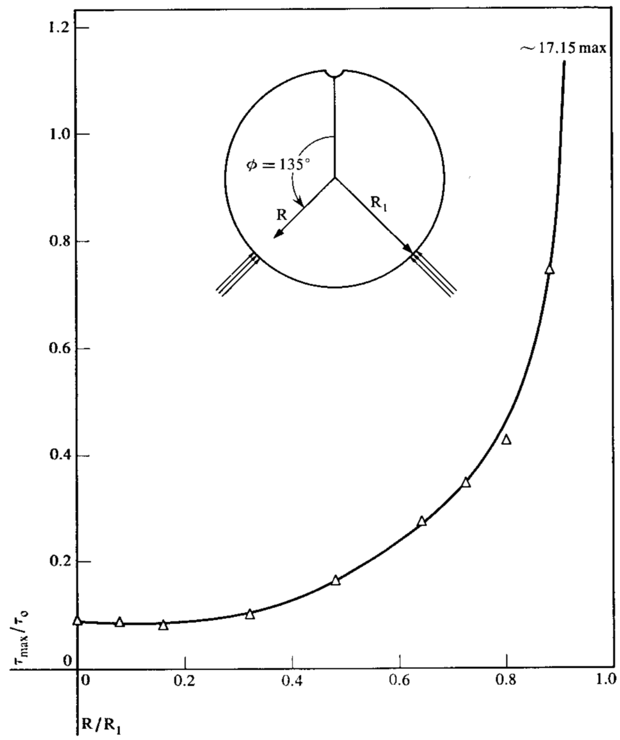
is taken to remove the stresses on the boundary of the notch introduced by Φ_1. This process of approximation is continued until the remaining boundary stresses become negligible. The final result is obtained by summing all of the superposed stresses.

The results for the maximum shear stress, τ_{max}, at various locations in the disk from three successive approximations, are shown in Figs. 2 to 5. τ_0 is the maximum shear stress at $x_1 = 0$. The photoelastic stress pattern shown in Fig. 6 is different from the one shown by Frocht[2] in the vicinity of the notch as well as the loaded portions of the boundary of the disk.

An enlarged (5 to 1 ratio) photoelastic model of the silicon disk was prepared from ¼-inch Paraplex P43* plastic. The reactions at I and II were approximated by supporting the model on two pieces of the plastic. Hydrostatic loading

* Registered Tradename, The Homalite Corp., Wilmington, Delaware.

Figure 4 τ_{max}/τ_0 vs R/R_1.



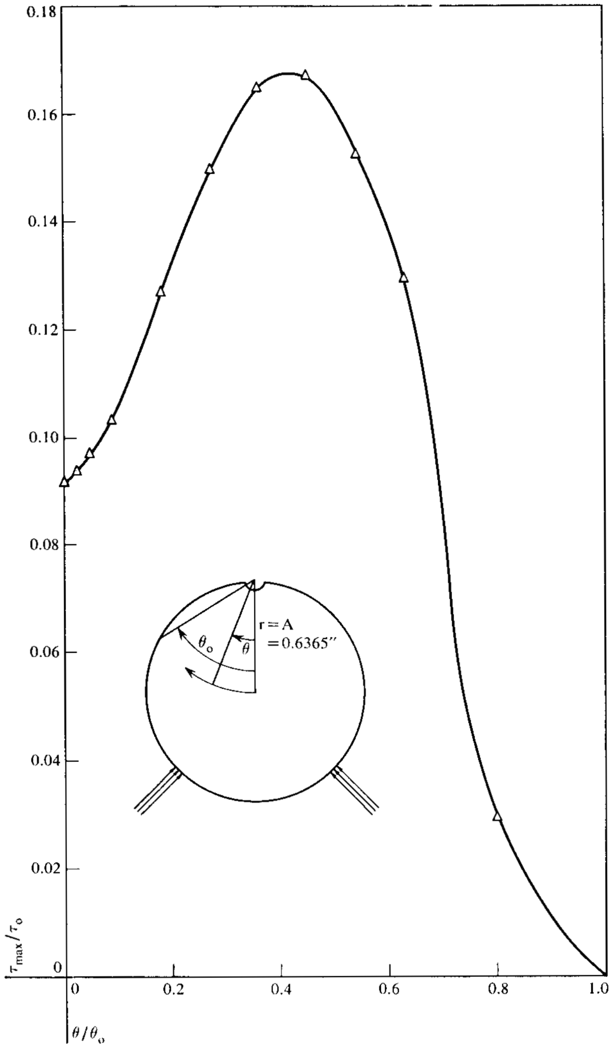


Figure 5 τ_{max}/τ_0 vs θ/θ_0.

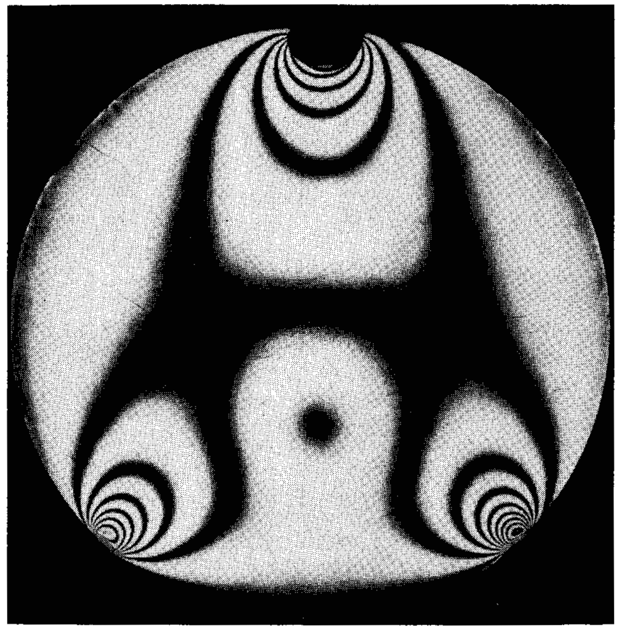


Figure 6 Photoelastic stress pattern in plastic disk.

at the top circular notch was approximated by applying an external load to a piece of soft rubber whose unloaded geometry matched the circular notch. Two pieces of transparent non-birefringent plastic, Plexiglas* in this case, were used to confine the rubber within the two planes established by the front and back sides of the model. As load was applied to the top side of the rubber, the confined conditions approximated a hydrostatic loading along the surface of the circular notch.

* Trademark, Rohm & Haas Co., Philadelphia, Pa.

The calculated stresses from the third successive approximation show good agreement with the photoelastic results away from regions I and II. This is due to the fact that the uniform radial pressure distribution on the boundary of the disk, assumed for the calculation, has not been exactly simulated by that in the photoelastic model. It is also realized that the elastic properties of the photoelastic material are different from those of silicon.

The error due to not proceeding beyond the third approximation is less than 5%. The expressions used to calculate the stresses converge very slowly near the boundary of the disk. Twenty-eight initial significant figures were needed to obtain three final significant figures near the boundary.

References

1. G. H. Schwuttke, "New X-ray Diffraction Microscopy Techniques for the Study of Imperfections in Semiconductor Crystals," *Journal of Applied Physics* **36,** No. 9, 2712 (1965).
2. M. M. Frocht, *Photoelasticity*, Vol. 1, John Wiley and Sons Inc., New York, 1946, p. 191.
3. W. R. Runyan, *Silicon Semiconductor Technology*, McGraw-Hill, New York, 1965, p. 221.
4. T. C. Ku, "Stress Concentration in a Rotating Disk with a Central Hole and Two Additional Symmetrically Located Holes," *Trans. ASME, Journal Appl. Mech., Series E* **82,** 359 (1960).

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