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SENSITIVITY ANALYSIS OF ADD-ON PRICE ESTIMATE FOR SELECT SILICON WAFERING TECHNOLOGIES

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ABSTRACT

Silicon sheet technology is being developed for the Low-Cost Solar Array (LSA) Project, sponsored by the U.S. Department of Energy. One way of producing silicon sheet is to grow ingots from polysilicon, either by the Czochralski (Cz) process or by casting, and slicing the ingots into wafers.

In order to achieve the LSA price goal of \$0.70/W_p, the price allocation for Cz ingot growth plus slicing is \$27.4/m^2 for circular wafers. The price allocation for cast ingot plus slicing is \$36.3/m^2 for square or rectangular wafers. The cost of producing wafers from silicon ingots is a major component of the add-on price of silicon sheet. Wafering technology therefore needs considerable improvement in order to meet the price goals.

Presently, internal-diameter (ID) sawing, multiblade slurry (MBS) sawing and fixed-abrasive slicing technique (FAST) are the three wafering methods being developed by the LSA Project.

Economic analyses of the add-on price estimates and their sensitivity for the ID, MBS, and FAST processes are presented. Interim Price Estimation Guidelines (IPEG) are used for estimating a process add-on price. Sensitivity analysis of price is performed with respect to cost parameters such as equipment, space, direct labor, materials (blade life) and utilities, and the production parameters such as slicing rate, slices per centimeter and process yield, using a computer program specifically developed to do sensitivity analysis with IPEG. The results aid in identifying the important cost parameters and assist in deciding the direction of technology development efforts.

INTRODUCTION

The Low-Cost Solar Array (LSA) Project, sponsored by the U.S. Department of Energy, is developing the technology for manufacturing photovoltaic modules. Project goals are to achieve technical readiness by 1982 and commercial readiness by 1986, by producing modules at the price of \$0.70/W_p (1980\$).

Developing the technology for producing large-area silicon sheets (LASS) is one of the project tasks. One approach is to grow molten polysilicon as ingots, using the Czochralski (Cz) method or casting processes such as the heat-exchanger method (HEM) with directional solidification, and to slice the ingots into wafers. The three wafering techniques that are being developed by the LASS Task are: (1) internal-diameter slicing by ID saw,

(2) the multiblade slurry (MBS) technique and (3) multiple-wire fixed-abrasive slicing technique (FAST). The economic analysis of the add-on price estimates for these wafering techniques, in the light of the LSA Project goals, is of particular interest in this study.

In order to achieve the module price goal, the price allocation for Cz ingot growth plus the slicing process is $\$27.4/m^2$ for circular wafers, and the price allocation for cast-ingot growth plus slicing is $\$36.3/m^2$ for square or rectangular wafers (Reference 1). Distributing the allocation equally between the two processes, the growth cost will be $\$14.m^2$ for Cz and $\$18/m^2$ for cast ingot. Assuming wafering at the rate of 25 slices/cm, the allocation for growth is \$14/kg for Cz ingot and \$18/kg for cast ingot, as the conversion factor for $\$/m^2$ to \$/kg is 1 for 25 slices/cm. However, it appears that for 15-cm-dia ingots the wafering rate may be as low as 17 slices/cm. The growth cost of \$14/kg would amount to $\$20.2/m^2$ for wafering of 17 slices/cm, leaving only $\$27.4 - \$20.2 = \$7.2/m^2$ for wafering. Taking into account the increased silicon utilization of thicker wafers, the allocation for wafering would be less than $\$7.2/m^2$ for 15-cm-dia ingots. For smaller-diameter ingots the growth cost will be more than that for 15-cm-dia ingots (Reference 2); however, the slices per centimeter can be increased. For square ingots, the allocation for wafering at 25 slices/cm would be $\$36.3 - \$18.0 = \$18.3/m^2$.

The price estimation method used is described below. The add-on price for each of the three wafering processes is computed and the important cost parameters are identified. Based on the sensitivity analyses of the key parameters, conclusions are drawn suggesting the direction of technology development.

SENSITIVITY ANALYSIS USING IPEG (SAIPEG)

The add-on price for a process is estimated using the Interim Price Estimation guidelines (IPEG) (Reference 3). The price is estimated by using the following equations from IPEG 2 (the improved version of IPEG) (Reference 4).

$$\text{AMC} = 0.52 \times \text{EQPT} + 109.0 \times \text{AREA} + 2.8 \times \text{DLAB} + 1.2 \times (\text{MATS} + \text{UTIL}) \qquad (1)$$

$$\text{PRICE } (\$/m^2) = \text{AMC } (\$/yr)/\text{QTYPYR } (m^2/yr) \qquad (2)$$

where

AMC = Annual manufacturing cost (\$/yr).

EQPT = Total installed cost of equipment (\$). Coefficient 0.52 corresponds to equipment life of 10 years.

AREA = Area required by the process equipment and its operators (ft^2).

DLAB = Annual cost of direct labor (\$/yr). Coefficient 2.8 is used if the fringe benefits are not included in DLAB.

MATS = Annual cost of materials and supplies (\$/yr).

UTIL = Annual cost of utilities (\$/yr).

QTYPYR = Quantity of wafers produced (m^2/yr).

The input data for the base case of a process for the production parameters and the cost parameters are obtained by projections based on experience and judgment.

SAIPEG is a computer program for doing sensitivity analysis using IPEG. The sensitivity analysis of a process add-on price is performed by SAIPEG with respect either to the production rate or to any cost parameters varied one at a time with the remaining data held constant. The production rate and the cost parameters in turn are varied by changing some of the base-case input parameters.

SAIPEG RESULTS OF WAFERING PROCESSES

The sensitivity analysis of the add-on price is performed for each of the three wafering techniques. The sensitivity of the key parameters and their impact on the price are discussed in detail below.

Multiple Ingot Wafering With ID Saw

An earlier study of wafering 15-cm ingots individually by ID saw has shown that it is hard to meet the price goals of \$7.20/m^2; it requires a plunge rate of 12 to 15 cm/min, which is not practicable (Reference 5). One of the ways of improving the throughput of ID wafering is to build a machine capable of handling multiple ingots simultaneously. The ID saw considered in this analysis is suitable for slicing three 15-cm-dia ingots simultaneously. The input data for the base case is given in Table 1. QTYPYR, AMC, the price and the price breakdown in terms of cost parameters are presented in Table 2. Each machine will produce 6139 m^2 of wafers annually at a cost of \$93,673, giving a price of \$15.26/m^2. The price breakdown reveals that utilities and area-related costs are negligible. Cost of EQPT, DLAB and MATS are distributed fairly equally, amounting to 25%, 32%, and 37%, respectively.

Effect of production variation in terms of the plunge rate and the blade life is shown in Figure 1. The base-case data assume a blade life of 1530 slices (3 ingots x 30 cm long x 17 slices/cm), requiring a new blade for each run. The price is reduced to \$10/m^2 by increasing the blade life to 4000 slices and the plunge rate to 5 cm/min. This requires improvements in the quality of the blade. It may be noticed in Figure 1 that for a given plunge rate the decrease in price with blade life beyond 2500-3000 slices or more is not significant. To achieve the price goal, a plunge rate of 5 cm/min or more and a blade life of 4000 slices may be required.

The effect of varying DLAB in terms of machines per operator (MPO) and labor pay rate is shown in Figure 2. By increasing MPO from 6 to 12, the price is reduced from \$15.26/m^2 to \$12.85/m^2. Due to the asymptotic nature of the curves, there is no significant saving in increasing MPO beyond 12.

Table 1. Base-Case Data For ID Wafering Process

INGOTS CUT PER RUN	3.00
INGOT LENGTH (CM)	30.00
INGOT DIAMETER (CM)	15.00
SLICES PER (CM)	17.00
PLUNGE RATE (CM/MIN)	3.80
INGOT SET UP TIME (HRS)	0.50
SAW SET UP TIME (HOURS)	0.50
BLADE LIFE (SLICES)	1530.00
NON PRODUCTIVE TIME/YR (DAYS)	20.00
PROCESS YIELD	0.95
MACHINE COST ($/EACH)	45000.00
MACHINE LIFE TIME (YEARS)	10.00
AREA PER MACHINE (FT^2)	50.00
LABOR PAY RATE ($/HR)	6.50
MACHINES PER OPERATOR	6.00
BLADE PRICE ($/EACH)	100.00
OTHER CONSUMABLES ($/RUN)	20.00
POWER CONSUMPTION (KW/EACH)	1.50
ENERGY RATE ($/KWH)	0.05

Table 2. Price Estimation Results of the ID Wafering Process Using Base-Case Data

PRODUCTION PER YEAR (M^2) = 6,138.83

ANNUAL COSTS ($) = 93,672.52

ADD-ON PRICE ($/M^2) = 15.26

PRICE BREAKDOWN	PERCENT
EQUIPMENT	24.98
AREA	5.82
DIRECT LABOR	31.69
MATERIALS	36.74
UTILITIES	0.77
TOTAL	100.00

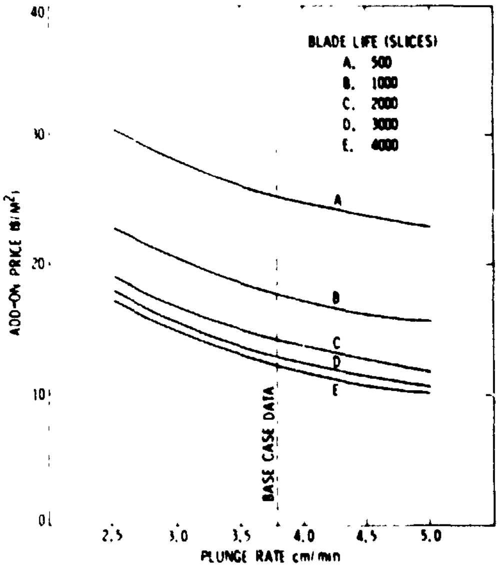

Fig. 1. Add-on Price vs Production Rate for Wafering 15-cm-Dia Silicon Ingots (17 slices/cm) With ID Saw

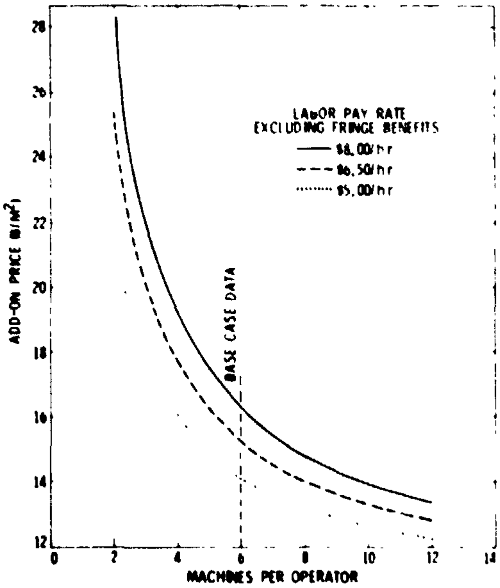

Fig. 2. Add-on Price vs Direct Labor Cost for Wafering 15-cm-Dia Silicon Ingots (17 slices/cm) With ID Saw

By increasing the blade cost from $100 to $140, the price is increased from $15.26/m^2 to $17.23/m^2. By reducing the blade cost to $60, the price would be reduced to $13.63/m^2. MATS cost contributes nearly one third of the price. It must be reduced, and blade life must be increased. By increasing EQPT cost from $45,000 each to $60,000 each, the corresponding increase in price amounts to only 8%.

In addition to the above analysis, a price estimate is made for wafering 10-cm-square ingots at 25 slices/cm and at a plunge rate of 5 cm/min. The blade is assumed to last for one run (2250 slices). The price for this case is $15.13/m^2, which is very close to that for wafering 15-cm-dia ingots (Table 3); its sensitivity is very similar to that for the 15-cm-dia ingots.

Table 3. Price Estimation Results of the Wafering Technologies

	ID		MBS				FAST	
INGOT SIZE	15 cm DIA	10 cm SQ	15 cm DIA	12.5 cm DIA	10 cm DIA	10 cm SQ	15 cm DIA	10 cm SQ
QUANTITY/YEAR (M^2)	6138.83	6797.25	3198.29	2657.31	2115.27	2693.25	5109.90	6483.75
AMC ($)	93,672.52	102,862.78	59,660.54	65,173.48	73,358.89	73,358 89	59,646.21	59,984.99
PRICE ($/M^2)	15.26	15.13	18.65	24.53	34.68	27.24	11.67	9.25
PRICE BREAKDOWN (PERCENT)								
EQUIPMENT	24.98	22.27	36.61	33.51	29.77	29.77	26.15	26.01
AREA	5.82	5.19	6.58	6.02	5.35	5.35	14 62	14.54
DIRECT LABOR	31.69	28.28	8.31	7.61	6.76	6.76	31.06	30.88
MATERIALS	36.74	43.58	47.06	51.55	56.96	56.96	25.07	25.48
UTILITIES	0.77	0.68	1.44	1.31	1.16	1.16	3.10	3.08
TOTAL	100.00	100.00	100.00	100.00	100.00	100.00	100 00	100.00
RELEVANT DATA FOR COMPARISON								
SLICES/CM	17.00	25.00	21.00	21.00	21.00	21.00	19.00	25.00
SLICING RATE (MM/MIN)	38.00	50.00	0.10	0 10	0.10	0 10	0.085	0.10
BLADE LIFE (RUNS)	1530†	2250†	1.00	1.00	1.00	1.00	3.00	5.00
MACHINE COST ($)	45,000.00	45,000.00	42,000.00	42,000.00	42,000.00	42,000.00	30,000.00	30,000.00
DUTY CYCLE	0.97	0.96	0.98	0.98	0.97	0.97	0.95	0.92
NON PROD (DAYS)	20.91	20.50	8.00	7.67	7.36	7.36	21.11	20.59
INGOTS/RUN	3.00	3.00	1.00	1.00	1.00	1.00	2.00	2.00

†BLADE LIFE IS SLICES INSTEAD OF RUNS.

Wafering With MBS Saw

The blades required to slice an ingot of a certain length are arranged with spacers according to the number of slices/cm required and are held in a blade head. The whole ingot is sliced into wafers simultaneously. Silicon carbide, used in a slurry, acts as an abrasive.

A circular ingot of 10-cm dia is considered for the analysis. The input data for the MBS wafering process, QTYPR, AMC and the price breakdown in terms of cost parameters, are given in Tables 4 and 5. Each machine produces 2115 m^2 of wafers annually at a cost of $73,359, resulting in an add-on price of $34.68/$m^2$. This price breakdown in terms of cost parameters indicates that materials cost is the primary contributor, amounting to nearly 57% of the price. The second important cost parameter is EQPT, amounting to nearly 30% of the price. Contributions of DLAB, AREA and UTIL are not significant.

Table 4. Base-Case Data For MBS Wafering Process

INGOTS CUT PER RUN	1.00
INGOT LENGTH (CM)	27.00
INGOT DIAMETER (CM)	10.00
SLICES PER CM	21.00
SLICING RATE (MM/MIN)	0.10
SET UP TIME (HOURS)	0.50
NON PRODUCTIVE TIME/YR (DAYS)	7.00
PROCESS YIELD	0.95
MACHINE COST ($/EACH)	42000.00
MACHINE LIFE TIME (YEARS)	10.00
AREA (SQ. FT.)	36.00
LABOR PAY RATE	4.88
MACHINES PER OPERATOR	27.00
BLADE PACK PRICE ($/PACK)	60.00
BLADE PACK LIFE TIME (RUNS)	1.00
ABRASIVE USED (POUNDS/RUN)	2.00
ABRASIVE COST ($/POUND)	3.30
VEHICLE USED (GALLONS/RUN)	4.00
VEHICLE COST ($/GALLON)	0.51
BEAM ($/RUN)	1.00
POWER CONSUMPTION (KW/EACH)	1.70
ENERGY RATE ($/KWH)	0.05

Table 5. Price Estimation Results of the MBS Wafering Process Using Base-Case Data

PRODUCTION PER YEAR (M^2) = 2,115.27

ANNUAL COSTS ($) = 73,358.89

ADD-ON PRICE ($/$M^2$) = 34.68

PRICE BREAKDOWN	PERCENT
EQUIPMENT	29.77
AREA	5.35
DIRECT LABOR	6.76
MATERIALS	56.96
UTILITIES	1.16
TOTAL	100.00

If it is possible to accommodate two ingots instead of one per run with a slight increase in slurry consumption, the production will be doubled, reducing the price to nearly $\$18.00/m^2$, which is in a reasonable range. Effect of production variation in terms of slices/cm and slicing rate is shown in Figure 3. By increasing the slicing rate from 0.1 mm/min to 0.2 mm/min, the price is reduced from $\$34.68/m^2$ to $\$17.84/m^2$. In addition, if two ingots are sliced simultaneously, the corresponding price would be $\$8.92/m^2$, which is close to the desired value. The decrease in the price achieved by increasing the slices/cm for slicing rates more than 0.15 mm/min is not significant. Efforts in increasing the throughput rate must be directed toward achieving multiple-ingot slicing simultaneously and increasing the slicing rate.

By reducing the EQPT cost from $42,000 each to $30,000 each, the price is reduced from $\$34.68/m^2$ to $\$31.73\ m^2$, which is not significant.

Material cost being the primary cost driver, every effort should be directed to reducing the materials cost. Effects of variation in blade-pack price and blade-pack lifetime (runs) on price are shown in Figure 4. By increasing blade-pack life to two runs and reducing the blade pack price to $30, the price is reduced from $\$34.68/m^2$ to $\$21.92/m^2$. In addition, if two ingots are sliced simultaneously, instead of individually, the corresponding price would be $\$10.96/m^2$.

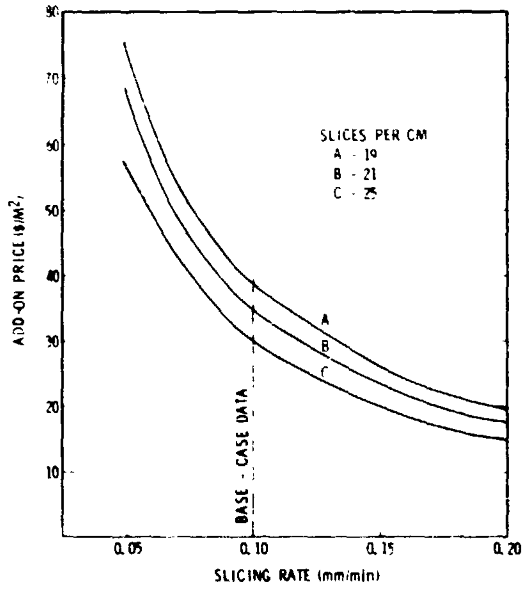

Fig. 3. Add-on Price vs Production Rate for Wafering 10-cm-Dia Silicon Ingots (21 slices/cm) with MBS Saw

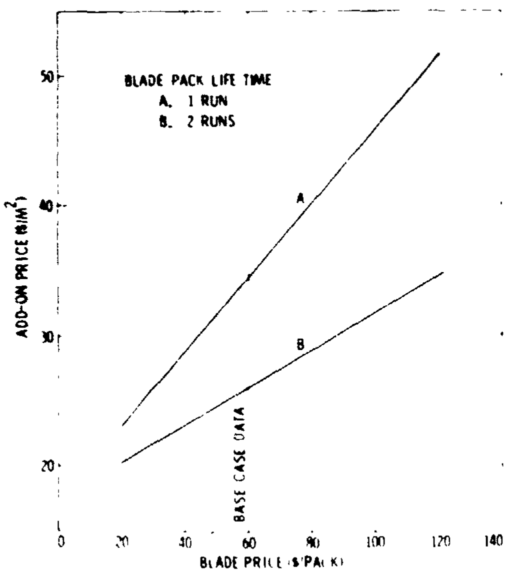

Fig. 4. Add-on Price vs Material Cost for Wafering 10-cm-Dia Silicon Ingots (21 slices/cm) with MBS Saw

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The effects of varying production in terms of slicing rate and process yield are presented in Figure 5. By increasing the slicing rate from the base case of 0.085 mm/min to 0.1 mm/min, the price is reduced from \$11.67/m^2 to \$9.99/m^2. In order to obtain a price less than \$10/m^2, it may be necessary to achieve a process yield of not less than 0.95, averaged over the wire-pack lifetime, and a slicing rate of at least 0.10 mm/min, which is the contract goal.

Direct labor cost is a major factor in the price. Sensitivity analysis with respect to MPO and the labor pay rate is presented in Figure 6. By increasing the MPO from 10 to 14, the price is reduced from \$11.67/m^2 to \$10.64/m^2. As the curves become asymptotic to the MPO axis, the impact of increasing MPO to more than 14 will not have a significant effect.

By varying the materials cost in terms of wire-pack life from three runs to five runs, the price is reduced from \$11.67/m^2 to \$10.50/m^2 (Figure 7). By further reducing the wire-pack cost to \$100, the price will be reduced to \$10.00/m^2. However, for a blade-pack life of one run, the price will be \$17.52/m^2.

By reducing the machine cost from \$30,000 each to \$20,000 each, the price is reduced to \$10.65/m^2. The advantage of increasing machine lifetime from 10 years to 15 years is of the order of 23 cents/m^2, which is not significant. Reduction of space requirement from 80 ft^2 to 60 ft^2 reduces price from \$11.67/m^2 to \$11.25/m^2. Increasing the space requirement to 100 ft^2 would raise the price \$12.10/m^2. Slight gain is achieved by reducing the space requirement.

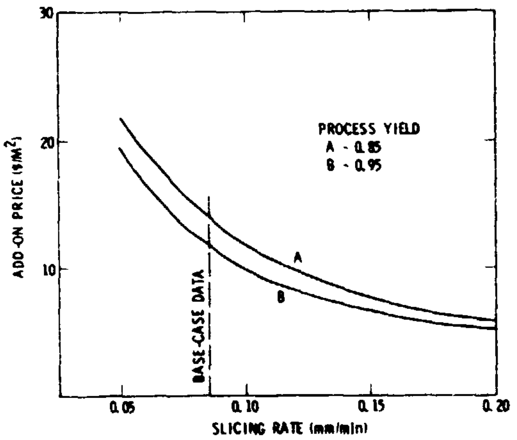

Fig. 5. Add-on Price vs Production Rate for Wafering 15-cm-Dia Silicon Ingots (19 slices/cm) by FAST

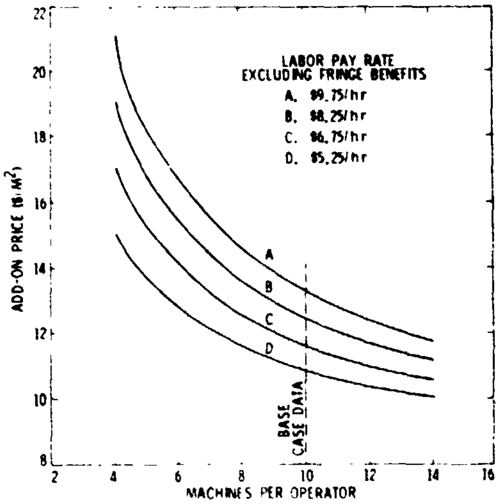

Fig. 6. Add-on Price vs Direct Labor Cost of Wafering 15-cm-Dia Silicon Ingots (19 slices/cm) by FAST

The production rate can be increased if the parameters such as slicing rate and slices per cm, given in Table 3, are valid for ingots of larger cross section. A considerable amount of technology development is needed to meet this requirement. Using the data of Table 3, the price estimates for 10-cm-sq, 12.5-cm-dia and 15-cm-dia ingots are $\$27.24/\mathrm{m}^2$, $\$24.53/\mathrm{m}^2$ and $\$18.65/\mathrm{m}^2$, respectively (Table 3).

Wafering With FAST

Multiple wires plated with diamonds are used as cutting edges. The wires are spaced according to the slices/cm required. The whole ingot is sliced simultaneously.

Two-15-cm-dia ingots sliced simultaneously are considered for analysis. The input data for the base case are given in Table 6. The QTYPYR, AMC and the price breakdown in terms of cost parameters are give in Table 7. Each machine produced 5110 m^2 annually at a cost of 59,646, resulting in an add-on price of $\$11.67/\mathrm{m}^2$. The direct labor cost contributes 31% of the price. Equipment and material cost influence are nearly equal, contributing 26% and 25% respectively. The area cost is 15% and utilities cost is 3%.

Table 6. Base-Case Data For FAST Wafering Process

INGOTS CUT PER RUN	2.00
INGOT LENGTH (CM)	30.00
INGOT DIAMETER (CM)	15.00
SLICES PER CM	19.00
SLICING RATE (MM/MIN)	0.085
SET UP TIME (HOURS)	1.50
NON PRODUCTIVE TIME/YR (DAYS)	20.00
PROCESS YIELD	0.95
MACHINE COST ($/EACH)	30,000.00
MACHINE LIFE TIME (YEARS)	10.00
AREA (FT^2)	80.00
LABOR PAY RATE ($/HR)	6.75
MACHINE PER OPERATOR	10.00
BLADE PRICE ($/TWIN PACK)	140.00
BLADE PACK LIFE TIME (RUNS)	3.00
POWER CONSUMPTION (KW/EACH)	3.73
ENERGY RATE ($/KWH)	0.05

Table 7. Price-Estimation Results for the FAST Wafering Process Using Base-Case Data

PRODUCTION PER YEAR (M^2)	=	5,109.90
ANNUAL COSTS ($)	=	59,946.21
ADD-ON PRICE ($\$/\mathrm{M}^2$)	=	11.67

PRICE BREAKDOWN	PERCENT
EQUIPMENT	26.15
AREA	14.62
DIRECT LABOR	31.06
MATERIALS	25.07
UTILITIES	3.10
TOTAL	100.00

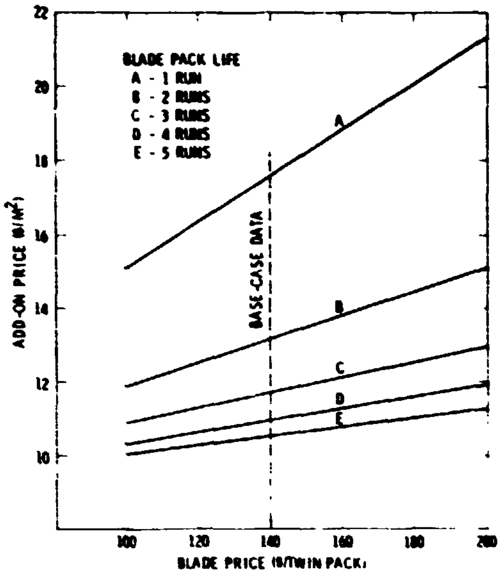

Fig. 7. Add-on Price vs Material Cost for Wafering 15-cm-Dia Silicon Ingots (19 slices/cm) by FAST

In addition to the above analysis, a price estimate is done for wafering 10-cm-square ingots at a rate of 25 slices/cm and a slicing rate of 0.10 mm/min. The wire pack is assumed to last for five runs. The price for this case is $9.25/m^2 (Table 3).

CONCLUSIONS

The add-on prices are estimated for the ID, MBS and FAST wafering processes. The important parameters are identified by the price breakdown in terms of cost parameters. Based on the sensitivity analysis of the key parameters, these conclusions are drawn:

1. The projected price estimates for the three wafering technologies are higher than the allocation for wafering circular ingots. Sensitivity analyses idicate that these technologies have the potential of achieving the price goal with appropriate development efforts. However, wafering multiple ingots 10 cm square at 25 slices/cm, using ID or FAST processes, does meet the goals.

2. For the ID wafering technique, it is highly desirable to investigate the possibility of slicing three 15-cm-dia ingots simultaneously. The efforts may be directed to achieve a plunge rate of 5 cm/min and a blade life of 4000 slices. The MPO may be increased to 12.

3. For the MBS wafering technique, the major cost driver is materials. The possibility of slicing ingots of large size, up to 15-cm dia, with the same projected data for those of 10-cm dia, may be investigated. The efforts may be directed toward slicing two ingots simultaneously. The production rate may be enhanced by achieving a slicing rate of 0.2 mm/min.

4. For the FAST process, the production rate may be increased by improving the slicing rate to 0.1 mm/min. It may be attempted to wafer 15-cm-dia ingots at a rate of more than 19 slices/cm. The labor cost may be reduced by increasing MPO to 14. Efforts may be made to increase the blade life to five runs and reduce the blade-pack price.

5. If the projections made in base-case input data could be achieved, the price estimate for FAST, being the lowest of the three, has a better potential of achieving the price goal. However, the ID sawing technique, being the most mature technology of the three, has a greater chance of success. For the MBS technique, achievement of multiple-ingot slicing and slicing of larger-sized, ingots would be necessary to meet the price goal.

ACKNOWLEDGMENTS

The author sincerely thanks T. Daud, A. Morrison and K. Dumas of Jet Propulsion Laboratory for supplying the base-case data for the ID sawing, MBS, and FAST processes, respectively, and for discussions.

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DISCUSSION:

DYER: Why was the down time only seven days on the multiblade saw and it was 20 days on the other saws?

MOKASHI: That was the data given in consultations with persons at JPL and the MBS contractor. They say that the machine shouldn't receive much maintenance and for annual maintenance seven days per year is more than enough. For general analysis (SAMICS) 20 days per year is considered for maintenance and repair. In the case of the MBS they feel the machines are more versatile and they don't need so much time for annual maintenance.

DYER: Are things like coffee breaks, employee meetings, and training and all that comprehended in that?

MOKASHI: In the equation used, it is assumed that eight hours per day includes coffee break and the person is assumed to work 220 days per year, allowing for vacation and all that. Allowing for shift operation, labor is assumed to be 4.7 times the eight-hour shift. That is how the labor cost is calculated.

OSWALD: You assumed there that you were cutting, with an ID saw, three-6-inch-diameter ingots simultaneously. Is there any such technology existing or anybody working on such a thing? I'd like to know how you get it.

MOKASHI: Although the attempt has not been made so far to slice more than one ingot of large diameter in ID saw, analysis indicates that one way of reducing the price is to increase the throughput. This is only an idea. These are the projections and it may be at the preliminary stage to think about how we can reduce the price. One way to increase the throughput is to slice more than one ingot simultaneously. That may require a larger internal diameter of the saw and some other developmental efforts.

MORRISON: I just wanted to add that, in the Project, we were seriously considering funding a proposal to do just that--three ingots simultaneously. With the cutback of FY81 funds, we were forced to drop that.

UNO: If Taher's (Daud) paper was good as far as the economics of using the squared-off ingot are concerned, what kind of price projection would you have if you mounted three of those, rather than rounded?

MOKASHI: It is given in my slide for three 10-cm-square ingots. And the price was close to that for the three 15-cm-diameter ingots.

LIU: Maybe I can clarify that a little bit. The numbers that Anant (Mokashi) is projecting down here are only for the slicing cost, so they do not take into account the packing factor. So if you do take that into account, you do get a benefit also.

SUREK: This thought always occurs to me whenever I see sensitivity analyses of things that don't yet exist...future technologies. If you were going to look at the base case as today's technologies, since these technologies are used today by existing industry, would you come up with somewhat different conclusions as to exactly how you would proceed to reduce the cost?

MOKASHI: That is how we started. In the first case we consider the existing technology and estimate the price and identify what are the major cost drivers. Based on that, thinking is initiated and even though today's technology may not show it is possible to do things at least from the analysis point of view we find out "if we can do this" how much effect it is and that may be the way to go ahead.

DAUD: There have been analyses done for the one-ingot cutting of 4, 5, 6-inch by various people and this is sort of an extension based on the work that JPL was proposing to fund.

WOLF: In looking at the big table that you just had on here a moment ago, it wasn't quite clear to me why in some cases going from the 15-cm-diameter to the 10-cm-square case, the cost per square meter stayed about constant, and in other cases it went up considerably, and some cases it went down considerably. What were the differences in the assumptions that made these prices behave this way?

LIU: The conventional thought is that changing the number of slices per centimeter doesn't affect the cost of wafering, but in the case of the multiblade saws and the multiwire saws, they do change it, because they potentially have higher throughput per unit saw and because you can pack more wires and cut more slices per same size ingot. So that's what the effect would be.

FUERST: Was your table the one that mentioned the price of $140 for the wire-packs used in the FAST method? (to F. Schmid) Two packs for $140? How many wires per pack? Less than 10¢ per wire? It's very ambitious. Right now you can buy steel strips direct from the mill for approximately the same cost, but you're going to take tungsten wire, diamond plating and diamonds, and get approximately the same cost?

SCHMID: Wire is very cheap. We are using plated steel wire, and the plated steel wire comes in at far below a cent per wire itself. And the process is a very low-cost process. I really do not think that $70 is ambitious.

FUERST: Do you have any estimates now of what you're paying for diamonds per wire, including the plating process?

SCHMID: Yes. All of that has been calculated, and I think that if you look at a concentration of 100--the cost works out to less than 5¢ a wire. Everything included.