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Multi-Wire Slurry Wafering Demonstrations

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ABSTRACT

A series of ten slicing demonstrations on a multi-wire slurry saw, manufactured by Yasunaga Engineering Company of Japan and distributed by GEOS Corporation of Stamford, Connecticut, was made to evaluate the silicon ingot wafering capabilities. The results revealed that the present sawing capabilities can provide usable wafer area from an ingot 1.05 m^2/kg (e.g. kerf width 0.135 mm and wafer thickness 0.265 mm). Satisfactory surface qualities and excellent yield of silicon wafers were found. One drawback is that the add-on cost of producing wafer from this saw, as presently used, is considerably higher than the systems being developed by Varian and Crystal Systems for the Low-cost Silicon Solar Array Project (LSSA), Task II, primarily because the Yasunaga saw uses a large quantity of wire. The add-on cost can be significantly reduced by extending the wire life and/or by reuse of properly plated wire to restore the diameter.

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SECTION I

INTRODUCTION

In the present solar cell technology, the most efficient solar cells are produced from single crystal, defect-free silicon wafers. The wafering technique to produce silicon wafers from a single crystal ingot becomes one of the important considerations for Low-cost Silicon Solar Array (LSSA) project, in that minimum kerf loss is required to achieve the required sheet cost. The conventional cutting techniques, such as O.D. saws and I.D. saws, do not appear capable of meeting the low kerf requirements. Efforts are underway to develop and evaluate several multi-sawing techniques, such as the multiblade slurry sawing process (Reference 1) and multi-wire fixed diamond slicing method (Reference 2). A new multi-wire-slurry wafering machine is available and developed for semiconductor manufacturing. Its potential for the use in LSSA project, Task II, needs to be evaluated.

In this report, the results of a series of ten silicon wafering demonstrations on a multi-wire-slurry slicing system by Yasunaga in Japan will be discussed, and the surface damage on the as-sawed wafers will be examined to evaluate the quality of wafers produced by this system.

SECTION II

SAW DESCRIPTION

The saw under evaluation is a multi-wire slurry type, Model No. YQ-100, manufactured by Yasunaga Engineering Company of Japan and distributed by the GEOS Corporation in Stamford , Connecticut. It is also called a "GEOS" saw. This saw is capable of slicing work pieces up to 4x4x4-in. into 250 wafers simultaneously with minimum kerf loss. The overall picture of the saw is shown in Figure 1. The present capabilities and specification of this saw are shown in Table 1. Each wire, from 5000 to 75,000 ft, was wound on a reel, routed around a rock-arm tensioning device, a wire guide cartridge, and then rewound on a take-up reel. The guides are grooved to achieve the desired wafer thickness. The continuous wire forms multiple wire loops around the wire guides.

In operation, the ingot is cemented to a mounting block. The ingot is positioned upon a platform which raises the workpiece to the multiple wires under constant, but adjustable load.

A recirculating, temperatured controlled, abrasive slurry is pumped to the cutting area. Slicing is accomplished by oscillating the multiple wires across the work and flushing away the kerf with the abrasive slurry.

The following working conditions are adjustable over wide ranges to meet the desired specifications:

(1)	Wire diameter	0.08 to 0.5 mm
(2)	Wire Guide Pitch	0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0, 1.1 mm
(3)	Abrasive Material	SiC, Diamond
(4)	Abrasive Particle Size	SiC: 5, 9, 12, 15, 20, 25, 30 μm
(5)	Cutting Pressure	Variable, up to tensile strength of wire
(6)	Wire Feed Rate	42 to 112 m/min
(7)	Multiple Wire Stroke Rate	30 to 80 cycles/min

Optimization of these variables would be required for the reduction of wafering cost in the LSSA project.

SECTION III

DEMONSTRATION RESULTS

In order to evaluate the capability of the multi-wire-slurry saw, a series of ten demonstrations were performed by Yasunaga Engineering Company in Japan through a contractual arrangement with GEOS Corporation. This series of demonstrations was conducted under conditions specified by the Jet Propulsion Laboratory (JPL) on material provided by JPL. The silicon ingots, provided by JPL for each demonstration, were approximately 3 in. in diameter and 1 in. long, cut from one Czochralski silicon single crystal supplied by Siltec Corp., Menlo Park, Ca. Several properties of this crystal are as follows:

{100} orientation

P-type, Boron doped

Resistivity at top = 2.7 ohm-cm

Resistivity at bottom = 2.0 ohm-cm

The JPL specified slicing conditions and the performed conditions for each of these ten demonstrations are given in Tables 2 through 11, respectively. The results of these demonstrations are also summarized in Tables 2 through 11. The cutting data reported by Yasunaga are in Appendix A.

SECTION IV

DISCUSSION

A. MINIMUM WIRE SIZE

Demonstration 10 (Table 11) showed that this saw failed to slice silicon with 0.1 mm ($\sim$0.004 in.) diameter steel wire due to wire breakage. The fact that the wire broke very quickly (13 min) raises doubt as to the conclusiveness of this test. Further development is necessary for the use of this size steel wire. On the other hand, tungsten wire may be used if the smaller wire is required and cost goals can be met. The minimum steel wire size for slicing silicon without wire breakage is 0.12 mm ($\sim$0.0047 in.).

B. WAFER YIELD

The wafer yield is defined as a ratio of the unbroken wafer and total number of wafer in the demonstration. The wafer yield ratio for each demonstration is given in Tables 2 through 11 and was generally greater than 95 percent. Demonstration 10 failed because the 0.10 mm diameter wire broke after 13 min of slicing. Effort was made to rewire, however, the wire broke again after 1 hr and 23 min of restart. Demonstration 8 (Table 9) failed because the wire was broken when the supporting dummy glass pieces came loose. Demonstration 5 (Table 6) has a relatively low yield which may have resulted from the excessive surface roughness and thickness variation. These wafer imperfections were found to have resulted from the improper control of wire cutting load. Except these three slicings, all the other slicings have demonstrated the potential of excellent wafer yield of this wafering machine. It should be pointed out that one major drawback is the possible loss of the whole ingot if wire breakage occurs during the slicing. The slicing systems being developed by Varian and Crystal Systems will lose two wafers if any wire breaks. This problem requires investigation to determine the probability of failure and restart potential.

C. KERF THICKNESS

The average kerf thickness for each slicing is given in Tables 2 through 11 and is summarized in Table 13. These values are taken from the data reported by Yasunaga (Appendix A).

As shown in Tables 2 through 11, the kerf thickness depends directly upon the combination of wire and abrasive sizes used for the slicing. Additional variables, such as wire feed rate, abrasive material types, etc, which were suggested (Reference 3) by GEOS as shown in Table 12, were not evaluated in these demonstrations.

In these demonstrations, the effects of wire, abrasive and guide roller pitch sizes on the kerf thickness and wafer thickness are defined in Figure 2 and summarized in Table 13. It is found that:

$$B - C \cong 3D$$

or (1)

$$B \cong C + 3D$$

Therefore, the kerf thickness (B) of a slicing can be estimated from wire size (C) plus three times the abrasive size (D). The wire size is thus the dominant factor controlling kerf loss.

D. WAFER THICKNESS

The average wafer thickness for each slicing demonstration is given in Tables 2 through 11 and is summarized in Table 13. The value is taken from the average wafer thickness data at position 5 (See Figure 3) reported by Yasunaga (Appendix A). The wafer thickness and kerf width of Demonstration 8 were not measured, since the wafering conditions were re-evaluated in Demonstration 9. An effort was made to measure wafer and kerf thicknesses on the ingot for Demonstration 10 by optical microscopy. It was found that the average wafer thickness and kerf width were 0.250 and 0.13 mm, respectively. Wafer thickness of a slicing should be related to guide roller pitch size and kerf thickness. This relationship can be illustrated in Figure 2 and expressed as:

$$E = A + B \qquad (2)$$

or

Wafer thickness + kerf thickness = Roller Pitch Size

The slicing results, as shown in Table 13, are reasonably in agreement with the relationship of Equation 2. By substitution of Equation 1 into 2, one finds that

$$A \approx E - (C + 3D)$$

Therefore,

Wafer thickness = Guide Roller Pitch Size
- Wire Diameter
- 3 Abrasive Particle Size

The minimum pitch size of the guide roller presently available is 0.4 mm (15.75 mils). Special finer pitch rollers would require development and evaluation. If we use a 0.12 mm diameter wire and 0.005 mm abrasive on 0.4 mm guide rollers, we will obtain a wafering of

Kerf width = 0.135 mm (5.3 mils)

and Wafer thickness = 0.265 mm (10.4 mils)

These values exceed the present sawing capabilities of Varian and Crystal System, and provide wafers at 1.05 m^2/kg.

E. WAFER THICKNESS VARIATION ON LOCATION IN INGOT

Since the ingot is sliced by one continuous wire which forms multiple wire loops around the wire guide, the wafers at the front side are sliced by the fresh wire while the wafers at the rear side are sliced by the worn wire. Therefore, the wafers at the front have the potential of being thinner than those at the rear side of the ingot.

The slice thickness data provided by Yasunaga (Appendix A) indicated no appreciable wafer thickness variation as a function of the location in ingot slicing. Considerable thickness variation of wafers was found in Demonstration 5, but this variation does not correlate to the wire wearing as discussed above. Neverthless, the effect of wire wear on the wafer thickness variation (if existent) can be corrected by the programmed pitch distance of the guide roller.

F. WAFER TAPER

In each ingot slicing demonstration, the wafer thickness was determined on five locations on the selected wafers for determining the taper. The locations of thickness measurements are shown in Figure 3. The measured data are provided by Yasunaga in Appendix A. The average value of selected 10 to 13 wafers at each location of thickness measurement for each slicing demonstration is given in Table 14. The results indicate that the wafer taper is not appreciable. It should be pointed out that variations in the wafer thickness did not correlate with location on the wafers. The minimum wafer thickness can occur at the top, bottom or the middle of the slices. The wafer taper in Demonstrations 5 and 7 was found to be approximately 0.020 mm in some wafers. However, in all the other demonstrations the taper was approximately 0.005 mm or less.

G. SURFACE QUALITY

As shown in Table 12, GEOS reported that the dominant factors affecting the surface quality of wafers are:

(1) Wire diameter tolerance

(2) Wire stroke rate

(3) Abrasive material

(4) Abrasive grit size

(5) Abrasive size tolerance

(6) Cutting pressure

Based on these factors, visual observation (macro) and optical microscope examination as well as scanning electron microscopy were utilized to examine the surface quality of wafers for various cutting conditions. The results of these examinations are as follows:

1. Visual Observation (Macro)

(1) Abrasive grit size appears to have the most significant effect on the surface condition of wafers. Demonstrations 4 and 5 were

sliced by 5μm (#3000 grit) SiC abrasive while all the other ingots were sliced by 10μm (#1500 grit) SiC abrasive. The macro surface finish on the wafers of Demonstrations 4 and 5 should be finer than those sliced by 10μm abrasive. However, visual observation showed the opposite. A considerably greater amount of cutting marks were observed on the wafers of Demonstrations 4 and 5 than those of other ingots. Figure 4 shows the typical cutting marks on the wafers of Demonstration 5.

(2) All the wafers sliced by using 10μm SiC abrasive have an excellent surface quality, except some minor sawing marks were found on wafers in Demonstrations 7 and 9. Some sawing marks shown on the wafers of Demonstration 7 at the area of the end of slicing may be due to some unexplained hesitations of wire at that point, as shown in Figure 5. A wire cutting mark was found on the wafers of Demonstration 9 at approximately 18 mm depth from the starting point. This mark was reported to result from the abrupt change of wire load (cutting pressure). Therefore, uniform control of wire loading is an important factor affecting the macro surface finish of the wafer.

The macroscopic surface roughness of several demonstrations was measured by a surface contour analyzer.* The analyzer was traced along the diameter of a wafer in the cutting direction, perpendicular to the wire cutting marks. The typical surface roughnesses of Samples 1-15, 5-45, 7-7 and 9-5 are shown in Figures 6, 7, 8 and 9, respectively. As shown in Figure 6, the maximum irregularity at the center area of wafer 1-15 is approximately 9μm. Figure 7 reveals the surface condition of Specimen 5-45 to have severe irregularities. The worst roughness occurred at center area of the wafer to be 70μm. Figure 8 shows a taper of 22μm over a distance of approximately 10 mm at the lower half of the Wafer 7-7. The sawing marks on this wafer at the area of the end of slicing was found to be approximately 12μm. Figure 9 shows the very good surface finish of Wafer 9-5 except for a step of 25μm at approximately 18 mm from the starting point, where a sawing mark was observed. The importance of these surface contour analyzer results to cell performance is not clear.

2. Microscopic Examination

a. Micro surface Roughness. The microscopic surface roughness of wafers sliced under various cutting conditions was examined by a stereo optical

ORIGINAL PAGE IS
OF POOR QUALITY

*Trade name, "Dektak Tracer," manufactured by Sloan Corp., Sunnyvale, CA.

microscope as well as by scanning electron microscope (SEM). The typical micro surface roughness of Demonstrations 1, 4, and 6 are shown in Figures 10, 11, and 12, respectively, by SEM examination. At the present time, no standard method for determination of the surface roughness has been established. In order to make a comparison on the microscopic surface roughness under various cutting conditions, the average surface irregularity spacing, estimated from SEM photos, of several samples are given in Table 15.

b. Surface Damage. The surface damage of a wafer was examined to determine the depth and nature of the saw-induced damage from the multi-wire-slurry slicing process. A method to reveal the damage by angle lapping and Sirtl etching was reported by Digges, et al (Reference 4). Optical microscopy was utilized to examine several selected samples prepared by this method. Their results are given in Table 15. Attempts have been made to relate the surface damage of wafer to the wafering variables. One can find that

Surface Damage = Abrasive size + X

where X is a small value and a function of cutting rate and wire size. Further investigation is necessary to identify these factors. However, present demonstration results imply that the wafer surface damage is approximately equal to one abrasive particle size under normal wafering conditions. The wafer surface damage from this wafering machine appears to be less than those produced by the Varian saw (∿18μm) (Reference 1a). A suggested explanation is illustrated in Figure 13.

H. WIRE WEAR RATE

The wire wear rate of each demonstration was given in the Yasunaga cutting data report (Appendix A). It is summarized as follows:

(1) In Demonstrations 1, 2, 8 and 9, approximately 6 to 7μm reduction in diameter was found by using 10μm abrasive under standard wire loading (∿20 gm/cm/wire).

(2) 5μm reduction in diameter was found by using 5μm abrasive under standard wire loading as in Demonstrations 4 and 5.

(3) Approximately 9μm wearing was found by using 10μm abrasive under 23 gm/cm/wire of wire loading as shown in Demonstrations 3 and 7.

Therefore, the wire wear rate appears to be dependent upon the abrasive particle size and wire loading and independent of the wire size. The larger the abrasive size, the greater wire wear rate will be. A similar effect of wire loading on wearing was found. It can be estimated that the wire wearing is approximately one abrasive particle size at the cutting loads and feed rates used here. Limits of wear rate, at which breakage occurs, were not reached.

The life of the wire is an important factor affecting the total cost of producing silicon solar cells since a major add-on cost in the use of this slicer is the cost of the wire.

N. Mardesich and M. Leipold (Reference 5) made an evaluation of a used wire from a previous silicon ingot demonstration. They found that the reduction in diameter during silicon ingot slicing appears to be the only effect. There is not an accompanying material deterioration or loss in physical properties. They suggested that the wire might be reused at lower loads or be plated to restore the diameter.

I. CUTTING SPEED

As reported by GEOS in Table 12, the dominant factors affecting the cutting speed of slicing are:

(1) Wire Size

(2) Wire stroke rate (cycle rate)

(3) Abrasive material (type of abrasive)

(4) Abrasive grit size

(5) Abrasive size tolerance

(6) Ratio of abrasive to suspendor (abrasive concentration)

(7) Cutting pressure (wire load)

Among these factors, wire stroke rate, abrasive material type, abrasive size tolerance and abrasive concentration in the slurry were not evaluated in these demonstrations. In order to evaluate the effect of wire size, abrasive grit size and cutting pressure (wire load) on the cutting speed of this slicing system, the cutting rate and wire loading versus cutting time of several ingot slicing are plotted in Figures 14 through 19. In these figures, the cutting rate versus wire loading at one-half ingot slicing will be used to make the comparison. The cutting rate per wire load at one-half ingot slicing is summarized in Table 16. These data indicate that greater abrasive size and wire load will increase cutting rate; however, the total cutting time of the demonstrations is not only determined by the cutting rate at half ingot but also by the control of wire load by adding and removal of weights.

It can be summarized that the maximum cutting speed is approximately 8μm/min and 11μm/min for 5 and 10μm abrasive, respectively, under one gm/cm of wire load.

J. SLURRY

The slurry used in the slicing demonstrations consists of SiC abrasive and lapping oil in a specified ratio. The lapping oil was John Crane 3μm lapping vehicle, supplied by Crane Packing Co., Morton Grove, IL. The ratio of abrasive and lapping oil, by weight, for each demonstration is given in Tables 2 through 11. The effect of abrasive concentration in the slurry on the cutting speed and wafer qualities was not examined quantitatively.

The reuse of slurry was evaluated in Demonstrations 6 through 10. The result showed that no deterioration in cutting capability of the reused slurry be found.

K. WAFERING COST

The variables affecting the wafering cost reported by GEOS Corporation are given in Table 12. The most significant add-on cost for this wafering will be the cost of the expendable materials as follows:

(1) Wire

(2) Abrasive

(3) Roller-guide, idler and V

The costs of steel wire, silicon carbide abrasive and rollers are given in Tables 17, 18 and 19, respectively. The cost of wire per cutting area used in the demonstrations is given in Table 20. Since the lives of the abrasive and rollers have not been evaluated, their cost per cutting area cannot be estimated. The total costs of abrasive and rollers as used in the demonstrations are given in Table 20. The present technologies of multiblade-slurry system (Reference 6) and the multi-wire-fixed abrasive system (Reference 7) have estimated the add-on cost to be $\$35.00/m^2$ and $\$11.57/m^2$, respectively. Therefore, the slicing cost ($\$68/m^2$ for wire alone) of the multi-wire-slurry system in its present state is too high. Further evaluation to determine the limits of wire wear as well as means of minimizing it are needed. As mentioned previously, the wire of the Yasunaga saw has the potential of being reused by proper plating to restore the diameter.

SECTION V

SUMMARY AND CONCLUSION

(1) The minimum size of steel wire successfully used in multi-wire slurry demonstrations for silicon ingot slicing without breakage was found to be 0.12 mm (∿0.0047 in.).

(2) The kerf thickness of this sawing can be estimated by one wire diameter plus three times the particle size of abrasive and was demonstrated as low as 0.135 mm.

(3) The wafer thickness of this sawing is estimated by guide roller pitch size minus the kerf width and reached 0.28 mm.

(4) The present capabilities of this slicer can product usable wafer area from an ingot of 1.05 m^2/kg (10 mils wafer thickness with 5 mils kerf loss). This wafering capability is consistent with the objectives of LSSA Task II.

(5) The wafer thickness variation and taper were shown to be consistent with expected cell requirements.

(6) This slicer has demonstrated the potential of excellent wafer yield.

(7) The wafer surface damage is approximately equal to one abrasive particle size under normal wafering conditions.

(8) The results indicate that wire wearing is approximately one abrasive particle size at the maximum cutting load and wire feed rate.

(9) The maximum cutting speed of this slicer is approximately 8μm/min and 11μm/min for 5μm and 10μm abrasive, respectively, under one gm/cm of wire pressure.

(10) The add-on cost of the Yasunaga saw as presently used is considerably higher than the systems being developed by Varian and Crystal Systems for LSSA Task II, primarily since the Yasunaga saw uses a large quantity of wire. The reuse of the wire was not investigated. It is believed that the add-on cost can be significantly reduced by extending the wire life and/or by the reuse of properly plated wire to restore the diameter. By such means, the slicing goal of LSSA Task II might be met.

SECTION VI

RECOMMENDATIONS

From the results of these demonstrations, the multi-wire-slurry slicing machine has been shown to have potential for use of silicon ingot wafering in the LSSA Project, Task II. It is recommended that several important wafering parameters be evaluated as follows:

(1) Determine more completely the wire wear limits, particularly with full size ingots

(2) Evaluate 0.30 and 0.35 mm roller pitch operation

(3) Determine the usability of 0.10 mm wire

(4) Determine abrasive/slurry requirements, limits and costs

(5) Optimize the cutting time as a function of wire and abrasive sizes

(6) Define the proper mounting method for silicon ingot and determine the time required for mounting ingot

(7) Determine the life and cost of minor components such as rollers

(8) Evaluate the cost factors as a function of cutting process parameters and ancillary equipment variables

(9) Modify wiring system for minimizing ingot loss due to any wire breakage and evaluate restart potential

(10) Investigate wire plating.

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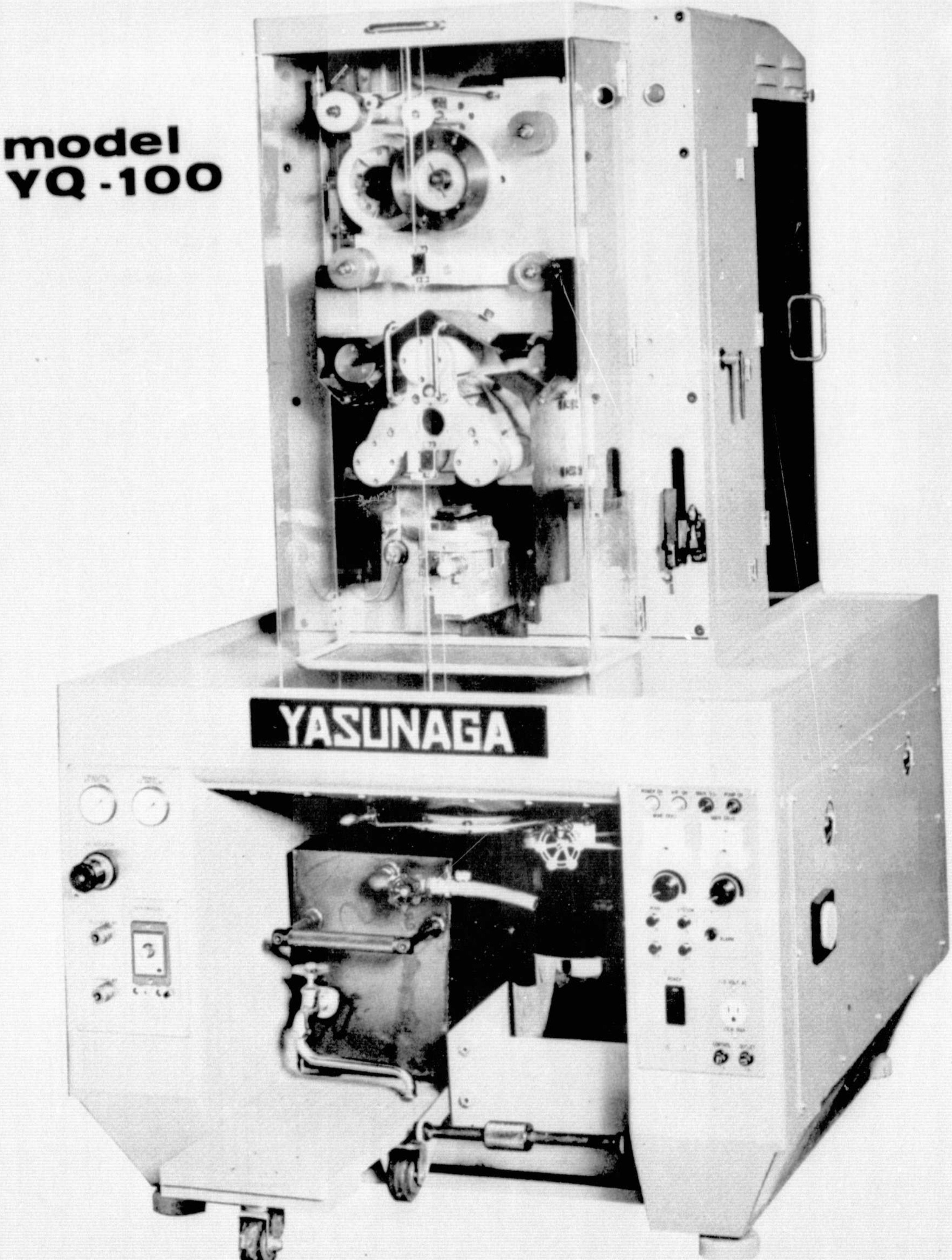

Figure 1. Overall photo of Yasunaga Multi-Wire Slurry Saw

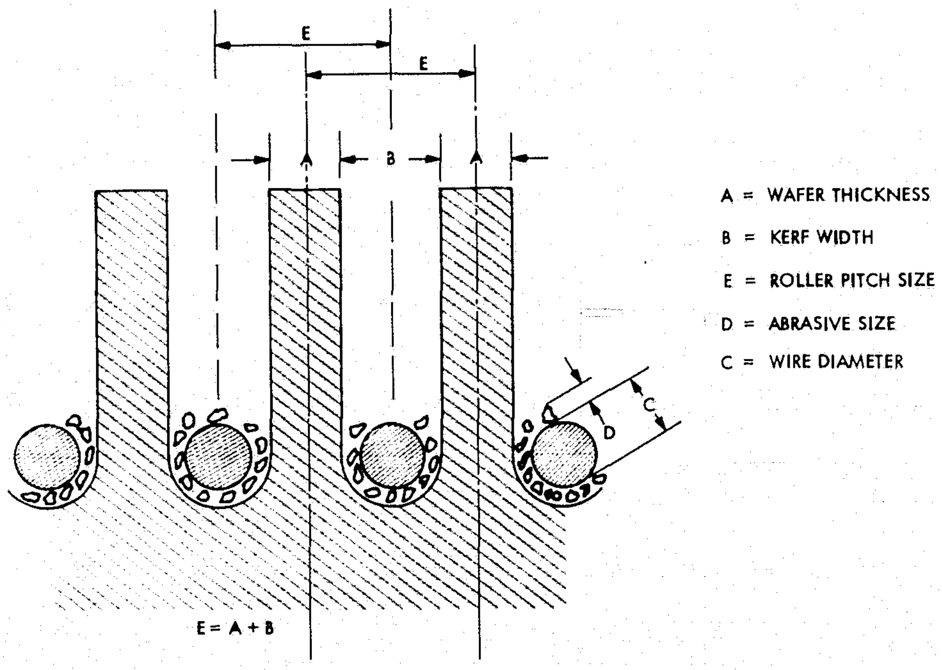

Figure 2. Relationship among wafer thickness, kerf width and guide roller pitch size

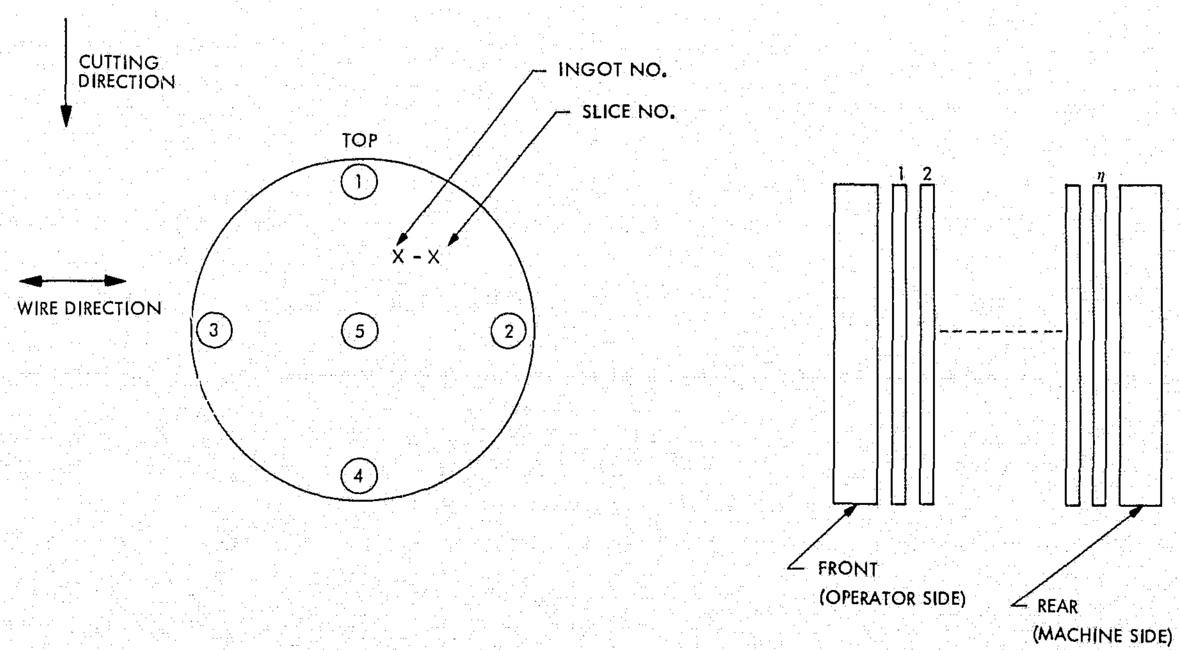

Figure 3. Location of thickness measurement on a wafer

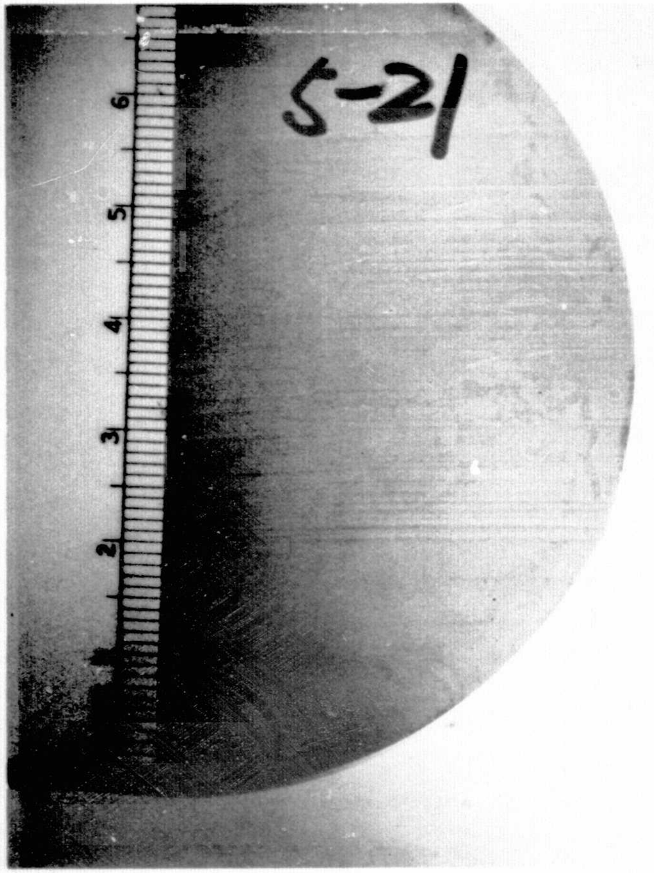

Figure 4. Typical cutting marks on the wafers of Demonstration 5

Figure 5. Typical cutting marks on the wafers of Demonstration 7

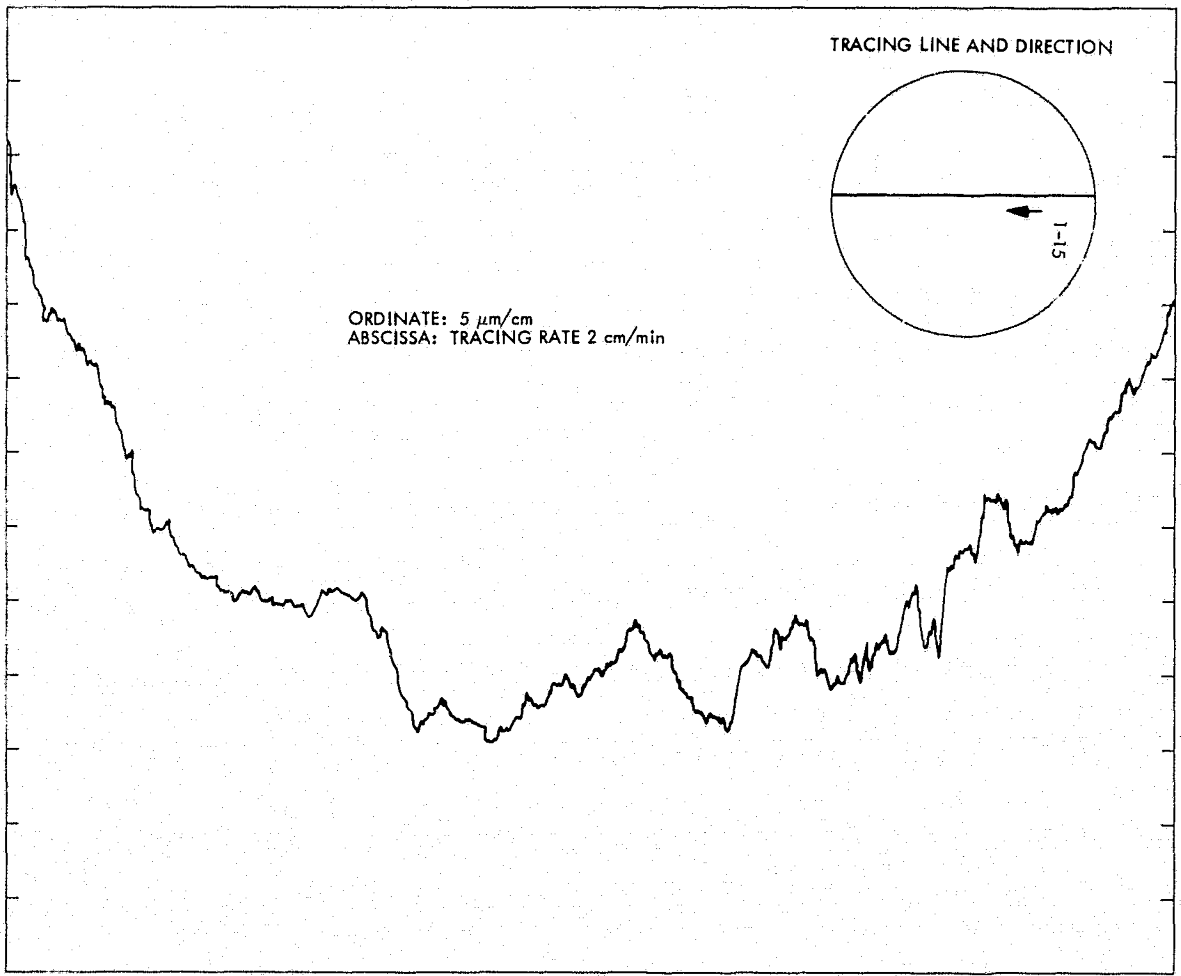

Figure 6. Macroscopic surface roughness of sample 1-15 measured by Dektak Tracer

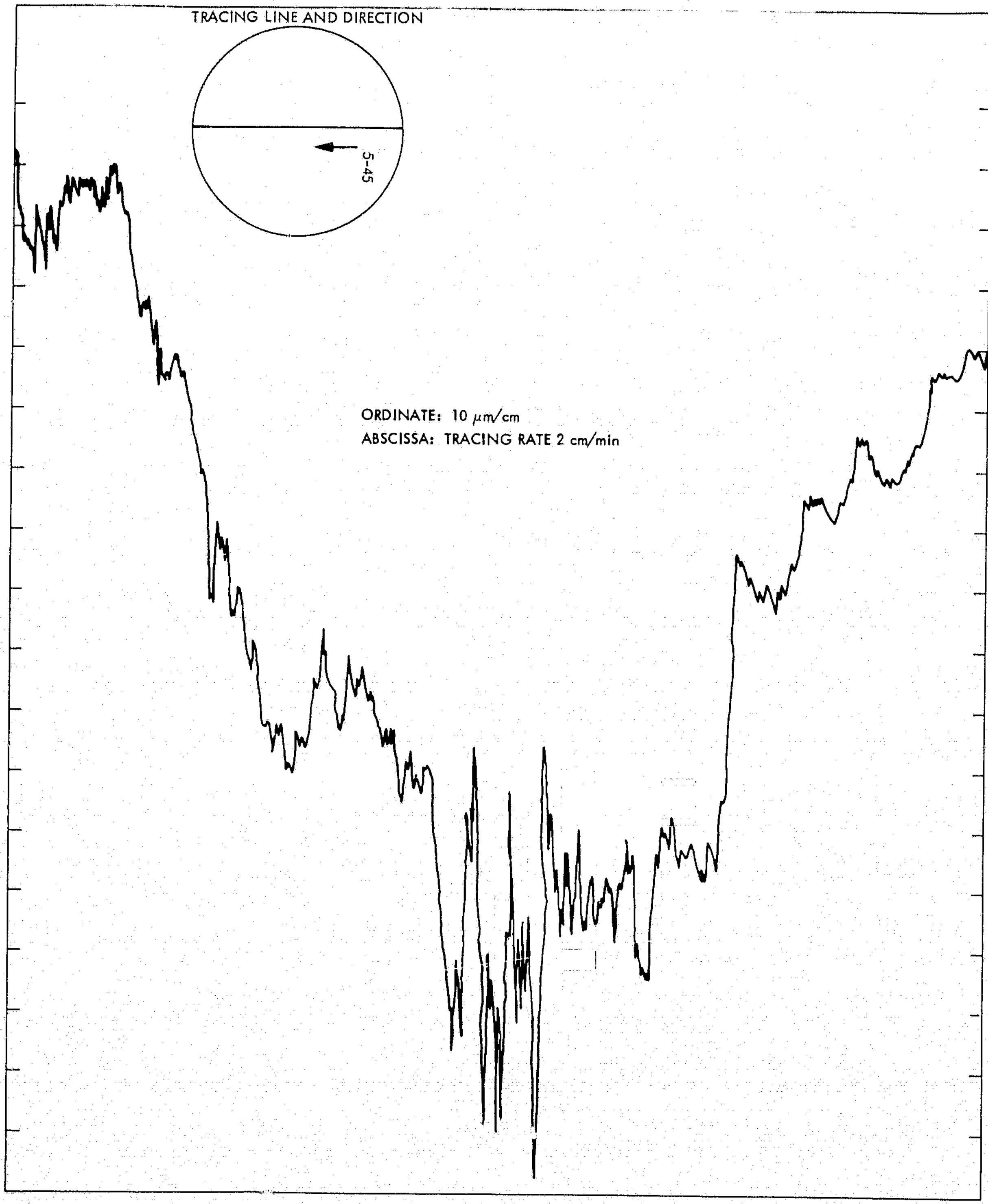

Figure 7. Macroscopic surface roughness of sample 5-45 measured by Dektak Tracer

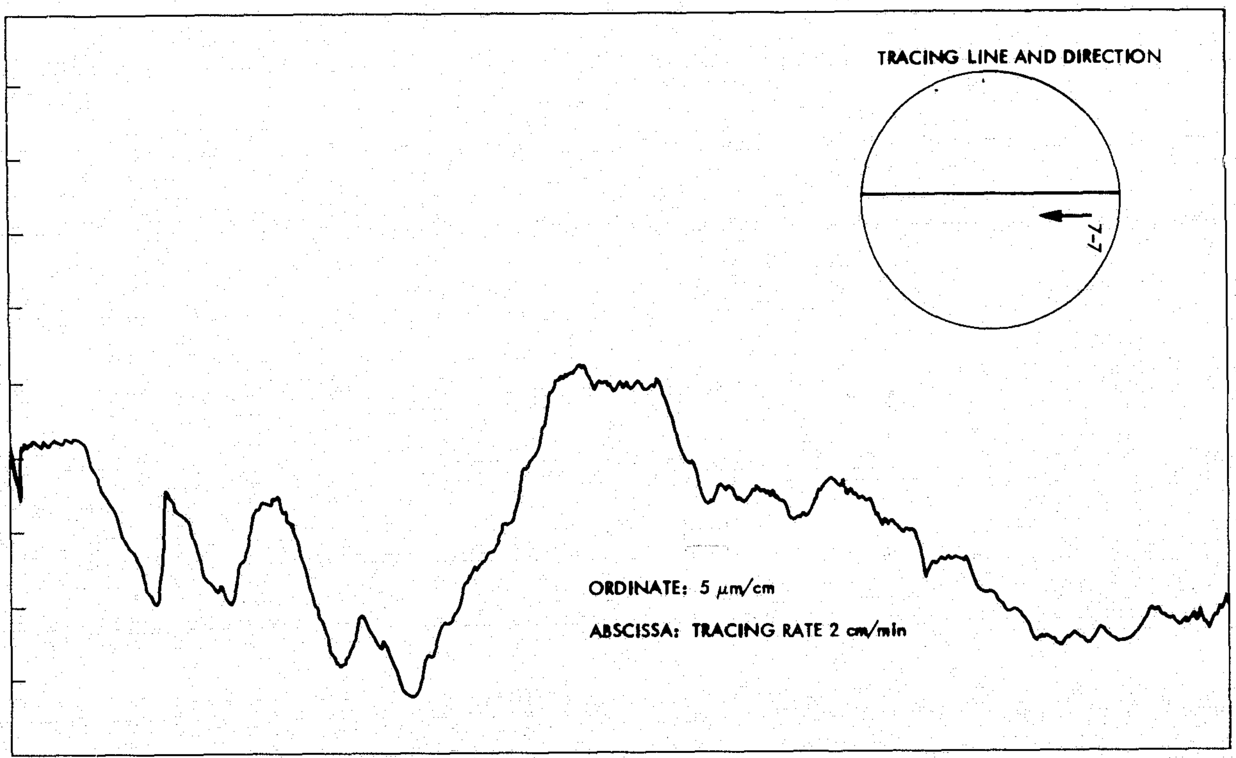

Figure 8. Macroscopic surface roughness of sample 7-7 measured by Dektak Tracer

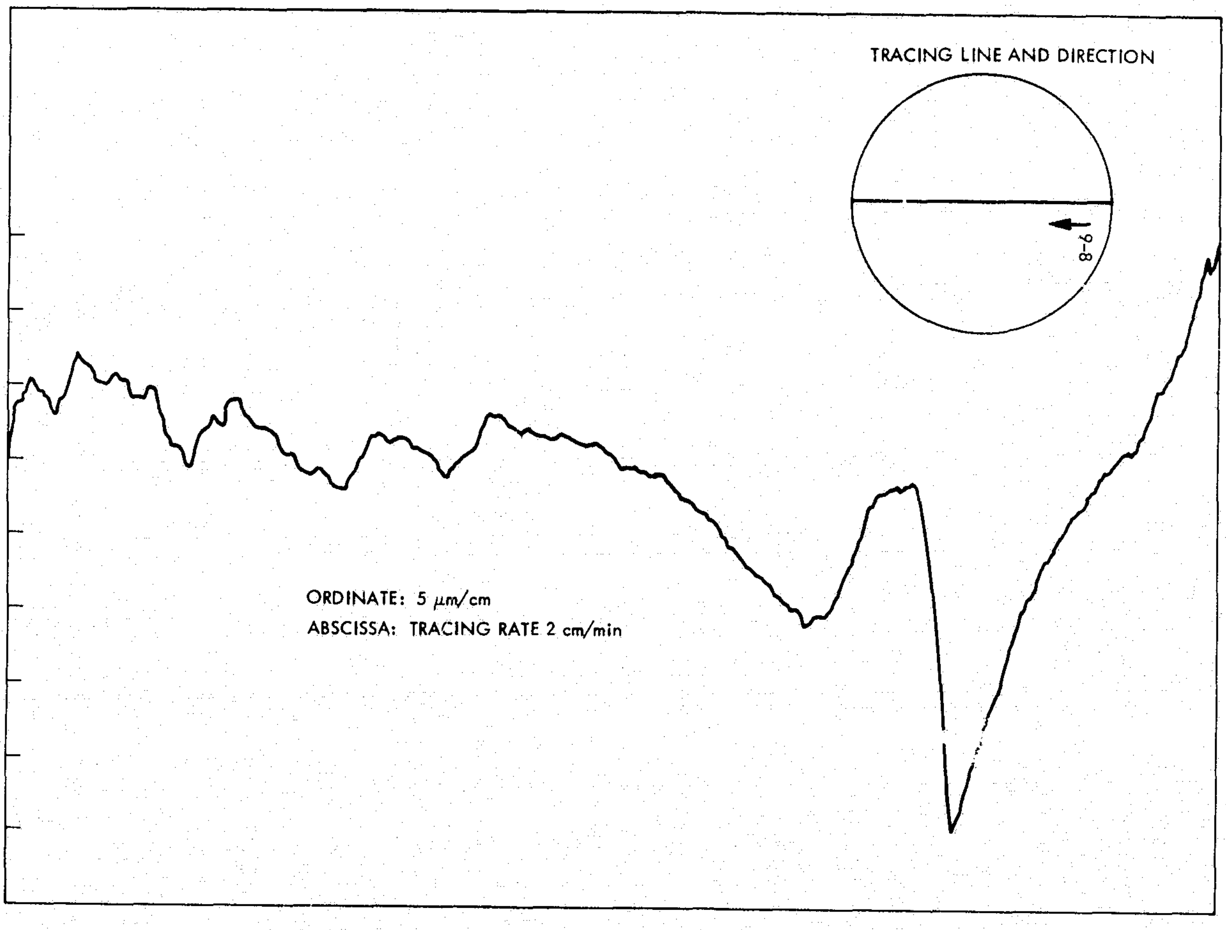

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Figure 9. Macroscopic surface roughness of sample 9-8 measured by Dektak Tracer

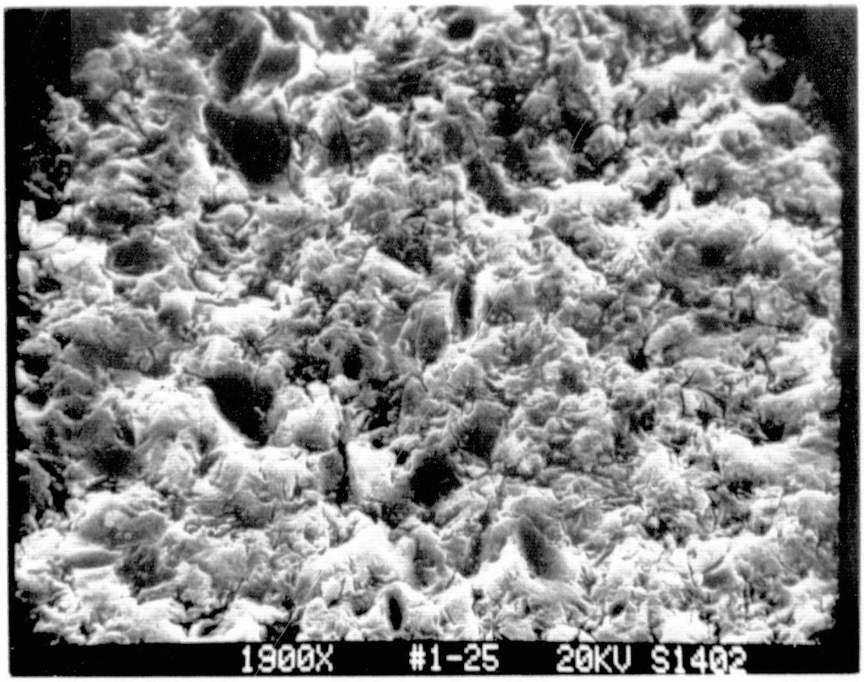

Figure 10. Typical microscopic surface roughness on the wafers of Demonstration 1

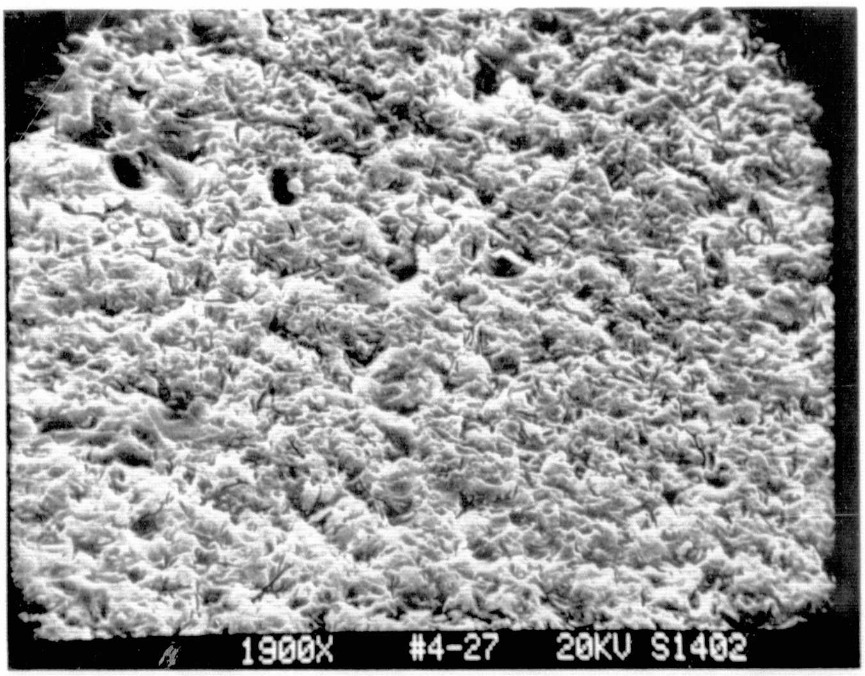

Figure 11. Typical microscopic surface roughness on the wafers of Demonstration 4

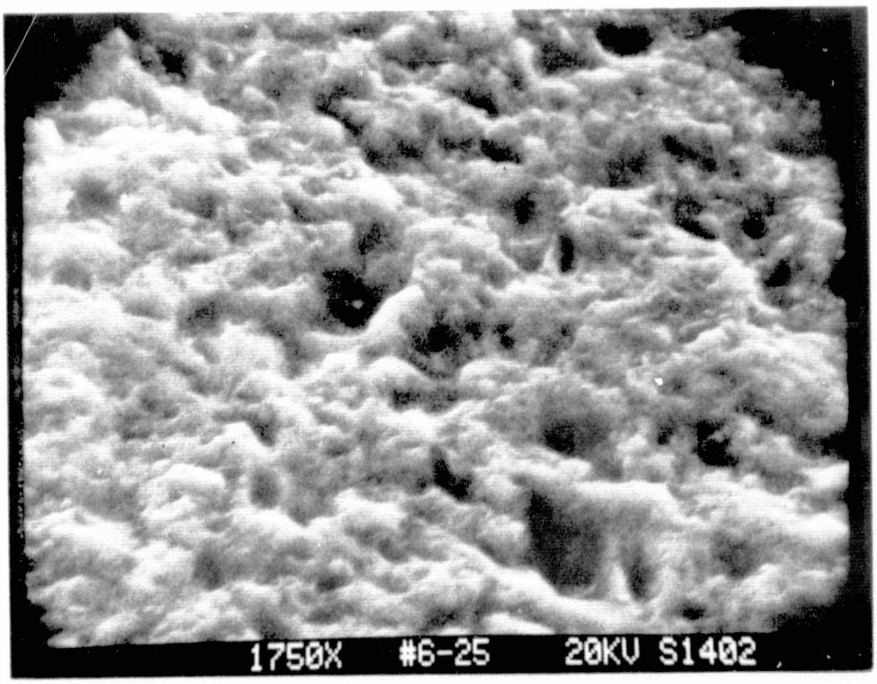

Figure 12. Typical microscopic surface roughness on the wafers of Demonstration 6

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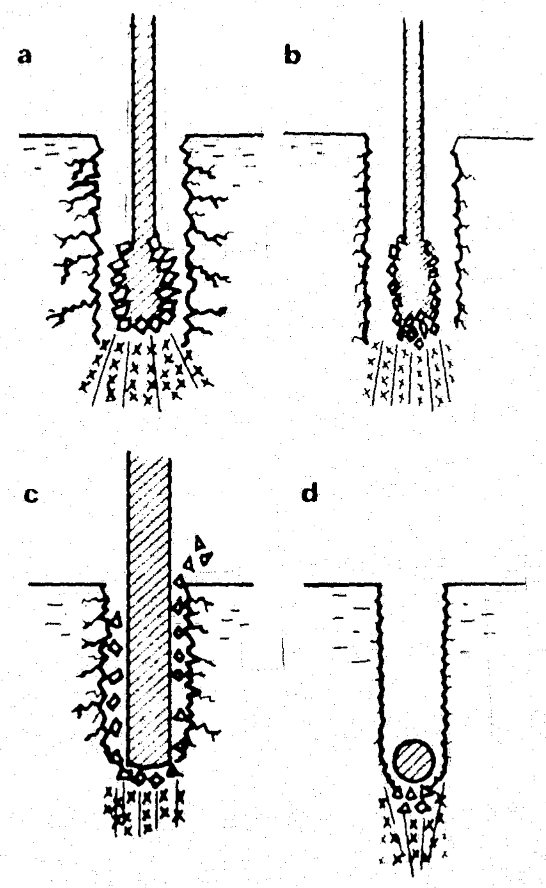

a. Conventional O.D. saws grind on a spreading band from the parallel into the wafer surface. Excessive blade flutter further damages the crystal structure.

b. Properly conditioned I.D. saws are stable and grind in a narrower band producing less than 12 micron sub-surface damage.

c. Band saws grind nearly parallel to the wafer surface, but the subsequent lapping action of the blade propagates deep sub-surface damage.

d. The YQ-100 Oscillating Wire Saw laps in the narrowest band, thereby generating very little crystal damage.

Figure 13. Schematic view of surface damage generation with saws

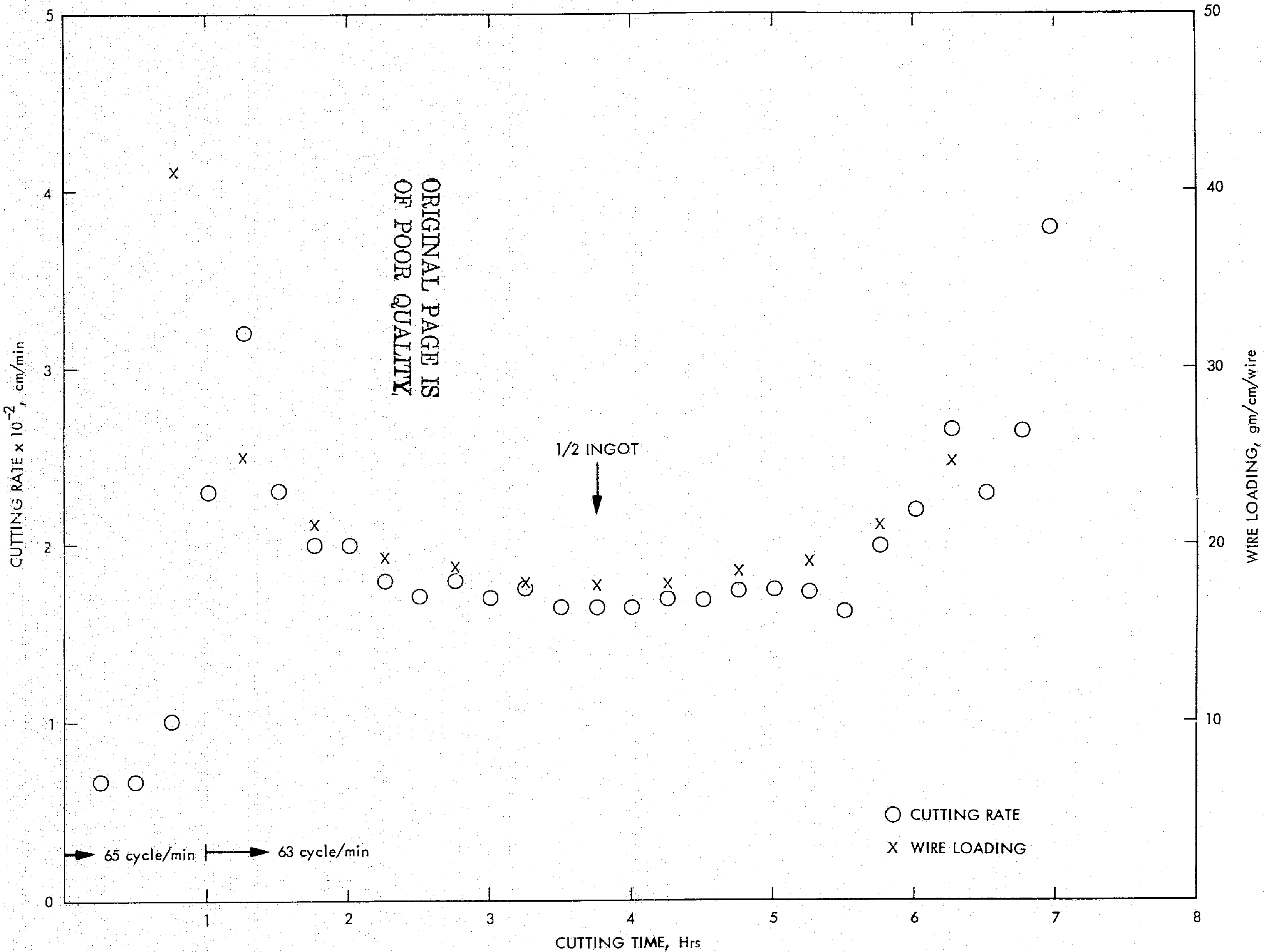

Figure 14. Cutting rate and wire loading vs cutting time of Demonstration 1

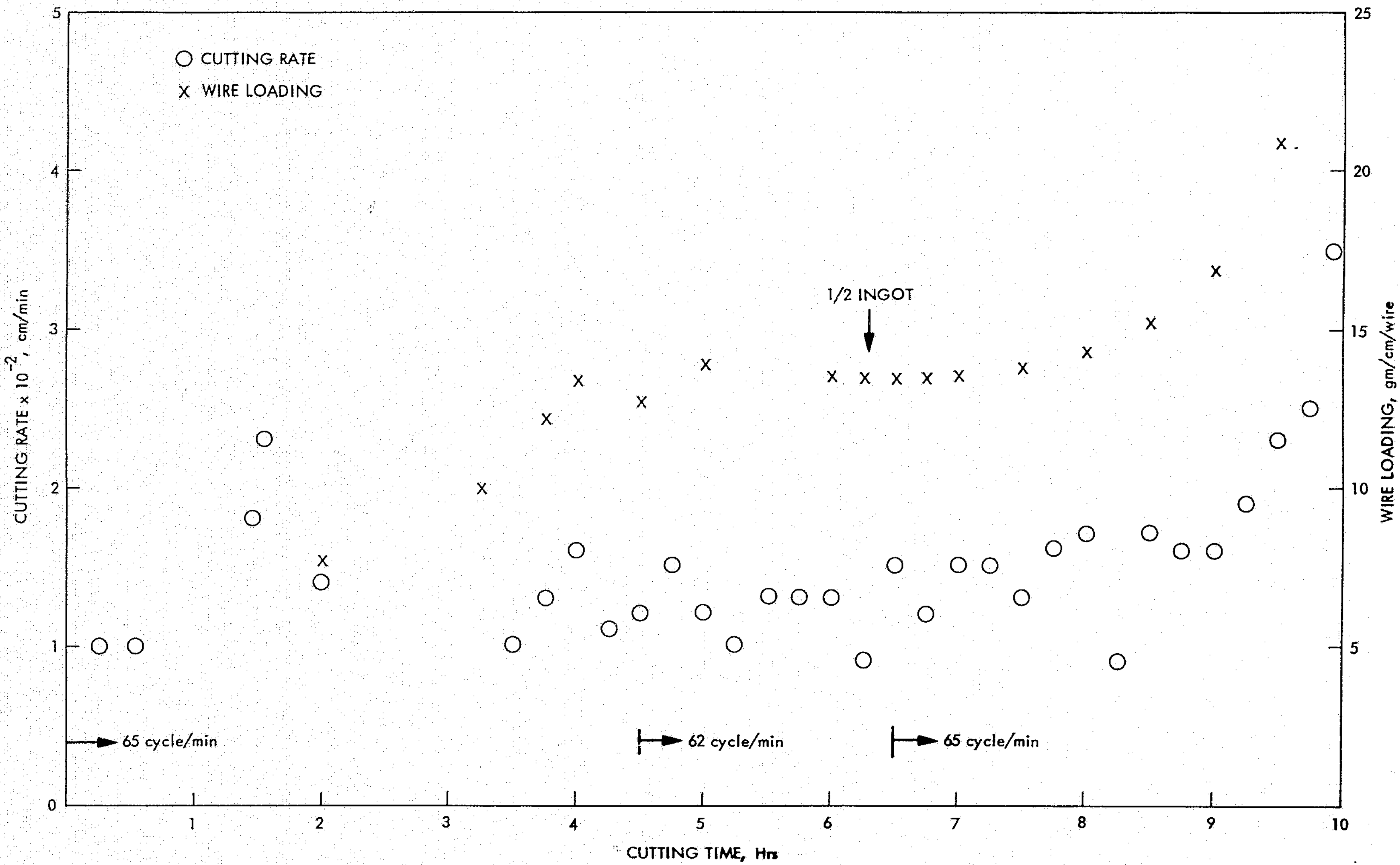

Figure 15. Cutting rate and wire loading vs cutting time of Demonstration 2

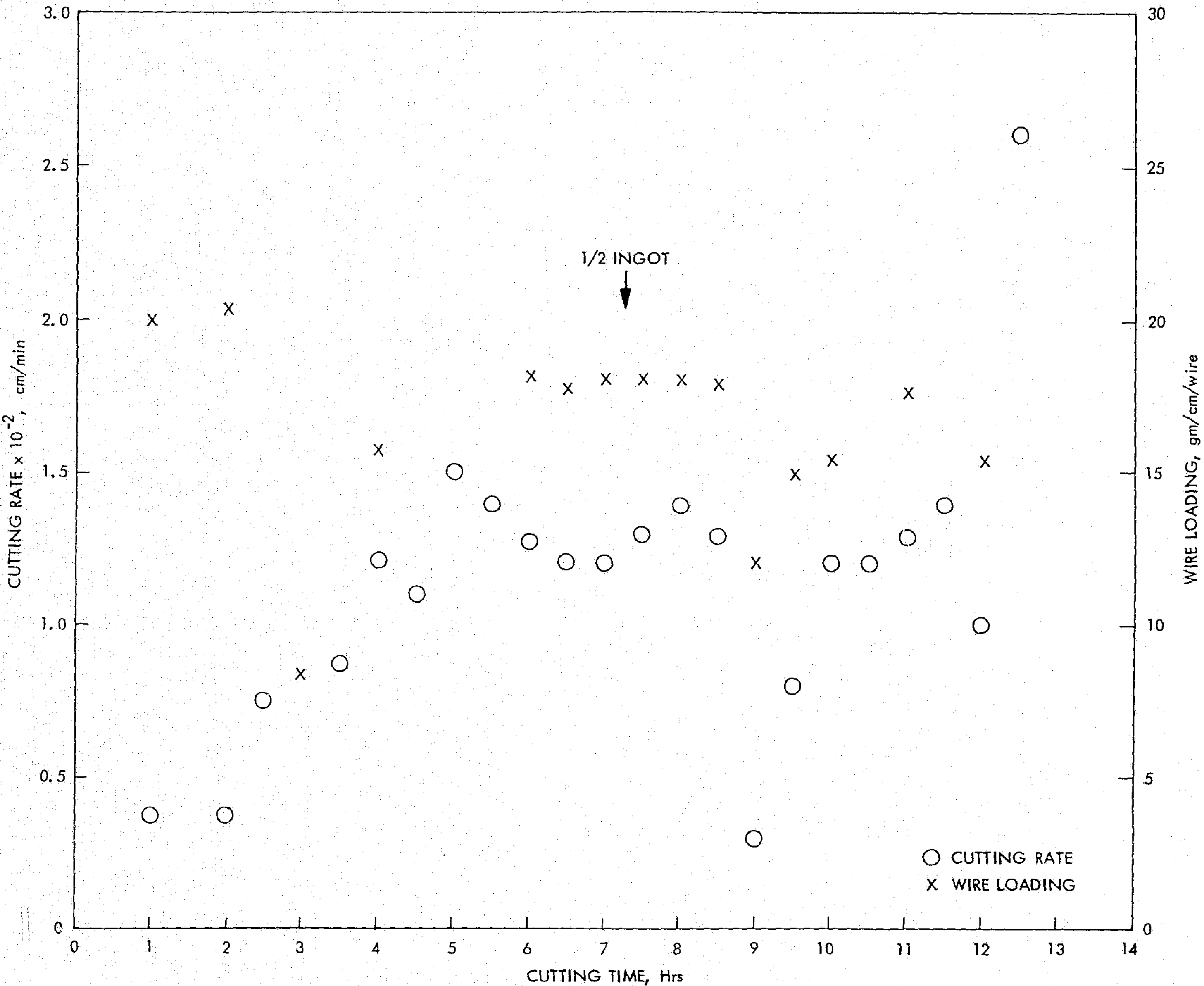

Figure 16. Cutting rate and wire loading vs cutting time of Demonstration 4

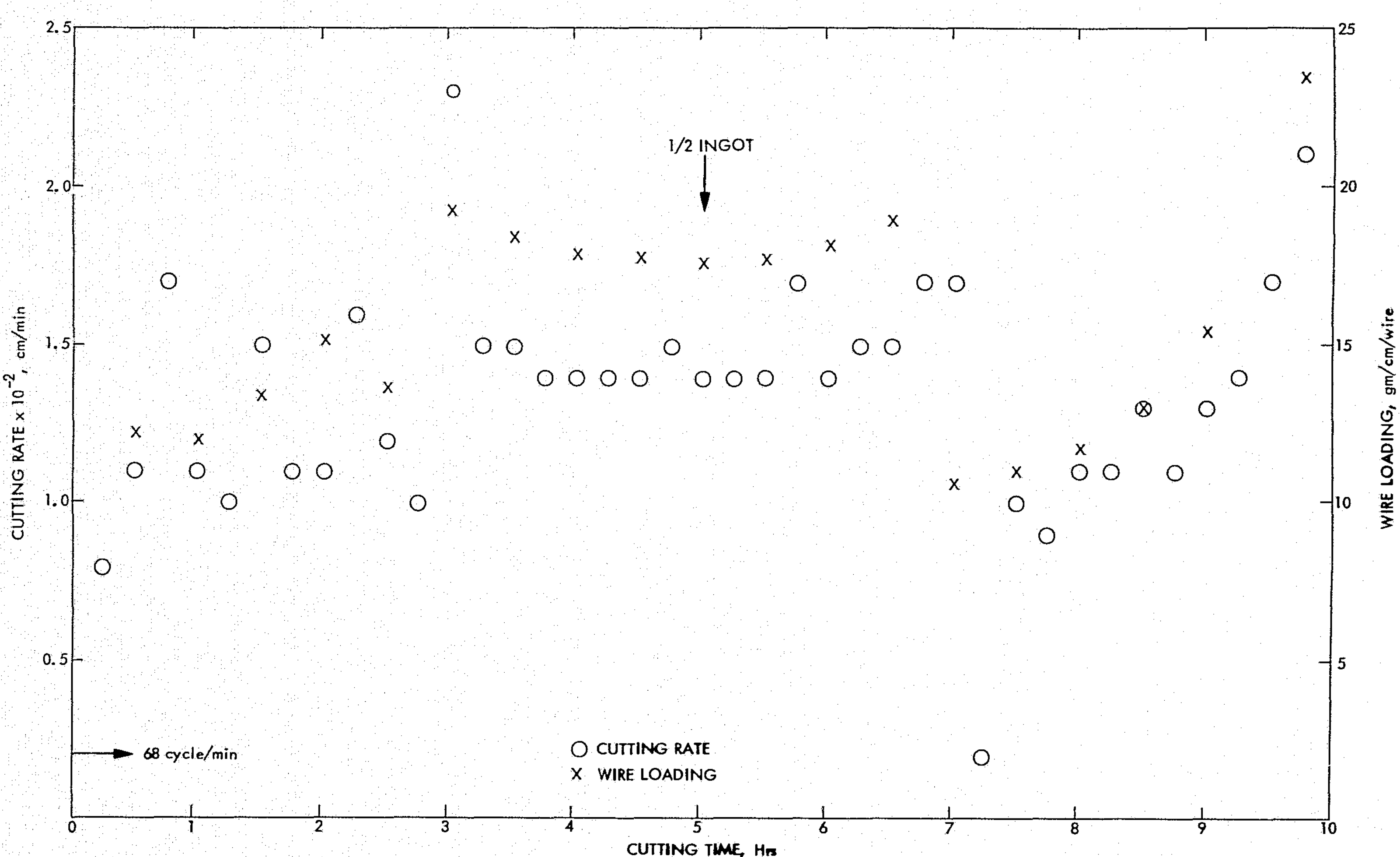

Figure 17. Cutting rate and wire loading vs cutting time of Demonstration 5

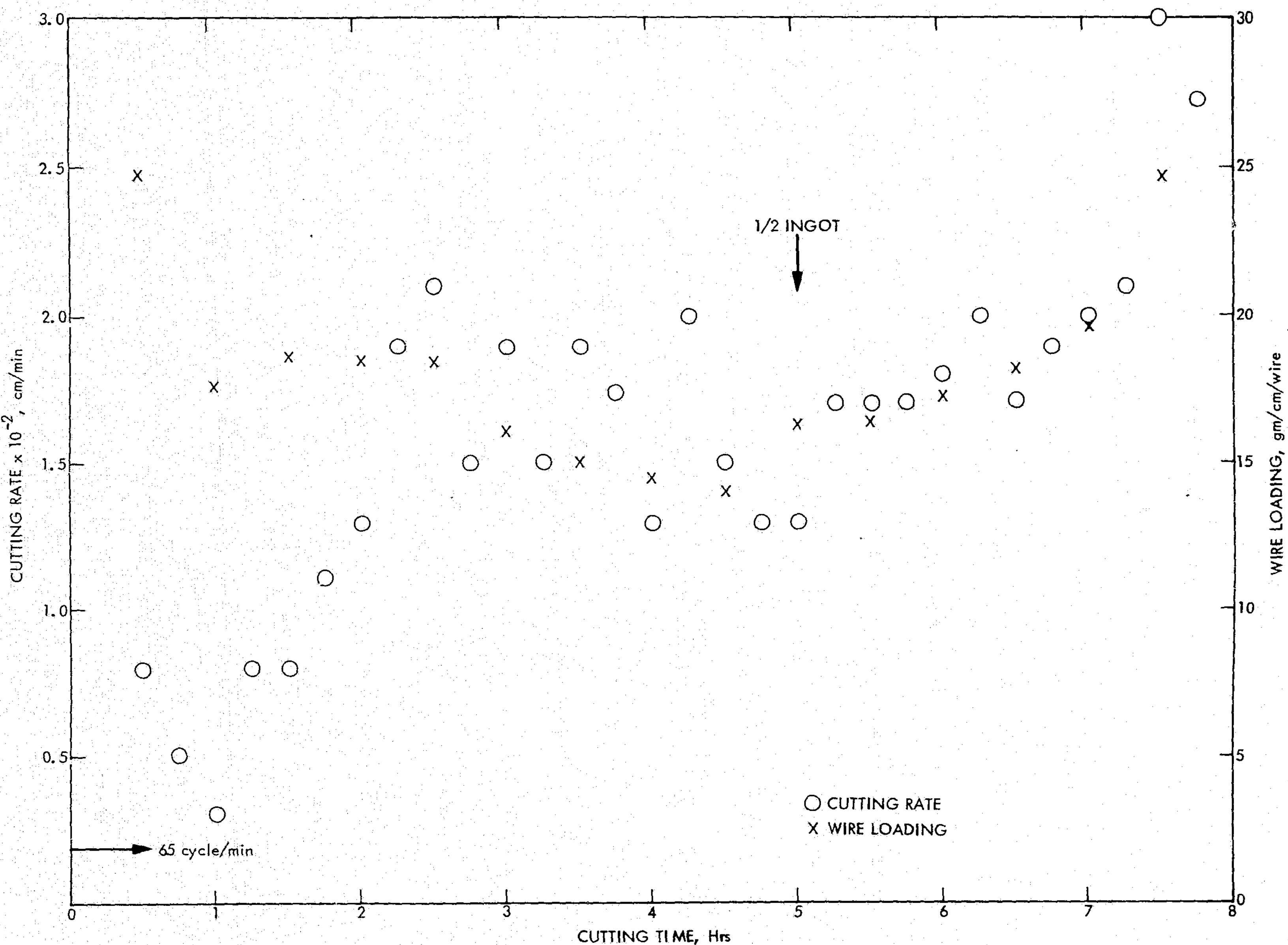

Figure 18. Cutting rate and wire loading vs cutting time of Demonstration 6

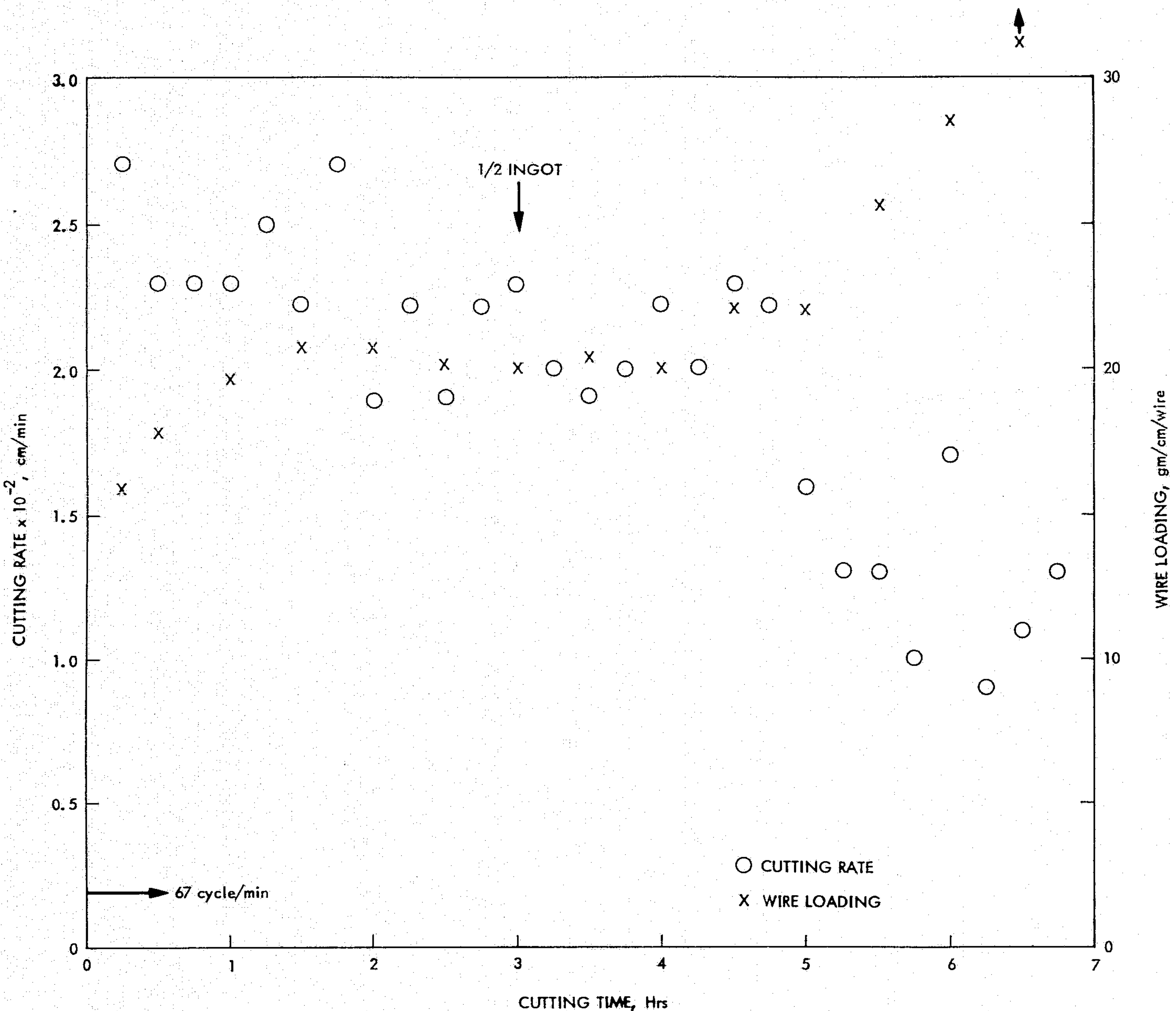

Figure 19. Cutting rate and wire loading vs cutting time of Demonstration 7

Table 1. Specification of Yasunaga Multi-Wire Slurry Saw

Work Size	100x100x100 mm (4x4x4 in.)
Simultaneous Cuts	Up to 250 wafers or slots
Kerf Thinness	Less than 0.1 mm (0.004 in.), using 0.08 mm wire and 5 μm abrasive
Wafer Thinness	Less than 0.15 mm (0.0006 in.)
Accuracy	Thickness: Less than ± 5μm (±0.0002 in.)@75% Less than ±10μm (±0.0004 in.)@ 3σ
	Surface Finish: 2μm using 10μm abrasive
	Parrallelism: 15μm (0.0006 in.) over 50 mm (2 in.)
	Slot Depth: Less than ±0.013 mm (±0.0005 in.)
Wire Guide Pitch	0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0, 1.1 mm (custom pitches available)
Wire	Steel wire from 0.08 to 0.5 mm dia.
Abrasive	SiC: 5, 9, 12, 15, 20, 30μm
Wire Stroke Length	700 mm one direction
Wire Stroke Rate	30 to 80 cycles/min., variable
Wire Speed	42 to 112 m/min. variable
Feeding Speed of new wire	0 to 15 m/min. variable
Motors	Main motor: 0.4 kW variable speed
	Wire Feeding Motor: 0.1 kW variable speed
	Abrasive Slurry Pump: 0.1 kW, 60 l/min.
Power Source	208V, 60 Hz, 3 phase, 20A
Air	1.5 kg/cm^2, 100 l/min.
Dimensions	Width: 1,034 mm (41¼ in.) Depth: 1,125 mm (45 in.) Height: 1,630 mm (64 in.)
Weight	1,400 kg (3,080 lbs)
Cutting Oil	3μm Lapping Oil

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Table 2. Cutting conditions and result of Demonstration 1

Variable Conditions	JPL Specified	Performed
Roller Pitch, mm	0.5	0.5
Wire size, in.	0.005	0.0055 (0.14 mm)
Abrasive size, μm	9	10
Cutting Oil	Std	Crane Lapping Vehicle, 3M
Slurry condition, abrasive/oil	New (Std)	New (1.67/1)
No. slices	Std	48
Wire tension, kg	Std	1.5
Breaking Pt. of wire, kg	Std	4.3
Wire feed rate, m/min	5	10
Wire cycle rate, cycle/min	60	63
Wire load, kg	Std	6.8 max
Unit wire load, gm/cm/wire	—	20

	Cutting Result
Total wire used, m	4150
Total cutting time, hr:min	6:55
Ave. wafer thickness, in.	0.013
mm	0.339
Ave. kerf width, in.	0.007
mm	0.17
Wafer yield, unbroken/total wafer	47/48
Wire wearing, μm	6
Length of wire/cutting area, m/cm^2	1.75

Table 3. Cutting conditions and result of Demonstration 2

Variable Conditions	JPL Specified	Performed
Roller Pitch, mm	0.5	0.5
Wire size, in.	0.004	0.0047 (.12 mm)
Abrasive size, μm	9	10
Cutting Oil	Std	Crane Lapping Vehicle 3M
Slurry condition, abrasive/oil	Reuse from Demo. 1	New (1.67/1)
No. slices	Std	47
Wire tension, kg	Std	1.1
Breaking Pt. of wire, kg	Std	3.2
Wire feed rate, m/min	5	10.3
Wire cycle rate, cycle/min	60	62∿65
Wire load, kg	Std	5 max
Unit wire load, gm/cm/wire	—	15

	Cutting Result
Total wire used, m	6130
Total cutting time, hr:min	9:55
Ave. wafer thickness, in. mm	0.014 0.367
Ave. kerf width, in. mm	0.006 0.15
Wafer yield, unbroken/total wafer	47/47
Wire wearing, μm	6
Length of wire/cutting area, m/cm^2	2.67

Table 4. Cutting conditions and result of Demonstration 3

Variable Conditions	JPL Specified	Performed
Roller Pitch, mm	0.5	0.5
Wire size, in.	0.004	0.0047 (.12 mm)
Abrasive size, μm	9	10
Cutting Oil	Std	Crane Lapping Vehicle 3M
Slurry condition, abrasive/oil	New	Reuse from Demo. 2 + 0.94 kg Abra. + 0.5 kg oil
No. slices	Std	44
Wire tension, kg	Std	1.2
Breaking Pt. of wire, kg	Std	3.2
Wire feed rate, m/min	5	10.5
Wire cycle rate, cycle/min	60	65∿68
Wire load, kg	1-1/3x Demo. 2	7.2 kg max.
Unit wire load, gm/cm/wire	—	23.1

	Cutting Result
Total wire used, m	5050
Total cutting time, hr:min	8:25
Ave. wafer thickness, in.	0.014
mm	0.362
Ave. kerf width, in.	0.006
mm	0.15
Wafer yield, unbroken/total wafer	42/44
Wire wearing, μm	9
Length of wire/cutting area, m/cm^2	2.35

Table 5. Cutting conditions and result of Demonstration 4

Variable Conditions	JPL Specified	Performed
Roller Pitch, mm	0.4	0.4
Wire size, in.	0.003	0.0047 (.12 mm)
Abrasive size, μm	5	5 (#3000)
Cutting Oil	Std	Crane Lapping Vehicle 3M
Slurry condition, abrasive/oil	New (Std)	New (1/1.6)
No. slices	Std	54
Wire tension, kg	Std	1.22
Breaking Pt. of wire, kg	Std	3.2
Wire feed rate, m/min	7.5	12.0
Wire cycle rate, cycle/min	60	68
Wire load, kg	Std	7.6 max.
Unit wire load, gm/cm/wire	—	20

	Cutting Result
Total wire used, m	9000
Total cutting time, hr:min	12:30
Ave. wafer thickness, in.	0.011
mm	0.283
Ave. kerf width, in.	0.005
mm	0.135
Wafer yield, unbroken/total wafer	53/54
Wire wearing, μm	5
Length of wire/cutting area, m/cm^2	3.38

Table 6. Cutting conditions and result of Demonstration 5

Variable Conditions	JPL Specified	Performed
Roller Pitch, mm	0.4	0.4
Wire size, in.	0.003	0.0047 (0.12 mm)
Abrasive size, μm	5	5
Cutting Oil	Std	Crane Lapping Vehicle 3M
Slurry condition	Reuse from Demo. 4	Reuse from Demo. 4
No. slices	Std	54
Wire tension, kg	Std	1.25
Breaking Pt. of wire, kg	Std	3.2
Wire feed rate, m/min	6	11.5
Wire cycle rate, cycle/min	60	68
Wire load, kg	Std	7.6 max
Unit wire load, gm/cm/wire	—	20

	Cutting Result
Total wire used, m	6727
Total cutting time, hr:min	9:45
Ave. wafer thickness, in. mm	0.011 0.287
Ave. kerf width, in. mm	0.005 0.135
Wafer yield, unbroken/total wafer	46/54
Wire wearing, μm	5
Length of wire/cutting area, m/cm^2	2.53

Table 7. Cutting conditions and result of Demonstration 6

Variable Conditions	JPL Specified	Performed
Roller Pitch, mm	0.4	0.4
Wire size, in.	0.003	0.0047 (0.12 mm)
Abrasive size, µm	9	10
Cutting Oil	Std	Crane Lapping Vehicle 3M
Slurry condition, abrasive/oil	New	New (1.53/1)
No. slices	Std	54
Wire tension, kg	Std	1.2
Breaking Pt. of wire, kg	Std	3.2
Wire feed rate, m/min	7.5	10
Wire cycle rate, cycle/min	60	65
Wire load, kg	Std	7 max
Unit wire load, gm/cm/wire	—	18.4

	Cutting Result
Total wire used, m	4800
Total cutting time, hr:min	8:0
Ave. wafer thickness, in.	0.011
mm	0.272
Ave. kerf width, in.	0.006
mm	0.15
Wafer yield, unbroken/total wafer	51/54
Wire wearing, µm	6
Length of wire/cutting area, m/cm^2	1.83

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Table 8. Cutting conditions and result of Demonstration 7

Variable Conditions	JPL Specified	Performed
Roller Pitch, mm	0.4	0.4
Wire size, in.	0.003	0.0047 (0.12 mm)
Abrasive size, μm	9	10
Cutting Oil	Std	Crane Lapping Vehicle 3M
Slurry condition	Reuse from Demo. 6	Reuse from Demo. 6
No. slices	Std	54
Wire tension, kg	Std	1.2
Breaking Pt. of wire, kg	Std	3.2
Wire feed rate, m/min	5	10
Wire cycle rate, cycle/min	60	67
Wire load, kg	Std	8.6 max
Unit wire load, gm/cm/wire	—	23.1

	Cutting Result
Total wire used, m	4050
Total cutting time, hr:min	6:45
Ave. wafer thickness, in.	0.011
mm	0.270
Ave. kerf width, in.	0.006
mm	0.15
Wafer yield, unbroken/total wafer	53/54
Wire wearing, μm	9
Length of wire/cutting area, m/cm^2	1.54

Table 9. Cutting conditions and result of Demonstration 8

Variable Conditions	JPL Specified	Performed
Roller Pitch, mm	0.4	0.4
Wire size, in.	0.003	0.0047 (0.12 mm)
Abrasive size, µm	9	10
Cutting Oil	Std	Crane Lapping Vehicle 3M
Slurry condition	Reuse from Demo. 7	Reuse from Demos. 6 and 7 +1 kg from Demo. 3
No. slices	Std	60
Wire tension, kg	Std	1.2
Breaking Pt. of wire, kg	Std	3.2
Wire feed rate, m/min	5	10
Wire cycle rate, cycle/min	60	67
Wire load, kg	Std	8.5 max
Unit wire load, gm/cm/wire	—	20.2

	Cutting Result
Total wire used, m	3870*
Total cutting time, hr:min	6:27*
Ave. wafer thickness, in.	—
mm	—
Ave. kerf width, in.	—
mm	—
Wafer yield, unbroken/total wafer	0
Wire wearing, µm	7
Length of wire/cutting area, m/cm^2	—

*Wafering failed because the wire broke at approximately 75 percent completion.

Table 10. Cutting conditions and result of Demonstration 9

Variable Conditions	JPL Specified	Performed
Roller Pitch, mm	0.4	0.4
Wire size, in.	0.003	0.0047 (0.12 mm)
Abrasive size, μm	9	10
Cutting Oil	Std	Crane Lapping Vehicle 3M
Slurry condition	Reuse from Demo. 8	Reuse from Demos. 6, 7, and 8
No. slices	Std	49
Wire tension, kg	Std	1.2
Breaking Pt. of wire, kg	Std	3.2
Wire feed rate, m/min	4.5	10
Wire cycle rate, cycle/min	max	65-67
Wire load, kg	Std	6.9 max
Unit wire load, gm/cm/wire	—	20

	Cutting Result
Total wire used, m	5300
Total cutting time, hr:min	8:50
Ave. wafer thickness, in. mm	0.011 0.268
Ave. kerf width, in. mm	0.006 0.15
Wafer yield, unbroken/total wafer	48/49
Wire wearing, μm	7
Length of wire/cutting area, m/cm^2	2.22

Table 11. Cutting conditions and result of Demonstration 10

Variable Conditions	JPL Specified	Performed
Roller Pitch, mm	0.4	0.4
Wire size, in.	0.003	0.0039 (0.10 mm)
Abrasive size, μm	9	10
Cutting Oil	Std	Crane Lapping Vehicle 3M
Slurry condition	Reuse from Demo. 9	Reuse from Demos. 6 through 9
No. slices	Std	55
Wire tension, kg	Std	0.9
Breaking Pt. of wire, kg	Std	2.2
Wire feed rate, m/min	4	10
Wire cycle rate, cycle/min	max	40-65
Wire load, kg	10% less Std	3.0
Unit wire load, gm/cm/wire	—	7.8

	Cutting Result
Total wire used, m	—
Total cutting time, hr:min	0:13 + 1:23*
Ave. wafer thickness, in.	0.010
mm	0.250
Ave. kerf width, in.	0.005
mm	0.130
Wafer yield, unbroken/total wafer	0
Wire wearing, μm	—
Length of wire/cutting area, m/cm^2	—

*Wire broke after 13 minutes of slicing; rewire was made, wire broke after 1 hr and 23 min of restart.

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Table 12. Variables affecting economical silicon wafer production

Variable	Kerf Width	Cutting Speed	Surface Quality	Cutting Costs
Wire Size	D	D	P	D
Wire Composition		P	P	D
Wire Coating (if any)		P	P	D
Wire Diameter Tolerance			D	D
Wire Stroke Rate	P	D	D	D
Wire Feed Rate	D	P	P	D
Abrasive Material	P	D	D	D
Abrasive Grit Size	D	D	D	D
Abrasive Size Tolerance	P	D	D	D
Abrasive Suspension Medium	P	P	P	D
Ratio of Abrasive to Suspendor	P	D	P	D
Cutting Pressure	P	D	D	D
Guide Roller Groove Pitch				D
Guide Roller Material (may affect minimum pitch)				D

D - Definite Effect
P - Possible Effect

Table 13. Summary of wafer and kerf thickness as function of the sizes of wire, abrasive and guide roller pitch

Demo No.	A Wafer Thickness, mm	B Kerf Thickness, mm	C Wire Size, mm	D Abrasive Size, mm	E Roller Pitch, mm	A + B	B - C
1	0.339	0.17	0.14	0.010	0.5	0.509	0.03
2	0.367	0.15	0.12	0.010	0.5	0.517	0.03
3	0.362	0.15	0.12	0.010	0.5	0.512	0.03
4	0.283	0.135	0.12	0.005	0.4	0.418	0.015
5	0.287	0.135	0.12	0.005	0.4	0.422	0.015
6	0.272	0.15	0.12	0.010	0.4	0.422	0.03
7	0.241	0.15	0.12	0.010	0.4	0.391	0.03
9	0.268	0.15	0.12	0.010	0.4	0.418	0.03
10	0.250	0.130	0.10	0.010	0.4	0.380	0.03

Table 14. Average value of wafer thickness at the location of measurement, mm

Ingot No.	Location of Measurement** 1	2	3	4	5	Maximum Variation, mm
1	0.346	0.336	0.335	0.339	0.339	0.011
2	0.368	0.363	0.363	0.369	0.367	0.006
3	0.360	*	*	0.363	0.362	0.003
4	0.272	*	*	0.282	0.283	0.011
5	0.269	0.284	0.274	0.274	0.287	0.018
6	0.271	*	*	0.276	0.272	0.005
7	0.267	*	*	0.243	0.241	0.025
9	0.265	*	*	0.268	0.268	0.003

*No significant change from 5.

**Location of measurement on a wafer is shown in Figure 3.

Table 15. Microscopic surface roughness and damage of several samples sliced by the multi-wire-slurry saw

Specimen No.	Roughness, μm*	Damage Depth, μm**
1-25	~5	10
4-27	~3	6.5
5-27	~3	6.5
6-25	~6	7.2
9-25	~5	8.5

*Average irregularity spacing observed on wafer surface by SEM.

**Optical microscopic examination on the angle lapped and Sirtl-etched wafer surface.

Table 16. Summary of cutting rate (μm/min. per gm of each cm of wire load) of several slicing demonstrations

Slicing No.	Abrasive Size, μm	Wire Size, mm	No. Reuse of Slurry	Cutting Rate, μm/min/gm/cm/wire	Total Slicing Time, hr-min
1	10	0.14	0	9.6	6-55
2	10	0.12	0	9.6	9-55
4	5	0.12	0	6.9	12-30
5	5	0.12	1	7.9	9-45
6	10	0.12	0	10.0	8-0
7	10	0.12	1	11.0	6-45

Table 17. Steel wire prices

Wire Size, in.	Appro. Meter/kg	$/kg	$/m
0.003	28,000	115.00	4.1×10^{-3}
0.004	16,000	71.00	4.44×10^{-3}
0.005	10,000	57.00	5.70×10^{-3}
0.006	7,000	40.00	5.70×10^{-3}
0.007	5,000	28.00	5.6×10^{-3}

Table 18. Milasil silicon carbide abrasive prices

μm Size	Price per 5 lbs.
5	$45.00
9	37.50
12	27.50
15	22.75
20	19.50
30	18.25

Table 19. Prices of rollers

Grooved guide roller, standard pitch	$ 91.25/set
Regrooving of guide roller	$ 60.00/set
Idler roller	$ 20.50/set
V-roller	$150.50/set

Table 20. Cost of wire, abrasive and rollers for the demonstrations

Demonstration	Wire, $\$/m^2$	Abrasive, Total $	Roller: Guide, Total $	Roller: Idler, Total $	Roller: V, Total $
1	99.75	82.50	91.25	20.50	150.50
2	152.20	82.50	-	-	-
3	104.35	16.50	-	-	-
4	150.10	89.30	91.25	20.50	-
5	112.33	-	-	-	-
6	81.25	86.00	-	-	-
7	68.40	-	-	-	-
8	*	-	-	-	-
9	98.60	-	-	-	-
10	*	-	-	-	-

*Failed to complete

-Reuse from previous demonstration

APPENDIX A

CUTTING DATA FOR JPL'S SILICON INGOT

(1) Data Sheet for Cutting Condition

(2) Time-Vertical Position Data Sheet

(3) Slice Thickness Data Sheet

Yasunaga Engineering Co., Ltd.

14 November 1977

SAMPLE CUTTING DATA SHEET
DEMONSTRATION 1
2 Nov. 1977

Specification of Prospect

1.	Materials of workpiece	Silicon
2.	Dimension of work	ϕ 78 × 28.2 mm
3.	Machine No.	YQ-100 #143
4.	Cartridge type	"G"
5.	Hour put to used of head rollers	0 hr, 0 min

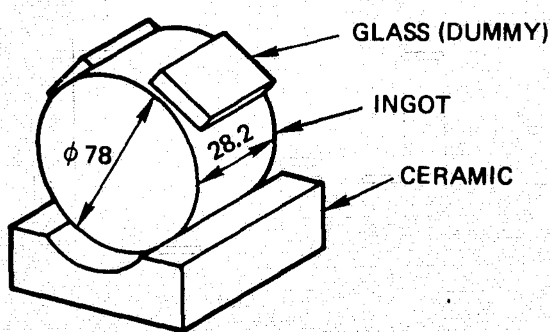
Cutting Condition

1.	Roller pitch	0.5 mm
2.	Diameter of wire	0.14 mm
3.	Abrasive	New GC #1500 (10 μm) 5 kg
4.	Lapping oil	New 3 kg
5.	Ratio of 3 to 4	1.67:1
6.	Bond	Sunlock SMD-01
7.	Mean amount of kerf	0.17 mm
8.	No. of wire under cutting	49
9.	Total weight	Max 6.8 kg
10.	Mean unit weight	Max 20 g/cm/wire
11.	Total wire tension	1.5 kg
12.	Breaking point of wire	4.3 kg
13.	Feeding amount of wire	10 m/min
14.	Reciprocation of wire	63 cycle/min
15.	Wears of wire	6 μm
16.	Total length of used wire	4150 m

Working Efficiency

1.	Total working time	6 hr, 55 min
2.	Number of works	48 pcs
3.	Working time of unit work	8.4 min
4.	Total cutting area	2371 cm^2
5.	Total volumes of kerf	40.3 cm^3
6.	Mean volumes of kerf	0.097 cm^3/min

Schematics of Work Installed



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SAMPLE CUTTING DATA SHEET (Cont.)
DEMONSTRATION 1
2 Nov. 1977

Remarks

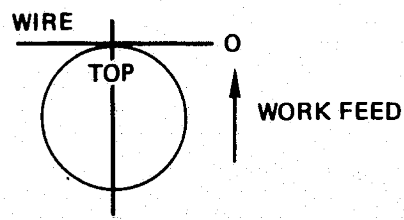
1. It was 40 minutes from the time the machine started to the silicon cutting in (this time is required to cut dummy glass), and so this time was subtracted from the actual time.

Note: same hereafter

2. At cutting in of silicon ingot, total weight was 5.1 kg; at 45 minutes after this, total weight was 6.6 kg; at 5 minutes later, total weight was 6.8 kg.

3. The beginning cycle rate was 65 cycles/min, but we dropped down to 63 cycles/min after 85 minutes (from when wire was cutting in silicon ingot) because the operator side's wire was delaying.

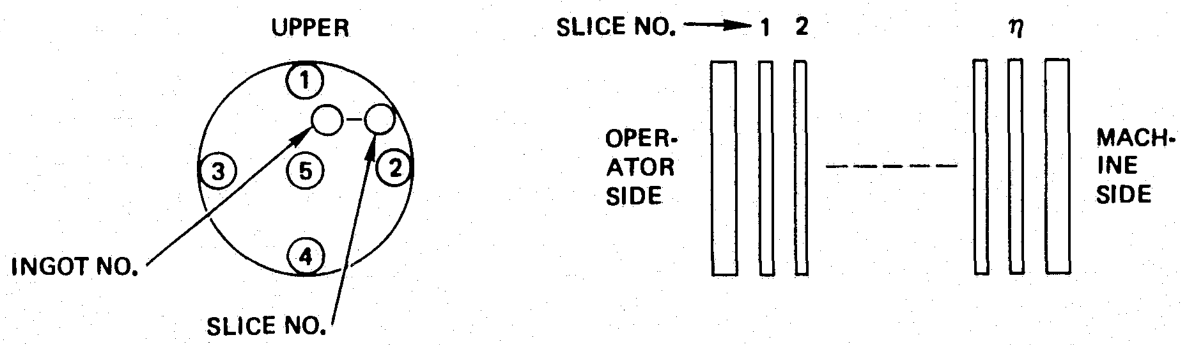
TIME-VERTICAL POSITION DATA SHEET
DEMONSTRATION 1
2 Nov. 1977



Time, Hr-Min	Vert. Pos., mm	Total Weight, kg	Cycle/ Min
00	0	5.1	65
15	1.0	5.1	65
30	2.0	5.1	65
45	3.5	6.6	65
1 - 00	7.0	6.8	63
15	11.8	6.8	63
30	15.2	6.8	63
45	18.2	6.8	63
2 - 00	21.3	6.8	63
15	24.0	6.8	63
30	26.5	6.8	63
45	29.2	6.8	63
3 - 00	31.7	6.8	63
15	34.3	6.8	63
30	36.7	6.8	63
45	39.1	6.8	63
4 - 00	41.5	6.8	63
15	44.0	6.8	63
30	46.5	6.8	63
45	49.1	6.8	63

Time, Hr-Min	Vert. Pos., mm	Total Weight, kg	Cycle/ Min
5 - 00	51.7	6.8	63
15	54.3	6.8	63
30	56.7	6.8	63
45	59.7	6.8	63
6 - 00	63.0	6.8	63
15	67.0	6.8	63
30	70.5	6.8	63
45	74.5	6.8	63
55	78.5	6.8	63

SLICE THICKNESS DATA SHEET
DEMONSTRATION 1
2 Nov. 1977



Slice No.	① mm	② mm	③ mm	④ mm	⑤ mm
2	0.354	0.310	0.310	0.294	0.315
5	0.354	0.345	0.346	0.361	0.349
10	0.332	0.335	0.329	0.325	0.334
15	0.347	0.342	0.339	0.359	0.343
20	0.348	0.344	0.345	0.352	0.348
25	0.337	0.326	0.327	0.324	0.327
30	0.341	0.334	0.331	0.345	0.333
35	0.347	0.337	0.338	0.335	0.341
40	0.360	0.342	0.341	0.340	0.349
45	0.344	0.345	0.344	0.353	0.348

SAMPLE CUTTING DATA SHEET
DEMONSTRATION 2
3 Nov. 1977

Specification of Prospect

1.	Materials of workpiece	Silicon
2.	Dimension of work	ϕ 78 × 29.5 mm
3.	Machine No.	YQ-100 #143
4.	Cartridge type	"G"
5.	Hour put to used of head rollers	6 hr, 55 min

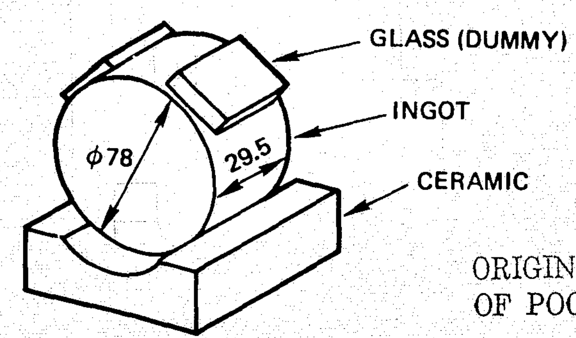
Cutting Condition

1.	Roller pitch	0.5 mm
2.	Diameter of wire	0.12 mm
3.	Abrasive	New GC #1500 (10 μm) 5 kg
4.	Lapping oil	New 3 kg
5.	Ratio of 3 to 4	1.67:1
6.	Bond	Sunlock SMD-01
7.	Mean amount of kerf	0.15 mm
8.	No. of wire under cutting	48
9.	Total weight	Max 5 kg
10.	Mean unit weight	Max 15 g/cm/wire
11.	Total wire tension	1.1 kg
12.	Breaking point of wire	3.2 kg
13.	Feeding amount of wire	10.3 m/min
14.	Reciprocation of wire	62 ~ 65 cycle/min
15.	Wears of wire	6 μm
16.	Total length of used wire	6130 m

Working Efficiency

1.	Total working time	9 hr, 55 min
2.	Number of works	47 pcs
3.	Working time of unit work	12.6 min
4.	Total cutting area	2293.6 cm^2
5.	Total volumes of kerf	34.4 cm^3
6.	Mean volumes of kerf	0.058 cm^3/min

Schematics of Work Installed



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SAMPLE CUTTING DATA SHEET (Cont.)
DEMONSTRATION 2
3 Nov. 1977

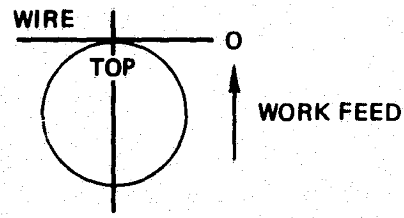
Remarks

1. Abrasive slurry for No. 2 ingot was instructed to be the same as for No. 1 ingot by GEOS. In cutting No. 1 ingot, some amount of abrasive slurry was leaked from pipe fitting of oil pump, so abrasive slurry volume became below one-half, and new abrasive slurry was used for this operation.

2. Cannot load normal total weight because operator side's wire was delayed by that wire tension being low.

3. Used some part of 3 roller set the same as for No. 1 ingot.

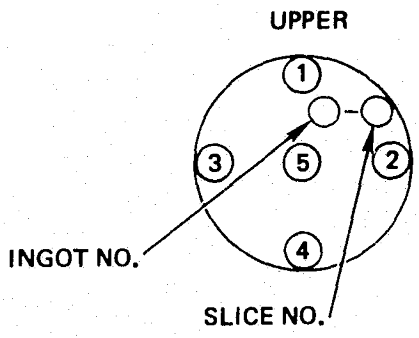
TIME-VERTICAL POSITION DATA SHEET
DEMONSTRATION 2
3 Nov. 1977

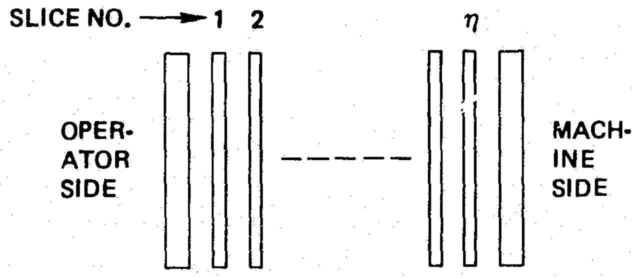


Time, Hr-Min	Vert. Pos., mm	Total Weight, kg	Cycle/ Min
00	0	6.6	65
15	1.5	6.6	65
35	3.0	4.0	65
45	2.3	1.0	65
1 - 00	3.0	1.0	65
15	3.5	1.0	65
22	4.3	2.0	65
25	5.3	3.0	65
32	6.9	4.0	65
53	10.5	5.0	65
2 - 01	11.0	2.0	65
47	14.0	3.0	65
3 - 15	16.0	3.0	65
30	17.5	4.0	65
45	19.5	4.0	65
50	20.7	4.5	65
4 - 00	22.0	4.5	65
15	23.7	4.5	65
30	25.5	4.5	65
33	26.2	5.0	62
45	27.7	5.0	62
5 - 00	29.5	5.0	62
15	31.0	5.0	62
30	33.0	5.0	62
45	34.9	5.0	62
6 - 00	36.9	5.0	62
15	38.3	5.0	62
30	40.5	5.0	65
45	42.3	5.0	65

Time, Hr-Min	Vert. Pos., mm	Total Weight, kg	Cycle/ Min
7 - 00	44.5	5.0	65
15	46.7	5.0	65
30	48.7	5.0	65
45	51.1	5.0	65
8 - 00	53.7	5.0	65
15	55.1	5.0	65
30	57.7	5.0	65
45	60.2	5.0	65
9 - 00	62.7	5.0	65
15	65.5	5.0	65
30	69.0	5.0	65
45	72.7	5.0	65
55	78.0	5.0	65

SLICE THICKNESS DATA SHEET
DEMONSTRATION 2
3 Nov. 1977





Slice No.	(1) mm	(2) mm	(3) mm	(4) mm	(5) mm
1	0.370	0.365	0.360	0.370	0.360
5	0.360	0.360	0.359	0.364	0.363
10	0.365	0.360	0.359	0.373	0.363
15	0.372	0.369	0.368	0.374	0.374
20	0.362	0.363	0.364	0.366	0.368
25	0.380	0.379	0.376	0.377	0.379
30	0.365	0.360	0.360	0.365	0.365
35	0.380	0.370	0.370	0.381	0.378
40	0.353	0.348	0.347	0.350	0.351
45	0.369	0.358	0.362	0.370	0.367

SAMPLE CUTTING DATA SHEET
DEMONSTRATION 3
4 Nov. 1977

Specification of Prospect

1.	Materials of workpiece	Silicon
2.	Dimension of work	ϕ 78 × 28.2 mm
3.	Machine No.	YQ-100 #143
4.	Cartridge type	"G"
5.	Hour put to used of head rollers	16 hr, 50 min

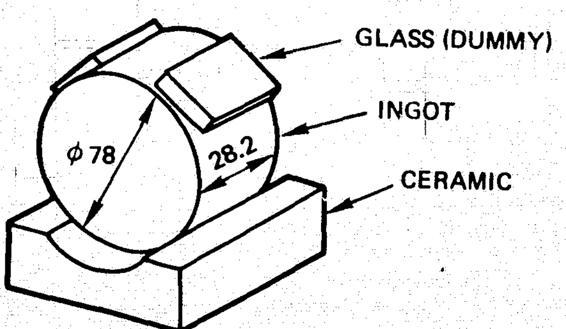
Cutting Condition

1.	Roller pitch	0.5 mm
2.	Diameter of wire	0.12 mm
3.	Abrasive }	Previous use No. 2
4.	Lapping oil }	and new abrasive 940 g and new oil 500 g
5.	Ratio of 3 to 4	1.67:1
6.	Bond	Sunlock SMD-01
7.	Mean amount of kerf	0.15 mm
8.	No. of wire under cutting	45
9.	Total weight	Max 7.2 kg
10.	Mean unit weight	Max 23.1 g/cm/wire
11.	Total wire tension	1.2 kg
12.	Breaking point of wire	3.2 kg
13.	Feeding amount of wire	10.5 m/min
14.	Reciprocation of wire	65 ~ 68 cycle/min
15.	Wears of wire	9 μm
16.	Total length of used wire	5050 m

Working Efficiency

1.	Total working time	8 hr, 25 min
2.	Number of works	44 pcs
3.	Working time of unit work	11.5 min
4.	Total cutting area	2150 cm^2
5.	Total volumes of kerf	32.3 cm^3
6.	Mean volumes of kerf	0.064 cm^3/min

Schematics of Work Installed



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SAMPLE CUTTING DATA SHEET (Cont.)
DEMONSTRATION 3
4 Nov. 1977

Remarks

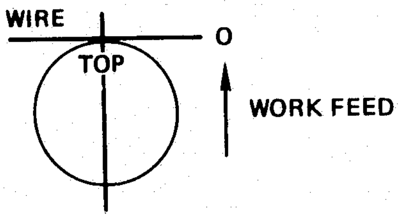
1. For abrasive slurry, 940 g of GC #1500 abrasive grain and 500 g of LAP-OIL was added to used abrasive slurry from No. 2 operation.

2. Used another part of used three-roller set from No. 1 and No. 2 operation.

3. After 85 minutes, operation was stopped for one minute and a spacer installed at the rear of V roller.

4. Cutting time was too large because of wire delaying during operation, so total weight was decreased.

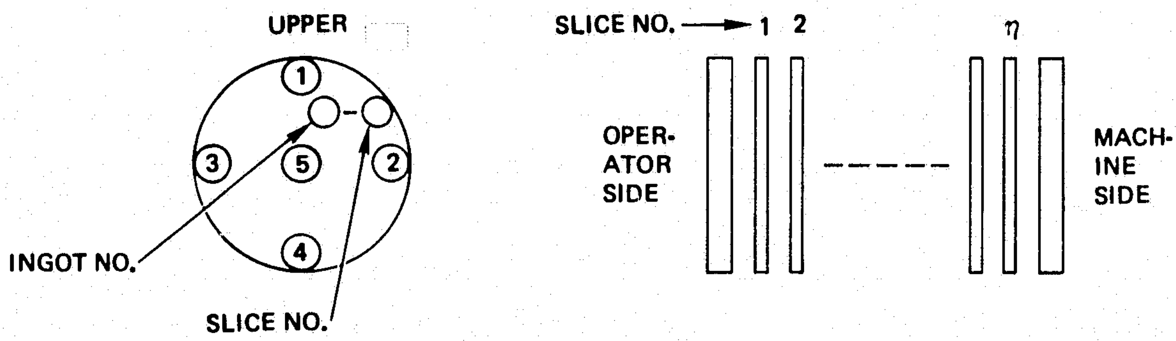
TIME-VERTICAL POSITION DATA SHEET
DEMONSTRATION 3
4 Nov. 1977



Time, Hr-Min	Vert. Pos., mm	Total Weight, kg	Cycle/ Min
00	0	4.0	65
15	1.7	5.6	65
30	2.7	5.6	65
45	2.5	1.0	65
1 - 00	2.5	1.0	65
15	3.5	1.0	65
30	3.5	1.0	65
40	5.0	3.0	65
45	5.1	3.0	65
2 - 00	6.1	3.0	65
15	8.7	4.0	65
30	10.9	5.0	68
45	12.3	5.0	68
3 - 00	14.5	5.3	68
15	16.5	5.6	68
30	18.0	5.6	68
45	19.9	5.6	68
4 - 00	21.7	5.6	68
15	23.8	5.6	68
30	26.0	5.6	68
45	27.9	5.6	68
5 - 00	29.5	5.6	68
15	31.1	5.6	68
30	33.7	5.6	68
45	36.0	5.6	68

Time, Hr-Min	Vert. Pos., mm	Total Weight, kg	Cycle/ Min
6 - 00	37.8	5.6	68
15	41.9	5.6	68
30	45.0	5.6	68
45	48.8	5.6	68
7 - 00	52.3	5.6	68
15	56.1	5.6	68
30	60.3	5.6	68
45	65.3	5.6	68
8 - 00	69.0	5.6	68
15	74.0	5.6	68
25	78.0	5.6	68

SLICE THICKNESS DATA SHEET
DEMONSTRATION 3
4 Nov. 1977



Slice No.	① mm	② mm	③ mm	④ mm	⑤ mm
1	0.355	0.362	0.354	0.363	0.359
5	0.364	0.363	0.364	0.366	0.365
10	0.373	0.373	0.371	0.378	0.369
15	0.365	0.373	0.365	0.369	0.372
20	0.360	0.359	0.358	0.372	0.362
25	0.371	0.372	0.370	0.374	0.371
30	0.361	0.367	0.360	0.363	0.364
35	0.346	0.347	0.347	0.353	0.349
40	0.359	0.360	0.360	0.360	0.365
44	0.349	0.347	0.349	0.335	0.347

SAMPLE CUTTING DATA SHEET
DEMONSTRATION 4
8 Nov. 1977

<u>Specification of Prospect</u>

1.	Materials of workpiece	Silicon
2.	Dimension of work	ϕ 78.5 × 27.3
3.	Machine No.	Model YQ-100 B-3707
4.	Cartridge type	"G"
5.	Hour put to used of head rollers	0 hr, 0 min

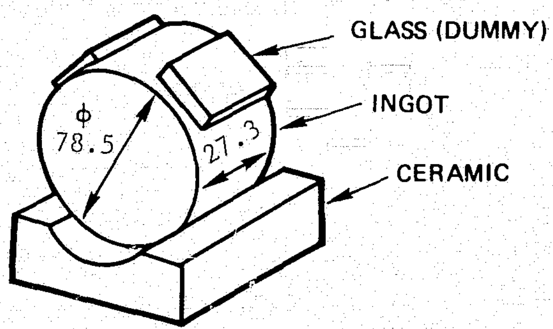
<u>Cutting Condition</u>

1.	Roller pitch	0.4 mm
2.	Diameter of wire	ϕ 0.12 mm
3.	Abrasive	New GC #3000 (5 μm) 4.5 kg
4.	Lapping oil	New 2.8 kg
5.	Ratio of 3 to 4	1:1.6
6.	Bond	Sunlock SMD-01
7.	Mean amount of kerf	0.135 mm
8.	No. of wire under cutting	55
9.	Total weight	Max 7.6 kg
10.	Mean unit weight	Max 20 g/cm/wire
11.	Total wire tension	1.22 kg
12.	Breaking point of wire	3.2 kg
13.	Feeding amount of wire	12.0 m/min
14.	Reciprocation of wire	68 cycle/min
15.	Wears of wire	5 μm
16.	Total length of used wire	9000 m

<u>Working Efficiency</u>

1.	Total working time	12 hr, 30 min
2.	Number of works	54 pcs
3.	Working time of unit work	13.9 min
4.	Total cutting area	2660.6 cm^2
5.	Total volumes of kerf	35.9 cm^3
6.	Mean volumes of kerf	0.0479 cm^3/min

<u>Schematics of Work Installed</u>



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SAMPLE CUTTING DATA SHEET (Cont.)
DEMONSTRATION 4
8 Nov. 1977

Remarks

1. Used new three-roller set, abrasive slurry and drive roller about 55 mm diameter.

2. As circular surface of ingot is not smooth as in following figure, two dummy glasses were bonded on ingot.

3. Spended cutting time was too large and, consequently, wire was delayed a little because both dummy glasses are not symmetrical.

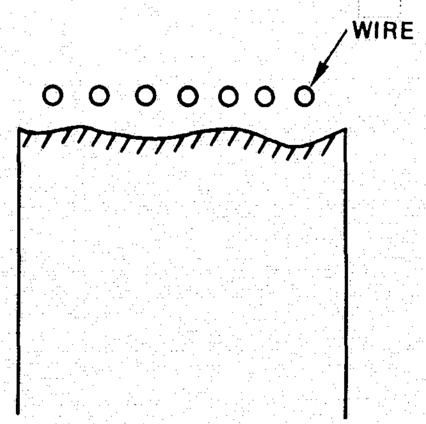
4. Finished cutting surface is not good. At a cutting condition with GC #3000 and wire 0.12 mm diameter, it is necessary to pay much time.

   Cutting under these conditions is difficult. We must study the cutting operation further.

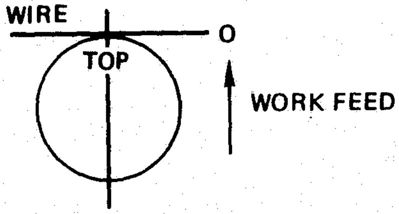
5. About calculation for cutting weight, we decided that work's width is as follows:

$$\frac{D \times \sqrt{\pi}}{2} = \frac{78.5 \times \sqrt{3.14}}{2} = 69.55 \text{ mm}$$

where D is work diameter

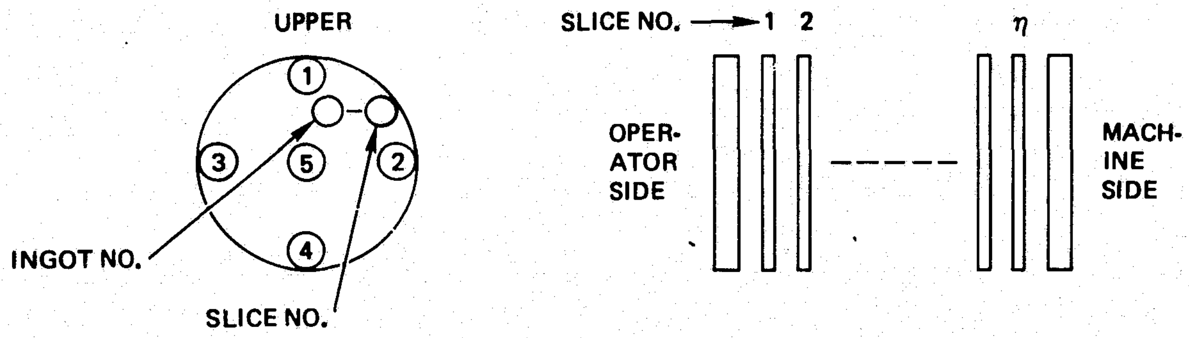


TIME-VERTICAL POSITION DATA SHEET
DEMONSTRATION 4
8 Nov. 1977



Time, Hr-Min	Vert. Pos., mm	Total Weight, kg	Cycle/ Min	Time, Hr-Min	Vert. Pos., mm	Total Weight, kg	Cycle/ Min
0 - 00	0	3.0	65	7 - 00	35.8	7.6	68
15	0.5	3.0	65	15	37.8	7.6	68
30	1.2	3.0	65	30	39.7	7.6	68
45	2.0	3.0	65	45	41.7	7.6	68
1 - 00	2.5	3.0	65	8 - 00	43.8	7.6	68
15	2.8	4.0	65	15	45.6	7.6	68
30	3.0	4.0	65	30	47.55	7.6	68
45	3.8	4.0	65	45	49.4	5.0	68
2 - 00	4.3	4.0	65	9 - 00	49.9	5.0	68
15	5.4	4.0	65	15	51.2	5.0	68
30	6.5	2.0	65	30	52.5	6.0	68
45	6.0	2.0	65	45	54.5	6.0	68
3 - 00	6.5	2.0	65	10 - 00	56.2	6.0	68
15	6.8	4.0	68	15	57.85	6.0	68
30	9.2	4.0	68	30	59.7	6.0	68
45	10.5	4.0	68	45	61.5	6.0	68
4 - 00	12.8	5.0	68	11 - 00	63.5	6.0	68
15	15.0	5.5	68	15	65.37	6.0	68
30	16.0	6.0	68	30	67.7	6.0	68
45	19.0	6.0	68	45	70.0	4.0	68
5 - 00	20.5	6.0	68	12 - 00	70.75	4.0	68
15	22.0	7.6	68	15	73.8	5.0	68
30	24.7	7.6	68	30	78.5	5.0	68
45	27.0	7.6	68	45			
6 - 00	28.5	7.6	68				
15	30.3	7.6	68				
30	32.2	7.6	68				
45	34.05	7.6	68				

SLICE THICKNESS DATA SHEET
DEMONSTRATION 4
8 Nov. 1977



Slice No.	① mm	② mm	③ mm	④ mm	⑤ mm
1	0.271	0.278	0.281	0.296	0.277
5	0.267	0.286	0.292	0.296	0.295
10	0.274	0.295	0.290	0.305	0.297
15	0.268	0.264	0.268	0.275	0.264
20	0.272	0.276	0.276	0.270	0.280
25	0.273	0.255	0.255	0.268	0.250
30	0.266	0.260	0.258	0.270	0.258
35	0.280	0.290	0.291	0.280	0.303
40	0.263	0.280	0.291	0.280	0.288
45	0.270	0.258	0.255	0.261	0.253
50	0.266	0.290	0.291	0.286	0.300
54	0.290	0.313	0.310	0.298	0.330

SAMPLE CUTTING DATA SHEET
DEMONSTRATION 5
9 Nov. 1977

Specification of Prospect

1.	Materials of workpiece	Silicon
2.	Dimension of work	ϕ 78.5 × 29
3.	Machine No.	YQ-100 B-5707
4.	Cartridge type	"G"
5.	Hour put to used of head rollers	0 hr, 00 min

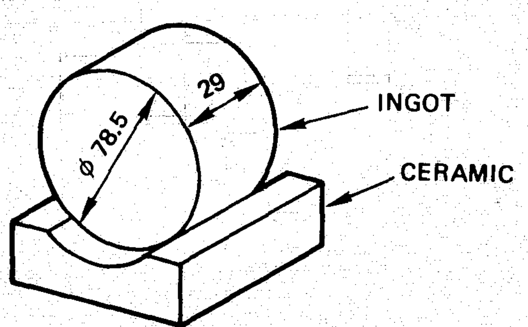
Cutting Condition

1.	Roller pitch	0.4 mm
2.	Diameter of wire	ϕ0.12 mm
3.	Abrasive }	
4.	Lapping oil }	Previous use No. 4
5.	Ratio of 3 to 4 }	
6.	Bond	Sunlock SMD-01
7.	Mean amount of kerf	0.135 mm
8.	No. of wire under cutting	55
9.	Total weight	Max 7.6 kg
10.	Mean unit weight	Max 20 g/cm/wire
11.	Total wire tension	1.25 kg
12.	Breaking point of wire	3.2 kg
13.	Feeding amount of wire	11.5 m/min
14.	Reciprocation of wire	68 cycle/min
15.	Wears of wire	5 μm
16.	Total length of used wire	6727 m

Working Efficiency

1.	Total working time	9 hr, 45 min
2.	Number of works	54 pcs
3.	Working time of unit work	10.8 min
4.	Total cutting area	2660.6 cm^2
5.	Total volumes of kerf	35.9 cm^3
6.	Mean volumes of kerf	0.0614 cm^3/min

Schematics of Work Installed



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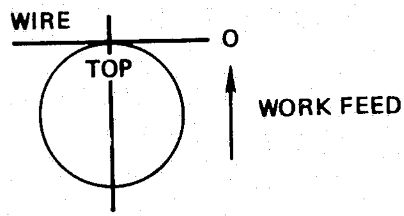
SAMPLE CUTTING DATA SHEET (Cont.)
DEMONSTRATION 5
9 Nov. 1977

Remarks:

1. Used the same three-roller set and abrasive slurry as No. 4 ingot operation.

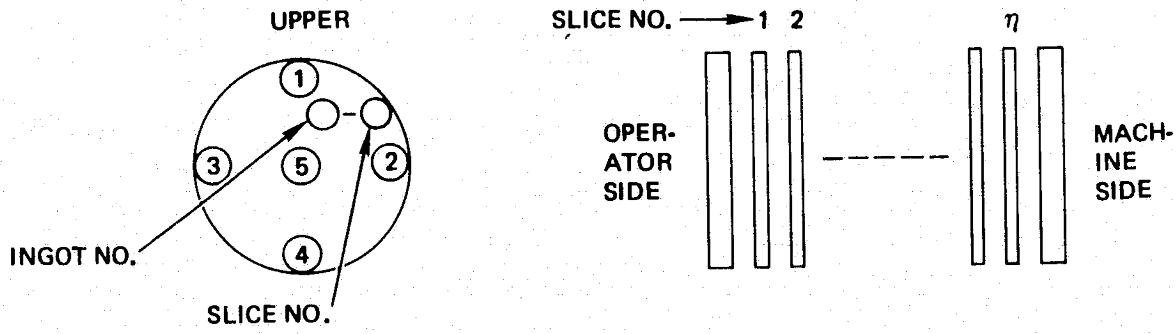
2. As in No. 4 operation, used MDC depth control with stopper serving to protect wire slipping.

TIME-VERTICAL POSITION DATA SHEET
DEMONSTRATION 5
9 Nov. 1977



Time, Hr-Min	Vert. Pos., mm	Total Weight, kg	Cycle/ Min	Time, Hr-Min	Vert. Pos., mm	Total Weight, kg	Cycle/ Min
0 - 00	0	2.0	68	5 - 00	40.02	7.6	68
15	1.22	2.0	68	15	42.35	7.6	68
30	2.94	2.0	68	30	44.5	7.6	68
45	5.45	3.0	68	45	47.0	7.6	68
1 - 00	7.15	3.0	68	6 - 00	49.15	7.6	68
15	8.7	4.0	68	15	51.4	7.6	68
30	10.9	4.0	68	30	53.65	7.6	68
45	12.5	4.0	68	45	56.15	7.6	68
2 - 00	14.15	5.0	68	7 - 00	58.6	4.0	68
15	16.5	5.0	68	15	58.85	4.0	68
30	18.25	5.0	68	30	60.32	4.0	68
45	19.8	7.6	68	45	61.7	4.0	68
3 - 00	23.2	7.6	68	8 - 00	63.35	4.0	68
15	25.4	7.6	68	15	65.0	4.0	68
30	27.6	7.6	68	30	66.95	4.0	68
45	29.75	7.6	68	45	68.65	4.0	68
4 - 00	31.85	7.6	68	9 - 00	70.6	4.0	68
15	33.9	7.6	68	15	72.75	4.0	68
30	35.95	7.6	68	30	75.3	4.0	68
45	38.15	7.6	68	45	78.5	4.0	68

SLICE THICKNESS DATA SHEET
DEMONSTRATION 5
9 Nov. 1977



Slice No.	① mm	② mm	③ mm	④ mm	⑤ mm
1	0.262	0.187	0.159	0.271	0.146
5	0.270	0.273	0.276	0.272	0.277
10	0.277	0.270	0.270	0.186	0.270
15	0.254	0.284	0.282	0.292	0.293
20	0.262	0.282	0.283	0.265	0.298
25	0.270	0.283	0.275	0.270	0.289
30	0.265	0.290	0.285	0.285	0.310
35	0.262	0.293	0.276	0.272	0.285
40	0.261	0.305	0.288	0.263	0.315
45	0.262	0.308	0.278	0.268	0.311
50	0.265	0.308	0.303	0.275	0.320
54	0.318	0.324	0.312	0.372	0.333

SAMPLE CUTTING DATA SHEET
DEMONSTRATION 6
5 Nov. 1977

Specification of Prospect

1.	Materials of workpiece	Silicon
2.	Dimension of work	ϕ 78 × 27.2
3.	Machine No.	YQ-100 #143
4.	Cartridge type	"G"
5.	Hour put to used of head rollers	0 hr, 0 min

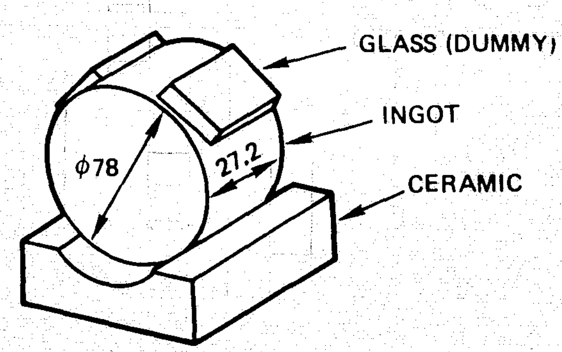
Cutting Condition

1.	Roller pitch	0.4 mm
2.	Diameter of wire	0.12 mm
3.	Abrasive	New GC #1500 (10 μm) 5.2 kg
4.	Lapping oil	New Oil 3.4 kg
5.	Ratio of 3 to 4	1.53:1
6.	Bond	Sunlock SMD-01
7.	Mean amount of kerf	0.15 mm
8.	No. of wire under cutting	55
9.	Total weight	Max 7 kg
10.	Mean unit weight	Max 18.4 g/cm/wire
11.	Total wire tension	1.2 kg
12.	Breaking point of wire	3.2 kg
13.	Feeding amount of wire	10 m/min
14.	Reciprocation of wire	65 cycle/min
15.	Wears of wire	6 μm
16.	Total length of used wire	4800 m

Working Efficiency

1.	Total working time	8 hr, 0 min
2.	Number of works	54 pcs
3.	Working time of unit work	8.9 min
4.	Total cutting area	2628 cm^2
5.	Total volumes of kerf	39.4 cm^3
6.	Mean volumes of kerf	0.082 cm^3/min

Schematics of Work Installed



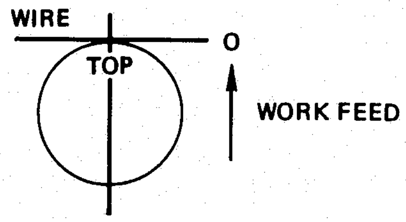
SAMPLE CUTTING DATA SHEET (Cont.)
DEMONSTRATION 6
5 Nov. 1977

Remarks

1. After 22 minutes of cutting in silicon ingot, one wire at middle of head roller was flying up, so it was mended and operation continued.

2. The time required for this mending time was subtracted from actual cutting time.

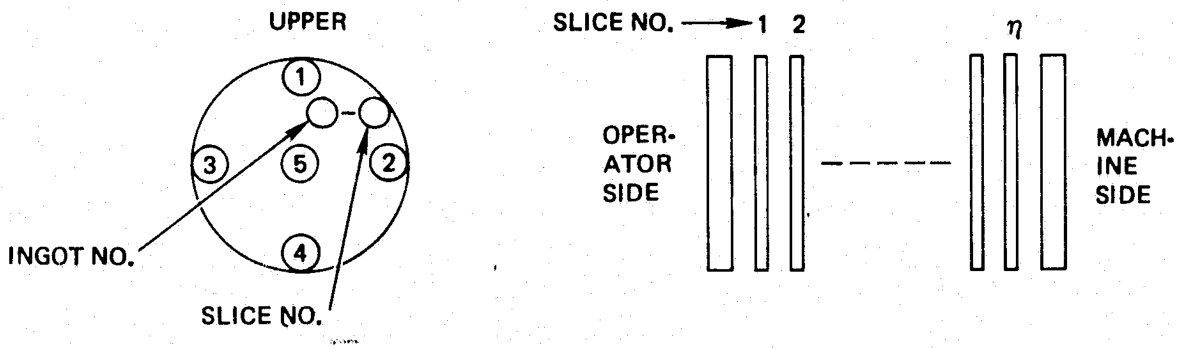
TIME-VERTICAL POSITION DATA SHEET
DEMONSTRATION 6
5 Nov. 1977



Time, Hr-Min	Vert. Pos., mm	Total Weight, kg	Cycle/ Min
00	0	3.0	65
15	0.3	3.0	65
30	1.6	3.0	65
45	2.3	3.0	65
1 - 00	2.8	3.0	65
15	4.1	3.5	65
30	5.3	4.0	65
45	7.0	4.5	65
2 - 00	9.0	5.0	65
15	11.8	5.5	65
30	15.0	6.0	65
45	17.3	6.0	65
3 - 00	20.1	6.0	65
15	22.5	6.0	65
30	24.8	6.0	65
45	27.3	6.0	65
4 - 00	29.3	6.0	65
15	32.3	6.0	65
30	34.8	6.0	65
45	36.8	6.5	65

Time, Hr-Min	Vert. Pos., mm	Total Weight, kg	Cycle/ Min
5 - 00	38.8	7.0	65
15	41.4	7.0	65
30	44.0	7.0	65
45	46.6	7.0	65
6 - 00	49.3	7.0	65
15	52.3	7.0	65
30	54.8	7.0	65
45	57.6	7.0	65
7 - 00	60.6	7.0	65
15	63.8	7.0	65
30	68.3	7.0	65
45	72.3	7.0	65
8 - 00	78.0	7.0	65

SLICE THICKNESS DATA SHEET
DEMONSTRATION 6
5 Nov. 1977



Slice No.	① mm	② mm	③ mm	④ mm	⑤ mm
1	0.263	0.285	0.276	0.296	0.285
5	0.274	0.270	0.273	0.268	0.277
10	0.274	0.270	0.272	0.275	0.273
15	0.270	0.265	0.267	0.295	0.269
20	0.274	0.269	0.270	0.282	0.270
25	0.266	0.265	0.267	0.268	0.270
30	0.272	0.272	0.265	0.261	0.271
35	0.274	0.274	0.270	0.272	0.274
40	0.273	0.269	0.276	0.268	0.274
50	0.269	0.266	0.265	0.270	0.268
54	0.275	0.270	0.271	0.265	0.263
14	0.270	0.273	0.268	0.285	0.270
31	0.263	0.270	0.265	0.285	0.269

SAMPLE CUTTING DATA SHEET
DEMONSTRATION 7
7 Nov. 1977

Specification of Prospect

1.	Materials of workpiece	Silicon
2.	Dimension of work	ϕ 78 × 27.2
3.	Machine No.	YQ-100 #143
4.	Cartridge type	"G"
5.	Hour put to used of head rollers	8 hr, 17 min

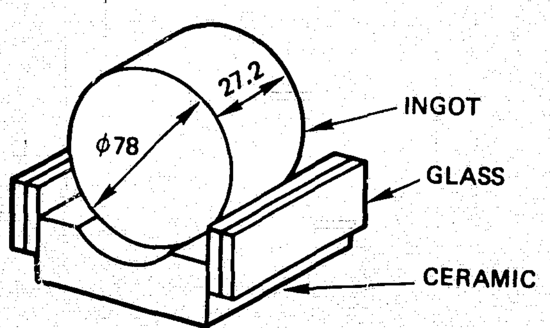
Cutting Condition

1.	Roller pitch	0.4 mm
2.	Diameter of wire	0.12 mm
3.	Abrasive	Previous use No. 6
4.	Lapping oil	
5.	Ratio of 3 to 4	
6.	Bond	Sunlock SMD-01
7.	Mean amount of kerf	0.15 mm
8.	No. of wire under cutting	55
9.	Total weight	Max 8.6 kg
10.	Mean unit weight	Max 23.1 g/cm/wire
11.	Total wire tension	1.2 kg
12.	Breaking point of wire	3.2 kg
13.	Feeding amount of wire	10 m/min
14.	Reciprocation of wire	67 cycle/min
15.	Wears of wire	9 μm
16.	Total length of used wire	4050 m

Working Efficiency

1.	Total working time	6 hr, 45 min
2.	Number of works	54 pcs
3.	Working time of unit work	7.5 min
4.	Total cutting area	2628 cm^2
5.	Total volumes of kerf	39.4 cm^3
6.	Mean volumes of kerf	0.097 cm^3/min

Schematics of Work Installed



SAMPLE CUTTING DATA SHEET (Cont.)
DEMONSTRATION 7
7 Nov. 1977

Remarks

1. Used same three-roller set which was used already for No. 6 operation, but wound wire on another part of roller.

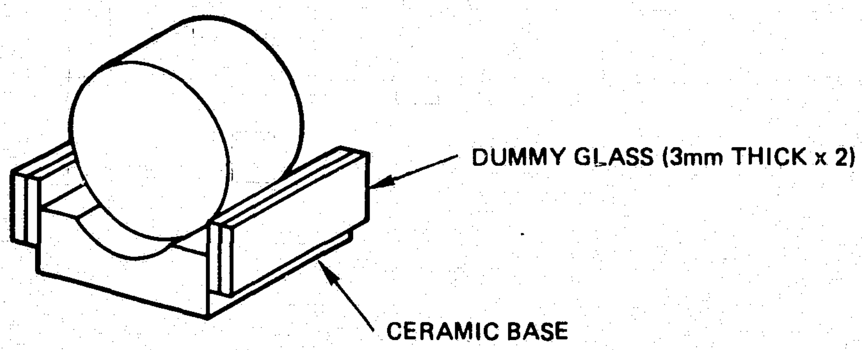
2. However, to measure sliced wafers in operations No. 1, No. 2, No. 3 and No. 6, the lower part thickness of each wafer was too large in deviation, and so a dummy glass was installed as shown below.

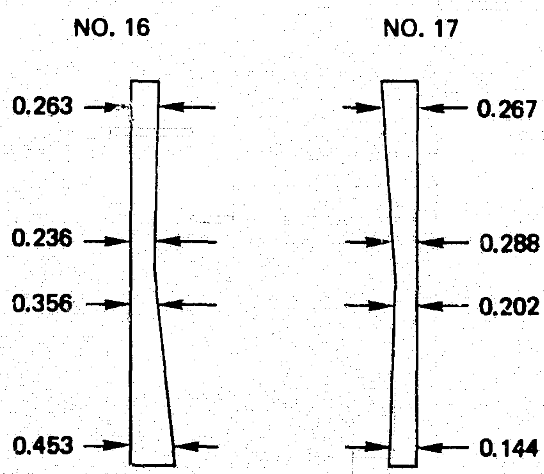
3. For No. 1, No. 2, No. 3, and No. 6 ingot after cutting was finished, the wire was removed from ingot by cutting it off.

   At this time, we tried a way in which work was dropped down slowly, but we again were unsuccessful and cut wire again.

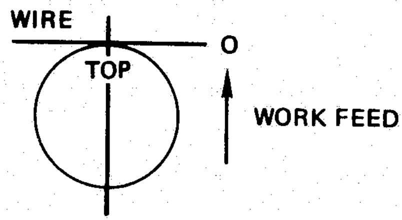
   Consequently, there was a brushing mark at the lower part of the wafer.

4. The cross section of No. 16 and No. 17 of wafer were as shown below. These may have been caused by wire slipping down.





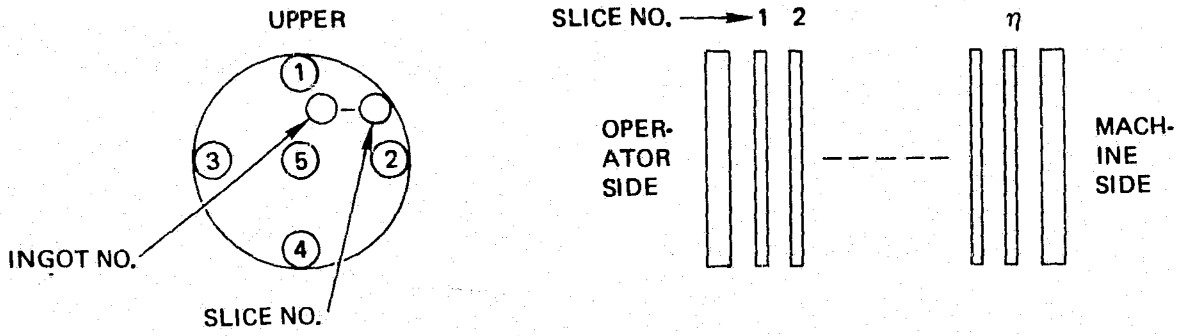
TIME-VERTICAL POSITION DATA SHEET
DEMONSTRATION 7
7 Nov. 1977



Time, Hr-Min	Vert. Pos., mm	Total Weight, kg	Cycle/ Min
00	0	1.5	67
05	1.5	2.0	67
10	2.7	2.5	67
15	4.0	3.0	67
20	5.0	3.5	67
25	6.5	4.0	67
30	7.5	4.5	67
35	8.5	5.0	67
45	11.0	6.0	67
1 - 00	14.5	6.5	67
15	18.2	7.5	67
30	21.5	8.0	67
45	25.5	8.6	67
2 - 00	28.3	8.6	67
15	31.5	8.6	67
30	34.3	8.6	67
45	37.5	8.6	67
3 - 00	41.0	8.6	67
15	44.0	8.6	67
30	46.8	8.6	67
45	49.8	8.6	67
4 - 00	53.0	8.0	67
15	56.0	8.0	67
30	59.5	8.0	67
45	62.7	8.0	67

Time, Hr-Min	Vert. Pos., mm	Total Weight, kg	Cycle/ Min
5 - 00	65.0	7	67
15	67.0	7	67
30	69.0	7	67
45	70.5	7	67
6 - 00	73.0	6	67
15	74.3	6	67
30	76.0	6	67
45	78.	6	67

SLICE THICKNESS DATA SHEET
DEMONSTRATION 7
7 Nov. 1977



Slice No.	① mm	② mm	③ mm	④ mm	⑤ mm
1	0.252	0.180	0.192	0.192	0.160
5	0.270	0.259	0.259	0.270	0.259
10	0.271	0.270	0.272	0.284	0.274
15	0.272	0.274	0.275	0.270	0.282
20	0.262	0.267	0.285	0.257	0.271
25	0.266	0.262	0.263	0.272	0.265
30	0.268	0.262	0.268	0.269	0.270
35	0.271	0.266	0.265	0.268	0.268
40	0.271	0.269	0.268	0.273	0.276
45	0.267	0.266	0.269	0.266	0.269
50	0.268	0.268	0.266	0.271	0.272
55	0.265	0.270	0.267	0.267	0.268

SAMPLE CUTTING DATA SHEET
DEMONSTRATION 8
8 Nov. 1977

Specification of Prospect

1.	Materials of workpiece	Silicon
2.	Dimension of work	ϕ 78 × 27.3
3.	Machine No.	YQ-100 #143
4.	Cartridge type	"G"
5.	Hour put to used of head rollers	15 hr, 12 min

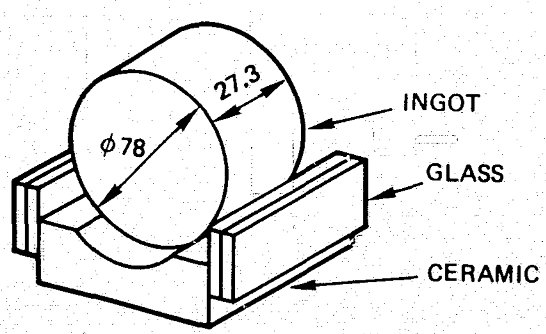
Cutting Condition

1.	Roller pitch	0.4 mm
2.	Diameter of wire	0.12 mm
3.	Abrasive	Previous use No. 6, No. 7 and No. 3 (1 kg)
4.	Lapping oil	
5.	Ratio of 3 to 4	
6.	Bond	Sunlock SMD-01
7.	Mean amount of kerf	0.15 mm
8.	No. of wire under cutting	61
9.	Total weight	Max 8.5 kg
10.	Mean unit weight	Max 20.2 g/cm/wire
11.	Total wire tension	1.2 kg
12.	Breaking point of wire	3.2 kg
13.	Feeding amount of wire	10 m/min
14.	Reciprocation of wire	67 cycle/min
15.	Wears of wire	7 μm
16.	Total length of used wire	3870 m

Working Efficiency

1.	Total working time	-
2.	Number of works	-
3.	Working time of unit work	-
4.	Total cutting area	-
5.	Total volumes of kerf	-
6.	Mean volumes of kerf	-

Schematics of Work Installed



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SAMPLE CUTTING DATA SHEET (Cont.)
DEMONSTRATION 8
8 Nov. 1977

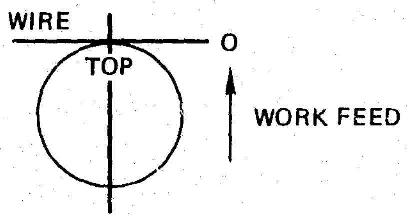
Remarks

1. After 6 hr 27 min from cutting start, the wire broke down, so operation had to be abandoned.

   Failure may have been caused by the peeling off of right dummy glass.

   At wire breaking, a bond for this dummy glass peeled off where softened, and so we concluded that this operation could not continue.

TIME-VERTICAL POSITION DATA SHEET
DEMONSTRATION 8
8 Nov. 1977



Time, Hr-Min	Vert. Pos., mm	Total Weight, kg	Cycle/ Min
0 - 00	0	1.5	67
05	0.7	2.0	67
10	2.0	2.5	67
15	2.7	3.0	67
20	4.4	3.5	67
25	5.9	4.0	67
30	7.0	4.5	67
35	8.0	5.0	67
40	9.0	5.0	67
45	10.5	5.5	67
50	11.0	6.0	67
55	12.0	6.5	67
1 - 10	15.5	7.0	67
25	19.3	8.0	67
40	22.5	8.5	67
55	25.9	8.5	67
2 - 10	28.2	7.0	67
25	30.0	7.0	67
40	32.7	7.0	67
55	35.0	7.0	67
3 - 10	37.5	7.0	67
25	39.7	7.0	67
40	41.5	7.0	67
55	43.8	7.0	67

Time Hr-Min	Vert. Pos., mm	Total Weight, kg	Cycle/ Min
4 - 10	46.3	8.5	67
25	49.5	8.5	67
40	52.3	8.5	67
55	54.5	8.5	67
5 - 10	57.0	8.5	67
25	59.5	8.5	67
40	62.5	8.5	67
55	65.0	8.5	67
6 - 10	67.5	8.5	67
25	69.5	8.5	67
27	WIRE WAS BROKEN		

SAMPLE CUTTING DATA SHEET
DEMONSTRATION 9
9 Nov. 1977

Specification of Prospect

1.	Materials of workpiece	Silicon
2.	Dimension of work	ϕ 78 × 28.4
3.	Machine No.	YQ-100 #143
4.	Cartridge type	
5.	Hour put to used of head rollers	21 hr, 12 min

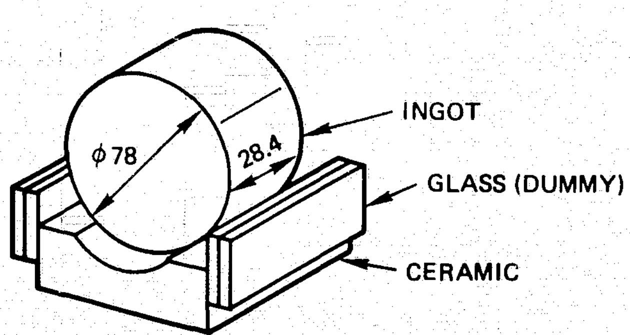
Cutting Condition

1.	Roller pitch	0.4 mm
2.	Diameter of wire	0.12 mm
3.	Abrasive	Previous use No. 8
4.	Lapping oil	
5.	Ratio of 3 to 4	
6.	Bond	Sunlock SMD-01
7.	Mean amount of kerf	0.15 mm
8.	No. of wire under cutting	50
9.	Total weight	Max 6.9 kg
10.	Mean unit weight	Max 20 g/cm/wire
11.	Total wire tension	1.2 kg
12.	Breaking point of wire	3.2 kg
13.	Feeding amount of wire	10 m/min
14.	Reciprocation of wire	65 ~ 67 cycle/min
15.	Wears of wire	7 μm
16.	Total length of used wire	5300 m

Working Efficiency

1.	Total working time	8 hr, 50 min
2.	Number of works	49 pcs
3.	Working time of unit work	10.8 min
4.	Total cutting area	2389 cm^2
5.	Total volumes of kerf	35.8 cm^3
6.	Mean volumes of kerf	0.068 cm^3/min

Schematics of Work Installed



SAMPLE CUTTING DATA SHEET (Cont.)
DEMONSTRATION 9
9 Nov. 1977

Remarks

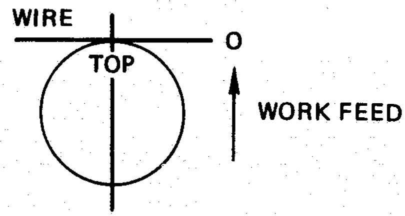
1. At 15 minutes from cutting start, total weight was decreased from 6.9 kg to 2.0 kg because of wire delaying.

2. At this time, wire cut 18 mm in silicon ingot. (See Time-Vertical Position Data Sheet.)

3. Investigation of sliced silicon wafers after cutting showed tool marks caused by wire on each wafer.

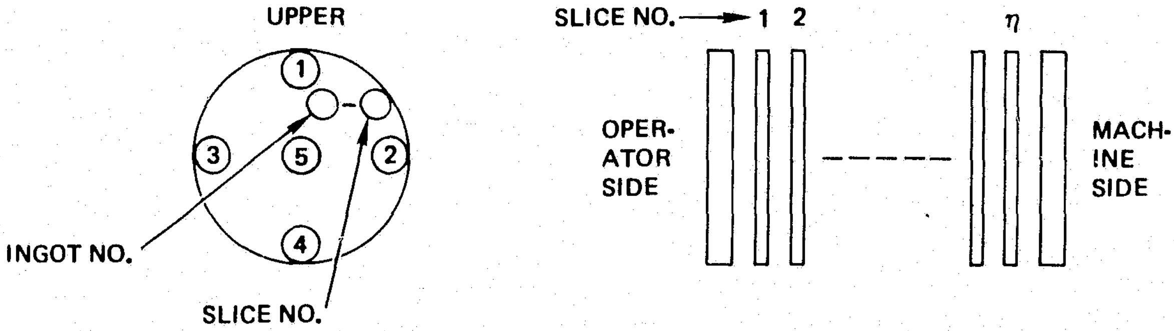
4. Total weight was changed radically under cutting operation.

TIME-VERTICAL POSITION DATA SHEET
DEMONSTRATION 9
9 Nov. 1977



Time, Hr-Min	Vert. Pos., mm	Total Weight, kg	Cycle/ Min	Time, Hr-Min	Vert. Pos., mm	Total Weight, kg	Cycle/ Min
00	0	1.5	65	3 - 10	33.0	5.5	67
05	1.2	2.0	67	25	35.5	5.5	67
10	2.3	2.5	67	40	37.5	5.5	67
15	4.0	3.0	67	55	39.7	5.5	67
20	5.5	3.5	67	4 - 10	41.8	5.5	67
25	6.8	4.0	67	25	44.0	5.5	67
30	8.0	4.5	67	40	46.2	5.5	67
35	9.5	5.0	67	55	48.4	5.5	67
40	10.7	5.5	67	5 - 10	50.6	5.5	67
45	12.0	6.0	67	25	53.5	5.5	67
50	14.0	6.5	67	40	55.5	5.5	67
55	15.5	6.9	67	55	58.0	5.5	67
1 - 10	18.8	6.9	67	6 - 10	60.6	5.5	67
15	18.0	2.0	67	25	63.5	5.5	60
25	18.8	2.0	67	40	65.5	5.5	60
40	19.0	2.5	67	55	66.5	5.5	60
45	19.8	3.0	67	7 - 10	67.6	5.5	60
50	20.2	3.5	67	25	69.2	5.5	60
55	21.0	4.0	67	40	70.5	5.5	60
2 - 00	22.0	4.5	67	55	72.5	5.5	60
5	23.0	5.0	67	8 - 10	73.6	5.5	60
10	24.0	5.5	67	25	75.6	5.5	60
25	26.5	5.5	67	40	77.0	5.5	60
40	28.4	5.5	67	50	78.0	5.5	60
55	31.0	5.5	67				

SLICE THICKNESS DATA SHEET
DEMONSTRATION 9
9 Nov. 1977



Slice No.	(1) mm	(2) mm	(3) mm	(4) mm	(5) mm
1	0.266	0.288	0.282	0.277	0.296
5	0.270	0.264	0.265	0.275	0.262
10	0.265	0.263	0.262	0.265	0.265
15	0.254	0.265	0.260	0.260	0.264
20	0.272	0.264	0.266	0.265	0.264
25	0.262	0.265	0.263	0.261	0.269
30	0.272	0.264	0.269	0.279	0.271
35	0.268	0.264	0.262	0.270	0.266
40	0.267	0.269	0.268	0.276	0.269
45	0.267	0.262	0.263	0.264	0.268
49	0.255	0.257	0.253	0.261	0.257

SAMPLE CUTTING DATA SHEET
DEMONSTRATION 10
10 and 12 Nov. 1977

Specification of Prospect

1.	Materials of workpiece	Silicon
2.	Dimension of work	ϕ 78 × 26.7
3.	Machine No.	YQ-100 #143
4.	Cartridge type	"G"
5.	Hour put to used of head rollers	0 hr, 0 min

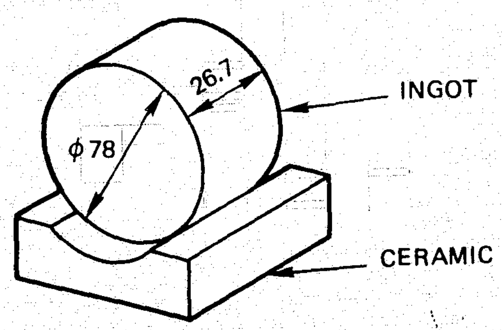
Cutting Condition

1.	Roller pitch	0.4 mm
2.	Diameter of wire	0.1 mm
3.	Abrasive }	
4.	Lapping oil }	Previous use No. 6 - No. 9
5.	Ratio of 3 to 4 }	
6.	Bond	Sunlock SMD-01
7.	Mean amount of kerf	0.13 mm
8.	No. of wire under cutting	56
9.	Total weight	Max 3.0 kg
10.	Mean unit weight	Max 7.8 g/cm/wire
11.	Total wire tension	0.9 kg
12.	Breaking point of wire	2.2 kg
13.	Feeding amount of wire	10 m/min
14.	Reciprocation of wire	40 ~ 65 cycle/min
15.	Wears of wire	5 μm
16.	Total length of used wire	-

Working Efficiency

1.	Total working time	-
2.	Number of works	-
3.	Working time of unit work	-
4.	Total cutting area	-
5.	Total volumes of kerf	-
6.	Mean volumes of kerf	-

Schematics of Work Installed



SAMPLE CUTTING DATA SHEET (Cont.)
DEMONSTRATION 10
10 and 12 Nov. 1977

Remarks

1. November 10th 1977

   a. After 13 minutes, cutting in 2 mm from starting, wire broke down. At this time, total weight was 1.5 kg and wire was barely worn, but three-roller set was a little injured.

   b. Work was replaced; operation discontinued.

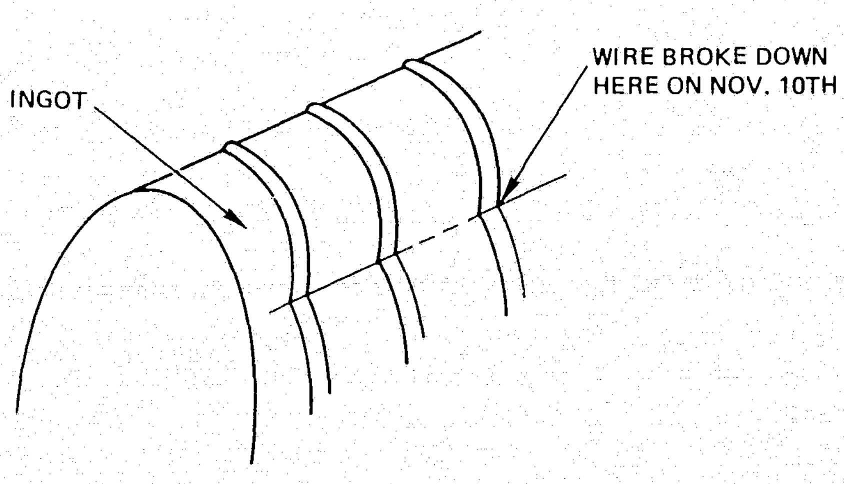
2. November 12th 1977

   a. Operated with new three-roller set with previously used 0.1 mm diameter wire and put together wire in previous cut slot.

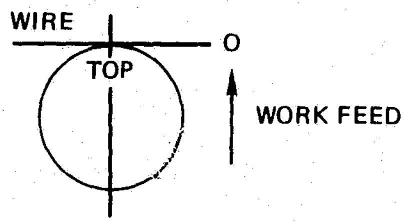
   b. Used MDC depth control to 4 mm depth from bottom of previous cut slot.

   c. After 1 hr - 23 min, wire broke once more. At this time, total weight was 3 kg; wear of wire was 5 μm.

   d. Wire breaking may have been caused by wire not fitting previous cut slot. The required cutting slot is as follows:



TIME-VERTICAL POSITION DATA SHEET
DEMONSTRATION 10
10 and 12 Nov. 1977



Time, Hr-Min	Vert. Pos., mm	Total Weight, kg	Cycle/ Min	Time, Hr-Min	Vert. Pos., mm	Total Weight, kg	Cycle/ Min
	[Nov. 10th 1977]						
0 - 00	0	0.5	62				
05	0.5	1.0	65				
10	1.7	1.5	65				
13	WIRE WAS BROKEN THIS						
	[Nov. 12th 1977]						
0 - 00	0	1.5	40				
10	0.7	2.0	50				
20	2.2	2.0	50				
25	2.7	2.0	60				
30	3.0	2.0	60				
35	3.7	2.0	60				
40	3.9	2.0	60				
45	4.1	2.0	60				
50	4.7	2.0	60				
55	5.0	2.5	60				
1 - 00	5.7	2.5	60				
05	6.7	2.5	60				
10	7.0	3.0	60				
15	7.7	3.0	60				
23	WIRE WAS BROKEN						

POSITION

MICRO DEPTH CONTROLLER WAS USED.

ORIGINAL PAGE IS
OF POOR QUALITY