



## **MEMS Cost and Price Model User Manual**

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### **Version 2019 model**

#### **Introduction**

This manual presents an overview of MEMS Cost and Price Model and the basic workings of the model.

#### **Model description**

The MEMS Cost and Price Model is designed to easily calculate the manufacturing cost and selling price of most MEMS products. The model support up to 2 MEMS die and up to 2 IC die per product. The IC process support is limited to processes that are typically included in MEMS products and the MEMS model is not a general usage IC Cost and Price calculator. For IC Cost and Price calculations we recommend our IC Cost and Price Model.

Please note that our cost models are cost of goods sold (COGS) models and do not include below the line costs such as research and development (R&D) or selling, general and administration costs (SG&A). Our pricing calculations are cost plus gross margin (GM). R&D and SG&A costs are absorbed in GM as well as profits.

#### **Support and updates**

As a licensee to the MEMS Cost and Price Model you will receive all updates made to the model for twelve months from the date of purchase emailed to your email address of record. If you change your email address it is your responsibility to notify us. Reasonable levels of phone and email support will be provided for twelve months from the date of purchase of the model. On-site or other forms of support are not provided. For more information, please see our Support Policy.

Our "Support Policy" and other support items for this model are available in the grey bar on the right side of the MEMS Cost and Price Model page on our web site here:

<http://www.icknowledge.com/products/memsmodel.html>

Please note that due to the complexity of MEMS products we do not have a standard add process request form for this model.

#### **Known Excel bugs and limitations**

- We occasionally see issues with dropdown menus not working properly in the model. If you click on a dropdown menu and can't see the dropdown list, right click in the cell, choose "Pick from Drop Down list" and then left click in the cell and the dropdown should appear. This is an Excel bug and not something we can address ourselves.
- Number formatting must use a decimal point to indicate decimals, e.g. 1.0. If you set up Excel to use a coma to indicate a decimal, e.g. 1,0 the model will not function correctly. This setting is an Excel option under advanced and you can set "Use system separators" for a "Decimal separator"

to be a . or ,. It is common practice in Europe to use a , but that will prevent the model from working correctly.

- We use a lot of dropdown lists in the model. Excel 2007 does not support dropdown lists that reference other sheets in the model. We have currently designed the model to work around this issue but at some point we will cease to support Excel 2007 because there is a lot of overhead involved in accommodating this.

### Model conventions

There are several conventions used throughout the model.

The gray areas on each model sheet contain the model inputs and outputs. The inputs that can be directly changed by the user are white areas within the gray areas; the gray areas contain labels and model driven outputs and cannot be directly changed by the user.

Throughout the model there are red dots indicating comments. Moving the cursor over the red dots displays information explaining input or outputs.

In this manual, regular, bold and underlined text describe the model and model features. Italic text provides background on the inner workings of the model.

### Tab color coding

All IC Knowledge Models follow the same worksheet tab color coding scheme.

Tab Color	Sheet Type	Examples
Grey	Information	License, Revisions, HELP, Price Calculator, Blank 1, 2 and 3, Revision History
Red	Main model wide selections	Main Selection
Brown	Model outputs	Product Cost, MEMS Labor. MEMS Depreciation & Maint, MEMS Facilities, MEMS Consumables, MEMS Cost Per Step
Blue	Process details and control	IC Process Adders, MEMS Process Override
Purple	Equipment and Facilities	MEMS Fab Override, MEMS Process Hours, MEMS Equipment
Green	Materials	MEMS Wafer Costs, MEMS Materials Prices, MEMS Material Usages

## Worksheet overview

The following is a brief description of the model worksheets and the purpose of each sheet. The sheet tabs are color coded, gray is informational (these sheets may in some cases be editable but do not drive the model results), red are the main drivers (these sheets are editable), brown are results (these sheets are not editable), blue modifies the processes or performs comparisons or calculations (these sheets are editable).

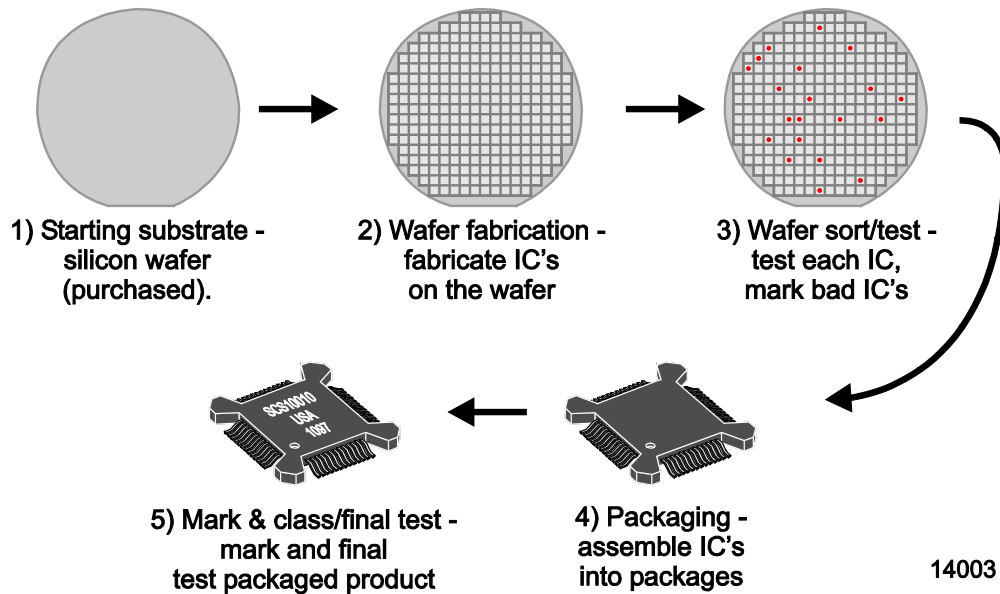
- License (gray tab) – the model software license. This sheet is not editable.
- Introduction (gray tab) – a brief introduction to IC Knowledge and our cost modeling product line as well as disclaimer and warranty information. This sheet is not editable.
- HELP (gray tab) – a listing of the various ways to get help with the model. This sheet is not editable.
- Main Selections (red tab) – this is the sheet where the main selections for the model are made.. This sheet is user editable.
- Product Cost (brown tab) - details of the product cost including up to MEMS wafers and up to two IC wafers, die costs, packaging and test. This sheet as some editable areas.
- Price Calculator (grey tab) - information and calculators to estimate product selling prices. This sheet has editable areas.
- MEMS Labor (brown tab) - the details of the labor calculations for the two MEMS processes. This sheet is not user editable.
- MEMS Depreciation & Maint. (brown tab) - the details of the depreciation and equipment maintenance cost for the two MEMS fabs. This sheet is not user editable.
- MEMS Facilities (brown tab) - details of the MEMS facilities costs. This sheet is not user editable.
- MEMS Consumable (brown tab) - details of the MEMS consumables costs. This sheet is not user editable.
- MEMS Cost Per Step (brown tab) - details of the cost for each different type of MEMS step supported by the model. This sheet is not user editable.
- IC Process Adders (blue tab) - presents a list of process adders that can be added to either of the two IC processes. This sheet is user editable.
- MEMS Process Override (blue tab) - lists out all the MEMS process steps supported by the model and gives the user the ability to change the number of times each step is used for either of the two MEMS processes. This sheet is user editable.
- MEMS Fab Override (purple tab) - presents the default characteristics for each of the two MEMS fabs and allows the user to override them. This sheet is user editable.
- MEMS Process Hour (purple tab) - lists the number of hours of wafer processing for each process supported by the model for each of the two MEMS process and allows the user to override them. This sheet is user editable.
- MEMS Equipment (purple tab) - presents the details of the calculated MEMS equipment sets for each of the two MEMS fabs and allows the user to override them. This sheet is user editable.
- MEMS Wafer Cost (green tab) - presents the wafer type and cost for each of up to five wafer types per MEMS process for each of the two MEMS processes and allows the user to override the costs. This sheet is user editable.
- MEMS Material Prices (green tab) - presents the material costs be year for each MEMS material type supported by the model and allows the user to override the default costs. This sheet is user editable.
- MEMS Material Usage (green tab) - presents the material usage for each of the two MEMS processes by material type and allows the user to override them. This sheet is user editable.

- Blank 1, Blank 2, Blank 3 (grey tabs) - unlocked sheets for user calculations. These sheets are user editable.
- Revision History (gray tab) – a history of changes made to the current year model. This sheet is not user editable.

Background – The IC Manufacturing Flow (MEMS is similar)

The following are the main steps in the IC manufacturing flow:

- Starting wafer – this is purchased by all IC manufacturers. Wafers come in a variety of sizes and types. When you select a process the appropriate wafer size and type is automatically selected.
- Wafer fabrication – anywhere between tens to tens of thousands of integrated circuits are fabricated on the surface of the wafer. The wafer yield is the number of wafers that complete fabrication process divided by the number of wafers started into the fab.
- Wafer sort (also called wafer test or wafer probe) – the ICs on the wafer surface are tested and the bad ICs are mark with an ink dot or in an electronic map so they won't be packaged. Die yield is the number of die that pass wafer sort divided by the total number of die on the wafer. Wafer sort may be a single pass test or may include multiple passes at different temperatures, or before and after bakes and burn-ins.
- Packaging – the individual ICs on the wafer are cut up and put into protective packages that provide electrical connections to the IC.
- Class test (also called final test) – the packaged ICs are tested to insure the ICs were correctly packaged without damage. For some ICs they can't be fully tested until they are packaged and this may be the first full test. Class test may be a single pass test or may include multiple passes at different temperatures, or before and after bakes and burn-ins.



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**IC Manufacturing Flow**

**Detailed worksheet descriptions**

In this section the “active” worksheets are described in more detail. Worksheet such as ‘License’, ‘Introduction’, ‘Help’, ‘Revision History’, ‘Lists’ and the blank worksheets are expected to be self-explanatory.

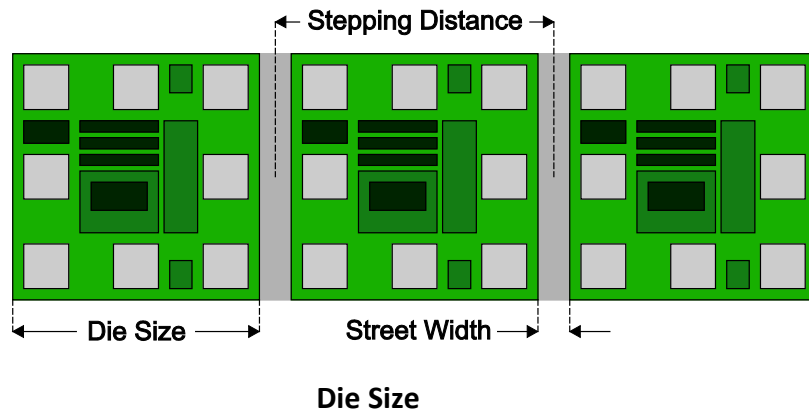
## Main Selections (red tab)

This is the main sheet driving the model.

- Year to model - At the top of the sheet in cell C6 is the year to model, 2015-Q1 to 2030-Q4 are supported. You should select the year the product was manufactured. The year effects labor and utility costs, depreciation and die yields.
- Select the product to model – in cell B8 there is a drop down of predefined MEMS products. If the product you wish to model is in the drop down list and all settings throughout the model are set to default, as soon as you select a product here you have a complete model. You can also override the product specific defaults throughout the model. If you select “User defined” here you must define the product in the other areas on this sheet. Please see the note after this section on how to build a “User Defined” product.
  
- MEMS Die 1 – starting at row 10 the first MEMS die is defined (if applicable). The MEMS model allows for up to 2 MEMS die and up to 2 IC die in each product.
  - MEMS Die 1 Process (default) – displays the default process used to produce the first MEMS die if applicable. The nomenclature is company (if applicable) – process – process details (optional). If there is no MEMS 1 die by default then “none” will display here.
  - MEMS Die 1 Process (selected) - if “default” is selected here the default process from the cell above will be used or you can override the default by selecting a process here. The process nomenclature is the same as the cell above. If you select “Enter steps” here you must define a process on the ‘Custom MEMS Process’ sheet.
  - Messages – if you select ‘Enter steps’ above a message will display reminding you to enter the steps on the ‘Custom MEMS Process’ sheet.
  - MEMS Process 1 Fab (default) – displays the default Fab used to run the MEMS die 1 process, if applicable. The nomenclature is company – fab location/name.
  - MEMS Process 1 Fab (selected) – if “default” is selected here, then the default fab displayed above will be used for the MEMS die 1 fab. You can also override the fab and pick any of the pre-defined fabs. The model does not filter processes and fabs so you can select any MEMS fab to run any MEMS process. If you select “User entered” you must define a fab yourself on the ‘Custom MEMS Fab’ sheet.
  - Messages – if you select ‘User entered’ above a message will display reminding you to define a fab on the ‘Custom MEMS Fab’ sheet.
  - MEMS Foundry Margin (default) - if the company making the MEMS product uses a foundry for MEMS die 1 fabrication the default foundry margin will display here. If the company making the MEMS product uses their own fab for the MEMS die 1 process, the default foundry margin will be 0%. Also if you selected “User defined” for the product the default foundry margin will be zero.
  - MEMS Foundry Margin (selected) – if “Default” is selected the default foundry margin displayed above will be used or you can override the default margin and select your own here.
  - MEMS Die 1 Size (default) – for predefined products selected in cell C8 a default die size will be displayed here for the MEMS die 1 if applicable. There are independent entries for die length and width.
  - MEMS Die 1 Size (user entry) – you can enter your own MEMS die 1 – die size here but the entered value will not be used unless select “User entry” in the cells below. There are independent entries for die length and width.

- MEMS Die 1 Size Source – if “Default” is selected then the default die size is used, if “User entered” is selected the user entered die size is used. There are independent entries for die length and width and each one is individually controlled.

The model assumes physical die size and a 2 millimeter edge exclusion.



- Starting wafer 1 (default) – the default first wafer type for the MEMS die 1 (if applicable) is displayed. For each MEMS die up to 5 starting wafers are supported and this is the first of 5 wafers.
- Starting wafer 1 (selected) – if “Default” is selected here the default wafer 1 displayed above is used or you can select a wafer type from the dropdown. The dropdown selections.

GaAs – gallium arsenide

Ge - germanium

Glass – Etched - glass substrates that have been etched

Glass - Ultrasonic drilled - glass substrates that have been ultrasonic drilled

LiNbO<sub>3</sub> – lithium niobate substrates

Nafion – nafion substrates (a fluoropolymer substrate)

Pyrex – pyrex glass substrates

Quartz – quartz glass substrates

Si - 1 side polished – single side polished silicon wafers

Si - 2 side polished – double side polished silicon wafers

Si – Epi – silicon wafer with an epitaxial layer on it

Si – SOI – silicon on insulator wafer

- Starting wafer 2 (default) – the default second wafer type for the MEMS die 2 (if applicable) is displayed. For each MEMS die up to 5 starting wafers are supported and this is the second of 5 wafers.
- Starting wafer 2 (selected) – if “Default” is selected here the default wafer 2 displayed above is used or you can select a wafer type from the dropdown.
- Starting wafer 3 (default) – the default third wafer type for the MEMS die 2 (if applicable) is displayed. For each MEMS die up to 5 starting wafers are supported and this is the third of 5 wafers.



- Starting wafer 3 (selected) – if “Default” is selected here the default wafer 5 displayed above is used or you can select a wafer type from the dropdown.
  - Starting wafer 4 (default) – the default fourth wafer type for the MEMS die 2 (if applicable) is displayed. For each MEMS die up to 5 starting wafers are supported and this is the fourth of 5 wafers.
  - Starting wafer 4 (selected) – if “Default” is selected here the default wafer 5 displayed above is used or you can select a wafer type from the dropdown.
  - Starting wafer 5 (default) – the default fifth wafer type for the MEMS die 2 (if applicable) is displayed. For each MEMS die up to 5 starting wafers are supported and this is the fifth of 5 wafers.
  - Starting wafer 5 (selected) – if “Default” is selected here the default wafer 5 displayed above is used or you can select a wafer type from the dropdown.
  - Gross die (default) – the model calculated gross whole die based on the default or user entered die size from above.
  - Gross die (user entry) – a user entered value for gross whole die. This number does not do anything unless ‘Gross die (select)’ down below this cell is set to “User entry”.
  - Gross die (select) – if “Default” is selected here the default gross die value is used, if “user entry” is selected the user entered gross die value is used.
  - Die yield (default) – the model default die yield is displayed here. For predefined products a default die yield is displayed that is product specific.
  - Die yield (user entry) – a user entered value for die yield. This number does not do anything unless ‘Die yield (select)’ down below this cell is set to “User entry”.
  - Die yield (select) – if “Default” is selected here the default die yield value is used, if “user entry” is selected the user entered gross die yield is used. There are also several different scenarios around process and design maturity listed here as options that fill in die yields based on those selections.
- MEMS Die 2 – starting at row 38 the second MEMS die is defined (if applicable). The MEMS model allows for up to 2 MEMS die and up to 2 IC die in each product.
    - MEMS Die 2 Process (default) – displays the default process used to produce the first MEMS die if applicable. The nomenclature is company (if applicable) – process – process details (optional). If there is no MEMS 2 die by default then “none” will display here.
    - MEMS Die 2 Process (selected) - if “default” is selected here the default process from the cell above will be used or you can override the default by selecting a process here. The process nomenclature is the same as the cell above. If you select “Enter steps” here you must define a process on the ‘Custom MEMS Process’ sheet.
    - Messages – if you select ‘Enter steps’ above a message will display reminding you to enter the steps on the ‘Custom MEMS Process’ sheet.
    - MEMS Process 2 Fab (default) – displays the default Fab used to run the MEMS die 2 process, if applicable. The nomenclature is company – fab location/name.
    - MEMS Process 2 Fab (selected) – if “default” is selected here, then the default fab displayed above will be used for the MEMS die 2 fab. You can also override the fab and pick any of the pre-defined fabs. The model does not filter processes and fabs so you can select any MEMS fab to run any MEMS process. If you select “User entered” you must define a fab yourself on the ‘Custom MEMS Fab’ sheet.
    - Messages – if you select ‘User entered’ above a message will display reminding you to define a fab on the ‘Custom MEMS Fab’ sheet.

- MEMS Foundry Margin (default) - if the company making the MEMS product uses a foundry for MEMS die 2 fabrication the default foundry margin will display here. If the company making the MEMS product uses their own fab for the MEMS die 2 process, the default foundry margin will be 0%. Also if you selected "User defined" for the product the default foundry margin will be zero.
- MEMS Foundry Margin (selected) – if "Default" is selected the default foundry margin displayed above will be used or you can override the default margin and select your own here.
- MEMS Die 2 Size (default) – for predefined products selected in row 9 a default die size will be displayed here for the MEMS die 2 if applicable. There are independent entries for die length and width.
- MEMS Die 2 Size (user entry) – you can enter your own MEMS die 2 – die size here but the entered value will not be used unless select "User entry" in the cells below. There are independent entries for die length and width.
- MEMS Die 2 Size Source – if "Default" is selected then the default die size is used, if "User entered" is selected the user entered die size is used. There are independent entries for die length and width and each one is individually controlled.
- Starting wafer 1 (default) – the default first wafer type for the MEMS die 2 (if applicable) is displayed. For each MEMS die up to 5 starting wafers are supported and this is the first of 5 wafers.
- Starting wafer 1 (selected) – if "Default" is selected here the default wafer 1 displayed above is used or you can select a wafer type from the dropdown. The dropdown selections.
- Starting wafer 2 (default) – the default second wafer type for the MEMS die 2 (if applicable) is displayed. For each MEMS die up to 5 starting wafers are supported and this is the second of 5 wafers.
- Starting wafer 2 (selected) – if "Default" is selected here the default wafer 2 displayed above is used or you can select a wafer type from the dropdown.
- Starting wafer 3 (default) – the default third wafer type for the MEMS die 2 (if applicable) is displayed. For each MEMS die up to 5 starting wafers are supported and this is the third of 5 wafers.
- Starting wafer 3 (selected) – if "Default" is selected here the default wafer 3 displayed above is used or you can select a wafer type from the dropdown.
- Starting wafer 4 (default) – the default fourth wafer type for the MEMS die 2 (if applicable) is displayed. For each MEMS die up to 5 starting wafers are supported and this is the fourth of 5 wafers.
- Starting wafer 4 (selected) – if "Default" is selected here the default wafer 4 displayed above is used or you can select a wafer type from the dropdown.
- Starting wafer 5 (default) – the default fifth wafer type for the MEMS die 2 (if applicable) is displayed. For each MEMS die up to 5 starting wafers are supported and this is the fifth of 5 wafers.
- Starting wafer 5 (selected) – if "Default" is selected here the default wafer 5 displayed above is used or you can select a wafer type from the dropdown.
- Gross die (default) – the model calculated gross whole die based on the default or user entered die size from above.
- Gross die (user entry) – a user entered value for gross whole die. This number does not do anything unless "Gross die (select)" down below this cell is set to "User entry".

- Gross die (select) – if “Default” is selected here the default gross die value is used, if “user entry” is selected the user entered gross die value is used.
  - Die yield (default) – the model default die yield is displayed here. For predefined products a default die yield is displayed that is product specific.
  - Die yield (user entry) – a user entered value for die yield. This number does not do anything unless ‘Die yield (select)” down below this cell is set to “User entry”.
  - Die yield (select) – if “Default” is selected here the default die yield value is used, if “user entry” is selected the user entered gross die yield is used. There are also several different scenarios around process and design maturity listed here as options that fill in die yields based on those selections.
- IC Die 1 – starting at row 66 the first IC die is defined (if applicable). The MEMS model allows for up to 2 MEMS die and up to 2 IC die in each product. For some products the IC process includes creating of the MEMS structures on top of the IC die and this is where those processes are selected.
    - IC Die 1 Process (default) – displays the IC process used to make the first IC die (if applicable). The nomenclature is wafer size – node – company (if foundry is displayed here it is a generic foundry process) – process name (if applicable or NA if not) – process type – process details (if applicable or NA if not) – poly layers/metal layers and type. If there is no IC 1 die by default then “none” will display here.

The abbreviations used in the process list are:

Process Type

BiCMOS = Bipolar and CMOS

BiCMOS SOI = Bipolar and CMOS on SOI

Bipolar = Bipolar

CMOS = Complimentary Metal Oxide Semiconductor

DRAM = Dynamic Random Access Memory

EEPROM = Electrically Erasable Programmable Read Only Memory

FDSOI = Fully Depleted Silicon On Insulator

ImgSen = Image Sensor

InterPos = Interposer

MG = Multi-Gate (FinFET or TriGate)

NAND = NAND Flash Memory

NMOS = N type Metal Oxide Semiconductor

NOR = NOR Flash Memory

PDSOI = Partially Depleted Silicon On Insulator

SiGe = Silicon Germanium

SRAM = Static Random Access Memory

Process details

100V = 100 volts

20V DMOS = 20 volts Double Diffused Metal Oxide Semiconductor

30V = 30 volts

30V DMOS = 30 volts Double Diffused Metal Oxide Semiconductor

40V DMOS = 40 volts Double Diffused Metal Oxide Semiconductor

500V DMOS = 500 volts Double Diffused Metal Oxide Semiconductor

5Vts = 5 threshold voltages  
60V = 60 volts  
60V DMOS = 60 volts Double Diffused Metal Oxide Semiconductor  
650V DMOS = 650 volts Double Diffused Metal Oxide Semiconductor  
65V DMOS = 65 volts Double Diffused Metal Oxide Semiconductor  
80V = 80 volts  
80V DMOS = 80 volts Double Diffused Metal Oxide Semiconductor  
Analog = Analog  
BSI = Backside Image Sensor  
Comp = Complimentary  
CPA = Common Platform Alliance  
DGO = Dual gate oxide  
DMOS = Double Diffused Metal Oxide Semiconductor  
DNW = Deep N-Well  
eDRAM = Embedded Dynamic Random Access Memory  
eFlash = Embedded Flash Memory  
FPGA = Field Programable Gate Array  
FSI = Front Side Illuminated Image Sensor  
Fuse = Fuse  
Ge PMOS = Germanium P Type Metal Oxide Semiconductor  
HfO/AIO = Hafnium Oxide/Aluminum Oxide High-K Dielectric  
HKMG = High-k metal gate  
HKMIM = High-K Metal -Insulator-Metal Capacitor  
HV = High Voltage  
LV = Low Voltage  
MIM = Metal-Insulator-Metal Capacitor  
Mixed Sig = Mixed Signal  
NMOS = N Type Metal Oxide Semiconductor  
PMOS = P Type Metal Oxide Semiconductor  
PPCaps = Polysilicon to Polysilicon capacitors  
Pressure Sensor = Pressure Sensor  
RCAT = Recessed Access Array Transistor  
RDL = Redistribution Layer  
RF = Radio Frequency  
Saddle Fin = Saddle FinFET Access Array Transistor  
Schottky = Schottky diode  
Schottky, TFR = Thin Film resistor  
SiGe = Silicon Germanium  
Silk ILD = A Low-K Spin-On Interlevel Dielectric  
TaN Res = Tantalum Nitride Resistor  
TGO = Triple Gate Oxide  
VNPN = Vertical P-Type/N-Type/P-Type Bipolar Transistor  
ZAZ = Zirconium Oxide/Aluminum Oxide/Zirconium Oxide High-K Dielectric

- IC Die 1 Process (selected) - if “default” is selected here the default process from the cell above will be used or you can override the default by selecting a process here. The process nomenclature is the same as the cell above.

- IC Foundry Margin (default) - if the company making the MEMS product uses a foundry for IC die 1 fabrication the default foundry margin will display here. If the company making the MEMS product uses their own fab for the IC die 1 process, the default foundry margin will be 0%. Also if you selected “User defined” for the product the default foundry margin will be zero.
  - IC Foundry Margin (selected) – if “Default” is selected the default foundry margin displayed above will be used or you can override the default margin and select your own margin here.
  - IC Die 1 Size (default) – for predefined products selected in row 9 a default die size will be displayed here for the IC die 1 if applicable. There are independent entries for die length and width.
  - IC Die 1 Size (user entry) – you can enter your own IC die 1 – die size here but the entered value will not be used unless select “User entry” in the cells below. There are independent entries for die length and width.
  - IC Die 1 Size Source – if “Default” is selected then the default die size is used, if “User entered” is selected the user entered die size is used. There are independent entries for die length and width and each one is individually controlled.
  - Gross die (default) – the model calculated gross whole die based on the default or user entered die size from above.
  - Gross die (user entry) – a user entered value for gross whole die. This number does not do anything unless ‘Gross die (select)’ down below this cell is set to “User entry”.
  - Gross die (select) – if “Default” is selected here the default gross die value is used, if “user entry” is selected the user entered gross die value is used.
  - Die yield (default) – the model default die yield is displayed here. For predefined products a default die yield is displayed that is product specific.
  - Die yield (user entry) – a user entered value for die yield. This number does not do anything unless ‘Die yield (select)’ down below this cell is set to “User entry”.
  - Die yield (select) – if “Default” is selected here the default die yield value is used, if “user entry” is selected the user entered gross die yield is used. There are also several different scenarios around process and design maturity listed here as options that fill in die yields based on those selections.
- IC Die 2 – starting at row 81 the first IC die is defined (if applicable). The MEMS model allows for up to 2 MEMS die and up to 2 IC die in each product. For some products the IC process includes creating of the MEMS structures on top of the IC die and this is where those processes are selected.
    - IC Die 2 Process (default) – displays the IC process used to make the first IC die (if applicable). The nomenclature is wafer size – node – company (if foundry is displayed here it is a generic foundry process) – process name (if applicable or NA if not) – process type – process details (if applicable or NA if not) – poly layers/metal layers and type. If there is no IC 1 die by default then “none” will display here.
    - IC Die 2 Process (selected) - if “default” is selected here the default process from the cell above will be used or you can override the default by selecting a process here. The process nomenclature is the same as the cell above.
    - IC Foundry Margin (default) - if the company making the MEMS product uses a foundry for IC die 2 fabrication the default foundry margin will display here. If the company making the MEMS product uses their own fab for the IC die 2 process, the default

foundry margin will be 0%. Also if you selected “User defined” for the product the default foundry margin will be zero.

- IC Foundry Margin (selected) – if “Default” is selected the default foundry margin displayed above will be used or you can override the default margin and select your own margin here.
  - IC Die 2 Size (default) – for predefined products selected in row 9 a default die size will be displayed here for the IC die 1 if applicable. There are independent entries for die length and width.
  - IC Die 2 Size (user entry) – you can enter your own IC die 1 – die size here but the entered value will not be used unless select “User entry” in the cells below. There are independent entries for die length and width.
  - IC Die 2 Size Source – if “Default” is selected then the default die size is used, if “User entered” is selected the user entered die size is used. There are independent entries for die length and width and each one is individually controlled.
  - Gross die (default) – the model calculated gross whole die based on the default or user entered die size from above.
  - Gross die (user entry) – a user entered value for gross whole die. This number does not do anything unless ‘Gross die (select)’ down below this cell is set to “User entry”.
  - Gross die (select) – if “Default” is selected here the default gross die value is used, if “user entry” is selected the user entered gross die value is used.
  - Die yield (default) – the model default die yield is displayed here. For predefined products a default die yield is displayed that is product specific.
  - Die yield (user entry) – a user entered value for die yield. This number does not do anything unless ‘Die yield (select)’ down below this cell is set to “User entry”.
  - Die yield (select) – if “Default” is selected here the default die yield value is used, if “user entry” is selected the user entered gross die yield is used. There are also several different scenarios around process and design maturity listed here as options that fill in die yields based on those selections.
- Test – this section starting at row 96 defines the tests for the product. There are multiple levels of test, each of 2 MEMS die (if applicable) and each of 2 IC die if applicable are wafer sorted (also known as wafer probe) and then the entire product is class tested (also known as final test).
    - MEMS Die 1 Sort (default) – if a pre-defined product is selected in row 9 and if a MEMS die 1 is used then the default wafer sort test is displayed here.
    - MEMS Die 1 Sort (select) – if “default” is selected here then the default MEMS die test displayed above is used or you can select your own MEMS die 1 test. For “user defined” products (row 9) you must select your own test here (if applicable).
    - MEMS Die 2 Sort (default) – if a pre-defined product is selected in row 9 and if a MEMS die 2 is used then the default wafer sort test is displayed here.
    - MEMS Die 2 Sort (select) – if “default” is selected here then the default MEMS die test displayed above is used or you can select your own MEMS die 2 test. For “user defined” products (row 9) you must select your own test here (if applicable).
    - IC Die 1 Sort (default) – if a pre-defined product is selected in row 9 and if an IC die 1 is used then the default wafer sort test is displayed here.
    - IC Die 1 Sort (select) – if “default” is selected here then the default IC 1 die test displayed above is used or you can select your own IC die 1 test. For “user defined” products (row 9) you must select your own test here (if applicable).

- IC Die 2 Sort (default) – if a pre-defined product is selected in row 9 and if an IC die 2 is used then the default wafer sort test is displayed here.
- IC Die 2 Sort (select) – if “default” is selected here then the default IC die 2 test displayed above is used or you can select your own IC die 2 test. For “user defined” products (row 9) you must select your own test here (if applicable).
- Class Test (default) – if a pre-defined product is selected in row 9 then the default class test displays here.
- Class Test (select) – if “default” is selected here then the default value from the row above is used or you can select a class test type here overriding the row above. For “user defined” products (row 9) you must select your own test here.
- Packaging – this section starting at row 108 defines the MEMS product package.
  - Package (default) – if a pre-defined product is selected in row 9 then a default MEMS product package is displayed here.
  - Package (selected) – if “default” is selected here then the default package type from the row above is used or you can select your own package here. For “user defined” products (row 9) you must select your own package here.

### User Defined Products

The MEMS Cost and Price Model includes predefined products when we have the necessary data available to us for a specific product. The selection of pre-defined products is limited and in most cases you the user must define your own product.

MEMS products come in several configurations, probably the most common is a MEMS die sensing something such as temperature, pressure, magnetism, acceleration, etc. There is also an IC die that provide signal conditioning and other data analysis and conversion functions. In other MEMS products the MEMS sensing element may be combined with the IC, for example Analog Devices accelerometers are made that way. A MEMS product may also be a single MEMS die with no IC or even two MEMS die. The MEMS Cost and Price Model allows up to two MEMS die and up to two IC die in the same package with test.

We will now walk through an example of an accelerometer with a MEMS sensing die and an IC signal conditioning die. In order to get the data to populate all of the required setting either ask your supplier or pay someone like TechInsights to do a construction analysis.

On the 'Main Selections sheet:

- Select a "Year to model" as described above.
- For "Select the product to model" select "User defined".
- For MEMS Die 1
  - Select a process for "MEMS Die 1 Process (selected)".
  - Select a fab for "MEMS Process 1 Fab (selected)".
  - Enter the "MEMS Die 1 Size (user entry)" both height and width.
  - For "MEMS Die 1 Size Source" select "User entry" for both height and width. If you don't select "User entry" the values you entered for height and width will not be used.
  - For "Die yield (select)" make the appropriate selection, typically "Established design - well characterized - established process" for production products.
- For MEMS Die 2 no selections are required under this scenario.
- For IC Die 1
  - For "IC Die 1 Process (selected)" select the appropriate process.
  - For "IC Die 1 Size (user entry)" enter the height and width.
  - For "IC Die 1 Size Source" select "User entry".
- For IC Die 2 no selections are required under this scenario.
- For Test
  - For "MEMS Die 1 Sort (select)" select "Accelerometer".
  - For "MEMS Die 2 Sort (select)" select "None".
  - For "IC Die 1 Sort (select)" select "Signal Conditioning IC".
  - For "IC Die 2 Sort (select)" select "None".
  - For "Class Test (select)" select either "Accelerometer – automotive" or "Accelerometer – commercial" whichever applies.
  - For "Package (selected)" select the required package, for example LGA 12 pin package 3.0mm x 3.0mm with 2 die (1 MEMS + 1 IC) is a common accelerometer package.



*If the part only has a MEMS die you do not need to fill out the IC Die 1 section. For a part that integrates the MEMS sensing element with the IC process such as for Analog Devices you do not need to fill in the MEMS Die 1 Section and select an ADI iMEMS process under IC Die 1. For a TI digital micro mirror or a MEMSIC accelerometer the IC Die 1 includes the MEMS element as well.*

### Foundry volumes and margin

There are basically three kinds of companies in the semiconductor (or MEMS) business:

- *Integrated Device Manufacturer (IDM) – IDM's design their own products, fabricate the wafers, test them, package the parts, test them again and take them to market.*
- *Fabless – fabless companies design semiconductors but rely on other companies to fabricate the parts for them. They may or may not test the parts themselves and they typically outsource the packaging as well.*
- *Foundry – a company that owns their own wafer fabs and fabricates wafers for others.*

*If the process you select is an IDM process (the company in the process description is an IDM) then the foundry margin will be zero. This is because the company transfers the fabricated wafers internally and only takes a margin at the end when the finished part is sold. If you select a foundry process (the company in the process is a foundry) then the foundry will sell the wafers to the fabless semiconductor company with a margin added to it (some IDMs also buy at least part of their wafer requirement from foundries).*

*The cost to make a wafer depends on the process, the wafer fab and how full the fab is. Unless a customer is so big that they largely determine how full a fab is the wafer cost is not sensitive to the customer volume, however, the margin is very sensitive to volume.*

Background – Cost Accounting

Cost accounting practices break out manufacturing costs in three categories:

1. *Material* – material only includes materials that become part of the final product that is shipped. Materials consumed in product are included in overhead and do not count as materials.
2. *Labor* – labor only include direct or “touch” labor, basically the operators who make the product. Indirect labor such as engineers, technicians, managers and supervisors are included in overhead.
3. *Overhead* – everything else.

The following table summarizes what is included in each category for different phases of IC production.

<b>Category</b>	<b>Wafer Fabrication</b>	<b>Packaging</b>	<b>Test</b>
<i>Material</i>	<i>Starting Wafer</i>	<i>Substrates, Leadframes, Wire, Mold Compound</i>	<i>None</i>
<i>Labor</i>	<i>Operators</i>	<i>Operators</i>	<i>Operators</i>
<i>Overhead</i>	<i>Depreciation, Equipment maintenance, Indirect labor, Monitor wafers, Facilities costs, Consumables</i>	<i>Depreciation, Equipment maintenance, Indirect labor, Facilities costs, Consumables</i>	<i>Depreciation, Equipment maintenance, Indirect labor, Facilities costs, Consumables</i>

### Background - Wafer Cost Calculation

As previously described, cost accounting practices break up the cost to manufacture a product for sale into three categories, material, labor and overhead:

- *Material* – material is confined to materials used to make the product that becomes part of the product that is shipped. Only if the material becomes a physical part of the product being shipped does it count in the material category. For wafer fabrication the only material is the starting wafer.
- *Labor* – labor in this case is restricted to direct labor sometimes referred to as touch labor. Direct labor is the labor cost for the operators who physically manufacture the product. Engineers, supervisors, technicians and managers do not count as direct labor and are included in the indirect labor category described below.
- *Overhead* – everything else required manufacturing the product. In the IC Knowledge cost models overhead is broken down into depreciation, equipment maintenance, monitor wafers, indirect labor, facilities and consumables.

As previously described overhead is everything other than material (starting wafers) and labor (direct labor from operators) required to produce the product. The following is a further breakout and discussion of the various overhead sub categories:

- *Depreciation* – equipment has a finite usable lifetime. The idea behind depreciation is to take the cost of a piece of equipment and write it off over the course of its useful life. For example if a piece of equipment costs one million dollar and has a useful lifetime of five years, two hundred thousand dollars would be charged to manufacturing cost each year for each of the first five years. In the semiconductor industry the useful life of some process equipment may be shorter than government regulations allow and furthermore regulations vary from country to country. Generally speaking the industry has settled on five year depreciation for process equipment when reporting results (although other rules may be used for tax purposes). The following are the default depreciation rates used in the cost models:

<i>Item</i>	<i>Useful life</i>	<i>Depreciation rate</i>
<i>Process tools</i>	<i>5 years</i>	<i>20%</i>
<i>Process tools installation</i>	<i>5 years</i>	<i>20%</i>
<i>Building systems (ultrapure water, gas and chemicals, cleanroom, HVAC)</i>	<i>10 years</i>	<i>10%</i>
<i>Automation</i>	<i>10 years</i>	<i>10%</i>
<i>Building structure</i>	<i>15 years</i>	<i>7%</i>

The depreciation calculation is the cost of the item multiplied by the depreciation rate. This amount is charged to the manufacturing cost each year until the useful life is reached at which time the depreciation for that items goes to zero.

*With expansions and upgrades there may be a wide variety of equipment ages in the same facility. The Cost Model provides for an initial equipment set and up to three upgrades/expansions and tracks each set individually.*

- *Equipment Maintenance – the cost of parts and service contracts for the process equipment are captured in this category. The company employees such as technicians and engineers that maintain the equipment are not counted in this category. Equipment maintenance is calculated as a percentage of the original acquisition cost of the equipment used to estimate yearly maintenance costs.*
- *Indirect labor – engineers (both process and equipment), technicians (both process and equipment), supervisors and managers are all counted in this category. Indirect labor hour per mask layer are used to estimate total indirect labor hours. Total indirect labor hour are then broken down by type using “typical” fab indirect labor profiles and labor rates for engineers, technicians, supervisors and managers by country are used to calculate indirect labor costs.*
- *Monitor wafers – test wafers used to monitor the performance of equipment. These wafers are used to perform a test by running them through one or more process steps and then measuring the result. The wafers are then scrapped or reclaimed.*
- *Facilities – the cost of utilities (electricity, natural gas and water), ultrapure water generation, waste water treatment, facility maintenance (HVAC, Ultrapure water, gas and chemical systems), insurance, occupancy (cleaning and waste disposal), landscaping and telecommunications.*
- *Consumables – reticles, photochemicals, cleaning chemicals, etching and deposition gases, bulk gases, CMP pads and slurries, sputter targets, implant sources, deposition precursors, etc.*

Background – Wafer fab equipment depreciation

**Please note this discussion is from our IC cost section of the model.**

Due to the complexity of the wafer fab equipment calculations they bear a more detailed examination. The model allows a fab to have an initial equipment set and up to 10 upgrades. In each case when and what came online and how much it cost is tracked. The model also allows the user to adjust the depreciation period.

In the simplest example a wafer fab is built with an initial equipment set and is never upgraded. If for example a one billion dollar equipment set is put online, then by default \$200 million dollars will be written off each of the first 5 years and in year 6 depreciation becomes zero. If a user were to change the depreciation to 7 years, then \$143 million dollars would be written off each of the first 7 years and then go to 0 in year 8.

If a fab is less than 6 years, old the depreciation be default would be 20% per year, if you switch from 5 year to 7 year depreciation the depreciation would switch to ~14% decreasing the depreciation charges. If however the fab is 6 years old the depreciation would be 0 by default and if you switched to 7 year depreciation the depreciation would become ~14% increasing the depreciation cost. Once a sufficient amount of time has passed changing the length of depreciation has no effect because the equipment is fully depreciated in all cases.

If the fab has gone through multiple upgrades the situation gets a lot more complicated. For example, if a fab had an initial equipment set of \$1 billion dollars and then each year had a \$100 million dollar equipment upgrade for the first 5 years the depreciation would look like the following.

	Initial set	Upgrade 1	Upgrade 2	Upgrade 3	Upgrade 4	Upgrade 5	Total
Year 1	\$200M	\$0M	\$0M	\$0M	\$0M	\$0M	\$200M
Year 2	\$200M	\$20M	\$0M	\$0M	\$0M	\$0M	\$220M
Year 3	\$200M	\$20M	\$20M	\$0M	\$0M	\$0M	\$240M
Year 4	\$200M	\$20M	\$20M	\$20M	\$0M	\$0M	\$260M
Year 5	\$200M	\$20M	\$20M	\$20M	\$20M	\$0M	\$280M
Year 6	\$0M	\$20M	\$20M	\$20M	\$20M	\$20M	\$100M
Year 7	\$0M	\$0M	\$20M	\$20M	\$20M	\$20M	\$80M
Year 8	\$0M	\$0M	\$0M	\$20M	\$20M	\$20M	\$60M
Year 9	\$0M	\$0M	\$0M	\$0M	\$20M	\$20M	\$40M
Year 10	\$0M	\$0M	\$0M	\$0M	\$0M	\$20M	\$20M
Year 11	\$0M	\$0M	\$0M	\$0M	\$0M	\$0M	\$0M
Year 12	\$0M	\$0M	\$0M	\$0M	\$0M	\$0M	\$0M
Year 13	\$0M	\$0M	\$0M	\$0M	\$0M	\$0M	\$0M

**Depreciation Versus Year.**

**5 Year depreciation, \$1 billion dollar initial investment and \$100 million dollar upgrade each of the first 5 years.**

The next table illustrates the depreciation for the same case except that the depreciation period is changed to seven years.

	<i>Initial set</i>	<i>Upgrade 1</i>	<i>Upgrade 2</i>	<i>Upgrade 3</i>	<i>Upgrade 4</i>	<i>Upgrade 5</i>	<i>Total</i>
<i>Year 1</i>	<i>\$143M</i>	<i>\$0M</i>	<i>\$0M</i>	<i>\$0M</i>	<i>\$0M</i>	<i>\$0M</i>	<i>\$143M</i>
<i>Year 2</i>	<i>\$143M</i>	<i>\$14M</i>	<i>\$0M</i>	<i>\$0M</i>	<i>\$0M</i>	<i>\$0M</i>	<i>\$157M</i>
<i>Year 3</i>	<i>\$143M</i>	<i>\$14M</i>	<i>\$14M</i>	<i>\$0M</i>	<i>\$0M</i>	<i>\$0M</i>	<i>\$171M</i>
<i>Year 4</i>	<i>\$143M</i>	<i>\$14M</i>	<i>\$14M</i>	<i>\$14M</i>	<i>\$0M</i>	<i>\$0M</i>	<i>\$186M</i>
<i>Year 5</i>	<i>\$143M</i>	<i>\$14M</i>	<i>\$14M</i>	<i>\$14M</i>	<i>\$14M</i>	<i>\$0M</i>	<i>\$200M</i>
<i>Year 6</i>	<i>\$143M</i>	<i>\$14M</i>	<i>\$14M</i>	<i>\$14M</i>	<i>\$14M</i>	<i>\$14M</i>	<i>\$214M</i>
<i>Year 7</i>	<i>\$143M</i>	<i>\$14M</i>	<i>\$14M</i>	<i>\$14M</i>	<i>\$14M</i>	<i>\$14M</i>	<i>\$214M</i>
<i>Year 8</i>	<i>\$0M</i>	<i>\$14M</i>	<i>\$14M</i>	<i>\$14M</i>	<i>\$14M</i>	<i>\$14M</i>	<i>\$71M</i>
<i>Year 9</i>	<i>\$0M</i>	<i>\$0M</i>	<i>\$14M</i>	<i>\$14M</i>	<i>\$14M</i>	<i>\$14M</i>	<i>\$57M</i>
<i>Year 10</i>	<i>\$0M</i>	<i>\$0M</i>	<i>\$0M</i>	<i>\$14M</i>	<i>\$14M</i>	<i>\$14M</i>	<i>\$43M</i>
<i>Year 11</i>	<i>\$0M</i>	<i>\$0M</i>	<i>\$0M</i>	<i>\$0M</i>	<i>\$14M</i>	<i>\$14M</i>	<i>\$29M</i>
<i>Year 12</i>	<i>\$0M</i>	<i>\$0M</i>	<i>\$0M</i>	<i>\$0M</i>	<i>\$0M</i>	<i>\$14M</i>	<i>\$14M</i>
<i>Year 13</i>	<i>\$0M</i>	<i>\$0M</i>	<i>\$0M</i>	<i>\$0M</i>	<i>\$0M</i>	<i>\$0M</i>	<i>\$0M</i>

***Depreciation Versus Year.***

***7 Year depreciation, \$1 billion dollar initial investment and \$100 million dollar upgrade each of the first 5 years.***

*Comparing the tables we can see that for the first five years the five year depreciation results in higher total depreciation costs, then for years seven through twelve seven year depreciation is higher.*

*In reality the situation is actually more complex than this with up to ten upgrades plus as upgrades take place some of the older equipment is removed and must be accounted for.*

*The model handles all of this accounting automatically and it isn't even visible to the user. If you feel you need to see the details of the equipment calculations and depreciation you need to purchase our strategic model where all of the calculation details are visible. We do not expose that detail in the IC model due to the audience the model is designed for.*

### Cost Summary (brown tab)

The cost summary sheet summarizes all of the cost results from the model. This page is not user editable.

#### **General information**

Rows 6 and 7 display information general information on the year being modeled and the product selected.

Rows 9 through 37 break out the wafer fabrication and die costs for each of the 4 possible die in a product. Column C has the MEMS die 1 (if applicable), column D has the MEMS die 2 (if applicable), column E has the IC die 1 (if applicable) and column F has the IC die 2 (if applicable).

#### **Wafer fab**

Rows 11 through 15 presents the wafer fab country, wafer size, wafer fab capacity in wafers per month), the year the wafer fab was built and the wafer fab equipment depreciation rate for the fabs used for each die type.

#### **Wafer cost**

Rows 18 through 28 break out the wafer costs by category for each die type. The costs are broken down into starting wafer, direct labor, depreciation, equipment maintenance, indirect labor, monitor wafers, facilities and consumables, wafer cost (total of the previous 8 items), wafer yield (wafers out of the fab divided by wafers into the fab) and finally the yielded wafer cost (wafer cost divided by wafer yield). The numbers are all dollars per wafer.

#### **Wafer cost override**

Row 31 allows the user to enter and override wafer cost for each of the four wafer types and row 32 allows the user to select whether to use the entered value or the default calculated values.

#### **Foundry margin**

Rows 35 through 37 present the foundry margin (%), foundry margin (\$/wafer) and wafer cost with foundry margin (wafer cost plus foundry margin) for each of the four die types.

#### **Sort cost**

Rows 40 and 41 present the wafer sorts cost and wafer cost with sort cost for the four die types (wafer cost with foundry margin plus wafer sort cost).

#### **Die cost**

Rows 44 through 47 present the gross die per wafer (whole die per wafer), die yield (%), net die (gross die multiplied by die yield) and die cost (wafer cost with margin and sort divided by net die).

#### **Product cost**

Rows 50 through 56 takes the die costs calculated above and combine the die, add the packaging and test cost and produce the final product cost. The row include total die cost (the sum of the four die type costs), packaging cost (the cost to package the die), packaging yield and packaged part cost. The packaged part cost is the total die cost divided by the packaging yield plus the packaging costs. This is based on outside packaging services where you only pay for good packages. The class test cost, class test yield and product cost are then presented. The product cost is the packaged part cost plus class test cost divided by class test yield. The packaging cost and yield and class test cost and yield can be overridden.



### Price (gray tab)

The price tab helps to calculate a selling price for the product.

Rows 6 and 7 display some basic information about the part.

Rows 9 and 10 display selling price versus margins.

Rows 12 and 13 allows you to choose a company (cell A13) and see what their average margins are by year.

Rows 15 and 16 allow you to enter a gross margin (cell B15) and see the resulting selling price with margin.

Rows 18 through 26 are a price versus volume calculator. You can enter a selling price in cell B18 and a volume that corresponds to that price in cell B19 and in cells E18 through E26 you will see the selling price at different volumes. This is particularly helpful if you look up a 1K piece price on a distributor site such as Digikey and want to know what the price would be in higher volume.

### MEMS Labor (brown tab)

The MEMS labor tab presents the labor costs for the two MEMS Fabs. Columns B and C present the first MEMS Fab costs and units and columns D and E presents the same information for the second MEMS Fab. This sheet is not user editable.

Row 6 begins the general data section., row 6 indicates the fabs, Fab 1 and Fab 2. Row 7 presents the wafers run in wafers per month for the two fabs. Wafers run is the wafer fab capacity multiplied by the utilization. Row indicates the wafer size for the two fabs.

Row 11 begins the direct labor calculation (operators who process the wafers). Row 12 presents the mask layers for the processes assigned to each fab. Row 13 presents the direct labor hours per mask layer metrics used to calculate labor. Row 14 presents direct labor hours per wafer, this is mask layers multiplied by direct labor hours per mask layer. Row 15 presents the direct labor rate for the two fabs, the direct labor rate depends on year and country. Row 16 presents the direct labor cost per wafer calculated by multiplying the direct labor hours per wafer by the direct labor rate. The total direct labor is the number of operators in each fab and is based on the wafers runs multiplied by the direct labor hours per wafer and assuming 42-hour work weeks except for France at 35 hours.

Row 19 begins the indirect labor calculations with MEMS Fab 1 covered from row 20 to 27 and MEMS Fab 2 from rows 28 to 35. The two Fab calculations are identical, we will describe Fab 1. In row 22 the engineer salary and operators per engineer are presented. The salary depends on the country and year and the operators per engineer is used to calculate the number of engineers required based on the direct labor headcount calculated in row 17. Row 23 presents the same calculations for technicians but uses technicians per engineer to calculate the number of technicians. Row 24 and 2 present similar calculations for supervisors and managers respectively. Row 26 presents the spending per year on indirect labor and total indirect labor headcount. Row 28 presents the indirect labor cost per wafer calculated by taking the total indirect labor spending and dividing it by the number of wafers run.

Starting on row 37 the cleanroom and safety supply spending for each fab is presented. Fab 1 is presented in row 38 and Fab 2 in row 39. The cleanroom personal is the number of direct and indirect labor in each fab calculated above. A cost per person is applied to get a cost per year and then this is divided by the number of wafers run to get cost per wafer.

MEMS Depreciation & Maint. (brown tab)

On this tab the depreciation for each of the two MEMS fabs is calculated. In rows 6 through 13 Fab 1 is presented and in rows 15 through 22 Fab 2 is presented. The two calculations are identical, and we will describe Fab 1. This sheet is not user editable.

In rows 7 through 11 the capital investment in millions of dollars is presented for each of equipment, equipment installation, automation, facility systems and the building. Facility systems include air handling, heating and air conditioning, ultrapure water, waste treatment, etc. Column C presents the depreciation rates. For equipment, equipment installation and automation the depreciation is 20% per year for 5 years, after 5 years a wafer size dependent minimum depreciation rate is applied to account for replacements. Facility systems are depreciated at 10% per year for 10 years and then go to 0 and the building is depreciated at 1/15 of value for 15 years and then goes to 0. Row 12 presents the capital investment and depreciations. Row 13 presents equipment maintenance calculated as a wafer size dependent percentage of the capital investment.

MEMS Facilities (brown tab)

This sheet presents a breakout of the individual elements that make up the facilities costs for the two MEMS Fabs. This sheet is not user editable.

Rows 6 through 15 present the costs for the MEMS Fab 1 and row 17 through 26 for MEMS Fab 2. The cost presented are the costs per wafer by category and in total.

MEMS Consumables (brown tab)

This sheet presents the MEMS consumables costs for the two MEMS die by consumable type. This sheet is not user editable.

The costs are presented in rows 6 through 27 with column B presents the MEMS die 1 costs and column C presents the MEMS die 2 costs. The costs are per wafer.

MEMS Cost Per Step (brown tab)

The cost per step tab presents the cost of different process steps used to manufacture the MEMS die. This sheet is not user editable.

Column A lists the process steps, column B lists the number of times each step is used to process MEMS die 1, columns H, K, L, M, N and V list the costs elements for each step for MEMS die 1 and column W lists the total cost per step for MEMS die 1. Column X lists the cost per wafer for MEMS die 1 (usage multiplied by cost per step).

Column Y lists the number of times each step is used to process MEMS die 2, columns AE, AH, AI, AJ, AK and AS list the costs elements for each step for MEMS die 2 and column AT lists the total cost per step for MEMS die 2. Column AU lists the cost per wafer for MEMS die 2 (usage multiplied by cost per step).

Background – Gross Margin

Gross margin is the selling price minus the cost of goods sold. Gross margin percentage is the gross margin divided by the selling price for example:

If a product has a cost of goods sold (COGS) of \$0.70 and sells for \$1.00, then the gross margin (GM) is \$0.30 making the gross margin 30%.

To convert from COGS to selling price for a given GM% use the following:

<i>GM%</i>	<i>Divisor</i>
<i>20%</i>	<i>0.80</i>
<i>30%</i>	<i>0.70</i>
<i>40%</i>	<i>0.60</i>
<i>50%</i>	<i>0.50</i>
<i>60%</i>	<i>0.40</i>
<i>70%</i>	<i>0.30</i>

For example, if COGS is \$1.40, then a 60% GM would give a selling price of \$3.50. A number of our customers have incorrectly made these calculations.

Background – Cost and Price

*Cost is what it costs to make a product; price is what the market is willing to pay for the product. If you produce and sell a product the hope is always that the price will be greater than the cost by a significant margin but this is not always that case. Profit is gross margin minus below the line costs such as research and development, and general, selling and administrative. Gross margins need to typically be greater than the high teens percentage to actually make a profit.*

$$\text{Price} = \text{cost} + \text{gross margin}$$

*If the cost is known (and that is primarily what this model calculates) and gross margin is known or can be estimated, then selling pricing is known and or can be estimated.*



IC Process Adders (blue tab)

This allows you to add process steps to the IC Die 1 or IC Die 2 process. This sheet is user editable.

In column A from rows 7 to row 27 various optional process adders are listed. Column B allows you to select "default" (Not added), or "Yes" (adds the step), or a number (add the step one or more times) or "No" for the IC Die 1 process. Column D allows you to do the same thing for the IC Die 2 process. This enables you to customize the base processes the model includes.

### MEMS Process Override (blue tab)

This sheet displays the number of times each of the standard process steps are used in the MEMS die 1 and MEMS die 2 processes and allows the user to override the step usage. This sheet is user editable.

Rows 1 and 2 display the selected MEMS die 1 and MEMS die 2 processes respectively from the 'Main Selections' sheet. If "None" is displayed for either process the overrides on this sheet are not active for that die. If "User Entered" is displayed, you must define the process below. For all other processes the default values are displayed, and you can override them.

Column B displays the number of times each process step is used by default for MEMS die 1. If "Default" is displayed in column C on the same row, then the default number is used. If a number is selected in column C, that number overrides the default value in column B.

Column D displays the number of times each process step is used by default for MEMS die 2. If "Default" is displayed in column E on the same row, then the default number is used. If a number is selected in column E, that number overrides the default value in column D.

### MEMS Fab Override (purple tab)

This sheet allows you to override the default values for the MEMS 1 or MEMS 2 fabs or define a custom fab.

Rows 6 through 14 define the MEMS die 1 fab. In row 7 the selected MEMS Fab from the 'Main Selection' sheet is shown. If "None" is shown here, then this section is disabled. If "User entered" is displayed, you must define the fab below. If any other fab name is displayed, then the values for the Fab will be shown below and you can override them if you so choose. For each row the value type is listed in column A, the default value in column B and the override selection is shown in column C. If "Default" is shown in column C then the default value from column B is used, if a value other than "Default" is shown in column C, that value will override the default value in column B.

Rows 16 through 24 define the same values for the MEMS die 2 fab and work the same way as the MEMS die 1 fab definitions.

### MEMS Process Hours (purple tab)

In order to estimate an equipment set we need to determine how much usage each tool gets for a given process flow. Because multiple processes running on the same tool can have different throughputs we translate the throughput of each process into equipment hours and then sum them up by tool. This sheet is user editable.

Column A lists all the MEMS process steps supported by the model.

For MEMS die 1

- Column B lists how many times each step is used in the process flow. These values are driven by the 'MEMS Process Override' sheet.
- Column C lists the default throughputs for each step.
- Column D allows you to override the default throughputs. If "Default" is shown in column D, then the default value is used. If a number is shown in column D, then the number overrides the default value and is used.
- In column E the throughput is translated to hours.
- Column F allows the equipment type that performs each step to be selected. This column is populated with the default values and can be overridden by selecting a different equipment type.

For MEMS die 2

- Column G lists how many times each step is used in the process flow. These values are driven by the 'MEMS Process Override' sheet.
- Column H lists the default throughputs for each step.
- Column I allows you to override the default throughputs. If "Default" is shown in column D, then the default value is used. If a number is shown in column D, then the number overrides the default value and is used.
- In column J the throughput is translated to hours.
- Column K allows the equipment type that performs each step to be selected. This column is populated with the default values and can be overridden by selecting a different equipment type.

## MEMS Equipment (purple tab)

On this sheet the equipment set is estimated for the MEMS Die 1 Fab and MEMS Die 2 Fab. This sheet is user editable.

Column A displays the MEMS equipment types supported by the model.

### MEMS Die 1/Fab 1

- Cell B1 displays the fab capacity from the 'MEMS Fab Override' sheet.
- Cell B2 displays the default OEE for the fab/process.
- Cell C2 allows the default OEE to be overridden. If "Default" is displayed here, the default value is used, if a number is visible here, the number displayed overrides the default value.
- Column B from rows 5 through 87 displays the total equipment hours for each tool. The equipment hours is the sum for each tool from the 'MEMS Process Hours' sheet.
- Column C from rows 5 through 87 displays the number of tools required. This is based on the equipment hours, OEE and fab capacity. This is a roundup calculation so fractional tools required are rounded up to the next whole number.
- Column D from rows 5 through 87 displays the default cost per tool.
- Column E from rows 5 through 87 allow you to override the equipment cost. If "Default" is displayed, the default value is used, if a number is displayed the number value overrides the default value.
- Column F from rows 5 through 87 displays the extended tool cost. This is the cost per tool multiplied by the number of tools.
- In cell F89 the cost for the facilities systems to accommodate the tool set is displayed.
- Column G from rows 5 through 87 displays the cost to install the tools for each tool type.
- Cell G89 displays the building cost to accommodate the tool set is displayed.
- Column H from rows 5 through 87 displays the footprint for the tools for each tool type.
- Cell H89 displays the size of the fab to accommodate the tools. The fab size is the sum of the tool footprints grossed up to include space for service chases and operator aisles.

### MEMS Die 2/Fab 2

- Cell I1 displays the fab capacity from the 'MEMS Fab Override' sheet.
- Cell I2 displays the default OEE for the fab/process.
- Cell J2 allows the default OEE to be overridden. If "Default" is displayed here, the default value is used, if a number is visible here, the number displayed overrides the default value.
- Column I from rows 5 through 87 displays the total equipment hours for each tool. The equipment hours is the sum for each tool from the 'MEMS Process Hours' sheet.
- Column J from rows 5 through 87 displays the number of tools required. This is based on the equipment hours, OEE and fab capacity. This is a roundup calculation so fractional tools required are rounded up to the next whole number.
- Column K from rows 5 through 87 displays the default cost per tool.
- Column L from rows 5 through 87 allow you to override the equipment cost. If "Default" is displayed, the default value is used, if a number is displayed the number value overrides the default value.
- Column M from rows 5 through 87 displays the extended tool cost. This is the cost per tool multiplied by the number of tools.
- In cell M89 the cost for the facilities systems to accommodate the tool set is displayed.
- Column N from rows 5 through 87 displays the cost to install the tools for each tool type.

- Cell N89 displays the building cost to accommodate the tool set is displayed.
- Column O from rows 5 through 87 displays the footprint for the tools for each tool type.
- Cell O89 displays the size of the fab to accommodate the tools. The fab size is the sum of the tool footprints grossed up to include space for service chases and operator aisles.

## OEE

*OEE stands for Overall Equipment Effectiveness.*

*OEE was developed by Sematech around 1995 to reflect the actual good shippable product from a tool versus its theoretical capacity. OEE is the actual good shippable parts per unit time divided by the tool capacity per unit time. OEE accounts for down time both scheduled and unscheduled, idle time due to no operator or no product, engineering tests, qualification tests, scrap and tools running slower than design. Initial industry surveys of OEE found it was only 30%. Even today in many fabs OEE is less than 50%. OEE tends to be higher the larger the fab and also is higher for fabs running a single process than for fabs running multiple processes.*

### MEMS Wafer Costs (green tab)

This sheet defines the costs for up to 5 wafers for each of MEMS die 1 and MEMS die 2. This sheet is user editable.

Column A lists the usage, die and wafer, column B lists the wafer size and type used (these values come from the 'Main Selections' sheet, column E lists the default costs for the wafers, column F allows user entered values and column G selects whether to use the default value of the user entered value.

Row 6 has the MEMS Fab 1 wafer size and rows 7 through 11 define each of the five wafers. Cell F13 has the total cost for the MEMS die 1 wafers.

Row 15 has the MEMS Fab 2 wafer size and rows 16 through 20 define each of the five wafers. Cell F22 has the total cost for the MEMS die 2 wafers.



### MEMS Material Prices (green tab)

This sheet defines the cost by year for all of the MEMS materials supported in the model. This sheet is user editable.

- Column A lists all of the materials the model supports.
- Column B lists the units the material is used in.
- Column C lists the units the material is purchased in. For example the pricing might be per kilogram and so Kg is shown in column C but the units of use might be grams so G is shown in column B.
- Columns N through AM display the costs for each year from 2010 to 2035.
- Cell AN2 displays the year being modeled and the balance of column AN display the prices for that year. These are the prices used in the current calculations. The year selected comes from the 'Main Selections' sheet.
- Column AO has a price erosion that is applied for each year starting after 2016.

### MEMS Material Usages (green tab)

This sheet calculates the materials usage and cost for each MEMS process supported by the model. This sheet is user editable.

- Column A lists each MEMS process supported by the model that uses materials. A process may appear in this column multiple times if the process uses multiple materials. Basically, for each process there will be a separate row for each material.
- Column B lists the film/operation being deposited, formed or operated on.
- Column C lists the material being used. The values in this column are selected from a dropdown of materials from the 'MEMS Material Prices' sheet. These values may be overridden.
- Columns D through G lists the usage by wafer size for 100mm, 150mm, 200mm and 300mm wafer sizes respectively. These values may be overridden.
- Column H lists the units of usage.
- Columns I and J list how many times each process is used from MEMS die 1 and die 2 respectively. These values come from the 'MEMS Process Override' sheet.
- Column K displays the material price for each material. The values in column K come from column AN on the 'MEMS Material Prices' sheet.
- Column L displays the units of pricing, for example dollars per gallon for the prices listed in column K.
- Columns M and N display the cost per die for die 1 and die 2 respectively. This is the total cost for each material based on material usage (based on the wafer size), cost per material and number of times the step occurs for each die.