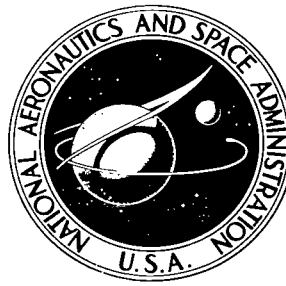


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SOME PRACTICAL ASPECTS OF SCRIBING

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SOME PRACTICAL ASPECTS OF SCRIBING

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SUMMARY

This report presents the results of a series of experiments performed in the diamond scribing of silicon wafers for the separation of dice. The factors considered are tool depth, tool direction, tool speed, tool geometry, scribing angle, and force.

The tests were made to evaluate the heel scribing approach, a relatively recent development in the scribing of silicon wafers, which utilizes the back or heel of the diamond tool rather than the front or toe of the standard truncated tool.

INTRODUCTION

For many years the separation of semiconductor devices produced on silicon wafers has received scant attention from process engineers in the industry. In the overall process of developing and manufacturing diodes, transistors, and integrated circuits, millions of man-hours were expended in developing more exotic and complex semiconductor devices. Unfortunately most of the effort was addressed to the problems encountered in batch producing the wafers. The subsequent separation and assembly of the hundreds of devices per wafer did not receive the attention required to maintain the quality and hold down the cost of the devices so produced. However, it has been finally recognized that the cost and quality of the finished product depend as much on how the wafer is processed and handled after the hundreds of devices are formed on the wafer as before this stage of the processing. This report addresses itself to one aspect of the post-wafer processing, namely, the separation of the circuits from the wafer for subsequent mounting and packaging.

There are at present four methods being used for the separation of devices and circuits. The individual units are referred to as dice. The dicing of wafers may be brought about by the use of (1) a diamond cutting wheel, (2) a diamond-tip scribing tool, (3) a laser beam, or (4) a chemical etching process. Although the diamond cutting wheel is still being used by some manufacturers, it is perhaps the least desirable method from a cost and quality point of view. The laser beam technique is under investigation as an alternate to the diamond-tip scribing method which

has been the industry standard for many years. The chemical etching process is used to good advantage in the separation of beam lead devices where (100) silicon may be etched along preferential planes.

EVALUATION OF SCRIBE LINES

The most widely used and accepted technique for the separation of devices is by the use of a diamond-tip scribing tool to score the surface of silicon wafers. It was determined from an examination of the scribing process that at least six elements of the process have to be closely controlled in order to meaningfully evaluate the quality of lines scribed on (111) silicon wafers.

A series of experiments was performed to evaluate the quality of scribe lines as a function of tool depth, direction, speed, geometry, angle, and force. The absence of substrate damage and fragmentation along the scribe lines were used as criteria for acceptable lines. As the work progressed, it became evident that a characteristic of good scribe lines was the presence of minute, trailing hash marks which point opposite to the direction from which the tool travels on contact. Further study of these trailing hash marks is presently underway to determine their significance in the effective scribing of (111) silicon. (See Figures 1 and 2.)

TOOL DEPTH

To minimize the effect of tool depth on the characteristics of the scribe lines, the tool was fixed at a minimum setting which would insure contact across the complete wafer. The depth of the tool at rest below the surface of the wafer was fixed as follows:

With the force and scribe angle set at predetermined values, the tool was lowered in increments of one quarter division until contact was made to the surface of the wafer. Then the tool was lowered one-half additional division in order to insure full contact across the wafer. Thus the tool depth may be designated as $.001 \text{ in.} + .0005 \text{ in.}$ regardless of the wafer thickness, which in these experiments varied from $.0084 \text{ in.}$ to $.0099 \text{ in.}$

TOOL DIRECTION

It can be shown that the direction of tool travel in the scribing of (111) silicon can affect the quality of the scribe lines and hence the subsequent separation of the dice.

In scribing perpendicular to the (110) orientation flat, one has the choice of moving the tool toward the flat in one case, or away from the flat in the other. For this series of scribe lines, the direction of tool travel is optional. See Figure 3.

However, such is not the case when scribing the series of lines parallel to the orientation flat, i.e., along the (110) planes. In order to minimize the damage to the substrate along these scribe lines, the direction of tool travel must be such that it approaches the apexes of the triangles formed by the intersecting (111) planes through the bases of the triangles so formed. This may be clarified by reference to Figure 4. In Figure 4, (a) is preferred. Figure 5 shows a photograph corresponding to Figure 4(a). Figure 6 is a photograph, taken under dark field illumination, which shows the effect of tool travel direction on the substrate.

With reference to the orientation flat, the triangles formed by the intersecting (111) planes may be pointing up (Figure 4a) or down (Figure 4b), depending on whether the flat is to the left or right. Line (a) of Figure 6 was scribed with the flat to the left as viewed, while line (b) was scribed with the flat of the same wafer to the right. Note the minimal damage to the substrate along line (a) compared to the damage along line (b). The former case invariably results in cleaner edges, less fragmentation along the edges of the dice, and less silicon debris when the dice are separated. It is axiomatic that more damage occurs in one direction than the other regardless of tool angle, depth, geometry, rate of travel, or force.

TOOL SPEED

The Tempress scribing machine used in all our experiments had a normal rate of tool travel of 36 c/min. At such a rate it was virtually impossible to eliminate tool bounce and skipping as the tool entered the edge of the wafer. It is obvious that if the scribe tool does not contact the wafer across its full width, the resulting dice separation will be less than perfect with excessive peripheral losses due to erratic fracturing of the wafer. By increasing the tool force and depth one may reduce tool bounce and

edge skipping. However, the scribe lines so formed are heavy and fragmented with excessive damage to the substrate resulting.

The rate of tool travel on the machine is easily varied by substituting readily available cam pulley assemblies. The tool speed was reduced to 18 c/min and acceptable scribe lines were obtained with no edge skipping.

TOOL GEOMETRY

The diamond-tip scribing tools used in these experiments were manufactured by the American Coldset Corporation, which at the time was the only known source for tools amenable to the "heel" scribing approach. Heel scribing is a relatively recent development in the scribing of semiconductor wafers, which utilizes the back or heel of the diamond tool rather than the front or toe of the standard truncated pyramid tool. Figure 7 points out the difference in the three tools used in our experiments.

It was expected that reducing the included angle θ would result in more of the preset tool force being brought to bear normal to the wafer surface and less of the force dissipated laterally along the scribe line. Indeed it was found that more acceptable scribe lines were produced over a wider range of tool force and scribing angles as θ decreased from 60° to 33° .

SCRIBING ANGLE*

The tool angle α , as depicted in Figure 7, restricts the minimum heel scribing angle to something greater than 35° . The Tempress scriber is designed to allow a maximum scribing angle of 45° .

To facilitate obtaining an accurate and repeatable tool angle for scribing, a series of simple jigs were designed and made to fix the scribing angle at 36° , 38° , 40° , 42° , and 44° . Figure 8 shows a jig being used to set the scribing angle. Figure 9 is a photograph of five successive scribe lines made at a tool force of 6.5 g and at angles of 36° to 44° . Only lines 1a and 2a are classified as acceptable. Lines 3a, 4a, and 5a are unacceptable because of fragmentation (i.e., chip-out) and substrate damage.

* By scribing angle is meant the included angle formed by the shank of the tool in its holder and a line normal to the wafer.

TOOL FORCE

The amount of force brought to bear on the substrate by the scribing tool is variable and can be preset on the machine by use of its force dial indicator. However, we were unable to reduce the force sufficiently to find the lower limit for acceptable lines until the ram head stud and washer were removed. At very low forces, i.e., 1 to 3 g, the tool fluttered to such a degree that it was impossible to control the scribe lines. The head was re-adjusted to provide a minimum force of 6.5 g and an external force gauge was used to recalibrate the force dial indicator.

Figures 10, 11, and 12 are photographs of typical lines scribed with increasing tool force. They clearly indicate upper limits of acceptability for each set of scribing parameters. As tool force increases so does substrate damage, fragmentation, and scribing debris. Care must be taken to examine marginal lines under dark field illumination. Figure 13a, taken under normal illumination, shows the line to be acceptable. However, the same line examined under dark field illumination, Figure 13b, shows enough substrate damage to cause the line to be rejected. The conditions under which the line shown in Figure 13 was scribed are scribing angle = 36° , and force = 6.5 g.

DICE SEPARATION

Using the conditions which led to acceptable scribe lines (see Table I), we scribed, and separated into dice, (111) silicon wafers with oxide-free surfaces, varying in thickness from 8 to 10 mils. The wafers were scribed into .061-in. x .068-in. dice, keeping the shorter edges of the dice parallel to the (110) orientation flat. The dice were separated by using a 1-in. diameter hand-held roller.

Figure 14 is a photograph of typical dice scribed as indicated and hand rolled for dice separation. Table I is a summary of the percent of dice yield realized and the scribing conditions under which the dice were produced.

TOE SCRIBING

Applying the same principles denoted in the heel-scribing experiments reported above, we made additional tests in order to compare the results of heel scribing with toe scribing of wafers. In toe scribing, the truncated pyramid, diamond-tip tool is set up such that the scribing angle is kept less than 35° . One must be aware that the geometry of the truncated pyramid tool is such that the angle ϕ , in Figure 15, is always 90° .

Angle θ , on the other hand, is variable (see Figure 7).

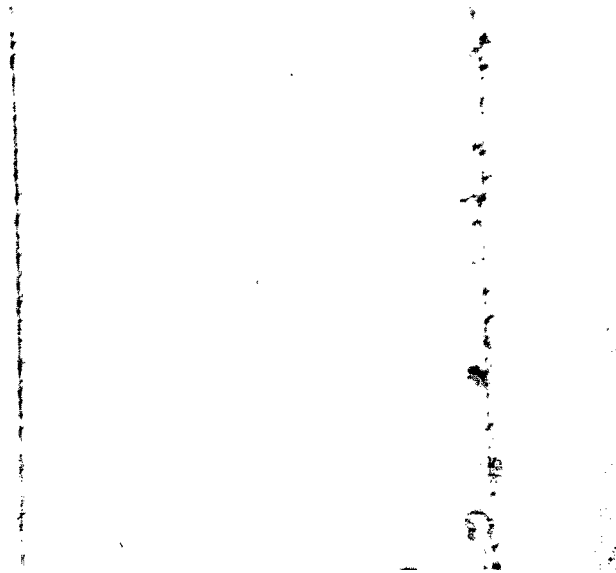
It may be significant that in toe scribing, no trailing hash marks were apparent on any of our scribed samples. In heel scribing, however, the presence of hash marks was found to be necessary for effective dice separation.

In traveling across a wafer, the contact of the flat of the tool with the surface of the wafer would appear as in Figure 16.

We found toe scribing along the (111) planes to be much more sensitive to tool force than heel scribing. In Figure 17 the (110) scribe lines evidence no damage, while the (111) scribe lines show enough fragmentation and substrate damage to be unacceptable.

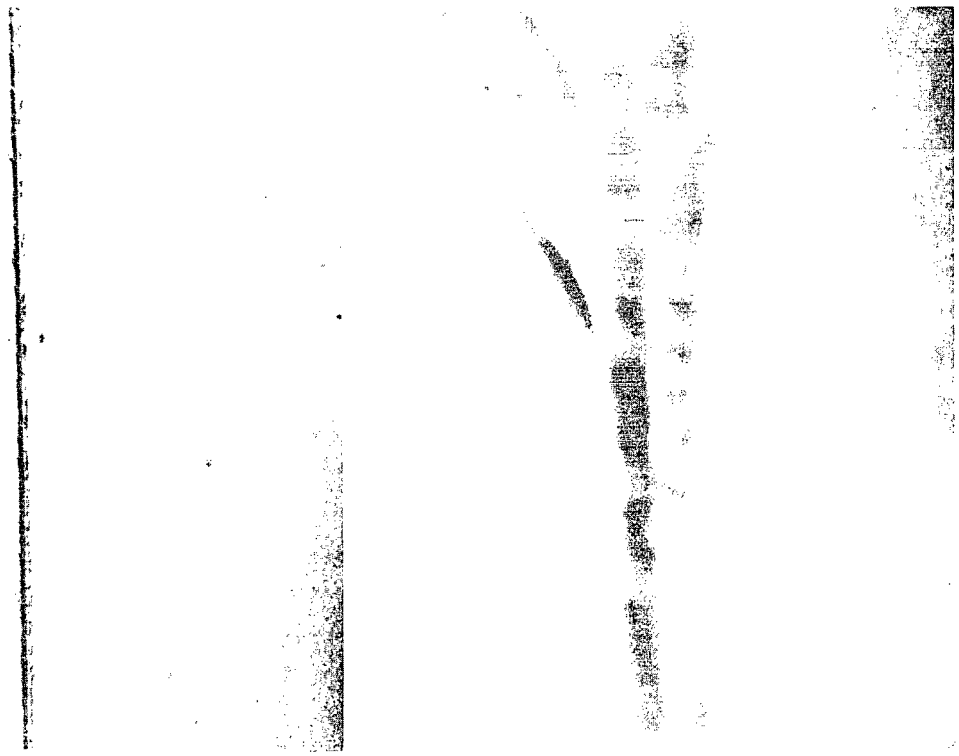
CONCLUSIONS

Considering the quality of the scribe lines, the very limited range of acceptable toe scribing parameters and, more importantly, the subsequent efficacy of dice separation for the production of dice with sharp, clean, non-fragmented edges, heel scribing is to be preferred over toe scribing under the conditions presented above.



a. (470X) b.

Figure 1.- Acceptable line (a) and unacceptable line because of fragmentation (b)



a. (470X) b. (3300X)

Figure 2.- Acceptable scribe line (note trailing hash marks)

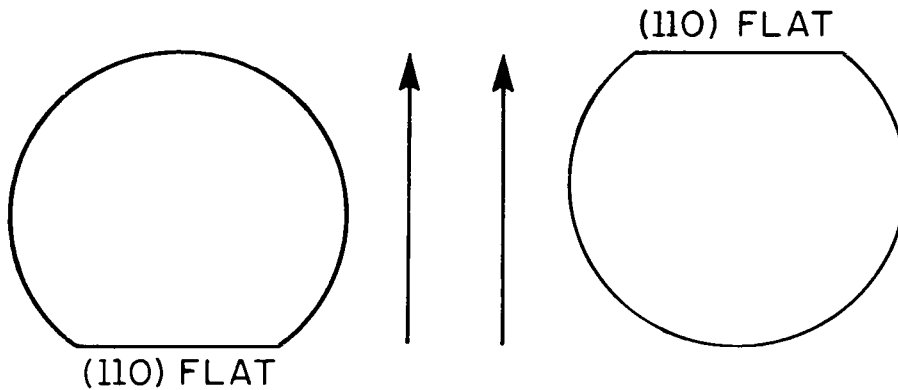


Figure 3.- Direction of tool travel perpendicular to (110) orientation flat is optional for good scribing

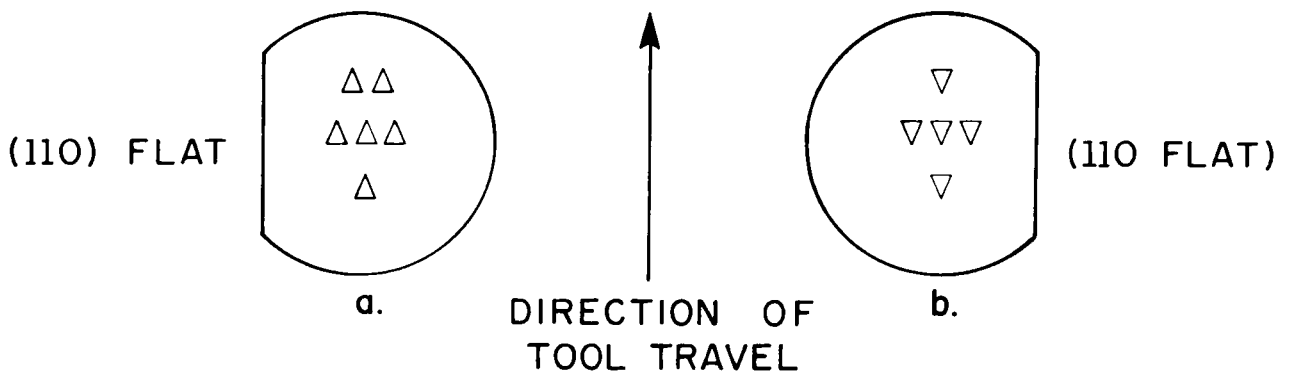
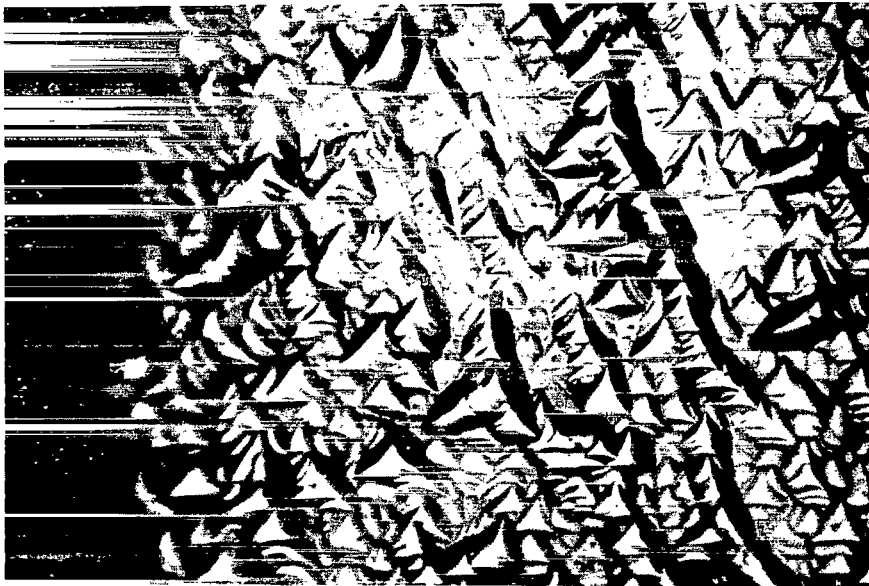
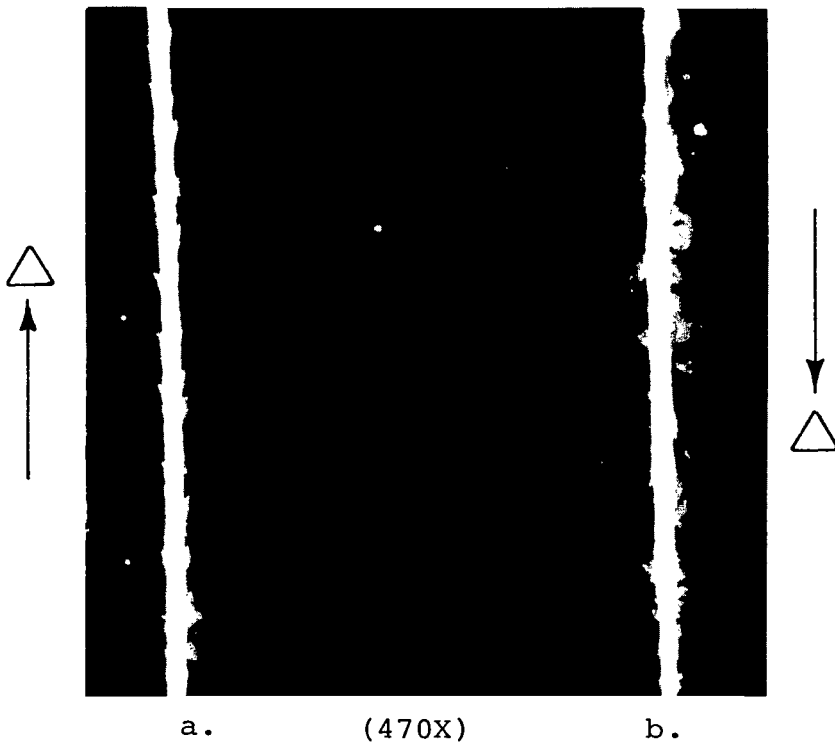


Figure 4.- Direction of tool travel parallel to (110) orientation flat is not optional for good scribing



(470X)

Figure 5.- Photograph corresponding to sketch in Figure 4(a)

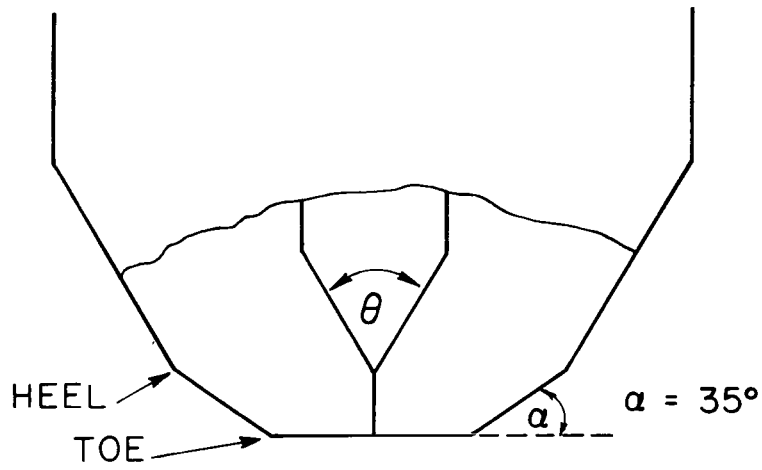


a.

(470X)

b.

Figure 6.- Photograph showing effect of tool travel direction



TOOL I $\theta = 60^\circ$
 TOOL II $\theta = 45^\circ$
 TOOL III $\theta = 33^\circ$

Figure 7.- Tool geometry

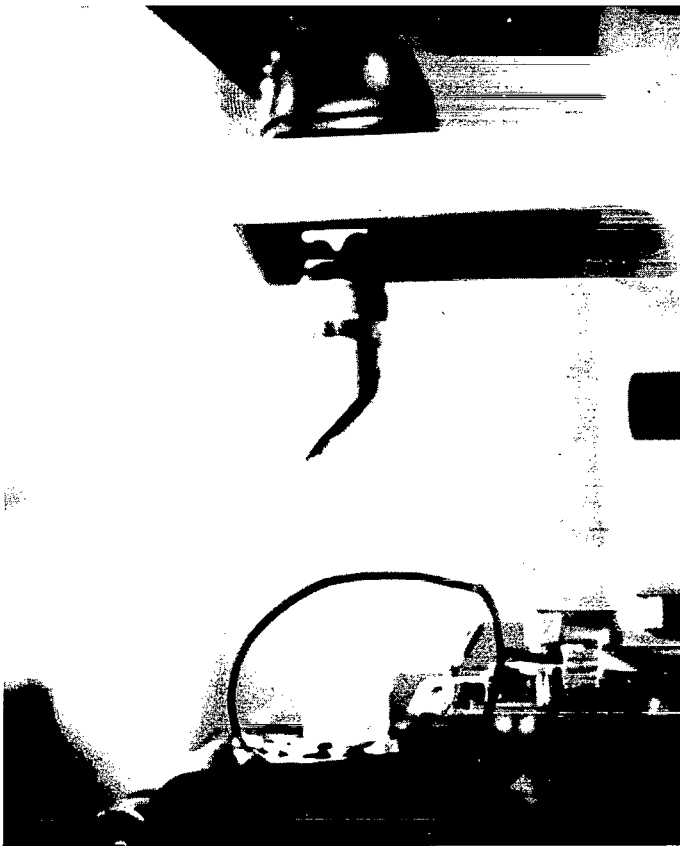


Figure 8.- Scribe angle fixture

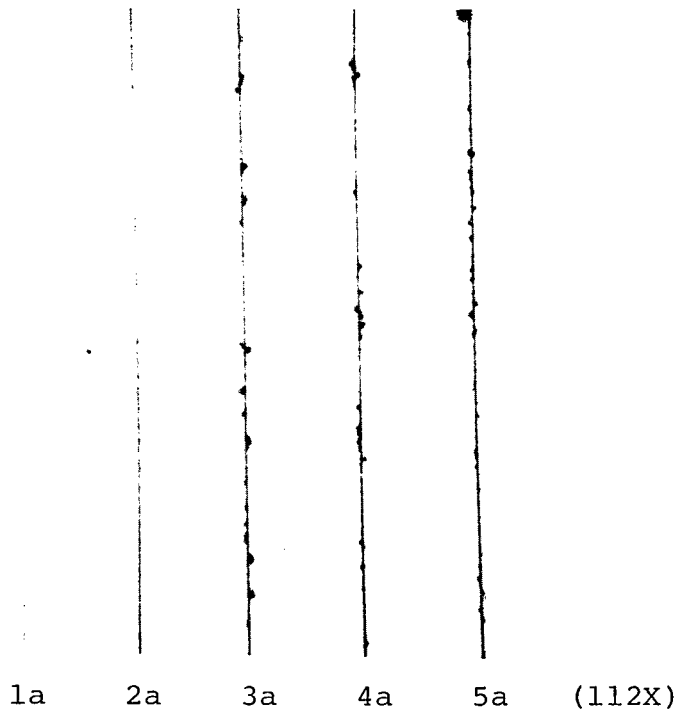


Figure 9.- Photo-
graph of scribe
lines made at dif-
ferent scribing
angles.

Scribe Angle:

1a = 36°

2a = 38°

3a = 40°

4a = 42°

5a = 44°

Force = 6.5 g

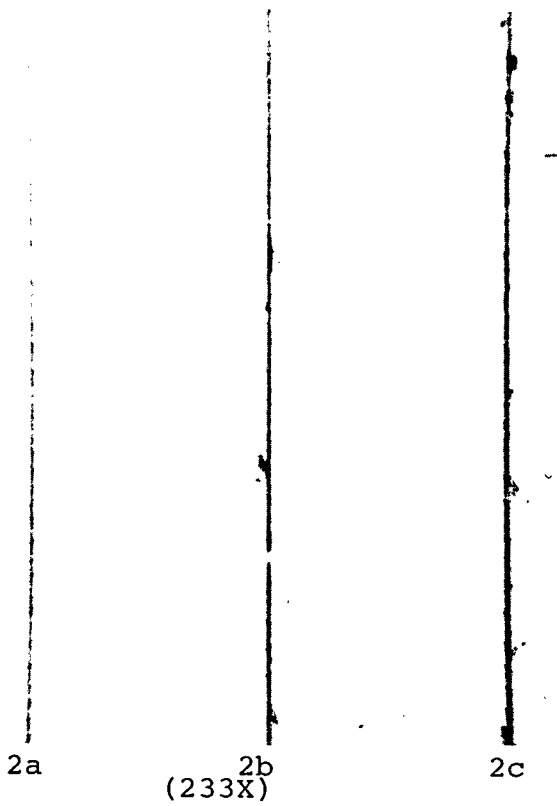


Figure 10.- Scribe line made
with Tool I, $\theta = 60^\circ$

Scribe Angle = 38°

Force 2a = 6.5 g (accepted)

2b = 10 g (rejected)

2c = 15 g (rejected)

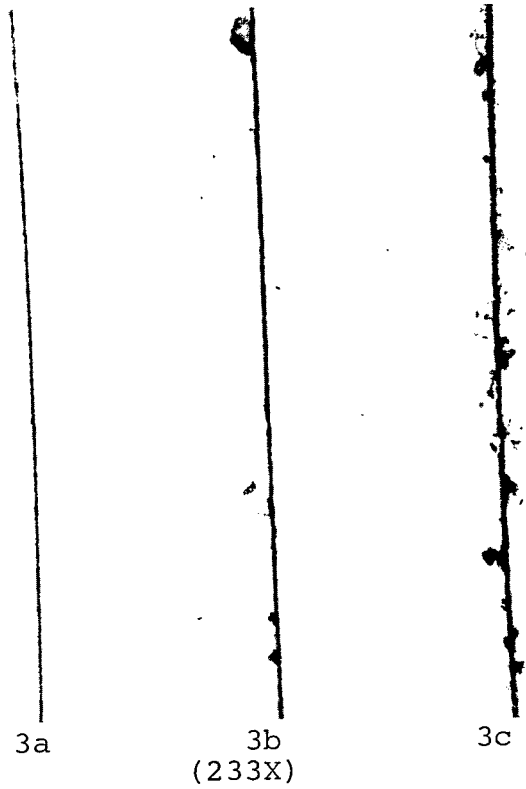


Figure 11.- Scribe line made
with Tool II, $\theta = 45^\circ$
Scribe Angle = 40°
Force 3a = 6.5 g (accepted)
3b = 10 g (rejected)
3c = 15 g (rejected)

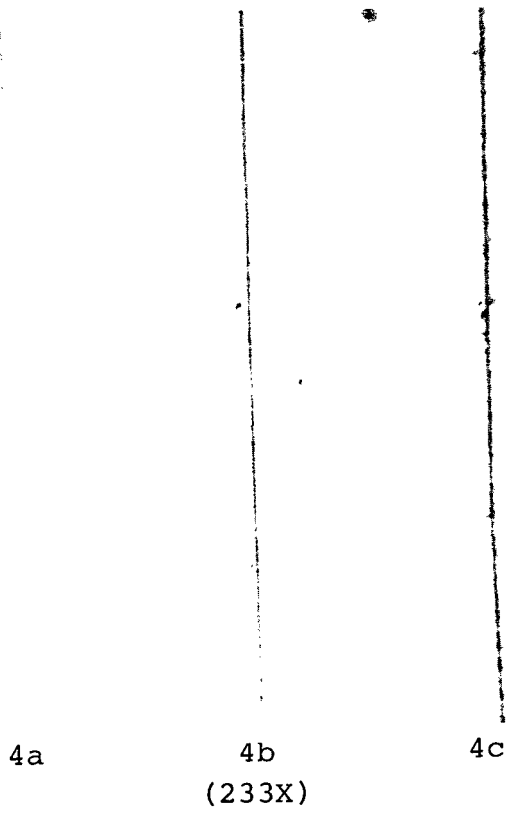
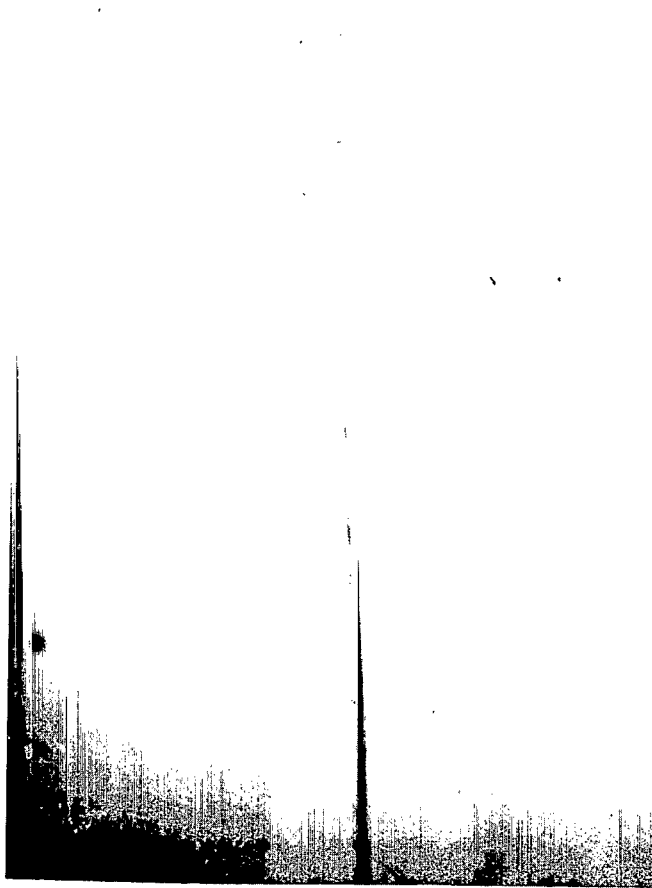
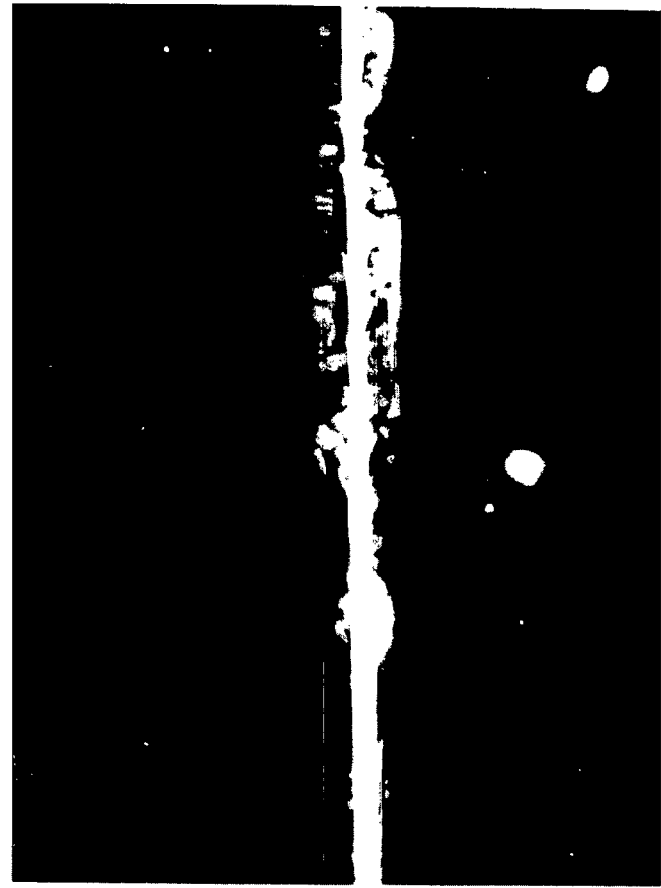


Figure 12.- Scribe line made
with Tool III, $\theta = 33^\circ$
Scribe Angle = 38°
Force 4a = 6.5 g (accepted)
4b = 10 g (accepted)
4c = 15 g (rejected)



a. (470X)



b. (470X)

Figure 13.- Scribe line under normal illumination (a), and under dark field illumination (b)

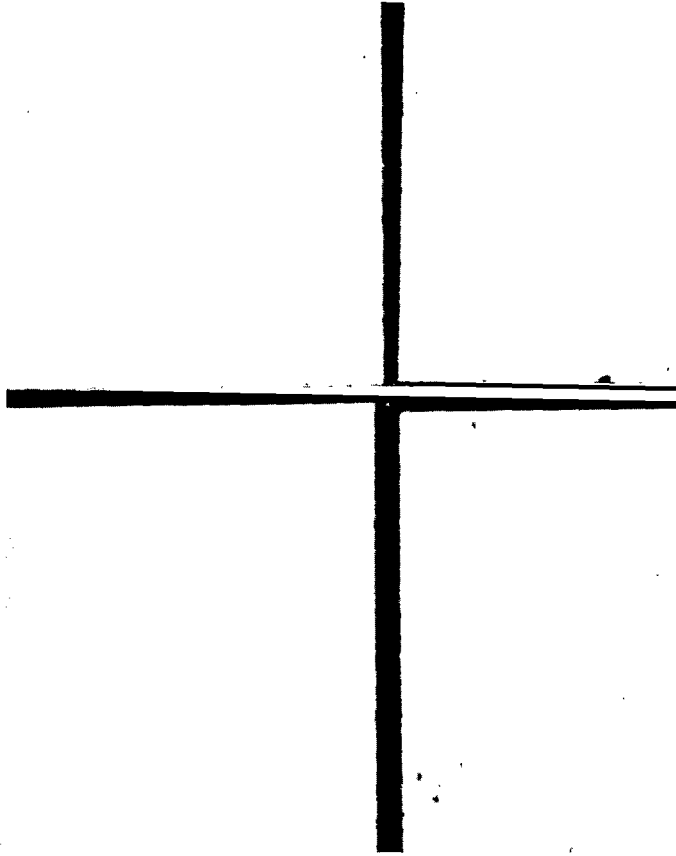


Figure 14.- $\theta = 33^\circ$; scribe angle = 44° ; force = 35 g (98% yield at dice separation)

(112X)

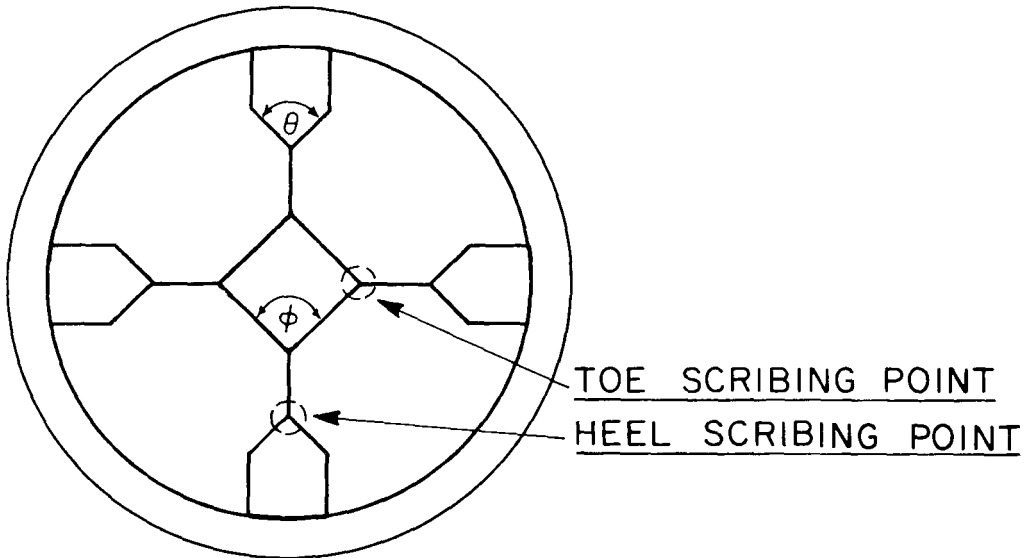
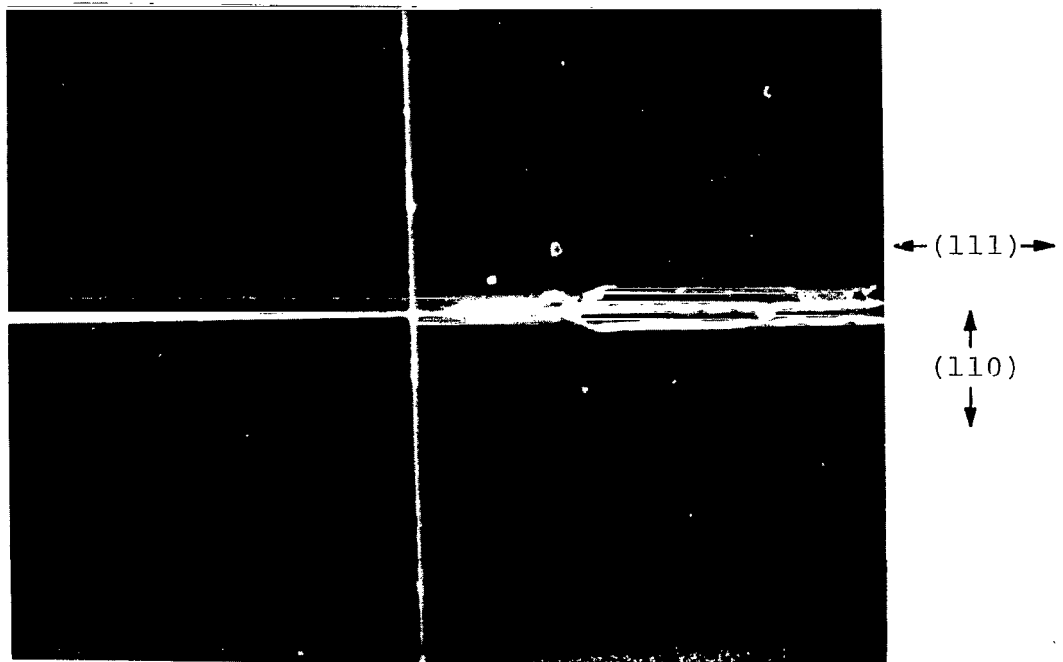


Figure 15.- End view



Figure 16.- Direction of tool travel →



(470X)

Figure 17.- Photograph showing effect of toe scribing along (111) and (110) planes

TABLE I

PERCENT GOOD DICE YIELD AS A FUNCTION OF TOOL GEOMETRY, FORCE,
AND SCRIBING ANGLE

Force, g	Scribing Angle				
	36°	38°	40°	42°	44°
$\theta_{\text{I}} = 60^\circ$					
6.5	76%	98%	X	X	X
10	100%	X			
15	100%	X			
20	98%	X			
$\theta_{\text{II}} = 45^\circ$					
6.5	100%	100%	98%	98%	98%
10	98%	98%	X	X	X
15	X				
$\theta_{\text{III}} = 33^\circ$					
6.5	98	95	98	94	X
10	100	100	100	98	X
15	100	X	X	X	X
20	X				50
35					98
40					X