IC KNOWLEDGE LLC

MEMS Cost Model revision 0905 Manual

Throughout this model areas where selections are made or data is input are inside blue boxes and the data entry area is white with black text. Data which is being displayed is inside taupe boxes and the data display area is dark grey with white text.

You can define up to 2 stand-alone MEMS die and 2 IC or integrated IC and MEMS die per product. You turn on or off calculations for each of the four die type by either selecting a process for each one or selecting “none” for the process for each one.

Work through the sheets from step1 to cost in order!

Throughout the model red warnings are displayed to highlight functions that are disabled by “none” being selected for the process for any of the four die types.

Step 1 – Product Select

Selecting a product on this page will display suggested settings throughout the model. The selections made on this sheet does not set up the model to do anything, it just displays suggestions! If you want to model a product not on the list, you can still create a model by using the Step 2 through Cost sheets but you will need to know what to enter at each point.

The next page provides a screen shot of the “Step 1 - Product Select” sheet.

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1 Select the product to model	Infineon - BAW Duplexer - Bulk Acoustic Wave filter

MEMS Process 1	Infineon - Bulk Accoustic Wave			
MEMS Fab 1	Infineon Fab 1			
MEMS die size 1	1.5	L (mm)	0.9	W (mm)
Foundry margin 1	0%			
MEMS Process 2	Infineon - Bulk Accoustic Wave			
MEMS Fab 2	Infineon Fab 1			
MEMS die size 2	0.6	L (mm)	0.9	W (mm)
Foundry margin 2	0			
Integrated Circuit (IC) Process 1	NA			
IC die size 1	NA	L (mm)	NA	W (mm)
Foundry or supplier margin 1	NA			
Integrated Circuit (IC) Process 2	NA			
IC die size 2	NA	L (mm)	NA	W (mm)
Foundry or supplier margin 2	NA			
Package	EPCOS' CSSPlus with 2 die			
MEMS wafer sort 1	Bulk Accoustic Wave Filter			
MEMS wafer sort 2	Bulk Accoustic Wave Filter			
IC or Integrated MEMS sort 1	None			
IC or Integrated MEMS sort 2	None			
Product test	Duplex Bulk Accoustic Wave Filter			

Step 2 – Define MEMS Processes

The model supports up to two MEMS die per product. These MEMS die are MEMS only devices, for MEMS integrated with IC processes you will define the processes in the IC section of the model.

Selection 2 is where you select the process for the first MEMS die and the suggested process to use is displayed just above selection 2. If you select “none” here all MEMS die 1 function in the model are disabled and any MEMS die 1 settings on subsequent sheets will be ignored. If you select “enter steps” you can define your own MEMS process in the step entry area below.

To define your own MEMS process select “enter steps” fro selection 2 and then fill in the number of times each step is used in white boxes in the process definition section. Note that “enter steps below” will be displayed at the top of the section if the step entry is enabled. There are several red dots in this section, moving the cursor over the red dots will pop open comment boxes with information on the step conditions. Also in this area is a process step labeled “special”. If you enter a value greater than 1 in special you must define the special process in the “definition of special process steps” blue box underneath the step entry box.

If the special process is active the red “Disabled” will be replaced with a red “Must be filled in”. The user must then define equipment cost, throughout, footprint and consumables cost. Throughput is the raw throughput in wafers per hour not assuming 100% uptime. The footprint is the number of square meters the equipment occupies not counting any access space requirements. Consumables are the cost per wafer for consumable items.

Selection 3 sets the year being modeled for the entire model. The year being modeled effects labor costs, energy costs, material costs and depreciation.

Selections 4a and 4b are used to define the die yield for the first MEMS device.

At the bottom of the sheet, selection 5 is the process for a second MEMS die if applicable. Please note that “enter steps” doesn’t function for the second MEMS die, only the first MEMS die. Selections 6a and 6b set the yield for the second MEMS die.

The next page provides a screen shot of the “Step 2 – Define MEMS Processes” sheet.

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Suggested MEMS Process 1	Infineon - Bulk Accoustic Wave

2 Select the process to model	Infineon - Bulk Accoustic Wave
3 Select the year to model	2009
4a Select the maturity of the process	Established process
4b Select the maturity of the design	Established design - well characterized
4c Select calculated yield or override value	Calculated
MEMS die yield	85%

Step Entry is for MEMS die 1 only — **Step Entry Disabled**

Process step	Steps entered		Steps used
Bond - Anodic	1	Number of steps	0
Bond - Temp	1	Number of steps	0
Bond - Thermal	1	Number of steps	0
Clean - RCA	1	Number of steps	2
Clean - SC1	1	Number of steps	8
CMP	1	Number of steps	1
Deposition - Epitaxial	1	Number of steps	0
Deposition - thick Silicon Nitride	1	Number of steps	0
Deposition - thick Oxide	1	Number of steps	5
Deposition - thick Polysilicon	1	Number of steps	0
Deposition - thin Silicon Nitride	1	Number of steps	3
Deposition - thin Oxide	1	Number of steps	1
Deposition - thin Polysilicon	1	Number of steps	0
Etch - DRIE	1	Number of steps	0
Etch - KOH	1	Number of steps	0
Etch - long Wet	1	Number of steps	3
Etch - short Wet	1	Number of steps	1
Etch - long Dry	1	Number of steps	3
Etch - short Dry	1	Number of steps	0
Furnace - long cycle	1	Number of steps	0
Furnace - short cycle	1	Number of steps	1
Grind	1	Number of steps	0
Tape	1	Number of steps	0
De Tape	1	Number of steps	0
Lift-off	1	Number of steps	1
Metal Deep - non precious	1	Number of steps	6
Metal Deep - precious	1	Number of steps	1
Metrology - Inspect	1	Number of steps	8
Metrology - Particle	1	Number of steps	0
Metrology - CD	1	Number of steps	2.64
Metrology - Film Thickness	1	Number of steps	9
Photo - Stepper	1	Number of steps	0
Photo - Contact	1	Number of steps	8
Plating	1	Number of steps	0
Saw	1	Number of steps	0
Special	1	Number of steps	0
Spin-on	1	Number of steps	0
Strip photoresist - Acid	1	Number of steps	0
Strip photoresist - Ashing	1	Number of steps	6
Strip photoresist - Solvent	1	Number of steps	1

Definition of special process steps — Disabled

Equipment cost per tool		$M
Tool throughput		wafs/hr
Tool footprint		M^2
Consumable cost		$/waf

Suggested MEMS Process 2	Infineon - Bulk Accoustic Wave

5 Select the process to model	Infineon - Bulk Accoustic Wave
6a Select the maturity of the process	Established process
6b Select the maturity of the design	Established design - well characterized
Calculated MEMS die yield	85%

Step 3 – Select MEMS Fab

Selection 7 on this sheet determines what Fab the 1st MEMS die process will be run in. Displayed above the selection is the suggested Fab to run the process in. The Fab selection determines the Fab capacity, when the Fab was built (effects depreciation), wafer size and the country the Fab is in (effects labor rates and energy rates). This selection has no effect if "none" is selected for the 1st MEMS process.

If selection 7 is set to "user entered" then selection 7a sets the country, 7b sets the wafer size, 7c sets the capacity and 7d sets the year the fab was built or the last upgrade was made to the fab. These settings have no effect if a specific fab is selected for selection 7.

Selection 8 sets the Fab for the second MEMS die. This selection has no effect if "none" is selected for the 2nd MEMS process.

The next page provides a screen shot of the "Step 3 – Select MEMS Fab" sheet.

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Suggested 1st MEMS Fab to Model	Infineon Fab 1

7 Select a 1st MEMS Fab to model	Infineon - Fab 1

	User Entered Values User entered values disabled
7a Select a country	United States
7b Select a Wafer Size	150mm
7c Enter a fab capacity	10,000 wafs/month
7d Select the year built or year of last upgrade	2015

Product	Pressure sensors
Country	Germany
Wafer size	150 mm
Capacity	21,000 wafs/month
Year built or year of last upgrade	1981

Suggested 2nd MEMS Fab to Model	Infineon Fab 1

8 Select a 2nd MEMS Fab to model	Infineon - Fab 1

Product	Pressure sensors
Country	Germany
Wafer size	150 mm
Capacity	21,000 wafs/month
Year built or year of last upgrade	1981

Step 4 – Materials Selection

On this sheet you define the materials (wafers) used for each of the two MEMS die. For each die up to four wafers may be selected. This provides support for products where cap wafers or other wafers are bonded together to produce a device. The order of the wafers has no effect; they are summed together for the final cost.

Selections 9a through 9d determine the wafers for the first MEMS die. These selections have no effect if "none" is selected as the process for the first MEMS die. The suggested wafer type for each one is displayed to the right. If you select "user entered" then you need to enter the material cost in the boxes to the right. There are red warnings that will appear next to the boxes to tell you whether the box is enable (enter a value) or disabled (any entered value ignored).

Selections 10a through 10d determine the wafers for the second MEMS die. These selections have no effect if "none" is selected as the process for the second MEMS die. The suggested wafer type for each one is displayed to the right.

The next page provides a screen shot of the "Step 4 – Materials Selection" sheet.

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Selected Materials for MEMS die 1		User entered	Suggested Materials
9a Select Material 1	150mm - 1s-silicon	$0.00 Disabled	150mm - 1s-silicon
9b Select Material 2	None	$0.00 Disabled	None
9c Select Material 3	None	$0.00 Disabled	None
9d Select Material 4	None	$0.00 Disabled	None

Selected Materials for MEMS die 2		User entered	Suggested Materials
10a Select Material 1	150mm - 1s-silicon	$0.00 Disabled	150mm - 1s-silicon
10b Select Material 2	None	$0.00 Disabled	None
10c Select Material 3	None	$0.00 Disabled	None
10d Select Material 4	None	$0.00 Disabled	None

Step 5 – Select IC Processes

On this sheet you can define up to two IC die processes.

Selection 11 determines the IC process for the first IC or integrated MEMS die. If selection 11 is set to “none” then all other settings relative to the first IC die are disabled. Above selection 11 are displayed the suggested process.

Selection 12 determines the IC process for the second IC or integrated MEMS die. If selection 12 is set to “none” then all other settings relative to the second IC die are disabled. Above selection 12 are displayed the suggested process.

The next page provides a screen shot of the “Step 5 – Select IC Processes” sheet.

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Suggested IC Process	NA
11 Select the 1st IC process to model	None
Suggested IC Process	NA
12 Select the 2nd IC process to model	None

Step 6 – Select a Package

This page sets the package for the product. Pay careful attention to the package details concerning the number of die. The number of die needs to match the total number of MEMS and IC die defined for the product. If none is selected the package cost is set to zero.

Selection 13 sets the package type. Above selection 13 the suggested package is displayed.

Selection 14 sets the MEMS singulation type.

The next page provides a screen shot of the “Step 6 – Select a Package“ sheet.

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Suggested Package	EPCOS' CSSPlus with 2 die

13 Select the package to model	EPCOS' CSSPlus with 2 die

14 Select MEMS singulation method	Saw

Step 7 - Select Test

On this sheet up to 4 wafer sort tests and one product test are defined.

Selections 15a through 15d set the tests for the 1st MEMS die, 2nd MEMS die, 1st IC die and 2nd IC die respectively. In each case if the corresponding process isn't defined the test is disabled and a red warning appears above the test selection. There are also suggested tests displayed above each selection.

Selection 15e selects the class test for the overall product.

The next page provides a screen shot of the "Step 7 - Select Test" sheet.

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Suggested MEMS 1 sort	Bulk Accoustic Wave Filter
15a Select MEMS 1 Sort	Bulk Acoustic Wave Filter
Suggested MEMS 2 sort	Bulk Accoustic Wave Filter
15b Select MEMS 2 Sort	Bulk Acoustic Wave Filter
Suggested IC or Integrated MEMS 1 sort	None
15c Select IC or Integrated MEMS 1 Sort	Disabled by NONE being selected for the IC 1 process None
Suggested IC or Integrated MEMS 2 sort	None
15d Select IC or Integrated MEMS 2 Sort	Disabled by NONE being selected for the IC 2 process None
Suggested product test	Duplex Bulk Accoustic Wave Filter
15e Select product test	Duplex Bulk Acoustic Wave Filter

Cost

The cost sheet presents the wafer and die cost results for each of the four die types that are defined.

In the middle of the page selection 16 allows the foundry or vendor margin to be entered. If a wafer foundry is used a margin should be entered and if a die is purchased from a third party a margin should be entered. If the die are manufactured in-house no margin is entered. Suggested margins are displayed above each entry box.

The next section displays wafer sort costs and suggested die costs.

Selection 17 sets the die size for the defined die. The die sizes are only active for die processes that have been defined.

The final section displays gross die, die yield, net die and die cost, followed by the packaging yield, cost and packaged die cost and then class test yield and cost. Finally the total product cost is displayed.

The next page provides a screen shot of the “Cost” sheet.

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Infineon - BAW Duplexer - Bulk Acoustic Wave filter

	MEMS Part 1	MEMS Part 2	Die Cost Off IC Part 1	Die Cost Off IC Part 2
Wafer fab capacity (wafs/mth)	21,000	21,000	NA	NA
Utilization (%)	90%	90%	NA	NA
Wafer size	150mm	150mm	NA	NA
	($/waf)	($/waf)	($/waf)	($/waf)
Starting wafers	$17.00	$17.00	$0.00	$0.00
Direct labor	$53.94	$53.94	$0.00	$0.00
Depreciation	$0.00	$0.00	$0.00	$0.00
Tool maintenance	$13.72	$13.72	$0.00	$0.00
Indirect labor	$12.41	$12.41	$0.00	$0.00
Monitor wafers	$4.64	$4.64	$0.00	$0.00
Facilities	$25.08	$25.08	$0.00	$0.00
Consumables	$39.42	$39.42	$0.00	$0.00
Total	$166.19	$166.19	$0.00	$0.00
Wafer yield (%)	91.9%	91.9%	0.0%	0.0%
Yielded wafer cost	$180.81	$180.81	$0.00	$0.00
Suggested margins	0%	0%	NA	NA

16 Enter foundry margin (%)	0%	0%	0%	0%

Wafer sort cost ($/waf)	$240.94	$607.22	$0.00	$0.00
Sorted wafer cost ($/waf)	$421.75	$788.03	$0.00	$0.00
Suggested die size	L 1.50 mm W 0.90 mm	L 0.60 mm W 0.90 mm	L NA W NA	L NA mm W NA mm

17 Enter actual die size	L 1.50 mm W 0.90 mm	L 0.60 mm W 0.90 mm	L 0.00 mm W 0.00 mm	L 0.00 mm W 0.00

	($/die)	($/die)	($/die)	($/die)
Gross die (n/waf)	12,047	30,361	0	0
Die yield (%)	85.0%	85.0%	NA	NA
Net die (n/waf)	10,239	25,806	0	0
Yielded die cost ($/die)	$0.041	$0.031	$0.00	$0.00

	($/part)
Packaging yield	97%
Package cost	$0.540
Packaged unit cost	$0.614
Class test yield	98%
Class test cost	$0.220
Product cost	**$0.851**

Detailed Output Pages

The following four pages provide a detailed breakout of the consumables, equipment and facilities details and cost per step for the MEMS Die 1 Fab.

Also included in the output pages is the MEMS equipment override where the overall Fab OEE and individual equipment cost and throughput can be set for each individual piece of equipment. This sheet only effects the MEMS 1 fab.

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These are consumables costs for MEMS die 1 only

	$/year	$/waf
Reticles	$2,721,600	$12.00
Photochemicals	$751,566	$3.31
Cleaning and etching chemicals	$3,072,410	$13.55
Spin-on	$0	$0.00
Bulk gases	$440,582	$1.94
Specialty gases	$153,090	$0.68
CMP	$300,000	$1.32
Quartzware	$47,440	$0.21
Cleanroom and safety supplies	$546,000	$2.41
Precious metals	$907,200	$4.00
User entered consumables	$0	$0.00
Total cost	$8,939,888	$39.42

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Wafer fab capacity (wafs/mth)	21,000
OEE	30%

This table presents detail of the MEMS Fab requirements for the MEMS die 1 only. This is based on a single process Fab.

	Passes per wafer	Sampling plan (%)	Passes per week	Throughput (wafs/hr)	Tools required	Cost per tool ($M)	Total cost per tool type ($M)
Bond - Anodic	0	100%	0	60	0	$0.991	$0.0
Bond - Temp	0	100%	0	60	0	$0.991	$0.0
Bond - Thermal	0	100%	0	60	0	$0.991	$0.0
Clean - RCA	2	100%	10,080	150	2	$0.254	$0.5
Clean - SC1	8	100%	40,320	300	3	$0.154	$0.5
CMP	1	100%	5,040	60	2	$1.000	$2.0
Deposition - Epitaxial	0	100%	0	30	0	$0.750	$0.0
Deposition - thick Silicon Nitride	0	100%	0	8	0	$0.330	$0.0
Deposition - thick Oxide	5	100%	25,200	17	30	$0.330	$9.9
Deposition - thick Polysilicon	0	100%	0	17	0	$0.330	$0.0
Deposition - thin Silicon Nitirde	3	100%	15,120	20	15	$0.330	$5.0
Deposition - thin Oxide	1	100%	5,040	40	3	$0.330	$1.0
Deposition - thin Polysilicon	0	100%	0	40	0	$0.330	$0.0
Etch - DRIE	0	100%	0	4	0	$0.901	$0.0
Etch - KOH	0	100%	0	3	0	$0.184	$0.0
Etch - long Wet	3	100%	15,120	100	3	$0.144	$0.4
Etch - short Wet	1	100%	5,040	300	1	$0.144	$0.1
Etch - long Dry	3	100%	15,120	12	25	$0.500	$12.5
Etch - short Dry	0	100%	0	60	0	$0.500	$0.0
Furnace - long cycle	0	100%	0	13	0	$0.130	$0.0
Furnace - short cycle	1	100%	5,040	25	4	$0.130	$0.5
Grind	0	100%	0	30	0	$0.500	$0.0
Tape	0	100%	0	60	0	$0.200	$0.0
De Tape	0	100%	0	60	0	$0.150	$0.0
Lift-off	1	100%	5,040	6	16	$0.134	$2.1
Metal Dep - non precious	6	33%	30,240	8	75	$0.500	$37.5
Metal Dep - precious	1	10%	5,040	8	13	$0.500	$6.5
Metrology - Inspect	8	10%	40,320	120	7	$0.242	$1.7
Metrology - Particle	0	25%	0	50	0	$0.100	$0.0
Metrology - CD	3	25%	13,306	50	6	$0.300	$1.8
Metrology - Film Thickness	9	10%	45,360	30	30	$0.300	$9.0
Photo - Stepper	0	100%	0	60	0	$2.000	$0.0
Photo - Contact	8	100%	40,320	30	27	$2.290	$61.8
Plating	0	100%	0	21	0	$0.534	$0.0
Saw	0	100%	0	30	0	$0.100	$0.0
Special	0	100%	0	0	0	$0.000	$0.0
Spin-on	0	100%	0	60	0	$0.500	$0.0
Strip photoresist - Acid	0	100%	0	150	0	$0.136	$0.0
Strip photoresist - Ashing	6	100%	30,240	30	20	$0.120	$2.4
Strip photoresist - Solvent	1	100%	5,040	75	2	$0.134	$0.3
Totals	71		356,026		284		$155.5

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This sheet effects MEMS Fab 1 equipment values only

OEE: Default 30%

	Default equipment throughput (Wafs/hr)	Source select	User entered equipment throughput (Wafs/hr)	Actual equipment throughput used (wafs/hr)	Default equipment cost ($M/tool)	Source select	User entered equipment cost ($M/tool)	Actual equipment cost used ($M/tool)
Bond - Anodic	60	Default		60	$0.991	Default		$0.991
Bond - Temp	60	Default		60	$0.991	Default		$0.991
Bond - Thermal	60	Default		60	$0.991	Default		$0.991
Clean - RCA	150	Default		150	$0.254	Default		$0.254
Clean - SC1	300	Default		300	$0.154	Default		$0.154
CMP	60	Default		60	$1.000	Default		$1.000
Deposition - Epitaxial	30	Default		30	$0.750	Default		$0.750
Deposition - thick Silicon Nitride	8	Default		8	$0.330	Default		$0.330
Deposition - thick Oxide	17	Default		17	$0.330	Default		$0.330
Deposition - thick Polysilicon	17	Default		17	$0.330	Default		$0.330
Deposition - thin Silicon Nitirde	20	Default		20	$0.330	Default		$0.330
Deposition - thin Oxide	40	Default		40	$0.330	Default		$0.330
Deposition - thin Polysilicon	40	Default		40	$0.330	Default		$0.330
Etch - DRIE	4	Default		4	$0.901	Default		$0.901
Etch - KOH	3	Default		3	$0.184	Default		$0.184
Etch - long Wet	100	Default		100	$0.144	Default		$0.144
Etch - short Wet	300	Default		300	$0.144	Default		$0.144
Etch - long Dry	12	Default		12	$0.500	Default		$0.500
Etch - short Dry	60	Default		60	$0.500	Default		$0.500
Furnace - long cycle	13	Default		13	$0.130	Default		$0.130
Furnace - short cycle	25	Default		25	$0.130	Default		$0.130
Grind	30	Default		30	$0.500	Default		$0.500
Tape	60	Default		60	$0.200	Default		$0.200
De Tape	60	Default		60	$0.150	Default		$0.150
Lift-off	6	Default		6	$0.134	Default		$0.134
Metal Dep - non precious	8	Default		8	$0.500	Default		$0.500
Metal Dep - precious	8	Default		8	$0.500	Default		$0.500
Metrology - Inspect	120	Default		120	$0.242	Default		$0.242
Metrology - Particle	50	Default		50	$0.100	Default		$0.100
Metrology - CD	50	Default		50	$0.300	Default		$0.300
Metrology - Film Thickness	30	Default		30	$0.300	Default		$0.300
Photo - Stepper	60	Default		60	$2.000	Default		$2.000
Photo - Contact	30	Default		30	$2.290	Default		$2.290
Plating	21	Default		21	$0.534	Default		$0.534
Saw	30	Default		30	$0.100	Default		$0.100
Special	0	Default		0	$0.000	Default		$0.000
Spin-on	60	Default		60	$0.500	Default		$0.500
Strip photoresist - Acid	150	Default		150	$0.136	Default		$0.136
Strip photoresist - Ashing	30	Default		30	$0.120	Default		$0.120
Strip photoresist - Solvent	75	Default		75	$0.134	Default		$0.134

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Facilities costs for MEMS die 1 only - single process fab

Wafer Fab capacity (wafs/mth)	21,000
Total tool foot print (ft^2)	12,200
Wafer size (mm)	150mm
Multiplier	2
Fab area adder (ft^2)	8,611
Total fab area	33,012
Cost per square foot ($/$ft^2$)	$1,500
Total facility size (ft^2)	$117,191
Building cost ($M)	$14.9
Building systems cost ($M)	$34.7
Total facility cost ($M)	$49.5
Recommended land area (acres)	12

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Approximate Average Cost per step costs for MEMS die 1 only

	Steps	Cost/step	Cost/waf
Bond	0.0	$0.00	$0.00
Clean	10.0	$1.33	$13.33
CMP	1.0	$2.87	$2.87
CVD Dep	9.0	$1.78	$15.98
DRIE	0.0	$0.00	$0.00
Dry Etch (excluding DRIE)	3.0	$2.26	$6.77
Wet Etch	4.0	$1.46	$5.83
Furnace	1.0	$1.81	$1.81
Grind	0.0	$0.00	$0.00
Lift-off	1.0	$9.53	$9.53
Metal Dep	7.0	$2.82	$19.75
Metrology	19.6	$1.18	$23.21
Lithography	8.0	$4.09	$32.76
Plating	0.0	$0.00	$0.00
Saw	0.0	$0.00	$0.00
Special	0.0	$0.00	$0.00
Spin-on	0.0	$0.00	$0.00
Strip (Photo)	7.0	$2.46	$17.19
Totals	**70.6**		**$149.03**