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IBIS

Quarterly Report

Analysis of Cost:
CVD Diamond Deposition

Contract Number: N00014-93-C2044

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IBIS Associates, Inc.
55 William Street
Suite 220
Wellesley, MA 02181

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3rd Quarter 1993

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Executive Summary

IBIS Associates has updated its predictive spreadsheet models of the DC arcjet and microwave chemical vapor deposition (CVD) diamond technologies. This report presents the results obtained with the new models and revised sets of baseline inputs for diamond heat sink manufacture. The cost of producing 1,000 polished diamond wafers, 1 mm thick, is estimated in the long run to be \$23.70 per square centimeter by the DC arcjet deposition technology (six inch diameter), and \$8.49 per square centimeter by the microwave deposition technology (sixteen inch diameter).

Fifty-one percent of the DC arcjet cost is due to the deposition step, which consumes process gases and is capital intensive. Overall, the material cost of 31.2% and labor cost of 30.2% are significant factors in the total cost.

Eighty-seven percent of the microwave cost is due to the deposition step, which is capital intensive. Overall, the equipment cost of 37.9% and the material, utility and maintenance costs each at about 15.5% are significant factors in the total cost.

The major revision of the DC Arcjet Model is the inclusion of the kinetic theory of DC arcjet deposition into the model. According to the model based on this theory, the key factors driving the cost of thermal management diamond produced by the DC arcjet technology are the gas temperature, the power of the reactor, and the substrate diameter. It is shown that maximizing the gas temperature is critical to reducing the cost of the diamond wafer due to its dramatic effect on growth rate.

The major revision of the Microwave Model is the incorporation of similar theory of deposition kinetics, adapted to the typical conditions of microwave deposition. According to the model, the key factor driving the cost of thermal management diamond produced by the microwave technology is the power of the reactor. The reactor power has such a strong effect on cost because it affects both the linear growth rate and the plasma ball diameter. There are two inputs to the diffusion model which have a strong effect on the deposition cost. Research in the area of those inputs, the surface recombination of hydrogen at the substrate and the plasma ball skew or shape factor, has not advanced far enough to predict these input values reliably. The values for these inputs in the current version of the model were reported to IBIS as typical values by Professor David Goodwin at the California Institute of Technology.

To be investigated further are the relationships between diamond growth rate and process yield for both the DC arcjet and microwave technologies. It is expected that as the growth rate increases, the yield decreases; yet a specific relation between these factors is unknown. Similarly, the relationship between substrate diameter and yield requires further investigation, due to the known complications with the increase of this parameter. Lastly, expert approval of the models is continually in progress.

Modeling Progress

The seven steps for the fabrication of diamond film are Surface Preparation, Deposition, Etching, Laser Trimming, Lapping, Microscopic Inspection, and Thermal Conductivity Inspection. The flowchart for the process is shown in Figure 1, and descriptions for the processes that existed before this quarter can be obtained from previous quarterly reports.

The progress of the CVD diamond thin film models has involved both deposition improvements and the addition of the secondary operation of laser trimming. The changes to the deposition steps are described later in this report, and the laser trimming operation is described in the following section.

Laser Trimming

During the deposition process, the gas plasma deposits diamond around the edges of the deposition substrate, causing low quality diamond to form on the periphery of the desired area. Through laser trimming, the final shape of the diamond wafer can be cut, removing excess material. This process is usually performed one wafer at a time.

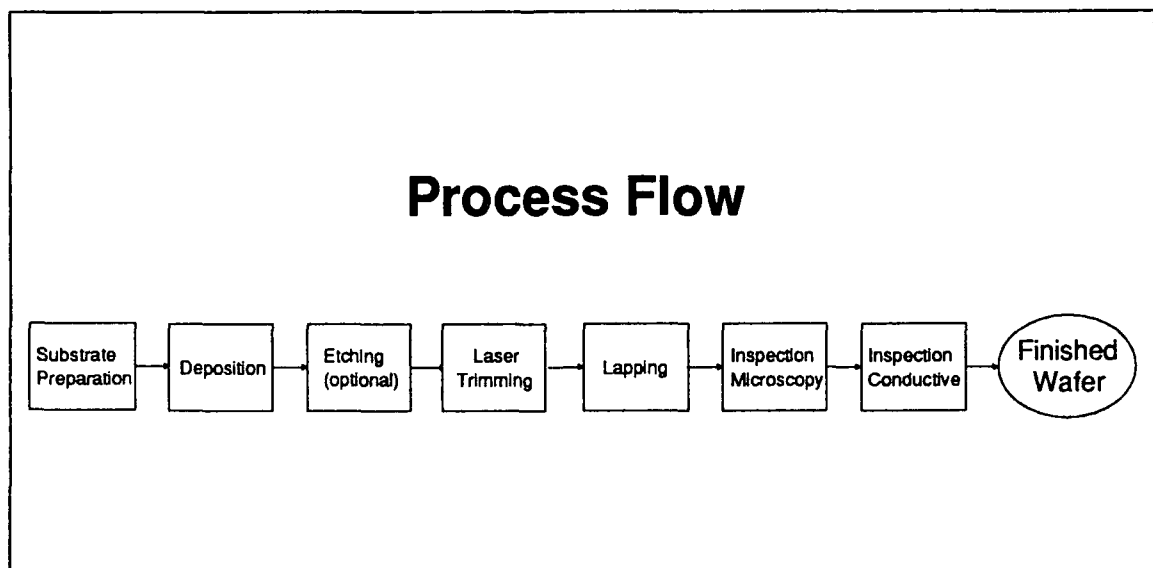


Figure 1

DC Arcjet Model

The progress of the DC Arcjet Model, as stated above, has involved the incorporation of deposition theory and a laser trimming step into the cost model. The incorporation of the theory has been accomplished with the help of Professor David Goodwin of Caltech and Dr. Richard Woodin of Technion. Subsequent progress by IBIS has been the conducting of analyses with the new model and soliciting expert review for its approval. A printout of the model is included in Appendix A, and the new deposition operation in the model are described in the following section.

Description of the DC Arcjet Deposition Theory

A theory of the physics and chemistry involved in the chemical vapor deposition of diamond by means of convective flows has been developed by Professor David Goodwin and Dr. Richard L. Woodin. With the help of Professor Goodwin and Dr. Woodin, IBIS Associates has successfully incorporated this theory into a Technical Cost Model for the manufacture of CVD diamond using the DC arcjet technology.

Figure 2 shows the two steps involved in modeling the linear growth rate of diamond, the basis of the theory being that the linear growth rate of diamond is proportional to the square of the concentration of atomic hydrogen at the growth surface. First, an energy balance from the input parameters determines the concentration of atomic hydrogen in the gas jet, then a boundary layer calculation leads to the determination of atomic hydrogen concentration at the substrate.

An energy balance of the gas jet physical and chemical reactions determines an equilibrium value for either the inlet gas temperature or the inlet gas volumetric flow rate, as well as the mole fraction of atomic hydrogen in this hot gas stream. The input side of the energy balance contains the power that is imparted to the gas by the DC arc power source. The output side of the energy balance contains the mean specific enthalpy of the gas mixture plus the kinetic energy of the gas stream.

The mole fractions in the gas mixture are calculated from gas flow rates (an input), the pressure inside the reactor (an input), the heat, entropy and free energy of reaction for the conversion of molecular hydrogen to atomic hydrogen. The heat, entropy and free energy of the reaction are determined from the temperature of the gas mix, the ideal gas constant and NASA enthalpy constants.

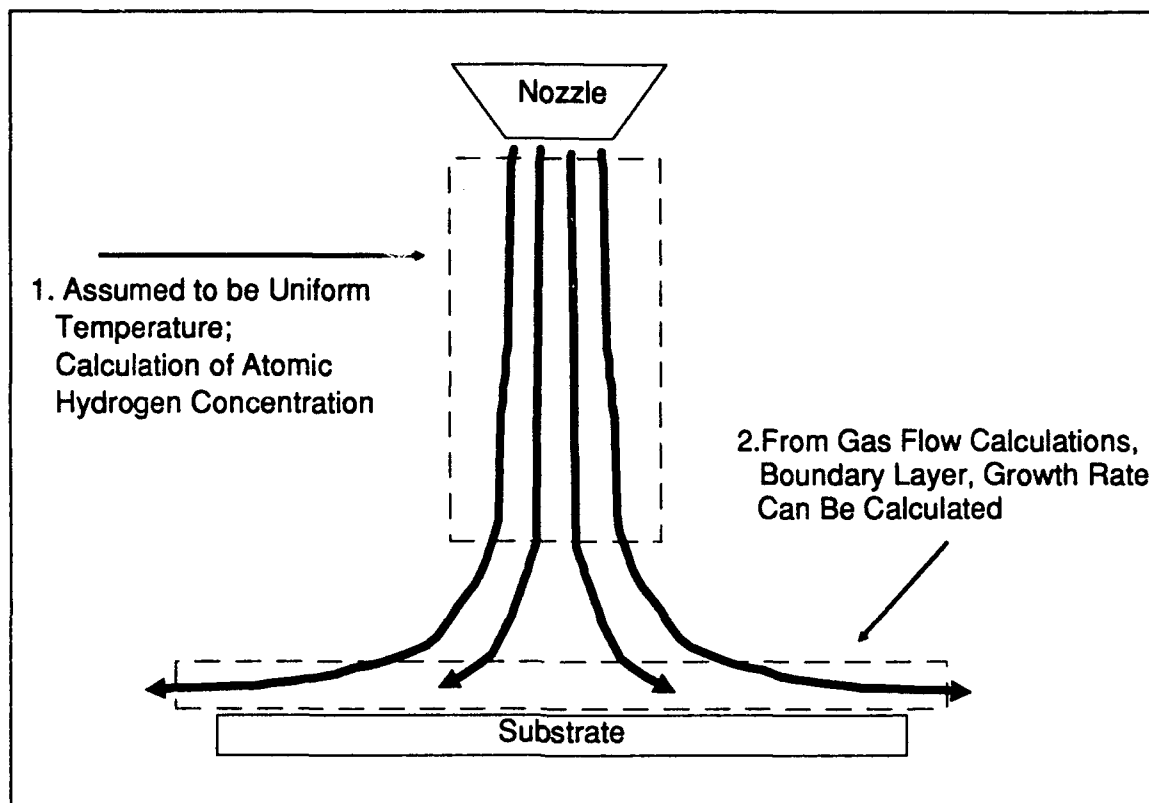


Figure 2

The gas velocity is calculated using the mass flow rate (which was calculated for the input side of the energy balance equation), the area of the gas duct (an input), the ideal gas constant, the temperature of the gas mix (an input), the pressure inside the reactor (an input) and the mean molecular weight.

Given the mole fraction of atomic hydrogen and the gas velocity, boundary layer transport theories are employed to determine the flux of hydrogen to the surface. Diamond deposition theory indicates that the linear growth rate is proportional to the concentration of atomic hydrogen at the substrate raised to some power between one and two. Using assumed values for growth rate, power and gas flow, a proportionality constant was found for the atomic hydrogen concentration exponent of two.

Linear growth rate is converted to a mass growth rate by assuming uniform growth across the surface. Mass growth rate is critical to the DC Arcjet Model because it has great impact on the costs for the deposition operation.

Sensitivity Analysis

One of the advantages of a Technical Cost Model is that it permits the flexibility of performing sensitivity analyses. Using sensitivity analyses, it is possible to explore the cost implications of changing key input variables such as production volume, material prices, product dimensions, etc. As an R&D management tool, these analyses help set development goals for cost effective manufacturing. Further, they help in long term planning, by indicating the cost savings that may be realized through scale-up. Presented in the following sections are the following analyses:

- Cost vs Gas Temperature and Substrate Area
- Cost vs Reactor Power and Substrate Area
- Cost vs Substrate Area (Constant Duct Area)

With the exception of the last sensitivity, the ratio of substrate to duct area is held constant. This constraint is due to the geometry of the DC arcjet methodology. The area of the gas duct is the cross-sectional area of the plasma jet before it is affected by the flow pattern around the substrate. For a DC arcjet CVD diamond plasma jet with a corresponding duct area impinging on an infinite plane, there will be a circular region of desirable diamond and a surrounding region of unacceptable diamond. Consider the similar case of a gas jet impinging on a substrate of the same area. As a substrate diameter increases while the duct diameter remains constant, there is a point at which the substrate extends into this zone of unacceptable diamond. Therefore, there is a maximum substrate:duct area ratio that should not be exceeded. Experts in DC arcjet CVD diamond suggest that this ratio is roughly 3:1. When the substrate diameter is varied in the following analyses, the duct diameter is adjusted so that the ratio of substrate to duct area is constant at three.

Wafer Cost per Square Centimeter vs Gas Temperature and Area

Figure 3 shows the cost per square centimeter as the gas temperature for the production run is varied for a range of wafer sizes, holding the substrate to duct area ratio (three) and reactor power (200 kW) constant. The graph shows that as the gas temperature increases, the cost of depositing a square centimeter of diamond decreases. The cost savings for increasing temperature are most dramatic at the lower end of the temperature range examined; a slight increase in temperature can result in a relatively large cost savings. At the high end of the temperature range there is little cost savings for slight increases in temperature. The equation shows the best fit for the area cost versus temperature and substrate area. This data regression shows that cost is inversely proportional to the temperature raised to the 5.45 power multiplied by substrate area raised to the 0.72 power. This relationship suggests that gas temperature is a variable of primary importance in the deposition process: an increase in temperature over the range in Figure 3 for the baseline diameter results in a cost reduction of 54%.

Cost vs Gas Temperature and Area

Substrate:Duct Ratio = 3

Reactor Power = 200 kW

$$\text{Cost} = 6.61\text{E}21 \times \text{Area}^{-0.72} \times \text{Temp}^{-5.45} + 7.30$$

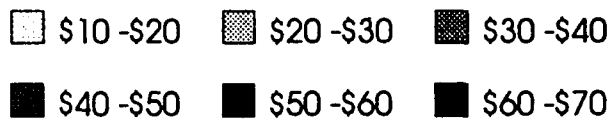
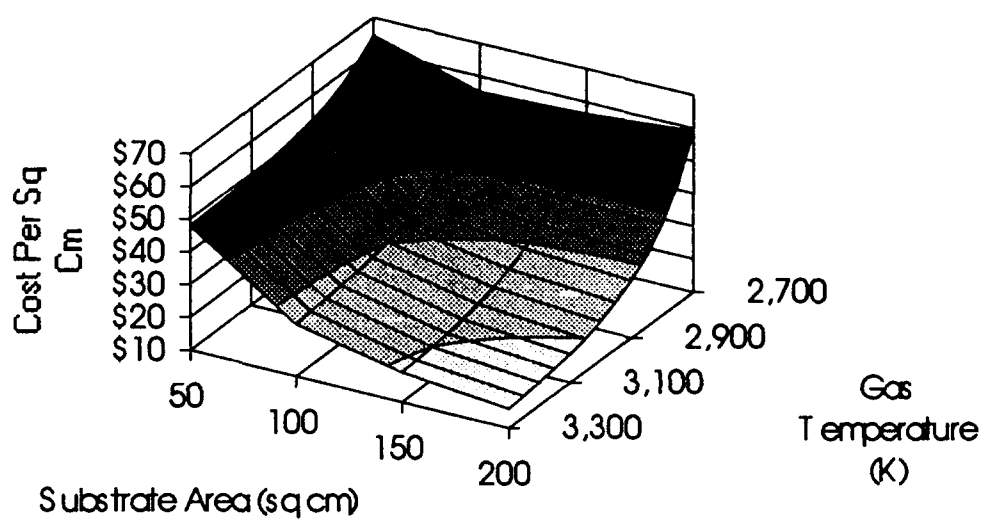


Figure 3

Figure 3 also shows the relationship between cost and substrate area. Over the range of temperatures examined, the cost of depositing diamond decreases with increasing wafer sizes. The importance of increasing the substrate area is evident toward the higher temperatures, where the slope of decreasing cost is more dramatic. For the range of substrate areas and at baseline temperature, the cost is reduced by 56%. Overall, a 75% reduction in cost (\$65 to \$16 per square centimeter) can occur by increasing both the gas temperature from 2,700K to 3,000K and the substrate area from 50 to 200 square centimeters.

Wafer Cost per Square Centimeter vs Reactor Power and Area

Figure 4 shows the dependence of cost on reactor power and substrate area, holding the substrate to duct area ratio (three) and the gas temperature (3,000 K) constant. The cost model reports that at our baseline data set, cost per square centimeter is inversely proportional to reactor power raised to the 0.28 power. This graph suggests that cost savings due to a small increase in power are much greater in the lower end of the power range examined than in the higher end: there are diminishing returns on increasing power in the higher end of the range examined. At constant gas temperature and area, the mach number of the gas flow is nearly directly proportional to reactor power. Therefore, this graph could also represent the behavior of cost as the mach number is increased while keeping the temperature constant. A closer look at the model reveals that at constant temperature, an increase in reactor power will further heat the gas mix. To sustain a constant gas temperature, the gas flow rate (mach number) must also increase to allow more gas to pass through the system to absorb the power increase. The lower cost per square centimeter and higher deposition rates of higher power reactors, at constant temperature, can be attributed directly to higher mach numbers.

Deposition Cost per Square Centimeter vs Substrate Area (Constant Duct Area)

Figure 5 recasts the data from Figure 3 at 200 kW showing the relationship between substrate area and cost for two cases: with duct area held constant at 58 square centimeters, and with the substrate to duct area ratio maintained at three. This graph suggests that great cost reductions may be accomplished by increasing the substrate area, especially at the low end of the area range examined.

For the curve with constant duct area in Figure 5, the largest valid substrate area is roughly 180 sq cm. This upper limit is determined from the assumption that the substrate:duct area ratio should not be greater than three, and the assumption of 58 square centimeters as the baseline duct area. At the baseline gas temperature of 3,000K

Cost vs Power and Area

Gas temperature = 3,000 K

Substrate:Duct ratio = 3

$$\text{Cost} = 2.69\text{E}3 \times \text{Area}^{-0.72} \times \text{Power}^{-0.28} + 8.00$$

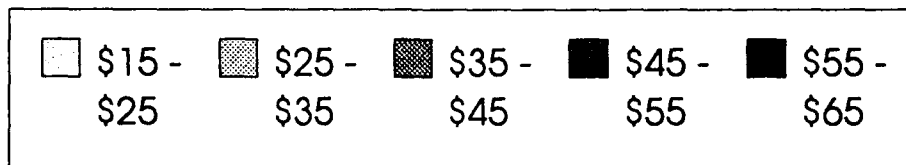
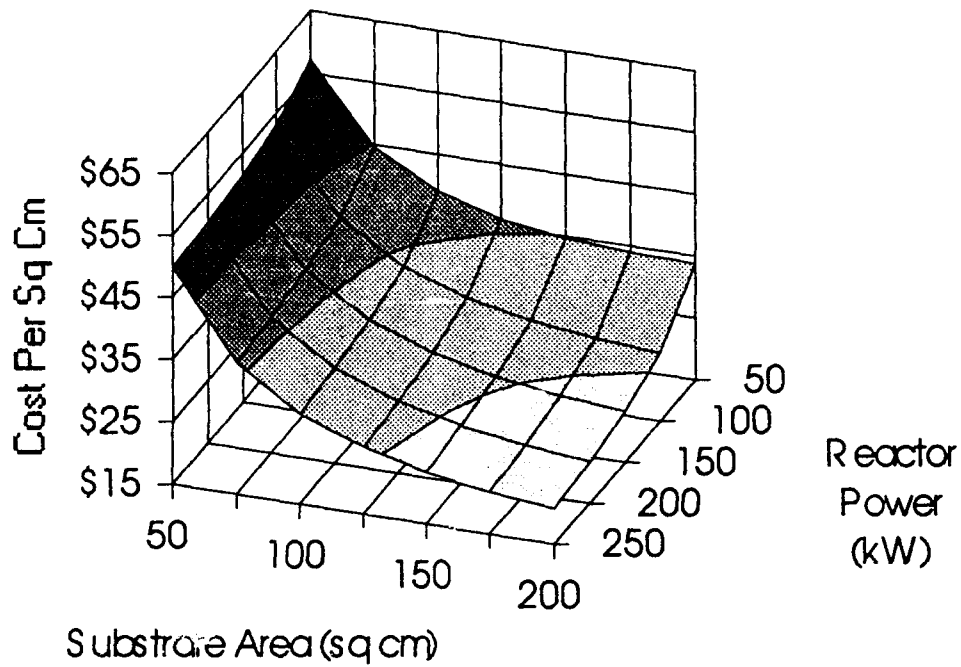


Figure 4

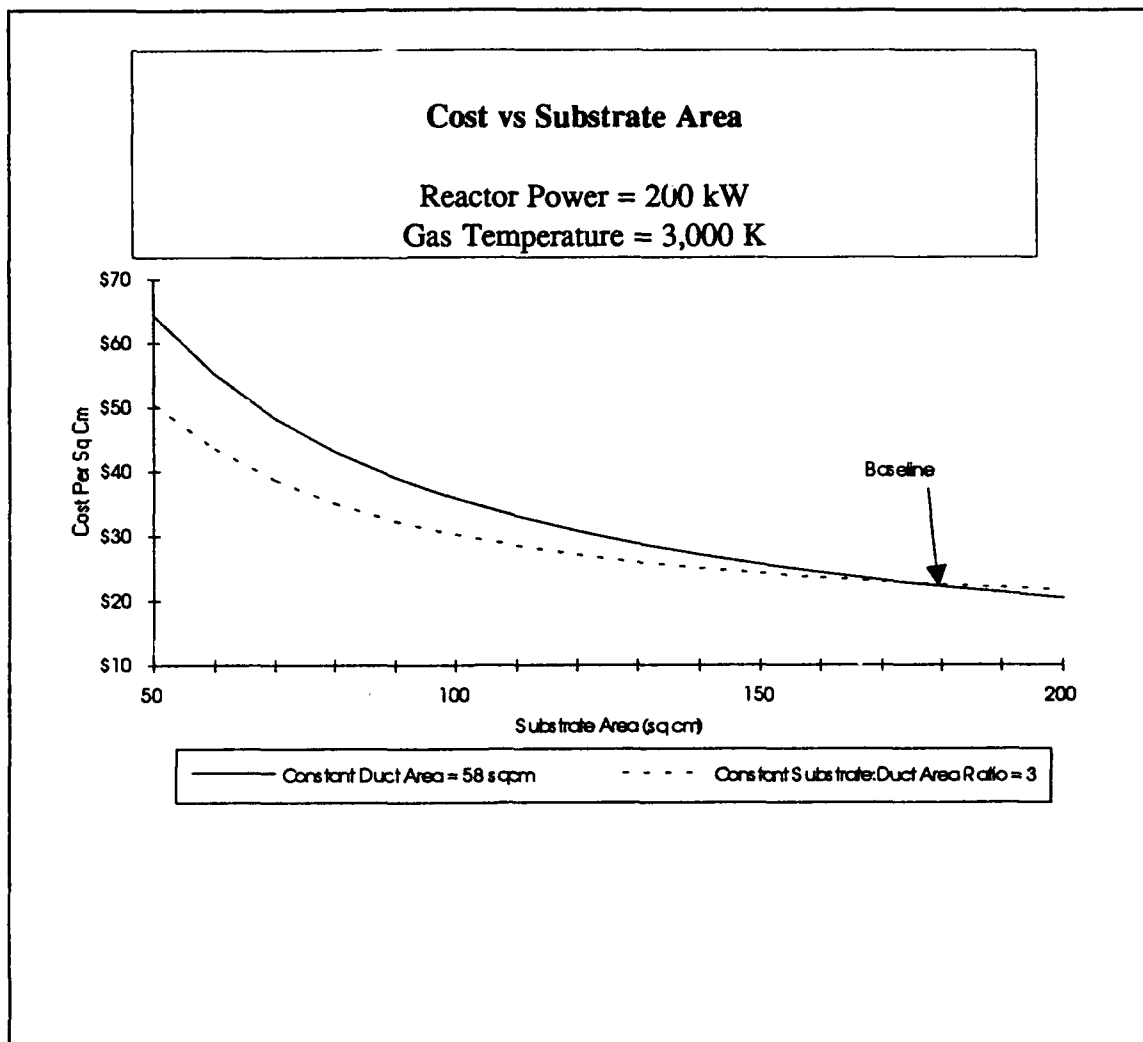


Figure 5

and reactor power of 200kW, the majority of cost reduction occurs while the substrate area is varying below this theoretical limit. The equation for this curve reveals that the cost varies inversely with the area raised to the 0.83 power, and that the cost approaches zero as the diameter nears a kilometer. Obviously, this diameter is infeasible, especially for such a duct area. The economics of substrate scale-up can be better examined by increasing the duct area with the substrate area to maintain a constant ratio.

Figure 5 also shows the result of this investigation by varying the substrate diameter while holding the substrate:duct ratio and gas temperature constant. From this graph, it is apparent that increasing the substrate area reduces cost significantly, even with the substrate:duct area ratio maintained at three. At the 200 kW baseline power, the cost per square centimeter varies inversely with the substrate area raised to the 2.01 power. For this graph, the cost reduces by 75% over the range of areas examined.

Future Work

Working towards a more powerful version of the DC Arcjet Model, a few goals remain. First, expert review is in progress and will continue for the duration of the project. Second, as mentioned in the Executive Summary, work remains in establishing correlations between growth rate and yield, and substrate diameter and yield. Lastly, investigations into alternative finishing technologies continue, with the goal of identifying preferable techniques.

Microwave Model

The progress of the Microwave Model has involved the incorporation of deposition theory into the cost model. This has been accomplished with the help of Professor David Goodwin of Caltech. Based on expert review of the microwave deposition theory, however, two versions of the IBIS Microwave CVD Diamond Technical Cost Model were developed: one model which uses the empirical relationship between growth rate and input microwave power only (printout in Appendix B), and one model which uses the hydrogen diffusion theory to determine growth rate (printout in Appendix C). IBIS has been conducting analyses with both models and soliciting expert review for their approval. The descriptions of microwave deposition and the diffusion theory are in the following sections.

Microwave Deposition

The microwave deposition operation involves the formation of the diamond film. The diamond growing substrate is mounted on a heated fixture perpendicular to the direction of flow in a gas flow tube (usually quartz), which is at a controlled pressure. The microwave generator is affixed outside of the sealed gas flow tube such that the tube's cross-sectional volume of energized gas is close to the substrate. The generator itself is contained in a radiation-proof jacket for safety considerations. A controlled mix of gases passes through the reaction chamber, and the frequency (usually about 2.45 GHz) is set so as to excite the gas into a plasma. The diamond then grows on the substrate, which is positioned on the periphery of the plasma ball. The relationship between this diamond growth rate and the deposition parameters is described in the next section.

Application of Zero-Order Hydrogen Plasma Diffusion Theory to the Model

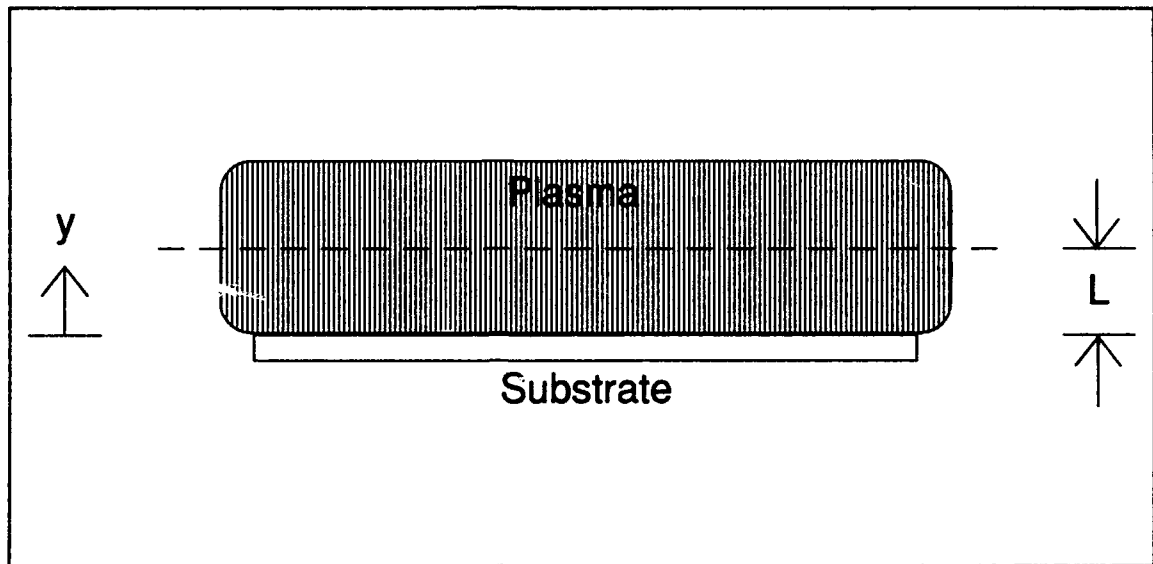
This section outlines a reduced mechanism for diamond growth which leads to a closed-form expression for the growth rate in terms of the local chemical environment at the substrate. The issue of atomic hydrogen transport to the substrate is considered in depth and relations are presented to allow the rapid estimation of the H concentration at the substrate for specified process parameters in diffusion-dominated flows.

This model assumes:

- *One dimensional diffusion*
- *No convective transport ($Pe \ll 1$)*
- *Neglect temperative gradients*
- *Constant atomic hydrogen volumetric production rate in the plasma*
- *Fraction of absorbed power used to dissociate H_2*

— Negligible homogeneous recombination of H to H₂

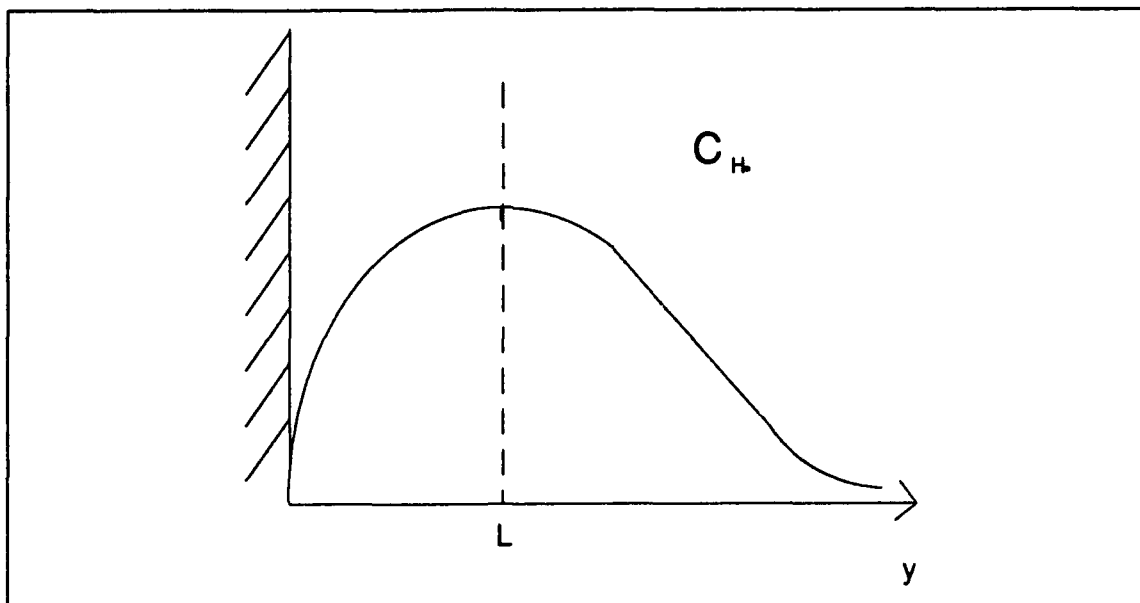
Consider the following geometry:



where L is the distance from the substrate to the "center" of the plasma and C_H is the atomic hydrogen concentration. The "center" of the plasma is defined such that:

$$\left. \frac{d C_H}{d y} \right|_{y=L} = 0$$

And the H concentration can be described by



Let $C_H = H$ concentration (moles/cm³), then the 1-D diffusion equation is

$$D \frac{d^2 C_H}{dy^2} = -P_H$$

Where D is the diffusion coefficient (m²/s) and P_H is the H volumetric production rate.

Boundary Conditions

Substrate:

Due to the conservation of mass, the flux of H to surface is equal to the recombination rate. At the substrate, the conservation of mass can be described by

$$C_H(0) - \frac{\lambda_H}{\gamma} \left(\frac{d C_H}{dy} \right)_{y=0} = 0$$

where λ_H is defined as defined as $4D / \bar{V}_H$ ($\bar{V}_H$ is the mean thermal speed) and γ is the recombination coefficient.

Center:

From our definition of L, the change of H concentration at the center of the plasma ball is

$$\left(\frac{d C_H}{d y} \right)_{y=L} = 0$$

Solution of the 1-D Diffusion Equation

The solution to the 1-D diffusion subject to the boundary conditions is

$$C_H(y) = \frac{P_H}{D} \left[L y - \frac{y^2}{2} + \frac{\lambda_H}{\gamma} L \right]$$

And at $y=0$

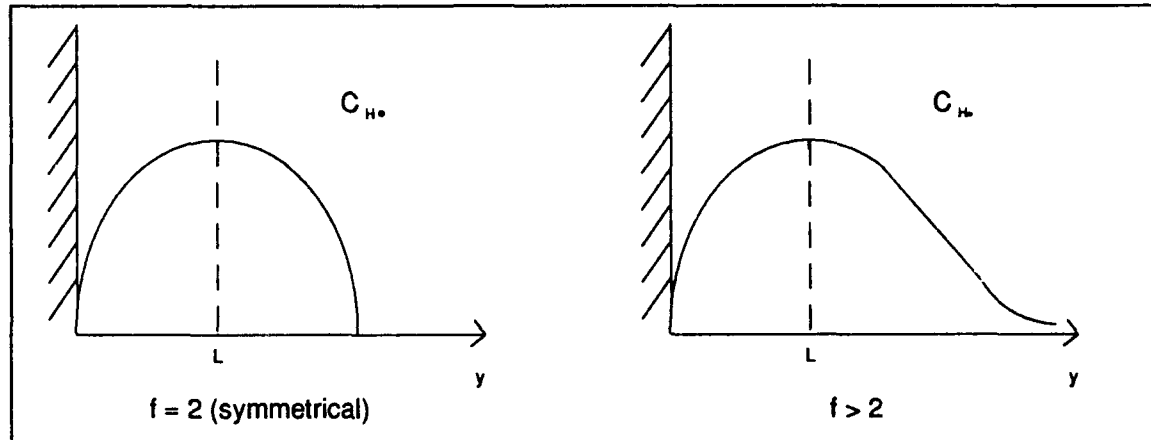
$$C_H(0) = \frac{4 P_H L}{V_H \gamma}$$

Now the H volumetric production rate is

$$P_H = \epsilon \frac{W}{V \Delta H}$$

where W is the power coupled to the plasma, V is the plasma volume, ΔH is the enthalpy of reaction for $H_2 \rightarrow H$ and ϵ is the efficiency factor to account for power lost to line radiation or other losses.

Assume that $V = f A L$ where A is the plasma ball footprint or deposition area, which is a function of power at a given pressure, L is the height of the center of the plasma ball and f is a geometrical factor that defines the relationship between the physical center of the plasma and the center as determined by the zero C_H gradient:



Substituting the H volumetric production rate into the 1-D diffusion equation results in

$$C_{H, (0)} = \frac{4 \epsilon W}{V_H \gamma f A \Delta H}$$

A comparison between an estimate of H concentration and a data point provided by Hsu¹ results in a value of 0.2 for the efficiency factor ϵ .

Once the atomic hydrogen concentration at the substrate has been calculated then the linear growth rate can be estimated by

$$\text{Linear Growth Rate} = z [C_{H, (0)}]^n$$

Where z is a calibration factor and n is between 1 and 2.

1 Hsu, J. Appl. Phys. 72, 3102-3109, (1992)

Future Work

Working towards a more powerful version of the Microwave Model, a few goals remain. First, expert review is in progress and will continue for the duration of the project. Second, as mentioned in the Executive Summary, work remains in establishing correlations between growth rate and yield, and substrate diameter and yield. Third, an investigation into the cost of new microwave tube prices and issues of tube reusability is currently being conducted. Lastly, investigations into alternative finishing technologies continue, with the goal of identifying preferable techniques.

Sensitivity Analysis

For the diffusion version of the model, two sensitivity analyses are presented below to indicate the sensitivity of cost to two inputs that cannot be easily characterized at this time.

The sensitivity analyses presented are

- Cost Per Sq Cm vs Reactor Power and Surface Recombination Coefficient
- Cost Per Sq Cm vs Reactor Power and Plasma Ball Skew Factor (f)

One assumption which extends through each of the analyses is that the deposition area is assumed to be a function of the reactor power. As the power of the reactor increases, the deposition area also increases.

Wafer Cost Per Square Centimeter vs Reactor Power and Surface Recombination Coefficient

Figure 6 shows the cost per square centimeter as a function of the coefficient describing the atomic hydrogen recombination at the substrate surface at various reactor powers. The graph shows that the cost is very strongly dependent on the surface recombination factor, especially at the low end of the reactor power scale. Even though the cost difference is most dramatic at the low end of the reactor power scale it should be noted that the difference in cost resulting from a surface recombination coefficient change from 0.2 to 0.05 results in an order of magnitude drop in cost all along the reactor power scale. The 50 kW reactors, which represent the low end of the reactor power scale, are among the state-of-the-art near term reactors. As stated earlier in this report, the surface recombination factor has not been studied to the extent that it can be easily characterized or predicted. Further research in this area will permit more accurate estimation of microwave CVD costs.

Cost vs Reactor Power and Surface Recombination Coefficient

Plasma Ball Skew Factor = 3

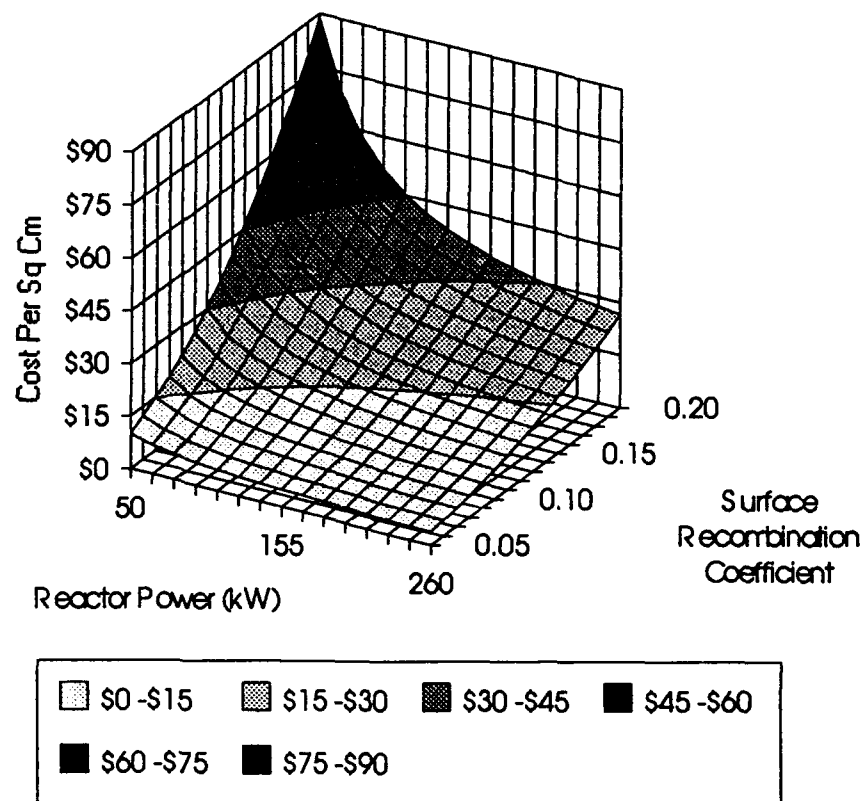


Figure 6

Wafer Cost Per Square Centimeter vs Reactor Power and Plasma Ball Skew Factor

Figure 7 shows the cost per square centimeter as a function of the plasma ball skew factor at various reactor powers. The graph shows that cost is strongly dependent on the plasma ball skew factor. As the plasma ball skew factor decreases from a value of 4 to 2 the cost per square centimeter drops by a factor of 3. Again, the low end of the scale on this graph represents the state-of-the-art near term reactor. Like the surface recombination coefficient, the plasma ball skew factor has not been studied to the extent that it can be easily characterized or predicted. The plasma ball skew factor is most likely strongly dependent on reactor geometry, so even if there was existing research in this area it may be difficult to apply that research to a generic microwave model. However, further research in this area will permit more accurate estimation of microwave CVD costs.

Cost vs Reactor Power and Plasma Ball Skew Factor

Surface Recombination Coefficient = 0.1

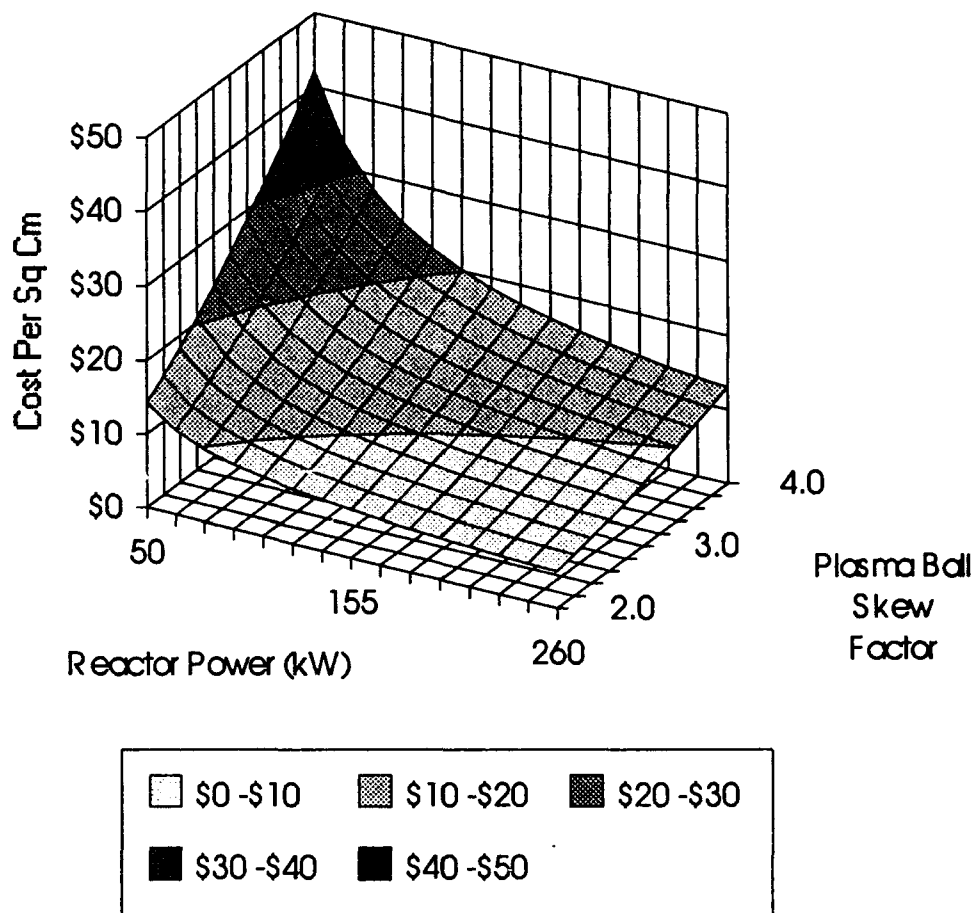


Figure 7

Summary & Conclusions

IBIS Associates, through Technical Cost Modeling (TCM), has updated its predictive spreadsheet models of the DC arcjet and microwave diamond deposition technologies. This report presents the results obtained with the new models and a revised set of baseline inputs for diamond heat sink manufacture.

The cost of producing 1,000 polished diamond wafers, 1 mm thick, is estimated in the long run to be \$23.70 per square centimeter by the DC arcjet deposition technology (six inch diameter), and \$8.49 per square centimeter by the microwave deposition technology (sixteen inch diameter). However, each of these estimates embodies many uncertain assumptions, and these estimates will be refined as work continues.

The major revision of the DC Arcjet Model is the inclusion of the kinetic theory of DC arcjet deposition into the model. According to this theory, the key factors driving the cost of thermal management diamond produced by the DC arcjet technology are the gas temperature, the power of the reactor, and the substrate diameter. It was shown that maximizing the gas temperature is critical to reducing the cost of the diamond wafer due to its dramatic effect on growth rate.

The major revision of the Microwave Model is the incorporation of similar theory of deposition kinetics, adapted to the typical conditions of microwave deposition. According to the model, the key factor driving the cost of thermal management diamond produced by the microwave technology is the reactor power. It is determined that research into atomic hydrogen surface recombination and plasma ball shaping factors would increase the accuracy of cost predictions.

To be investigated further are the relationships between diamond growth rate and process yield for both the DC arcjet and microwave technologies. It is expected that as the growth rate increases, the yield decreases; yet a specific relation between these factors is unknown. Similarly, the relationship between substrate diameter and yield requires further investigation, due to the known complications with the increase of this parameter. Lastly, expert approval of the models is continually in progress.

Appendix A

Revision Date: 9/93

PRODUCT SPECIFICATIONS

Part Name 6 in. substrate
 Wafer Diameter 15.24 cm
 Finished Wafer Thickness 1,000 um
 Annual Production Volume 1.0 (000/yr)
 Length of Production Run 5.00 yrs

PROCESS RELATED FACTORS - SURFACE PREPARATION

Process In Use? 1.00 [1-Y 0-N]
 Dedicated Investment 1.00 [1-Y 0-N]
 Process Yield 95.0%
 Average Equipment Downtime 20.0%
 Direct Laborers Per Station 0.50

Substrate Material 11.00 (menu #)
 Pieces Per Batch 20.00 pcs/batch
 Process Time 60.00 min/batch
 Building Space Requirement 250 sqft/sta

PROCESS RELATED FACTORS - DEPOSITION

Process In Use? 1.00 [1-Y 0-N]
 Dedicated Investment 1.00 [1-Y 0-N]
 Process Yield 87.5%
 Average Equipment Downtime 15.0%
 Direct Laborers 0.40 /sta

Machine Power 200 kW
 Power to Gas Efficiency 0.40
 Machine Load/Unload Time 120.00 min/batch
 Available Deposition Time 8,640 hrs/yr
 Coolant Temp. Rise 50.00 C
 Heat Capacity of Coolant 1.0 cal/g/C
 Building Space Requirement 1,500 sqft/sta

Reactor Pressure 50.0 torr
 Substrate Temperature 1,173 K
 Gas Temperature (>1000K) 3,000 K

Hydrogen Gas Flow Rate 393.6 slm
 Carbon Gas Flow Rate 0.4 slm
 Argon Gas Flow Rate 196.8 slm
 Other Gas Flow Rate 0.0 slm
 Total Gas Flow Rate 590.76 slm

Menu # vol%
 Hydrogen 1 66.6%

Revision Date: 9/93

GAS DATABASE

#	Gas	Source	Purity	Price \$/SCM	No. of Carbons	Liq Gas	Tank gal	Price Update
0	None			\$0.00	0.00	0.00		
1	Liq Hydrogen	Airco 99.998%		\$0.34	0.00	1.00	6000	1/93
2	Liq Hydrogen	Airco 99.998%		\$0.32	0.00	1.00	11000	1/93
3	Liq Hydrogen	Airco 99.998%		\$0.30	0.00	1.00	20000	1/93
4	Liq Argon	Airco 99.998%		\$1.41	0.00	1.00	3000	1/93
5	Liq Argon	Airco 99.998%		\$1.32	0.00	1.00	6000	1/93
6	Liq Argon	Airco 99.998%		\$1.29	0.00	1.00	11000	1/93
7	Hydrogen	MG Ind. 99.999%		\$29.86	0.00	0.00		1/93
8	Hydrogen	MG Ind. 99.999%		\$40.61	0.00	0.00		1/93
9	Hydrogen	MG Ind. 99.999%		\$10.28	0.00	0.00		1/93
10	Hydrogen	Air Prod. 99.95%		\$1.59	0.00	0.00		1/93
11	Argon	MG Ind. 99.999%		\$33.09	0.00	0.00		1/93
12	Argon	Air Prod. 99.999%		\$37.33	0.00	0.00		1/93
13	Argon	Air Prod. 99.999%		\$11.74	0.00	0.00		1/93
14	Argon	Air Prod. 99.997%		\$2.03	0.00	0.00		1/93
15	Methane	Air Prod. 99.99%		\$21.99	1.00	0.00		1/93
16	Methane	Air Prod. 99%		\$13.76	1.00	0.00		1/93
17	Methane	Air Prod. 93%		\$4.93	1.00	0.00		1/93
18	Acetylene	Air Prod. 99.6%		\$6.80	2.00	0.00		1/93
19	Acetylene	Air Prod. 98%		\$5.85	2.00	0.00		1/93
20	Helium	Air Prod. 99.995%		\$15.90	0.00	0.00		1/93
21	Helium	Air Prod. 99.995%		\$4.77	0.00	0.00		1/93
22	Nitrogen	Air Prod. 99.996%		\$45.50	0.00	0.00		1/93
23	Nitrogen	MG Ind. 99.999%		\$9.23	0.00	0.00		1/93
24	Nitrogen	Air Prod. 99.998%		\$1.24	0.00	0.00		1/93
25	Oxygen	Air Prod. 99.998%		\$2.00	0.00	0.00		1/93
26								

SUBSTRATE DATABASE

#	Substrate	Source	Price \$/ea	Thick um	Diam cm	Etch um/min	Life use#	Price Update
0	None		\$0.00	1	1.00	1.00	1.00	
1	Silicon	SI-Tech	\$2.65	1270.00	5.08	20.00	1	1/93
2	Silicon	SI-Tech	\$3.50	1270.00	7.62	20.00	1	1/93
3	Silicon	SI-Tech	\$6.25	1270.00	10.16	20.00	1	1/93
4	Silicon	SI-Tech	\$9.70	1270.00	12.70	20.00	1	1/93
5	Silicon	SI-Tech	\$18.60	1270.00	15.24	20.00	1	1/93
6	Silicon	SI-Tech	\$57.95	1270.00	20.32	20.00	1	1/93
7	Silicon	SI-Tech	\$4.35	3810.00	5.08	20.00	1	1/93
8	Silicon	SI-Tech	\$8.15	3810.00	7.62	20.00	1	1/93
9	Silicon	SI-Tech	\$14.50	3810.00	10.16	20.00	1	1/93
10	Silicon	SI-Tech	\$22.65	3810.00	12.70	20.00	1	1/93

GASA VOLA

Trimming Rate 1.00 cm/s RATE4
Machine Power 0.00 kW POW4
Building Space Requirement 100 sqft/sta FLR4

PROCESS RELATED FACTORS - LAPPING

Process In Use? 1.00 [1-Y 0=N] USE5
Dedicated Investment 1.00 [1-Y 0=N] DED5
Process Yield 90.0% YLD5
Average Equipment Downtime 15.0% DOWN5
Direct Laborers Per Station 1.00 NLAB5
Lapped Material Removal 10.0% by wgt TLAP5
No of Lapping Steps 2.00 LAP5
Pieces Per Batch 5.00 PCS5

Load/Unload and Clean Wafers 40.00 min/batch PTIME5
Average Lapping Rate 1.0 um/hr RATE5
Lapping Slurry Cost \$53 /liter LAPSL5
Lapping Slurry Usage Rate 0.50 liter/hr LAPR5
Lapping Plate Life 320.00 hrs PLAL5

Available Lapping Time 8,640 hrs/yr DAYHR5
Building Space Requirement 400 sqft/sta FLR5
/rnd

PROCESS RELATED FACTORS - INSPECTION - MICROSCOPY

Process In Use? 1.00 [1-Y 0=N] USE6
Dedicated Investment 1.00 [1-Y 0=N] DED6
Process Yield 95.0% YLD6
Average Equipment Downtime 5.0% DOWN6
Direct Laborers Per Station 1.00 NLAB6

Average Inspection Time 15.00 min/batch PTIME6
Percent Inspection 100% INSP6
Machine Cost \$50,000 /sta MCH6

Machine Power 0.10 kW POW6
Building Space Requirement 50 sqft/sta FLR6

PROCESS RELATED FACTORS - INSPECTION - THERMAL CONDUCTIVITY

Process In Use? 1.00 [1-Y 0=N] USE7
Dedicated Investment 1.00 [1-Y 0=N] DED7
Process Yield 95.0% YLD7
Average Equipment Downtime 5.0% DOWN7
Direct Laborers Per Station 1.00 NLAB7

Average Inspection Time 15.00 min/batch PTIME7
Percent Inspection 100% INSP7
Machine Cost \$50,000 /sta MCH7

Machine Power 0.10 kW POW7
Building Space Requirement 50 sqft/sta FLR7

OPTIONAL INPUTS

override estimate

Tank 2 \$ Capacity Constant	370.00	TANK2X
Tank 2 \$ Capacity Coef	0.03	TANK2Y
-Etching-		
-Lapping-		
Machine Cost Constant	2.719	MCH5A
Machine Cost Capacity Coef	1.844	MCH5B
Machine Power Constant	-0.75	PWR5A
Machine Power Capacity Coef	1.00	PWR5B
Tool Cost Constant	771.00	TOOL5A
Tool Cost Capacity Coef	0.92	TOOL5B
Tool Cost Capacity Exponent	2.90	TOOL5C

#####

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TECHNICAL COST MODEL (C) 1993
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		per piece	per year percent	investment	VARIABLE COST ELEMENTS		
VARIABLE COST ELEMENTS							
Material Cost	\$65.66	\$65,660	50.0%		Material Cost	\$552.54	\$552,543
Direct Labor Cost	\$0.85	\$850	0.6%		Direct Labor Cost	\$199.45	\$199,449
Utility Cost	\$0.07	\$72	0.1%		Utility Cost	\$212.38	\$212,383
					per piece	per year percent	investment
FIXED COST ELEMENTS					FIXED COST ELEMENTS		
Equipment Cost	\$19.73	\$19,732	15.0%	\$98,661	Equipment Cost	\$614.59	\$614,593
Tooling Cost	\$0.00	\$0	0.0%	\$0	Tooling Cost	\$0.00	\$0
Building Cost	\$1.25	\$1,250	1.0%	\$25,000	Building Cost	\$30.00	\$30,000
Maintenance Cost	\$9.89	\$9,893	7.5%		Maintenance Cost	\$293.84	\$293,837
Overhead Labor Cost	\$25.00	\$25,000	19.1%		Overhead Labor Cost	\$80.00	\$80,000
Cost of Capital	\$8.76	\$8,764	6.7%		Cost of Capital	\$230.75	\$230,751
TOTAL FABRICATION COST	\$131.22	\$131,221	100.0%	\$123,661	TOTAL FABRICATION COST	\$2,213.56	\$2,213,556
						100.0%	\$3,672,964

INTERMEDIATE CALCULATIONS				INTERMEDIATE CALCULATIONS			
Process In Use	1.00 [1-Y 0=N]	PRO1	Process In Use	1.00 [1-Y 0=N]	PRO2		
Cumulative Yield	66.2%	CYLD1	Cumulative Yield	69.7%	CYLD2		
Effective Production Volume	1,511 /yr	ENUM1	Effective Production Volume	1,436 /yr	ENUM2		
Substrate Area				ENERGY BALANCE CALCULATIONS			
New Substrate Cost	\$43.45 /pc	SUB1	Enthalpy Per Unit Mass	44,019	271,987	1,406	J/g
Substrate Useful Life	1.00 cycle	LIFE1	Molar Enthalpy	88,734	274,136	56,160	J/mol
Process Cycle Time	3 min/pc	CTIME1	Molar Entropy	202.79	162.59	202.72	J/K mol
Runtime for One Station	3%	RTIME1	Molar Heat Capacity (Cp)	37.11	20.79	20.79	J/K mol
Number of Parallel Stations	1.00	NSTAT1	Heat of Reaction (H2==>2H)	459,538	J/mol		
Energy Requirement	0.959 kWh/pc	ENERGY1	Entropy of Rxn (H2==>2H)	122	J/K mol		
Building Space/Station	250 sqft	SPACE1	Free Energy of Rxn (H2==>2H)	92,362	J/mol		
Machine Cost	\$65,774 /sta	MCH1	Equilibr Const Kp (H2==>2H)	2.47E-02			
Machine Power	19.2 kW	POW1					
Installed Equipment Cost	\$88,795 /sta	IEQUIP1	Mole Fraction H	36.75%			
Auxiliary Equipment Cost	\$9,866 /sta	AEQUIP1	Mole Fraction Argon	27.21%			
			Mole Fraction H2	36.04%			
Equipment Annuity	\$25,155 /yr	EINT1	Total Molar Enthalpy	148,004	J/mole		
Tooling Annuity	\$0 /yr	TINT1	Mean Molecular Weight	11.97	g/mole		
Building Annuity	\$2,895 /yr	BINT1	Mean Specific Enthalpy	12,369	J/g		
Working Annuity	\$103,171 /yr	WINT1	Mean Molar Heat Capacity	26.67	J/K mol		
*****				*****			
Deposition Arc Power				DAPOW2			
Duct Area (A inf.)				60.80 sqcm			
Mass Flux				6.44 g/s			
Gas Velocity (U inf.)				33,113 cm/s			
Specific Heat Ratio (gamma)				1.45			
Speed of Sound				174,029 cm/s			
*****				*****			
DCTAREA				DCTAREA			

DC ARC CVD TCM:			DC ARC CVD TCM:			SER TRIMMING			Copyright (c) 1991 v4.0			Copyright (c) 1991 v4.0		
IBIS ASSOCIATES, INC.			IBIS ASSOCIATES, INC.			IBIS ASSOCIATES, INC.			IBIS ASSOCIATES, INC.			IBIS ASSOCIATES, INC.		
ETCHING			ETCHING			ETCHING			ETCHING			ETCHING		
per piece			per piece			per piece			per piece			per piece		
per year percent			per year percent			per year percent			per year percent			per year percent		
investment			investment			investment			investment			investment		
VARIABLE COST ELEMENTS			VARIABLE COST ELEMENTS			VARIABLE COST ELEMENTS			VARIABLE COST ELEMENTS			VARIABLE COST ELEMENTS		
Material Cost	\$3.98	\$3,980	6.2%	\$0.00	\$0.00	Material Cost	\$0.00	\$0.00	\$0.00	\$0.00	\$0.00	Material Cost	\$0.00	\$0.00
Direct Labor Cost	\$4.62	\$4,616	7.1%	\$0.00	\$0.00	Direct Labor Cost	\$0.33	\$331	\$0.33	\$0.33	\$0.33	Direct Labor Cost	\$0.33	\$331
Utility Cost	\$0.00	\$0	0.0%	\$0.00	\$0.00	Utility Cost	\$0.00	\$0	\$0.00	\$0.00	\$0.00	Utility Cost	\$0.00	\$0
FIXED COST ELEMENTS			FIXED COST ELEMENTS			FIXED COST ELEMENTS			FIXED COST ELEMENTS			FIXED COST ELEMENTS		
Equipment Cost	\$1.80	\$1,800	2.8%	\$0.00	\$0.00	Equipment Cost	\$1.80	\$1,800	\$1.80	\$1,800	\$1.80	Equipment Cost	\$1.80	\$1,800
Tooling Cost	\$0.00	\$0	0.0%	\$0.00	\$0.00	Tooling Cost	\$0.00	\$0	\$0.00	\$0	\$0.00	Tooling Cost	\$0.00	\$0
Building Cost	\$0.50	\$500	0.8%	\$10,000	\$10,000	Building Cost	\$0.50	\$500	\$0.50	\$500	\$0.50	Building Cost	\$0.50	\$500
Maintenance Cost	\$1.52	\$1,520	2.4%	\$0.00	\$0.00	Maintenance Cost	\$1.52	\$1,520	\$1.52	\$1,520	\$1.52	Maintenance Cost	\$1.52	\$1,520
Overhead Labor Cost	\$0.00	\$0	0.0%	\$0.00	\$0.00	Overhead Labor Cost	\$0.00	\$0	\$0.00	\$0	\$0.00	Overhead Labor Cost	\$0.00	\$0
Cost of Capital	\$2.16	\$2,157	3.3%	\$0.00	\$0.00	Cost of Capital	\$2.02	\$2,019	\$2.02	\$2,019	\$2.02	Cost of Capital	\$2.02	\$2,019
TOTAL FABRICATION COST	\$64.57	\$64,574	100.0%	\$19,000	\$19,000	TOTAL FABRICATION COST	\$56.17	\$56,170	\$56.17	\$56,170	\$56.17	TOTAL FABRICATION COST	\$56.17	\$56,170

INTERMEDIATE CALCULATIONS			INTERMEDIATE CALCULATIONS			INTERMEDIATE CALCULATIONS			INTERMEDIATE CALCULATIONS			INTERMEDIATE CALCULATIONS		
Process In Use			Process In Use			Process In Use			Process In Use			Process In Use		
Cumulative Yield			Cumulative Yield			Cumulative Yield			Cumulative Yield			Cumulative Yield		
Effective Production Volume			Effective Production Volume			Effective Production Volume			Effective Production Volume			Effective Production Volume		
Process Cycle Time			Process Cycle Time			Process Cycle Time			Process Cycle Time			Process Cycle Time		
Runtime for One Station			Runtime for One Station			Runtime for One Station			Runtime for One Station			Runtime for One Station		
Number of Parallel Stations			Number of Parallel Stations			Number of Parallel Stations			Number of Parallel Stations			Number of Parallel Stations		
Energy Requirement			Energy Requirement			Energy Requirement			Energy Requirement			Energy Requirement		
Building Space/Station			Building Space/Station			Building Space/Station			Building Space/Station			Building Space/Station		
Installed Equipment Cost			Installed Equipment Cost			Installed Equipment Cost			Installed Equipment Cost			Installed Equipment Cost		
Auxiliary Equipment Cost			Auxiliary Equipment Cost			Auxiliary Equipment Cost			Auxiliary Equipment Cost			Auxiliary Equipment Cost		
Equipment Annunity			Equipment Annunity			Equipment Annunity			Equipment Annunity			Equipment Annunity		
Tooling Annunity			Tooling Annunity			Tooling Annunity			Tooling Annunity			Tooling Annunity		
Building Annunity			Building Annunity			Building Annunity			Building Annunity			Building Annunity		
Working Annunity			Working Annunity			Working Annunity			Working Annunity			Working Annunity		
PRO3	1.00	1.00	1.00	1.00	1.00	PRO3	1.00	1.00	1.00	1.00	1.00	PRO3	1.00	1.00
CYLD3	79.6%	79.6%	79.6%	79.6%	79.6%	CYLD3	79.6%	79.6%	79.6%	79.6%	79.6%	CYLD3	79.6%	79.6%
ENUM3	1,256	1,256	1,256	1,256	1,256	ENUM3	1,256	1,256	1,256	1,256	1,256	ENUM3	1,256	1,256
ETHIK3	3,810	3,810	3,810	3,810	3,810	ETHIK3	3,810	3,810	3,810	3,810	3,810	ETHIK3	3,810	3,810
ERATE3	20.00	20.00	20.00	20.00	20.00	ERATE3	20.00	20.00	20.00	20.00	20.00	ERATE3	20.00	20.00
CTIME3	0.18	0.18	0.18	0.18	0.18	CTIME3	0.18	0.18	0.18	0.18	0.18	CTIME3	0.18	0.18
RTIME3	9%	9%	9%	9%	9%	RTIME3	9%	9%	9%	9%	9%	RTIME3	9%	9%
NSTAT3	1.00	1.00	1.00	1.00	1.00	NSTAT3	1.00	1.00	1.00	1.00	1.00	NSTAT3	1.00	1.00
CHEM3	\$5.00	\$5.00	\$5.00	\$5.00	\$5.00	CHEM3	\$5.00	\$5.00	\$5.00	\$5.00	\$5.00	CHEM3	\$5.00	\$5.00
ENERGY3	0	0	0	0	0	ENERGY3	0	0	0	0	0	ENERGY3	0	0
SPACE3	100	100	100	100	100	SPACE3	100	100	100	100	100	SPACE3	100	100
IEQUIP3	\$8,100	\$8,100	\$8,100	\$8,100	\$8,100	IEQUIP3	\$8,100	\$8,100	\$8,100	\$8,100	\$8,100	IEQUIP3	\$8,100	\$8,100
AEQUIP3	\$900	\$900	\$900	\$900	\$900	AEQUIP3	\$900	\$900	\$900	\$900	\$900	AEQUIP3	\$900	\$900
EINT3	\$2,295	\$2,295	\$2,295	\$2,295	\$2,295	EINT3	\$2,295	\$2,295	\$2,295	\$2,295	\$2,295	EINT3	\$2,295	\$2,295
TINT3	\$0	\$0	\$0	\$0	\$0	TINT3	\$0	\$0	\$0	\$0	\$0	TINT3	\$0	\$0
BINT3	\$1,158	\$1,158	\$1,158	\$1,158	\$1,158	BINT3	\$1,158	\$1,158	\$1,158	\$1,158	\$1,158	BINT3	\$1,158	\$1,158
WINT3	\$61,121	\$61,121	\$61,121	\$61,121	\$61,121	WINT3	\$61,121	\$61,121	\$61,121	\$61,121	\$61,121	WINT3	\$61,121	\$61,121

DC ARC CVD TCM: LAPPING			DC ARC CVD TCM: INSPECTION - MICROSCOPY		
IBIS ASSOCIATES, INC.			IBIS ASSOCIATES, INC.		
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per place	per year percent	investment	per place	per year percent	investment
VARIABLE COST ELEMENTS					
Material Cost	\$725.01	\$725,009	42.8%	\$0.00	\$0
Direct Labor Cost	\$586.32	\$586,316	34.6%	\$5.25	\$5,249
Utility Cost	\$5.79	\$5,786	0.3%	\$0.00	\$1
FIXED COST ELEMENTS					
Equipment Cost	\$14.33	\$14,327	0.8%	\$15.00	\$15,000
Tooling Cost	\$74.41	\$74,415	4.4%	\$0.00	\$0
Building Cost	\$8.00	\$8,000	0.5%	\$0.25	\$250
Maintenance Cost	\$18.53	\$18,531	1.1%	\$6.40	\$6,400
Overhead Labor Cost	\$200.00	\$200,000	11.8%	\$50.00	\$50,000
Cost of Capital	\$60.58	\$60,581	3.6%	\$5.48	\$5,482
TOTAL FABRICATION COST	\$1,692.97	\$1,692,966	100.0%	\$82.38	\$82,382
		\$603,707			\$80,000

INTERMEDIATE CALCULATIONS			INTERMEDIATE CALCULATIONS		
Process In Use	1.00 [1-Y 0-N]	PRO5	Process In Use	1.00 [1-Y 0-N]	PRO6
Cumulative Yield	81.2%	CYLD5	Cumulative Yield	90.3%	CYLD6
Effective Production Volume	1,231 /yr	ENUM5	Effective Production Volume	1,108 /yr	ENUM6
Thickness of Material Lapped	111.11 um	HLAP5	Process Cycle Time	0.25 hrs	CTIME6
Setup Time	1.33 hrs/batch	CTIME5A	Runtime for One Station	10%	RTIME6
Lapping Time	111.11 hrs/batch	CTIME5B	Number of Parallel Stations	1.00	NSTAT6
Runtime for One Station	377%	RTIME5	Energy Requirement	0 kWh/pc	ENERGY6
Number of Parallel Stations	4.00	NSTAT5	Building Space/Station	50 sq ft	SPACE6
Lapping Plate Cost	\$869 /ea	PLA5	Installed Equipment Cost	\$67,500 /sta	IEQUIP6
Lapping Plate Life	14 pcs	WHEEL5	Auxiliary Equipment Cost	\$7,500 /sta	AEQUIP6
Number of Plates Required	428.00	PLAT5	Equipment Annunity	\$19,122 /yr	EINT6
Lapping Slurry Consumption	11.11 l/pc	GRIT5	Tooling Annunity	\$0 /yr	TINT6
Machine Power	4.2 kW	PWR5	Building Annunity	\$579 /yr	BINT6
Energy Requirement	94 kWh/pc	ENERGY5	Working Annunity	\$62,680 /yr	WINT6
Machine Cost	\$11,939 /sta	MCH5			
Building Space/Station	400 sq ft	SPACE5			
Installed Equipment Cost	\$16,118 /sta	IEQUIP5			
Auxiliary Equipment Cost	\$1,791 /sta	AEQUIP5			
Equipment Annunity	\$18,264 /yr	EINT5			
Tooling Annunity	\$94,865 /yr	TINT5			
Building Annunity	\$18,528 /yr	BINT5			
Working Annunity	\$1,561,308 /yr	WINT5			

DC ARC CVD TCM: IBIS ASSOCIATES, INC.			INSPECTION - THERMAL CONDUCTIVITY Copyright (c) 1991 v4.0			DC ARC CVD TCM: IBIS ASSOCIATES, INC.			COST SUMMARY Copyright (c) 1991 v4.0		
			per place	per year percent	investment	VARIABLE COST ELEMENTS			per place	per year percent	investment
VARIABLE COST ELEMENTS											
Material Cost	\$0.00	\$0	0.0%			Material Cost	\$1,347.19	\$1,347,192	31.2%		
Direct Labor Cost	\$4.99	\$4,986	6.1%			Direct Labor Cost	\$801.80	\$801,797	18.5%		
Utility Cost	\$0.00	\$1	0.0%			Utility Cost	\$218.24	\$218,245	5.0%		
FIXED COST ELEMENTS						FIXED COST ELEMENTS					
Equipment Cost	\$15.00	\$15,000	18.3%		\$75,000	Equipment Cost	\$682.25	\$682,252	15.8%	\$3,411,259	
Tooling Cost	\$0.00	\$0	0.0%		\$0	Tooling Cost	\$74.41	\$74,415	1.7%	\$372,073	
Building Cost	\$0.25	\$250	0.3%		\$5,000	Building Cost	\$40.75	\$40,750	0.9%	\$815,000	
Maintenance Cost	\$6.40	\$6,400	7.8%			Maintenance Cost	\$338.10	\$338,101	7.8%		
Overhead Labor Cost	\$50.00	\$50,000	60.9%			Overhead Labor Cost	\$505.00	\$505,000	11.7%		
Cost of Capital	\$5.48	\$5,477	6.7%			Cost of Capital	\$315.23	\$315,232	7.3%		
TOTAL FABRICATION COST	\$82.11	\$82,115	100.0%		\$80,000	TOTAL FABRICATION COST	\$4,322.98	\$4,322,983	100.0%	\$4,598,332	

INTERMEDIATE CALCULATIONS			SUMMARY INFORMATION		
Process In Use	1.00	[1-Y 0-N]	PRO7	Part Name 6 In. substrate	
Cumulative Yield	95.0%		CYLD7	10.10 /shift	
Effective Production Volume	1,053	/yr	ENUM7	8,150 sqft	
Process Cycle Time	0.25	hrs	CTIME7	\$4.6 MM	
Runtime for One Station	10%		RTIME7		
Number of Parallel Stations	1.00		NSTAT7		
Energy Requirement	0	kWh/pc	ENERGY7		
Building Space/Station	50	sq ft	SPACE7		
Installed Equipment Cost	\$67,500	/sta	IEQUIP7		
Auxiliary Equipment Cost	\$7,500	/sta	AEQUIP7		
Equipment Annuity	\$19,122	/yr	EINT7		
Tooling Annuity	\$0	/yr	TINT7		
Building Annuity	\$579	/yr	BINT7		
Working Annuity	\$62,413	/yr	WINT7		
Total - \$4,323			Total - \$4,323		

Appendix B

MICROWAVE CVD DIAMOND TECHNICAL COST MODEL
IBIS ASSOCIATES, INC.

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MICROWAVE CVD DIAMOND TECHNICAL COST MODEL
IBIS ASSOCIATES, INC.

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Revision Date: 8/10/93

PRODUCT SPECIFICATIONS

Part Name 6 in. substrate
Wafer Diameter 15.24 cm
Finished Wafer Thickness 1,000 um
Annual Production Volume 1 (000/yr)
Length of Production Run 5 yrs

PROCESS RELATED FACTORS - SURFACE PREPARATION

Process In Use? 1.00 [1-Y 0-N]
DED1
Process Yield 95.0%
YLD1
Average Equipment Downtime 20.0%
DOWN1
Direct Laborers Per Station 0.50
NLAB1

Substrate Material 37 [menu #]
MATL1
Pieces Per Batch 20.00 pcs/batch
PCS1
Process Time 60.00 min/batch
PTIME1
Building Space Requirement 250 sqft/sta
FLR1

PROCESS RELATED FACTORS - DEPOSITION

Process In Use? 1.00 [1-Y 0-N]
USE1
Dedicated Investment 1.00 [1-Y 0-N]
DED2
Process Yield 90.0%
YLD2
Average Equipment Downtime 15.0%
DOWN2
Direct Laborers 0.20 /sta
NLAB2

Menu # vol%

Hydrogen 9 88.7% GASA VOLA
Carbon Containing Gas 16 10.0% GASB VOLB
Carrier Gas 0 0.0% GASC VOLC
Other Gas 25 1.3% GASD VOLD
100.0%

Hydrogen Recycle Rate 0.0%
Carrier Gas Recycle Rate 0.0%
Gas Recycle Equipment Cost \$250,000 total

Machine Power 250 kW
Carbon Capture Factor 15.0%
Machine Load/Unload Time 30.00 min/batch
Available Deposition Time 8,640 hrs/yr
Microwave Tube Life 3000 hrs

Coolant Temp. Rise 50.00 C
Heat Capacity of Coolant 1.0 cal/g/C
Building Space Requirement 400 sqft/sta

GAS DATABASE

#	Gas	Source	Purity	Price \$/SCM	No. of Carbons	Liq Gas	Tank gal	Price Update
0	None			\$0.00	0.00	0.00	6000	1/93
1	Liq Hydrogen	Airco 99.998%		\$0.34	0.00	1.00	11000	1/93
2	Liq Hydrogen	Airco 99.998%		\$0.32	0.00	1.00	20000	1/93
3	Liq Hydrogen	Airco 99.998%		\$0.30	0.00	1.00	3000	1/93
4	Liq Argon	Airco 99.998%		\$1.41	0.00	1.00	6000	1/93
5	Liq Argon	Airco 99.998%		\$1.32	0.00	1.00	11000	1/93
6	Liq Argon	Airco 99.998%		\$1.29	0.00	1.00	11000	1/93
7	Hydrogen	MG Ind. 99.999%		\$29.86	0.00	0.00	1/93	1/93
8	Hydrogen	MG Ind. 99.999%		\$40.61	0.00	0.00	1/93	1/93
9	Hydrogen	MG Ind. 99.999%		\$10.28	0.00	0.00	1/93	1/93
10	Hydrogen	Air Prod. 99.99%		\$1.59	0.00	0.00	1/93	1/93
11	Argon	MG Ind. 99.999%		\$33.09	0.00	0.00	1/93	1/93
12	Argon	Air Prod. 99.997%		\$37.33	0.00	0.00	1/93	1/93
13	Argon	Air Prod. 99.999%		\$11.74	0.00	0.00	1/93	1/93
14	Argon	Air Prod. 99.997%		\$2.03	0.00	0.00	1/93	1/93
15	Methane	Air Prod. 99.99%		\$21.99	1.00	0.00	1/93	1/93
16	Methane	Air Prod. 99%		\$13.76	1.00	0.00	1/93	1/93
17	Methane	Air Prod. 93%		\$4.93	1.00	0.00	1/93	1/93
18	Acetylene	Air Prod. 99.6%		\$6.80	2.00	0.00	1/93	1/93
19	Acetylene	Air Prod. 98%		\$5.85	2.00	0.00	1/93	1/93
20	Helium	Air Prod. 99.999%		\$15.90	0.00	0.00	1/93	1/93
21	Helium	Air Prod. 99.99%		\$4.77	0.00	0.00	1/93	1/93
22	Nitrogen	Air Prod. 99.999%		\$45.50	0.00	0.00	1/93	1/93
23	Nitrogen	MG Ind. 99.999%		\$9.23	0.00	0.00	1/93	1/93
24	Nitrogen	Air Prod. 99.998%		\$1.24	0.00	0.00	1/93	1/93
25	Oxygen	Air Prod. 99.998%		\$2.00	0.00	0.00	1/93	1/93
26								

#	Substrate	Source	Price \$/ea	Thick um	Diam cm	Etch um/min	Life use#	Price Update
0	None		\$0.00	1	1.00	1.00	1.00	1/93
1	Silicon	SI-Tech	\$2.65	1270.00	5.08	20.00	1	1/93
2	Silicon	SI-Tech	\$3.50	1270.00	7.62	20.00	1	1/93
3	Silicon	SI-Tech	\$6.25	1270.00	10.16	20.00	1	1/93
4	Silicon	SI-Tech	\$9.70	1270.00	12.70	20.00	1	1/93
5	Silicon	SI-Tech	\$18.60	1270.00	15.24	20.00	1	1/93
6	Silicon	SI-Tech	\$57.95	1270.00	20.32	20.00	1	1/93
7	Silicon	SI-Tech	\$4.35	3810.00	5.08	20.00	1	1/93
8	Silicon	SI-Tech	\$8.15	3810.00	7.62	20.00	1	1/93
9	Silicon	SI-Tech	\$14.50	3810.00	10.16	20.00	1	1/93
10	Silicon	SI-Tech	\$22.65	3810.00	12.70	20.00	1	1/93

Average Equipment Downtime 15.0% DOWN6
 Direct Laborers Per Station 0.25 NLAB6

Material Removed 10.0% by wgt TLAP6
 No of Polishing Steps 1.00 LAPS6
 Pieces Per Batch 5.00 PCS6

Load/Unload and Clean Wafers 40.00 min/batch PTIME6
 Average Polishing Rate 5.000 um/hr RATE6
 Useful Polishing Plate Life 10.00 cycles PLAL6

Available Polishing Time 8,640 hrs/yr DAYHR6
 Building Space Requirement 400 sqft/sta FLR6

PROCESS RELATED FACTORS - OXYGEN PLASMA POLISHING
 Process In Use? 0.00 [1-Y 0-N] USE7
 Dedicated Investment 1.00 [1-Y 0-N] DED7
 Process Yield 90.0% YLD7
 Average Equipment Downtime 15.0% DOWN7
 Direct Laborers Per Station 0.25 NLAB7

Menu # vol%
 Oxygen 25 100.0% GAS7A VOL7A
 Argon 0 0.0% GAS7B VOL7B
 Other Gas 0 0.0% GAS7C VOL7C
 100.0%

Material Removed 10.0% by wgt TLAP7
 No of Polishing Steps 1.00 LAPS7
 Pieces Per Batch 1.00 PCS7

Oxygen Gas Consumption 500.00 sccm TFLOW7
 Load/Unload and Clean Wafers 40.00 min/batch PTIME7
 Average Polishing Rate 3.300 um/hr RATE7

Machine Power 10.00 kW POW7
 Machine Cost \$300,000 /sta MCH7
 Available Polishing Time 8,640 hrs/yr DAYHR7
 Building Space Requirement 400 sqft/sta FLR7

PROCESS RELATED FACTORS - OXYGEN ION MILLING
 Process In Use? 0.00 [1-Y 0-N] USE8
 Dedicated Investment 1.00 [1-Y 0-N] DED8
 Process Yield 90.0% YLD8
 Average Equipment Downtime 15.0% DOWN8
 Direct Laborers Per Station 0.25 NLAB8

Menu # vol%
 Oxygen 25 100.0% GAS8A VOL8A
 Argon 4 0.0% GAS8B VOL8B
 Other Gas 0 0.0% GAS8C VOL8C
 100.0%

6 Nickel Tosoh \$0.95 30.00 8.91 1/93
 7 Palladium Tosoh \$8.45 210.00 12.02 1/93
 8 Silicon Tosoh \$0.80 15.00 2.33 1/93

EVAPORATION DATABASE				Price	Dep.Rt.	Density	Price
#	Metal	Vendor		\$/g	A/kWh	g/cc	Update
0	None		#####	\$0		1.00	
1	Titanium	re Tech Inc		\$4.40	9,520.00	4.51	1/93
2	Platinum	re Tech Inc		\$18.59	6,428.57	21.45	1/93
3	Gold	re Tech Inc		\$14.58	6,428.57	19.32	1/93
4	Silver	re Tech Inc		\$3.12	215.00	10.50	1/93
5	Copper	re Tech Inc		\$1.08	210.00	8.96	1/93
6	Nickel	re Tech Inc		\$1.49	30.00	8.91	1/93
7	Palladium	re Tech Inc		\$7.03	210.00	12.02	1/93
8	Silicon	re Tech Inc		\$7.51	15.00	2.33	1/93

#####

100.0%

Material Removed	10.0% by wgt	TLAP8
No of Polishing Steps	1.00	LAPS8
Pieces Per Batch	3.00	PCS8
Oxygen Gas Consumption	10.00 sccm	TFLOW8
Ion Source Life	1,000 hrs	SOUL8
Ion Source Cost	\$1,000 /ea	SCOST8
Load/Unload and Clean Wafers	40.00 min/batch	PTIME8
Preheat Time	5.00 min	PREHT8
Linear Polishing Rate	0.240 um/hr	RATE8
Machine Power	1.00 kW	POW8
Machine Cost	\$500,000 /sta	MCH8
Available Polishing Time	8,640 hrs/yr	DAYHR8
Building Space Requirement	400 sqft/sta	FLR8

PROCESS RELATED FACTORS - METALLIZATION - SPUTTERING

Process In Use?	1.00 [1-Y 0=N]	USE9
Dedicated Investment	1.00 [1-Y 0=N]	DED9
Process Yield	99.0%	YLD9
Average Equipment Downtime	20.0%	DOWN9
Direct Laborers Per Station	0.10	NLAB9
Load/Unload Laborers	1.00	LLAB9

Metal Layers	Menu #	Thick (um)
Titanium	1 MET9A	0.10 THK9A
Platinum	2 MET9B	0.10 THK9B
Gold	3 MET9C	0.10 THK9C

Load Time	15 min/batch	PTIME9
Target Preheat Time	1 min/kW	HTIME9
Pieces Per Batch	3 pcs/batch	PCS9
Metallization Magnetron Power	3 kW	POW9
Building Space Requirement	400 sqft/sta	FLR9

PROCESS RELATED FACTORS - METALLIZATION - EVAPORATION

Process In Use?	0.00 [1-Y 0=N]	USE10
Dedicated Investment	1.00 [1-Y 0=N]	DED10
Process Yield	99.0%	YLD10
Average Equipment Downtime	20.0%	DOWN10
Direct Laborers Per Station	0.10	NLAB10
Load/Unload Laborers	1.00	LLAB10

Metal Layers	Menu #	Thick (um)
Titanium	1 MET10A	0.10 THK10A
Platinum	2 MET10B	0.10 THK10B
Gold	3 MET10C	0.10 THK10C

Load Time
 Target Preheat Time
 Pieces Per Batch
 Evaporator Power
 Building Space Requirement
 Percent Inspection
 Process In Use?
 Dedicated Investment
 Process Yield
 Average Equipment Downtime
 Direct Laborers Per Station
 Average Inspection Time
 Percent Inspection
 Machine Cost
 Machine Power
 Building Space Requirement

15 min/batch
 1.00 min/kW
 5.00 pcs/batch
 7.00 kW
 400 sqft/sta
 100%
 1.00 [1-Y 0-N]
 1.00 [1-Y 0-N]
 95.0%
 5.0%
 1.00
 15.00 min/batch
 100%
 \$50,000 /sta
 0.10 kW
 50 sqft/sta

PTIME10
 HTIME10
 PCS10
 POW10
 FLR10
 INSP10
 USE11
 DED11
 YLD11
 DOWN11
 NLAB11
 PTIME11
 INSP11
 MCH11
 POW11
 FLR11

PROCESS RELATED FACTORS - MICROSCOPY

PROCESS RELATED FACTORS - THERMAL CONDUCTIVITY

Process In Use?
 Dedicated Investment
 Process Yield
 Average Equipment Downtime
 Direct Laborers Per Station
 Average Inspection Time
 Percent Inspection
 Machine Cost
 Machine Power
 Building Space Requirement

1.00 [1-Y 0-N]
 1.00 [1-Y 0-N]
 95.0%
 5.0%
 1.00
 15.00 min/batch
 100%
 \$50,000 /sta
 0.10 kW
 50 sqft/sta

USE12
 DED12
 YLD12
 DOWN12
 NLAB12
 PTIME12
 INSP12
 MCH12
 POW12
 FLR12

OPTIONAL INPUTS

Surface Preparation
 Machine Cost
 Machine Power
 Deposition
 Deposition Rate
 Deposition Equipment Cost
 Microwave Tube Cost
 Etching
 Process Cycle Time
 Chemical Requirement
 Laser Trimming
 Process Cycle Time
 Lapping
 Lapping Time
 Lapping Plate Cost

override estimate
 \$0
 0.0
 0.00
 \$0
 \$0
 0.00
 \$0
 0.00
 0.00
 0.00
 0.00

\$65,774 /sta
 15.2 kW
 3.25 g/hr
 \$1,829 k\$/sta
 \$25,977 /sta
 0.29 hrs
 \$5.00 /pc
 0.01 hrs
 111.11 hrs
 \$869 /ea

OMCH1
 OP0W1
 ODRATE2
 OMCH2
 OTUBE2
 OCTIME3
 OCHEM3
 OCTIME4
 OCTIME5
 OMHEEL5

Lapping Machine Cost	\$0	\$11,939 /sta	OMCH5
Lapping Machine Power	0.00	4.2 kW	OPWR5
Hot Iron Polish			
Lapping Time	0.00	34.34 hrs	OCTIME6
Lapping Plate Cost	\$0	\$784 /ea	OWHEEL6
Machine Cost	\$0	\$11,939 /sta	OMCH6
Lapping Machine Power	\$0	45.84 kW	OPWR6
Oxygen Plasma Polishing			
Process Cycle Time	0.00	34.34 hrs	OCTIME7
Oxygen Ion Milling			
Process Cycle Time	0.00	154.57 hrs	OCTIME8
Metallization-Sputtering			
Process Cycle Time	0.00	0.29 hrs	OSPUT9
Machine Cost	\$0	\$225,516	OMCH9
Metallization-Evaporation			
Process Cycle Time	0.00	#VALUE!	OCTIME10
Metallization Time	0.00	0.07 hrs	OEVPAP10

EXOGENOUS COST FACTORS

Direct Wages	\$13.33 /hr	WAGE
Indirect Salary	\$50,000 /yr	SALARY * exc. dep. & lap
Indirect:Direct Labor Ratio	1.00	ILAB
Benefits on Wage and Salary	35.0%	BENI
Working Days per Year	360.00	DAYS
Working Hours per Day (*)	8.00 /hr	HRS
Capital Recovery Rate	10%	CRR
Capital Recovery Period	5.00 yrs	ELIFE
Building Recovery Life	20.00 yrs	BLIFE
Working Capital Period	3.00 months	WCP
Price of Electricity	\$0.050 /kWh	ELEC
Price of Natural Gas	\$6.50 /MBTU	GAS
Price of Building Space	\$100 /sqft	PBLD
Price of Cooling Water	\$0.03 /100 gal	WATER
Auxiliary Equipment Cost	15.0%	AUX
Equipment Installation Cost	35.0%	INST
Maintenance Cost	8.0%	MNT

REGRESSION CONSTANTS, COEFFICIENTS, AND EXPONENTS

-Surface Preparation-		
Machine Cost Constant	1.334	MCH1A
Machine Cost Capacity Coef	3.222	MCH1B
Machine Power Constant	-0.75	PWR1A
Machine Power Capacity Coef	1.00	PWR1B
-Deposition-		
Deposition Rate Constant	0.013	CYC2
Machine Cost Power Coef	68,276	MCH2Y
Machine Cost Power Exponent	0.58	MCH2Z
Machine Cost Power Constant	150,000	MCH2X
Tube Cost Constant	1724	TUBE2Y
Tube Cost Coef	97.01	TUBE2Z

Tank 1 \$ Capacity Constant 1.175 TANK2A
Tank 1 \$ Capacity Coef 0.165 TANK2B
Tank 2 \$ Capacity Constant 370.00 TANK2X
Tank 2 \$ Capacity Coef 0.03 TANK2Y

-Etching-

-Lapping-

Machine Cost Constant 2.719 MCH5A
Machine Cost Capacity Coef 1.844 MCH5B
Machine Power Constant -0.75 PWR5A
Machine Power Capacity Coef 1.00 PWR5B
Tool Cost Constant 771.00 TOOL5A
Tool Cost Capacity Coef 0.92 TOOL5B
Tool Cost Capacity Exponent 2.90 TOOL5C

-Hot Iron Polish-

Machine Cost Constant 21.752 MCH6A
Machine Cost Capacity Coef 14.752 MCH6B
Machine Power Constant 6.00 PWR6A
Machine Power Capacity Coef 7.97 PWR6B
Tool Cost Constant 771.00 TOOL6A
Tool Cost Capacity Coef 0.92 TOOL6B
Tool Cost Capacity Exponent 2.90 TOOL6C

--Metallization-Sputtering-

Machine Cost Constant 160.720.00 MCH9A
Machine Cost Capacity Coef1 129.43 MCH9B
Machine Cost Capacity Coef2 -0.02 MCH9C
Machine Cost Capacity Coef2 0.00 MCH9D

-Metallization-Evaporation-

Machine Cost Constant 367,070.00 MCH10A
Machine Cost Capacity Coef1 (3,797.80) MCH10B
Machine Cost Capacity Coef2 22.02 MCH10C
Machine Cost Capacity Coef3 (0.05) MCH10D
Machine Cost Capacity Coef4 0.00 MCH10E

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TECHNICAL COST MODEL (C) 1993
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MICROWAVE CVD TCM: SURFACE PREPARATION				MICROWAVE CVD TCM: DEPOSITION			
IBIS ASSOCIATES, INC.				IBIS ASSOCIATES, INC.			
Copyright (c) 1991 v4.0				Copyright (c) 1991 v4.0			
VARIABLE COST ELEMENTS				VARIABLE COST ELEMENTS			
	per piece	per year percent	investment		per piece	per year percent	investment
Material Cost	\$2.89	\$2,890	4.3%	Material Cost	\$142.30	\$142,304	2.4%
Direct Labor Cost	\$0.83	\$826	1.2%	Direct Labor Cost	\$132.72	\$132,721	2.3%
Utility Cost	\$0.07	\$70	0.1%	Utility Cost	\$393.42	\$393,424	6.8%
FIXED COST ELEMENTS				FIXED COST ELEMENTS			
Equipment Cost	\$19.73	\$19,732	29.3%	Equipment Cost	\$2,743.63	\$2,743,631	47.2%
Tooling Cost	\$0.00	\$0	0.0%	Tooling Cost	\$337.69	\$337,695	5.8%
Building Cost	\$1.25	\$1,250	1.9%	Building Cost	\$10.00	\$10,000	0.2%
Maintenance Cost	\$9.89	\$9,893	14.7%	Maintenance Cost	\$1,113.45	\$1,113,452	19.2%
Overhead Labor Cost	\$25.00	\$25,000	37.1%	Overhead Labor Cost	\$50.00	\$50,000	0.9%
Cost of Capital	\$7.71	\$7,714	11.4%	Cost of Capital	\$890.59	\$890,595	15.3%
TOTAL FABRICATION COST	\$67.38	\$67,377	100.0%	TOTAL FABRICATION COST	\$5,813.82	\$5,813,821	100.0%

INTERMEDIATE CALCULATIONS				INTERMEDIATE CALCULATIONS			
Process In Use				Process In Use			
Cumulative Yield				Cumulative Yield			
Effective Production Volume				Effective Production Volume			
	1.00 [1-Y 0-N]	PRO1			1.00 [1-Y 0-N]	PRO2	
	68.1%	CYD1			71.6%	CYD2	
	1,469 /yr	ENUM1			1,396 /yr	ENUM2	
Substrate Area	182.4 sq cm	AREA1		Mass of Diamond Deposited	71.34 g	MASS2	
New Substrate Cost	\$90.50 /pc	SUB1		Mass Deposition Rate	3.25 g/hr	MASDEP2	
Substrate Useful Life	46.00 cycle	LIFE1		Linear Deposition Rate	51 um/hr	LINDEP2	
Process Cycle Time	3 min/pc	CTIME1		Deposition Time	21.95 hrs	CTIMEB2	
Runtime for One Station	3%	RTIME1		Machine Setup Time	0.50 hrs	CTIMEA2	
Number of Parallel Stations	1.00	NSTAT1		Runtime for One Station	427%	RTIME2	
Energy Requirement	0.959 kWh/pc	ENERGY1		Number of Parallel Stations	5.00	NSTAT2	
Building Space/Station	250 sqft	SPACE1		Total Carbon Gas Volume	0.97 SCM	CARGAS2	
Machine Cost	\$65,774 /sta	MCH1		Total Gas Volume	10 SCM	TVOL2	
Machine Power	19.2 kW	POW1		Total Gas Flow Rate	7,358 sccm	FLOWR2	
Installed Equipment Cost	\$88,795 /sta	IEQUIP1		Consumption	Cost		
Auxiliary Equipment Cost	\$9,866 /sta	AEQUIP1		(SCM/pc)	(\$/pc)		
Equipment Annuity	\$25,155 /yr	EINT1		Hydrogen Consumption	8.60	GASA2	COSTA2
Tooling Annuity	\$0 /yr	TINT1		Carbon Gas Consumption	0.97	GASB2	COSTB2
Building Annuity	\$2,895 /yr	BINT1		Carrier Gas Consumption	0.00	GASC2	COSTC2
Working Annuity	\$39,327 /yr	WINT1		Other Gas Consumption	0.13	GASD2	COSTD2
*****				*****			
				Energy Requirement			
					5,488 kWh/pc	ENERGY2	
				Physical Tube Life			
					0.41 years	TLIFE2	
				Number of Tubes per Station			
					13.00	NTUBE2	
				New Microwave Tube Cost			
					\$25,977 /tube	TUBE2	

Cooling Water Flow Rate	18.9 gal/min	WATER2
Cooling Water Requirement	24,927 gal/pc	COOL2
Building Space/Station	400 sqft	SPACE2
Recycle Equipment Cost	\$0 /sta	REC2
Liquid Hydrogen Tank Rental	\$0 /mo/tank	HYD2
Liq Carrier Gas Tank Rental	\$0 /mo/tank	CAR2
Gas Storage Equipment Rent	\$0 /year	GTANK2
Machine Cost	\$1,829,087 /sta	MCH2B
Installed Equipment Cost	\$2,469,268 /sta	IEQUIP2
Auxiliary Equipment Cost	\$274,363 /sta	AEQUIP2
Equipment Annuity	\$3,497,643 /yr	EINT2
Tooling Annuity	\$430,501 /yr	TINT2
Building Annuity	\$23,161 /yr	BINT2
Working Annuity	\$1,862,517 /yr	WINT2

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MICROWAVE CVD TCM: ETCHING				MICROWAVE CVD TCM: SER TRIMMING			
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VARIABLE COST ELEMENTS				VARIABLE COST ELEMENTS			
	per piece	per year	percent	per piece	per year	percent	investment
Material Cost	\$0.00	\$0	#DIV/0!	\$0.00	\$0	0.0%	\$0
Direct Labor Cost	\$0.00	\$0	#DIV/0!	\$0.33	\$334	0.6%	\$0
Utility Cost	\$0.00	\$0	#DIV/0!	\$0.00	\$4	0.0%	\$0
FIXED COST ELEMENTS				FIXED COST ELEMENTS			
Equipment Cost	\$0.00	\$0	#DIV/0!	\$1.80	\$1,800	3.2%	\$9,000
Tooling Cost	\$0.00	\$0	#DIV/0!	\$0.00	\$0	0.0%	\$0
Building Cost	\$0.00	\$0	#DIV/0!	\$0.50	\$500	0.9%	\$10,000
Maintenance Cost	\$0.00	\$0	#DIV/0!	\$1.52	\$1,520	2.7%	\$0
Overhead Labor Cost	\$0.00	\$0	#DIV/0!	\$50.00	\$50,000	89.0%	\$0
Cost of Capital	\$0.00	\$0	#DIV/0!	\$2.02	\$2,019	3.6%	\$0
TOTAL FABRICATION COST	\$0.00	\$0	#DIV/0!	\$56.18	\$56,178	100.0%	\$19,000

INTERMEDIATE CALCULATIONS				INTERMEDIATE CALCULATIONS			
Process In Use	0.00 [1-Y 0-N]	PRO3		Process In Use	1.00 [1-Y 0-N]	PRO4	
Cumulative Yield	79.6%	CYLD3		Cumulative Yield	79.6%	CYLD4	
Effective Production Volume	1,256 /yr	ENUM3		Effective Production Volume	1,256 /yr	ENUM4	
Total Etched Thickness	3,175 um	ETHIK3		Process Cycle Time	0.01 hrs/pc	CTIME4	
Average Etchant Rate	10.00 um/min	ERATE3		Runtime for One Station	1%	RTIME4	
Process Cycle Time	0.29 hrs/pc	CTIME3		Number of Parallel Stations	1.00	NSTAT4	
Runtime for One Station	14%	RTIME3					
Number of Parallel Stations	1.00	NSTAT3					
Chemical Requirement	\$5.00 /pc	CHEM3		Energy Requirement	0 kWh/pc	ENERGY4	
Energy Requirement	0 kWh/pc	ENERGY3		Building Space/Station	100 sq ft	SPACE4	
Building Space/Station	100 sq ft	SPACE3		Installed Equipment Cost	\$8,100 /sta	IEQUIP4	
Installed Equipment Cost	\$8,100 /sta	IEQUIP3		Auxiliary Equipment Cost	\$900 /sta	AEQUIP4	
Auxiliary Equipment Cost	\$900 /sta	AEQUIP3		Equipment Annuity	\$2,295 /yr	EINT4	
Equipment Annuity	\$0 /yr	EINT3		Tooling Annuity	\$0 /yr	TINT4	
Tooling Annuity	\$0 /yr	TINT3		Building Annuity	\$1,158 /yr	BINT4	
Building Annuity	\$0 /yr	BINT3		Working Annuity	\$52,725 /yr	WINT4	
Working Annuity	\$0 /yr	WINT3					

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VARIABLE COST ELEMENTS				VARIABLE COST ELEMENTS			
	per piece	per year	percent investment		per piece	per year	percent investment
Material Cost	\$732.33	\$732,333	66.4%	Material Cost	\$0.00	\$0	#DIV/0!
Direct Labor Cost	\$148.06	\$148,060	13.4%	Direct Labor Cost	\$0.00	\$0	#DIV/0!
Utility Cost	\$5.84	\$5,845	0.5%	Utility Cost	\$0.00	\$0	#DIV/0!
FIXED COST ELEMENTS				FIXED COST ELEMENTS			
Equipment Cost	\$14.33	\$14,327	1.3%	Equipment Cost	\$0.00	\$0	#DIV/0!
Tooling Cost	\$75.11	\$75,110	6.8%	Tooling Cost	\$0.00	\$0	#DIV/0!
Building Cost	\$8.00	\$8,000	0.7%	Building Cost	\$0.00	\$0	#DIV/0!
Maintenance Cost	\$18.53	\$18,531	1.7%	Maintenance Cost	\$0.00	\$0	#DIV/0!
Overhead Labor Cost	\$50.00	\$50,000	4.5%	Overhead Labor Cost	\$0.00	\$0	#DIV/0!
Cost of Capital	\$51.06	\$51,065	4.6%	Cost of Capital	\$0.00	\$0	#DIV/0!
TOTAL FABRICATION COST	\$1,103.27	\$1,103,269	100.0%	TOTAL FABRICATION COST	\$0.00	\$0	#DIV/0!

INTERMEDIATE CALCULATIONS

Process In Use	1.00 [1-Y 0-N]	PRO5
Cumulative Yield	80.4%	CYLD5
Effective Production Volume	1,244 /yr	ENUM5
Thickness of Material Lapped	111.11 um	HLP5
Setup Time	1.33 hrs/batch	CTIME5A
Lapping Time	111.11 hrs/batch	CTIME5B
Runtime for One Station	381%	RTIME5
Number of Parallel Stations	4.00	NSTAT5

Lapping Plate Cost	\$869 /ea	PLA5
Lapping Plate Life	14 pcs	WHEEL5
Number of Plates Required	432.00	PLAT5
Lapping Slurry Consumption	11.11 l/pc	GRIT5
Machine Power	4.2 kW	PWR5
Energy Requirement	94 kWh/pc	ENERGY5
Machine Cost	\$11,939 /sta	MCH5
Building Space/Station	400 sq ft	SPACE5
Installed Equipment Cost	\$16,118 /sta	IEQUIP5
Auxiliary Equipment Cost	\$1,791 /sta	AEQUIP5
Equipment Annuity	\$18,264 /yr	EINT5
Tooling Annuity	\$95,752 /yr	TINT5
Building Annuity	\$18,528 /yr	BINT5
Working Annuity	\$970,725 /yr	WINT5

INTERMEDIATE CALCULATIONS

Process In Use	0.00 [1-Y 0-N]	PRO6
Cumulative Yield	89.3%	CYLD6
Effective Production Volume	1,119 /yr	ENUM6
Volume of Material Lapped	111.11 um	HLP6
Setup Time	0.67 hrs/batch	CTIME6A
Lapping Time	22.22 hrs/batch	CTIME6B
Runtime for One Station	70%	RTIME6
Number of Parallel Stations	1.00	NSTAT6

Lapping Plate Cost	\$784 /ea	PLA6
Lapping Plate Life	50 pcs	WHEEL6
Number of Plates Required	112.00	PLAT6
Machine Power	45.8 kW	PWR6
Energy Requirement	204 kWh/pc	ENERGY6
Machine Cost	\$21,939 /sta	MCH6
Building Space/Station	400 sq ft	SPACE6
Installed Equipment Cost	\$29,618 /sta	IEQUIP6
Auxiliary Equipment Cost	\$3,291 /sta	AEQUIP6
Equipment Annuity	\$0 /yr	EINT6
Tooling Annuity	\$0 /yr	TINT6
Building Annuity	\$0 /yr	BINT6
Working Annuity	\$0 /yr	WINT6

MICROWAVE CVD TCM: OXYGEN PLASMA POLISHING
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MICROWAVE CVD TCM: OXYGEN ION MILLING
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VARIABLE COST ELEMENTS				VARIABLE COST ELEMENTS			
	per piece	per year	percent	per piece	per year	percent	investment
Material Cost	\$0.00	\$0	#DIV/0!	Material Cost	\$0.00	\$0	#DIV/0!
Direct Labor Cost	\$0.00	\$0	#DIV/0!	Direct Labor Cost	\$0.00	\$0	#DIV/0!
Utility Cost	\$0.00	\$0	#DIV/0!	Utility Cost	\$0.00	\$0	#DIV/0!
FIXED COST ELEMENTS				FIXED COST ELEMENTS			
Equipment Cost	\$0.00	\$0	#DIV/0!	Equipment Cost	\$0.00	\$0	#DIV/0!
Tooling Cost	\$0.00	\$0	#DIV/0!	Tooling Cost	\$0.00	\$0	#DIV/0!
Building Cost	\$0.00	\$0	#DIV/0!	Building Cost	\$0.00	\$0	#DIV/0!
Maintenance Cost	\$0.00	\$0	#DIV/0!	Maintenance Cost	\$0.00	\$0	#DIV/0!
Overhead Labor Cost	\$0.00	\$0	#DIV/0!	Overhead Labor Cost	\$0.00	\$0	#DIV/0!
Cost of Capital	\$0.00	\$0	#DIV/0!	Cost of Capital	\$0.00	\$0	#DIV/0!
TOTAL FABRICATION COST	\$0.00	\$0	#DIV/0!	TOTAL FABRICATION COST	\$0.00	\$0	#DIV/0!

INTERMEDIATE CALCULATIONS

INTERMEDIATE CALCULATIONS

	0.00	[1-Y 0-N]	PRO7		0.00	[1-Y 0-N]	PRO8
Process In Use			CYLD7	Process In Use			CYLD8
Cumulative Yield	89.3%		ENUM7	Cumulative Yield	89.3%		ENUM8
Effective Production Volume	1,119	/yr		Effective Production Volume	1,119	/yr	
Thickness of Material Lapped	111.11	um	HLAP7	Thickness of Material Lapped	111.11	um	HLAP8
Polishing Time	33.67	hrs/batch	CTIME7A	Polishing Time	462.96	hrs/batch	CTIME8A
Load/Unload Time	0.00	min	LTIME7	Load/Unload Time	0.00	min	LTIME8
Total Process Cycle Time	34.34	hrs/pc	CTIME7	Total Process Cycle Time	154.57	hrs/pc	CTIME8
Runtime for One Station	523%		RTIME7	Runtime for One Station	785%		RTIME8
Number of Parallel Stations	6.00		NSTAT7	Number of Parallel Stations	8.00		NSTAT8
Consumption (SCM/pc) Cost (\$/pc)				Consumption (SCM/pc) Cost (\$/pc)			
Oxygen Consumption	1.03	\$2.31	GASA7	Oxygen Consumption	0.09	\$0.21	GASA8
Argon Consumption	0.00	\$0.00	GASB7	Argon Consumption	0.00	\$0.00	GASB8
Other Gas Consumption	0.00	\$0.00	GASC7	Other Gas Consumption	0.00	\$0.00	GASC8
Energy Requirement	343	kWh/pc	ENERGY7	Energy Requirement	155	kWh/pc	ENERGY8
Building Space/Station	400	sq ft	SPACE7	Building Space/Station	400	sq ft	SPACE8
Installed Equipment Cost	\$405,000	/sta	IEQUIP7	Ion Source Life	19	pcs	SLIFE8
Auxiliary Equipment Cost	\$45,000	/sta	AEQUIP7	Number of Sources Required	289.00		SNUM5
Equipment Annuity	\$0	/yr	EINT7	Installed Equipment Cost	\$675,000	/sta	IEQUIP8
Tooling Annuity	\$0	/yr	TINT7	Auxiliary Equipment Cost	\$75,000	/sta	AEQUIP8
Building Annuity	\$0	/yr	BINT7	Equipment Annuity	\$0	/yr	EINT8
Working Annuity	\$0	/yr	WINT7	Tooling Annuity	\$0	/yr	TINT8
				Building Annuity	\$0	/yr	BINT8
				Working Annuity	\$0	/yr	WINT8

MICROWAVE CVD TCM: METALLIZATION - SPUTTERING				MICROWAVE CVD TCM: METALLIZATION - EVAPORATION			
IBIS ASSOCIATES, INC.				IBIS ASSOCIATES, INC.			
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VARIABLE COST ELEMENTS				VARIABLE COST ELEMENTS			
per piece	per year	percent	investment	per piece	per year	percent	investment
Material Cost	\$1.52	\$1,520	1.2%	Material Cost	\$0.00	\$0	\$0
Direct Labor Cost	\$0.24	\$242	0.2%	Direct Labor Cost	\$0.00	\$0	\$0
Utility Cost	\$0.02	\$16	0.0%	Utility Cost	\$0.00	\$0	\$0
FIXED COST ELEMENTS				FIXED COST ELEMENTS			
Equipment Cost	\$67.65	\$67,655	52.6%	Equipment Cost	\$0.00	\$0	\$0
Tooling Cost	\$0.00	\$0	0.0%	Tooling Cost	\$0.00	\$0	\$0
Building Cost	\$2.00	\$2,000	1.6%	Building Cost	\$0.00	\$0	\$0
Maintenance Cost	\$30.26	\$30,262	23.5%	Maintenance Cost	\$0.00	\$0	\$0
Overhead Labor Cost	\$5.00	\$5,000	3.9%	Overhead Labor Cost	\$0.00	\$0	\$0
Cost of Capital	\$21.84	\$21,844	17.0%	Cost of Capital	\$0.00	\$0	\$0
TOTAL FABRICATION COST	\$128.54	\$128,539	100.0%	TOTAL FABRICATION COST	\$0.00	\$0	\$0

INTERMEDIATE CALCULATIONS				INTERMEDIATE CALCULATIONS			
Process In Use				Process In Use			
Cumulative Yield				Cumulative Yield			
Effective Production Volume				Effective Production Volume			
Consumption (g/pc)	Cost (\$/pc)	Dep. Time (min)		Consumption (g/pc)	Cost (\$/pc)	Dep. Time (min)	
Titanium	0.01	\$0.02	4.17	Titanium	0.01	\$0.04	0.02
Platinum	0.04	\$0.74	2.67	Platinum	0.04	\$0.73	0.02
Gold	0.04	\$0.60	1.45	Gold	0.04	\$0.51	0.02
Metallization Thickness				Metallization Thickness			
Metallization Time				Metallization Time			
Preheat Time				Preheat Time			
Load/Unload Time				Load/Unload Time			
Total Process Cycle Time				Total Process Cycle Time			
Runtime for One Station	5%			Runtime for One Station	3%		
Number of Parallel Stations	1.00			Number of Parallel Stations	1.00		
Wafer Capacity per Station				Wafer Capacity per Station			
Machine Cost				Machine Cost			
Energy Requirement				Energy Requirement			
Building Space/Station				Building Space/Station			
Installed Equipment Cost	\$304,447	/sta		Installed Equipment Cost	\$191,570	/sta	
Auxiliary Equipment Cost	\$33,827	/sta		Auxiliary Equipment Cost	\$21,286	/sta	
Equipment Annuity				Equipment Annuity			
Tooling Annuity				Tooling Annuity			
Building Annuity				Building Annuity			
Working Annuity				Working Annuity			

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MICROWAVE CVD TCM: INSPECTION - THERMAL CONDUCTIVITY
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VARIABLE COST ELEMENTS			VARIABLE COST ELEMENTS		
per piece	per year percent	investment	per piece	per year percent	investment
Material Cost	\$0.00	0.0%	Material Cost	\$0.00	0.0%
Direct Labor Cost	\$5,249	6.4%	Direct Labor Cost	\$4,986	6.1%
Utility Cost	\$0.00	0.0%	Utility Cost	\$1	0.0%
FIXED COST ELEMENTS			FIXED COST ELEMENTS		
Equipment Cost	\$15,000	18.2%	Equipment Cost	\$15,000	18.3%
Tooling Cost	\$0.00	0.0%	Tooling Cost	\$0.00	0.0%
Building Cost	\$250	0.3%	Building Cost	\$250	0.3%
Maintenance Cost	\$6,400	7.8%	Maintenance Cost	\$6,400	7.8%
Overhead Labor Cost	\$50,000	60.7%	Overhead Labor Cost	\$50,000	60.9%
Cost of Capital	\$5,482	6.7%	Cost of Capital	\$5,477	6.7%
TOTAL FABRICATION COST	\$82.38	100.0%	TOTAL FABRICATION COST	\$82.11	100.0%
		\$80,000			\$80,000

INTERMEDIATE CALCULATIONS			INTERMEDIATE CALCULATIONS		
Process In Use	1.00 [1-Y 0-N]	PRO12	Process In Use	1.00 [1-Y 0-N]	PRO12
Cumulative Yield	90.3%	CYLD11	Cumulative Yield	95.0%	CYLD12
Effective Production Volume	1,108 /yr	ENUM11	Effective Production Volume	1,053 /yr	ENUM12
Process Cycle Time	0.25 hrs	CTIME11	Process Cycle Time	0.25 hrs	CTIME12
Runtime for One Station	10%	RTIME11	Runtime for One Station	10%	RTIME12
Number of Parallel Stations	1.00	NSTAT11	Number of Parallel Stations	1.00	NSTAT12
Energy Requirement	0 kWh/pc	ENERGY11	Energy Requirement	0 kWh/pc	ENERGY12
Building Space/Station	50 sq ft	SPACE11	Building Space/Station	50 sq ft	SPACE12
Installed Equipment Cost	\$67,500 /sta	IEQUIP11	Installed Equipment Cost	\$67,500 /sta	IEQUIP12
Auxiliary Equipment Cost	\$7,500 /sta	AEQUIP11	Auxiliary Equipment Cost	\$7,500 /sta	AEQUIP12
Equipment Annuity	\$19,122 /yr	EINT11	Equipment Annuity	\$19,122 /yr	EINT12
Tooling Annuity	\$0 /yr	TINT11	Tooling Annuity	\$0 /yr	TINT12
Building Annuity	\$579 /yr	BINT11	Building Annuity	\$579 /yr	BINT12
Working Annuity	\$62,680 /yr	WINT11	Working Annuity	\$62,413 /yr	WINT12

MICROWAVE CVD TCM: COST SUMMARY				
IBIS ASSOCIATES, INC.				
Copyright (c) 1991 v4.0				
VARIABLE COST ELEMENTS				
	per piece	per year percent	investment	
Material Cost	\$879.05	\$879,047	12.0%	
Direct Labor Cost	\$292.42	\$292,417	4.0%	
Utility Cost	\$399.36	\$399,362	5.4%	
FIXED COST ELEMENTS				
Equipment Cost	\$2,877.14	\$2,877,145	39.2%	\$14,385,724
Tooling Cost	\$412.80	\$412,805	5.6%	\$2,064,023
Building Cost	\$22.25	\$22,250	0.3%	\$445,000
Maintenance Cost	\$1,186.46	\$1,186,458	16.2%	
Overhead Labor Cost	\$280.00	\$280,000	3.8%	
Cost of Capital	\$984.20	\$984,196	13.4%	
TOTAL FABRICATION COST	\$7,333.68	\$7,333,680	100.0%	\$16,894,747

SUMMARY INFORMATION		
Part Name 6 in. substrate	6.25 /shift	
Total Direct Laborers	6,750 sqft	
Total Floor Space	\$16.9 MM	
Total Capital Investment		
Area Cost	\$40.20 /sqcm	
Cost Per Carat	\$22.91 /ct	

Operation	Equipment	Material	Labor	Other
Surface Preparation	\$20	\$3	\$26	\$19
Deposition	\$2,744	\$142	\$183	\$2,745
Etching	\$0	\$0	\$0	\$0
Laser Trimming	\$2	\$0	\$50	\$4
Lapping	\$14	\$732	\$198	\$159
Hot Iron Polishing	\$0	\$0	\$0	\$0
Oxygen Plasma Polishing	\$0	\$0	\$0	\$0
Oxygen Ion Beam Polishing	\$0	\$0	\$0	\$0
Metallization - Sputtering	\$68	\$2	\$5	\$54
Metallization - Evaporation	\$0	\$0	\$0	\$0
Inspect - Microscopy	\$15	\$0	\$55	\$12
Inspect - Thermal Cond'vity	\$15	\$0	\$55	\$12
Total	\$2,877	\$879	\$572	\$3,005
Total -				\$7,334

Appendix C

MICROWAVE CVD DIAMOND TECHNICAL COST MODEL
IBIS ASSOCIATES, INC.
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Revision Date: 10/18/93

PRODUCT SPECIFICATIONS

Part Name 6 in. substrate
Finished Wafer Thickness 1,000 um

Annual Production Volume 1 (000/yr)
Length of Production Run 5 yrs

PROCESS RELATED FACTORS - SURFACE PREPARATION

Process In Use? 1.00 (1-Y 0-N)
Dedicated Investment 1.00 (1-Y 0-N)
Process Yield 95.0%
Average Equipment Downtime 20.0%
Direct Laborers Per Station 0.50

Substrate Material 2 (menu #)
Pieces Per Batch 20.00 pcs/batch
Process Time 60.00 min/batch
Building Space Requirement 250 sqft/sta

PROCESS RELATED FACTORS - DEPOSITION

Process In Use? 1.00 (1-Y 0-N)
Dedicated Investment 0.00 (1-Y 0-N)
Process Yield 90.0%
Average Equipment Downtime 15.0%
Direct Laborers 0.20 /sta

Gas Temperature (>1000K) 3,000 K
Substrate Temperature 1,200 K
Reactor Pressure 110.0 torr

Recombine Coef. (gammaH) 0.10
Plasma Ball Skew Factor (f) 3.00 (2-sym.)
Hydrogen Concentration Exp 2.00
Diamond Quality Factor (Z) 1.42E-19
Diamond Density 3.52 g/cc
Ideal Gas Constant (R) 62,358 c torr/K mol
Ideal Gas Constant 2 (R) 8.31 J / mol K

NASA Enthalpy Constants

	H2	H
a1	2.99E+00	2.50E+00
a2	7.00E-04	0.00E+00
a3	-5.63E-08	0.00E+00
a4	-9.23E-12	0.00E+00
a5	1.58E-15	0.00E+00
a6	-8.35E+02	2.55E+04
a7	-1.36	-0.46
MW	2.02	1.01

Meru # vol%

MICROWAVE CVD DIAMOND TECHNICAL COST MODEL
IBIS ASSOCIATES, INC.
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GAS DATABASE

#	Gas	Source	Purity	Price \$/SCM	No. of Carbons	Liq Gas	Tank gal	Price Update
0	None			\$0.00	0.00	0.00		
1	Liq Hydrogen	Airco 99.998%		\$0.34	0.00	1.00	6000	1/93
2	Liq Hydrogen	Airco 99.998%		\$0.32	0.00	1.00	11000	1/93
3	Liq Hydrogen	Airco 99.998%		\$0.30	0.00	1.00	20000	1/93
4	Liq Argon	Airco 99.998%		\$1.41	0.00	1.00	3000	1/93
5	Liq Argon	Airco 99.998%		\$1.32	0.00	1.00	6000	1/93
6	Liq Argon	Airco 99.998%		\$1.29	0.00	1.00	11000	1/93
7	Hydrogen	MG Ind. 99.999%		\$29.86	0.00	0.00		1/93
8	Hydrogen	MG Ind. 99.999%		\$40.61	0.00	0.00		1/93
9	Hydrogen	MG Ind. 99.999%		\$10.28	0.00	0.00		1/93
10	Hydrogen	Air Prod. 99.95%		\$1.59	0.00	0.00		1/93
11	Argon	MG Ind. 99.999%		\$33.09	0.00	0.00		1/93
12	Argon	Air Prod. 99.997%		\$37.33	0.00	0.00		1/93
13	Argon	Air Prod. 99.999%		\$11.74	0.00	0.00		1/93
14	Argon	Air Prod. 99.997%		\$2.03	0.00	0.00		1/93
15	Methane	Air Prod. 99.99%		\$21.99	1.00	0.00		1/93
16	Methane	Air Prod. 99%		\$13.76	1.00	0.00		1/93
17	Methane	Air Prod. 93%		\$4.93	1.00	0.00		1/93
18	Acetylene	Air Prod. 99.6%		\$6.80	2.00	0.00		1/93
19	Acetylene	Air Prod. 98%		\$5.85	2.00	0.00		1/93
20	Helium	Air Prod. 99.999%		\$15.90	0.00	0.00		1/93
21	Helium	Air Prod. 99.995%		\$4.77	0.00	0.00		1/93
22	Nitrogen	Air Prod. 99.999%		\$45.50	0.00	0.00		1/93
23	Nitrogen	MG Ind. 99.999%		\$9.23	0.00	0.00		1/93
24	Nitrogen	Air Prod. 99.998%		\$1.24	0.00	0.00		1/93
25	Oxygen	Air Prod. 99.998%		\$2.00	0.00	0.00		1/93
26								

SUBSTRATE DATABASE

#	Substrate	Source	Price Exp.	Price Coef.	Price Const.	Etch um/min	Life use#	Price Update
0	None		0.000	0.00	0	1.00	1.00	
1	Silicon	SI-Tech	4.335	0.00	2.81	####	1	1/93
2	Molybdenum	logies Corp	2.000	0.34	11.17	####	46.00	1/93
3	Tungsten	logies Corp	1.366	12.97	-80.44	####	46.00	1/93
4								

TARGET DATABASE

#	Metal	Vendor	Price \$/g A/kWh	Dep.Rt.	Density g/cc	Price Update
0	None		\$0	#####	1.00	
1	Titanium	Tosoh	\$1.90	80.00	4.51	1/93

Hydrogen	9	88.7%	GASA VOLA	2	Platinum	Tosoh	\$19.00	125.00	21.45	1/93
Carbon Containing Gas	16	10.0%	GASB VOLB	3	Gold	Tosoh	\$17.00	230.00	19.32	1/93
Carrier Gas	0	0.0%	GASC VOLC	4	Silver	Tosoh	\$2.45	215.00	10.10	1/93
Other Gas	25	1.3%	GASD VOLD	5	Copper	Tosoh	\$1.15	210.00	8.96	1/93
				6	Nickel	Tosoh	\$0.95	30.00	8.91	1/93
				7	Palladium	Tosoh	\$8.45	210.00	12.02	1/93
				8	Silicon	Tosoh	\$0.80	15.00	2.33	1/93

Hydrogen Recycle Rate	0.0%	RECYC
Carrier Gas Recycle Rate	0.0%	RECYC2
Gas Recycle Equipment Cost	\$250,000 total	MCH2A

Rated Microwave Power	75 kW	POW2
Microwave Coupling Eff.	98%	P2GEFF2
Total Power Multiplier	200%	TPM2
Carbon Capture Factor	10.0%	CCF2
Machine Load/Unload Time	30.00 min/batch	PTIME2
Available Deposition Time	8,640 hrs/yr	DAYHR2
Microwave Tube Life	5000 hrs	LIFE2

Coolant Temp. Rise	50.00 C	TEMP2
Heat Capacity of Coolant	1.0 cal/g/C	CP2
Building Space Requirement	400 sqft/sta	FLR2

PROCESS RELATED FACTORS - ETCHING		
Process In Use?	0.00 (1-Y 0=N)	USE3
Dedicated Investment	1.00 (1-Y 0=N)	DED3
Process Yield	99.0%	YLD3
Average Equipment Downtime	10.0%	DOWN3
Direct Laborers Per Station	1.00	NLAB3

Load/Unload and Rinse Time	30.00 min/batch	PTIME3
Pieces Per Batch	20.00	PCS3
Machine Cost	\$6,000 /sta	MCH3
Etchant Cost	\$70 /liter	ETCH3A
Etchant Disposal Cost	\$30 /liter	ETCH3B
Machine Etchant Capacity	1.00 l/batch	CAP3

Machine Power	0.00 kW	POW3
Building Space Requirement	100 sqft/sta	FLR3

PROCESS RELATED FACTORS - LASER TRIMMING		
Process In Use?	1.00 (1-Y 0=N)	USE4
Dedicated Investment	1.00 (1-Y 0=N)	DED4
Process Yield	99.0%	YLD4
Average Equipment Downtime	10.0%	DOWN4
Direct Laborers Per Station	1.00	NLAB4

Machine Cost	\$6,000 /sta	MCH4
Trimming Rate	1.00 cm/s	RATE4

Machine Power	5.00 kW	POW4
Building Space Requirement	100 sqft/sta	FLR4

>5 kW

EVAPORATION DATABASE									
#	Metal	Vendor	Price \$/g	Dep.Rt. A/kWh	Density g/cc	Price Update			
0	None		\$0	#####	1.00				
1	Titanium re	Tech Inc	\$4.40	9,520.00	4.51	1/93			
2	Platinum re	Tech Inc	\$18.59	6,428.57	21.45	1/93			
3	Gold re	Tech Inc	\$14.58	6,428.57	19.32	1/93			
4	Silver re	Tech Inc	\$3.12	215.00	10.50	1/93			
5	Copper re	Tech Inc	\$1.08	210.00	8.96	1/93			
6	Nickel re	Tech Inc	\$1.49	30.00	8.91	1/93			
7	Palladium re	Tech Inc	\$7.03	210.00	12.02	1/93			
8	Silicon re	Tech Inc	\$7.51	15.00	2.33	1/93			

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PROCESS RELATED FACTORS - LAPPING

Process In Use?	1.00 [1-Y 0-N]	USE5
Dedicated Investment	1.00 [1-Y 0-N]	DED5
Process Yield	90.0%	YLD5
Average Equipment Downtime	15.0%	DOWN5
Direct Laborers Per Station	0.25	NLAB5
Lapped Material Removal	10.0% by wgt	TLAP5
No of Lapping Steps	2.00	LAPS5
Pieces Per Batch	5.00	PCS5
Load/Unload and Clean Wafers	40.00 min/batch	PTIME5
Average Lapping Rate	1.0 um/hr	RATES
Lapping Slurry Cost	\$53 /liter	LAPSL5
Lapping Slurry Usage Rate	0.50 liter/hr	LAPRS
Lapping Plate Life	320.00 hrs	PLAL5
Available Lapping Time	8,640 hrs/yr	DAYHR5
Building Space Requirement	400 sqft/sta	FLR5

PROCESS RELATED FACTORS - INSPECTION - MICROSCOPY

Process In Use?	1.00 [1-Y 0-N]	USE6
Dedicated Investment	1.00 [1-Y 0-N]	DED6
Process Yield	95.0%	YLD6
Average Equipment Downtime	5.0%	DOWN6
Direct Laborers Per Station	1.00	NLAB6
Average Inspection Time	15.00 min/batch	PTIME6
Percent Inspection	100%	INSP6
Machine Cost	\$50,000 /sta	MCH6
Machine Power	0.10 kW	POW6
Building Space Requirement	50 sqft/sta	FLR6

PROCESS RELATED FACTORS - INSPECTION - THERMAL CONDUCTIVITY

Process In Use?	1.00 [1-Y 0-N]	USE7
Dedicated Investment	1.00 [1-Y 0-N]	DED7
Process Yield	95.0%	YLD7
Average Equipment Downtime	5.0%	DOWN7
Direct Laborers Per Station	1.00	NLAB7
Average Inspection Time	15.00 min/batch	PTIME7
Percent Inspection	100%	INSP7
Machine Cost	\$50,000 /sta	MCH7
Machine Power	0.10 kW	POW7
Building Space Requirement	50 sqft/sta	FLR7

OPTIONAL INPUTS

	override	estimate	
Surface Preparation			
Machine Cost	\$0	\$65,774 /sta	OMCH1
Machine Power	0.0	19.2 kW	OPOW1
Deposition			
Plasma Ball Area	0.00	633.19 sq cm	OBAREA2

Plasma Ball Height 0.00 7.10 cm OBGHT2
 Deposition Diameter 0.00 25.8" cm ODDIAM2
 Deposition Rate 0.00 2.35 g/hr ODRATE2
 Deposition Equipment Cost \$0 \$688 k\$/sta OMCH2
 Microwave Tube Cost \$4,500 \$4,500 /sta OTUBE2
 Etching Process Cycle Time 0.00 0.03 hrs OCTIME3
 Chemical Requirement \$0 \$5.00 /pc OCHEM3
 Laser Trimming Process Cycle Time 0.00 0.02 hrs OCTIME4

Lapping Lapping Time 0.00 111.11 hrs OCTIME5
 Lapping Plate Cost \$0 \$869 /ea OWHEEL5
 Lapping Machine Cost \$0 \$11,939 /sta OMCH5
 Lapping Machine Power 0.00 4.2 kW OPWR5

EXOGENOUS COST FACTORS

	\$13.33 /hr	WAGE	SALARY * exc. dep. & lap
Direct Wages	\$50,000 /yr	ILAB	
Indirect Salary	1.00	BENI	
Indirect:Direct Labor Ratio	35.0%	DAYS	
Benefits on Wage and Salary	360.00	HRS	
Working Days per Year	8.00 /hr	CRR	
Working Hours per Day (*)	10%	ELIFE	
Capital Recovery Rate	5.00 yrs	BLIFE	
Capital Recovery Period	20.00 yrs	WCP	
Building Recovery Life	3.00 months	ELEC	
Working Capital Period	\$0.050 /kWh	GAS	
Price of Electricity	\$6.50 /MBTU	PBLD	
Price of Natural Gas	\$100 /sqft	WATER	
Price of Building Space	\$0.03 /100 gal	AUX	
Price of Cooling Water	15.0%	INST	
Auxiliary Equipment Cost	35.0%	MNT	
Equipment Installation Cost	8.0%		
Maintenance Cost			

REGRESSION CONSTANTS, COEFFICIENTS, AND EXPONENTS

-Surface Preparation-	
Machine Cost Constant	1.334 MCH1A
Machine Cost Capacity Coef	3.222 MCH1B
Machine Power Constant	-0.75 PWR1A
Machine Power Capacity Coef	1.00 PWR1B
-Deposition-	
sma Ball Diam Power Exponent	0.38 BD1AM2X
Ball Diam Power Coefficient	5.01 BD1AM2Y
Plasma Ball Diam Constant	2.54 BD1AM2Z
Plasma Ball Area:Height	4.00 BAHRA2
Machine Cost Power Coef	4.658 MCH2Y
Machine Cost Power Exponent	1.00 MCH2Z
Machine Cost Power Constant	338,896 MCH2X
Tube Cost Constant	1724 TUBE2Y

Tube Cost Coef 97.01 TUBE22
Tank 1 \$ Capacity Constant 1.175 TANK2A
Tank 1 \$ Capacity Coef 0.165 TANK2B
Tank 2 \$ Capacity Constant 370.00 TANK2X
Tank 2 \$ Capacity Coef 0.03 TANK2Y

-Etching-

-Lapping-
Machine Cost Constant 2.719 MCH5A
Machine Cost Capacity Coef 1.844 MCH5B
Machine Power Constant -0.75 PWR5A
Machine Power Capacity Coef 1.00 PWR5B
Tool Cost Constant 771.00 TOOL5A
Tool Cost Capacity Coef 0.92 TOOL5B
Tool Cost Capacity Exponent 2.90 TOOL5C

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MICROWAVE CVD TCM: SURFACE PREPARATION MICROWAVE CVD TCM: DEPOSITION
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VARIABLE COST ELEMENTS			VARIABLE COST ELEMENTS		
per piece	per year	percent	per piece	per year	percent
Material Cost	\$7.45	10.4%	Material Cost	\$608.16	7.4%
Direct Labor Cost	\$0.82	1.1%	Direct Labor Cost	\$514.93	6.3%
Utility Cost	\$0.07	0.1%	Utility Cost	\$919.02	11.2%
FIXED COST ELEMENTS			FIXED COST ELEMENTS		
Equipment Cost	\$19.73	27.4%	Equipment Cost	\$3,418.17	41.6%
Tooling Cost	\$0.00	0.0%	Tooling Cost	\$74.80	0.9%
Building Cost	\$1.25	1.7%	Building Cost	\$33.11	0.4%
Maintenance Cost	\$9.89	13.7%	Maintenance Cost	\$1,420.24	17.3%
Overhead Labor Cost	\$25.00	34.7%	Overhead Labor Cost	\$165.55	2.0%
Cost of Capital	\$7.79	10.8%	Cost of Capital	\$1,064.15	12.9%
TOTAL FABRICATION COST	\$72.01	100.0%	TOTAL FABRICATION COST	\$8,218.14	100.0%

INTERMEDIATE CALCULATIONS			INTERMEDIATE CALCULATIONS		
Process In Use	PRO1		Process In Use	PRO2	
Cumulative Yield	CYLD1		Cumulative Yield	CYLD2	
Effective Production Volume	ENUM1		Effective Production Volume	ENUM2	
			Delivered Power	EPW2	
Substrate Area	AREAL				
New Substrate Cost	SUB1				
Substrate Useful Life	LIFE1				
Process Cycle Time	CTIME1				
Runtime for One Station	RTIME1				
Number of Parallel Stations	NSTAT1				
Energy Requirement	ENERGY1				
Building Space/Station	SPACE1				
Machine Cost	MCH1				
Machine Power	POW1				
Installed Equipment Cost	IEQUIP1				
Auxiliary Equipment Cost	AEQUIP1				
Equipment Annunity	EINT1				
Tooling Annunity	TINT1				
Building Annunity	BINT1				
Working Annunity	WINT1				

DEPOSITION RATE CALCULATIONS			DEPOSITION RATE CALCULATIONS		
Mass of Diamond Deposited	205.32	g	Mass of Diamond Deposited	205.32	g
Mass Deposition Rate	2.3	g/hr	Mass Deposition Rate	2.3	g/hr
Linear Deposition Rate	12.7	μ/hr	Linear Deposition Rate	12.7	μ/hr
Deposition Time	87.49	hrs	Deposition Time	87.49	hrs
Machine Setup Time	0.50	hrs	Machine Setup Time	0.50	hrs

Runtime for One Station	1655*	RTIME2
Number of Parallel Stations	16.55	NSTAT2
Total Carbon Gas Volume	4.18 SCM	CARGAS2
Total Gas Volume	42 SCM	TVOL2
Total Gas Flow Rate	7,970 sccm	FLOWR2
	Consumption	Cost
	(SCM/pc)	(\$/pc)
Hydrogen Consumption	37.11	\$527.12
Carbon Gas Consumption	4.18	\$79.54
Carrier Gas Consumption	0.00	\$0.00
Other Gas Consumption	0.54	\$1.50
Energy Requirement	13,123 kWh/pc	ENERGY2
Physical Tube Life	0.68 years	TLIFE2
Number of Tubes per Station	8.00	NTUBE2
New Microwave Tube Cost	\$4,500 /tube	TUBE2A
Reworked Microwave Tube Cost	\$2,500 /tube	TUBE2B
Cooling Water Flow Rate	5.7 gal/min	WATER2
Cooling Water Requirement	29,803 gal/pc	COOL2
Building Space/Station	400 sqft	SPACE2
Recycle Equipment Cost	\$0 /sta	REC2
Liquid Hydrogen Tank Rental	\$0 /mo/tank	HYD2
Liq Carrier Gas Tank Rental	\$0 /mo/tank	CAR2
Gas Storage Equipment Rent	\$0 /year	GTANK2
Machine Cost	\$688,246 /sta	MCH2B
Installed Equipment Cost	\$929,132 /sta	IEQUIP2
Auxiliary Equipment Cost	\$103,237 /sta	AEQUIP2
Equipment Annuity	\$4,357,560 /yr	EINT2
Tooling Annuity	\$95,357 /yr	TINT2
Building Annuity	\$76,684 /yr	BINT2
Working Annuity	\$3,688,536 /yr	WINT2

MICROWAVE CVD TCM: ETCHING				MICROWAVE CVD TCM: SER TRIMMING			
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per piece				per piece			
per year percent				per year percent			
investment				investment			
VARIABLE COST ELEMENTS				VARIABLE COST ELEMENTS			
Material Cost	\$0.00	\$0	#VALUE!	Material Cost	\$0.00	\$0	0.0%
Direct Labor Cost	\$0.00	\$0	#VALUE!	Direct Labor Cost	\$0.56	\$561	1.0%
Utility Cost	\$0.00	\$0	#VALUE!	Utility Cost	\$0.01	\$7	0.0%
FIXED COST ELEMENTS				FIXED COST ELEMENTS			
Equipment Cost	\$0.00	\$0	#VALUE!	Equipment Cost	\$1.80	\$1,800	3.2%
Tooling Cost	\$0.00	\$0	#VALUE!	Tooling Cost	\$0.00	\$0	0.0%
Building Cost	\$0.00	\$0	#VALUE!	Building Cost	\$0.50	\$500	0.9%
Maintenance Cost	\$0.00	\$0	#VALUE!	Maintenance Cost	\$1.52	\$1,520	2.7%
Overhead Labor Cost	\$0.00	\$0	#VALUE!	Overhead Labor Cost	\$50.00	\$50,000	88.6%
Cost of Capital	\$0.00	\$0	#VALUE!	Cost of Capital	\$2.02	\$2,023	3.6%
TOTAL FABRICATION COST	\$0.00	\$0	#VALUE!	TOTAL FABRICATION COST	\$56.41	\$56,411	100.0%
							\$19,000

INTERMEDIATE CALCULATIONS				INTERMEDIATE CALCULATIONS			
Process In Use	0.00	[1-Y 0-N]	PRO3	Process In Use	1.00	[1-Y 0-N]	PRO4
Cumulative Yield	80.4%		CYLD3	Cumulative Yield	80.4%		CYLD4
Effective Production Volume	1,244	/yr	ENUM3	Effective Production Volume	1,244	/yr	ENUM4
Total Etched Thickness	0	um	ETHIK3	Process Cycle Time	0.02	hrs/pc	CTIME4
Average Etchant Rate	10.00	um/min	ERATE3	Runtime for One Station	1%		RTIME4
Process Cycle Time	0.03	hrs/pc	CTIME3	Number of Parallel Stations	1.00		NSTAT4
Runtime for One Station	1%		RTIME3				
Number of Parallel Stations	1.00		NSTAT3				
Chemical Requirement	\$5.00	/pc	CHEM3	Energy Requirement	0	kWh/pc	ENERGY4
Energy Requirement	0	kWh/pc	ENERGY3	Building Space/Station	100	sq ft	SPACE4
Building Space/Station	100	sq ft	SPACE3	Installed Equipment Cost	\$8,100	/sta	IEQUIP4
Installed Equipment Cost	\$8,100	/sta	IEQUIP3	Auxiliary Equipment Cost	\$900	/sta	AEQUIP4
Auxiliary Equipment Cost	\$900	/sta	AEQUIP3	Equipment Annuity	\$2,295	/yr	EINT4
Equipment Annuity	\$0	/yr	EINT3	Tooling Annuity	\$0	/yr	TINT4
Tooling Annuity	\$0	/yr	TINT3	Building Annuity	\$1,158	/yr	BINT4
Building Annuity	\$0	/yr	BINT3	Working Annuity	\$52,959	/yr	WINT4
Working Annuity	\$0	/yr	WINT3				

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VARIABLE COST ELEMENTS		per piece	per year percent	investment	VARIABLE COST ELEMENTS		per piece	per year percent	investment
Material Cost		\$725.01	\$725,009	66.3%	Material Cost		\$0.00	\$0	0.0%
Direct Labor Cost		\$146.58	\$146,579	13.4%	Direct Labor Cost		\$5.25	\$5,249	6.4%
Utility Cost		\$5.79	\$5,786	0.5%	Utility Cost		\$0.00	\$1	0.0%
TOTAL FABRICATION COST		\$1,093.37	\$1,093,372	100.0%	TOTAL FABRICATION COST		\$82.38	\$82,382	100.0%

FIXED COST ELEMENTS		per piece	per year percent	investment	FIXED COST ELEMENTS		per piece	per year percent	investment
Equipment Cost		\$14.33	\$14,327	1.3%	Equipment Cost		\$15.00	\$15,000	18.2%
Tooling Cost		\$74.41	\$74,415	6.8%	Tooling Cost		\$0.00	\$0	0.0%
Building Cost		\$8.00	\$8,000	0.7%	Building Cost		\$0.25	\$250	0.3%
Maintenance Cost		\$18.53	\$18,531	1.7%	Maintenance Cost		\$6.40	\$6,400	7.8%
Overhead Labor Cost		\$50.00	\$50,000	4.6%	Overhead Labor Cost		\$50.00	\$50,000	60.7%
Cost of Capital		\$50.73	\$50,725	4.6%	Cost of Capital		\$5.48	\$5,482	6.7%
TOTAL FABRICATION COST		\$1,093.37	\$1,093,372	100.0%	TOTAL FABRICATION COST		\$82.38	\$82,382	100.0%

INTERMEDIATE CALCULATIONS		PRO5	PRO6
Process In Use		1.00 (1=Y 0=N)	1.00 (1=Y 0=N)
Cumulative Yield		81.2%	90.3%
Effective Production Volume		1,231 /yr	1,108 /yr
Thickness of Material Lapped		111.11 um	0.25 hrs
Setup Time		1.33 hrs/batch	10%
Lapping Time		111.11 hrs/batch	1.00
Runtime for One Station		377%	
Number of Parallel Stations		4.00	
Lapping Plate Cost		\$869 /ea	
Lapping Plate Life		14 pcs	
Number of Plates Required		428.00	
Lapping Slurry Consumption		11.11 l/pc	
Machine Power		4.2 kW	
Energy Requirement		94 kWh/pc	
Machine Cost		\$11,939 /sta	
Building Space/Station		400 sq ft	
Installed Equipment Cost		\$16,118 /sta	
Auxiliary Equipment Cost		\$1,791 /sta	
Equipment Annuity		\$18,264 /yr	
Tooling Annuity		\$94,865 /yr	
Building Annuity		\$18,528 /yr	
Working Annuity		\$961,714 /yr	

INTERMEDIATE CALCULATIONS		PRO5	PRO6
Process In Use		1.00 (1=Y 0=N)	1.00 (1=Y 0=N)
Cumulative Yield		81.2%	90.3%
Effective Production Volume		1,231 /yr	1,108 /yr
Thickness of Material Lapped		111.11 um	0.25 hrs
Setup Time		1.33 hrs/batch	10%
Lapping Time		111.11 hrs/batch	1.00
Runtime for One Station		377%	
Number of Parallel Stations		4.00	
Lapping Plate Cost		\$869 /ea	
Lapping Plate Life		14 pcs	
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Tooling Annuity		\$94,865 /yr	
Building Annuity		\$18,528 /yr	
Working Annuity		\$961,714 /yr	

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MICROWAVE CVD TCM: COST SUMMARY
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		per piece	per year percent	investment			per piece	per year percent	investment
VARIABLE COST ELEMENTS					VARIABLE COST ELEMENTS				
Material Cost	\$0.00	\$15,000	18.3%	\$75,000	Material Cost	\$1,340.63	\$1,340,626	13.9%	
Direct Labor Cost	\$4.99	\$4,986	6.1%	\$0	Direct Labor Cost	\$696.21	\$673,119	7.2%	
Utility Cost	\$0.00	\$0	0.0%	\$0	Utility Cost	\$924.89	\$924,887	9.6%	
FIXED COST ELEMENTS					FIXED COST ELEMENTS				
Equipment Cost	\$15.00	\$15,000	18.3%	\$75,000	Equipment Cost	\$3,484.03	\$3,484,028	36.2%	\$17,879,568
Tooling Cost	\$0.00	\$0	0.0%	\$0	Tooling Cost	\$149.21	\$149,215	1.5%	\$746,073
Building Cost	\$0.25	\$250	0.3%	\$5,000	Building Cost	\$43.36	\$43,360	0.5%	\$885,000
Maintenance Cost	\$6.40	\$6,400	7.8%		Maintenance Cost	\$1,462.99	\$1,462,987	15.2%	
Overhead Labor Cost	\$50.00	\$50,000	60.9%		Overhead Labor Cost	\$390.55	\$390,550	4.1%	
Cost of Capital	\$5.48	\$5,477	6.7%		Cost of Capital	\$1,135.65	\$1,135,652	11.8%	
TOTAL FABRICATION COST	\$82.11	\$82,115	100.0%	\$80,000	TOTAL FABRICATION COST	\$9,627.51	\$9,604,423	100.0%	\$19,510,641

INTERMEDIATE CALCULATIONS

Process In Use	1.00 [1-Y 0-N]	PRO7
Cumulative Yield	95.0%	CYLD7
Effective Production Volume	1,053 /yr	ENUM7
Process Cycle Time	0.25 hrs	CTIME7
Runtime for One Station	10%	RTIME7
Number of Parallel Stations	1.00	NSTAT7
Energy Requirement	0 kWh/pc	ENERGY7
Building Space/Station	50 sq ft	SPACE7
Installed Equipment Cost	\$67,500 /sta	IEQUIP7
Auxiliary Equipment Cost	\$7,500 /sta	AEQUIP7
Equipment Annuity	\$19,122 /yr	EINT7
Tooling Annuity	\$0 /yr	TINT7
Building Annuity	\$579 /yr	BINT7
Working Annuity	\$62,413 /yr	WINT7

SUMMARY INFORMATION

Part Name 6 in. substrate	8.90 /shift
Total Direct Laborers	8,950 sqft
Total Floor Space	\$19.5 MM
Total Capital Investment	
Area Cost	\$18.34 /sqcm
Cost Per Carat	\$10.45 /ct

Operation	Equipment	Material	Labor	Other
Surface Preparation	\$20	\$7	\$26	\$19
Deposition	\$3,418	\$608	\$680	\$3,511
Etching	\$0	\$0	\$0	\$0
Laser Trimming	\$2	\$0	\$51	\$4
Lapping	\$14	\$725	\$197	\$157
Inspect - Microscopy	\$15	\$0	\$55	\$12
Inspect - Thermal Cond'vity	\$15	\$0	\$55	\$12
Total	\$3,484	\$1,341	\$888	\$3,716
Total -	\$9,604			