

LEDCOM

The DOE Simple Modular LED Cost Model

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Important Information about the Cost Model

This software program is intended as a starting point for the analysis of costs associated with the manufacture of an LED package. The software includes certain data which has been derived from many sources but no warranty is provided as to the accuracy or otherwise of the supplied data, nor the cost modeling methodology employed. In particular, the LED Package manufacturing process modeled by the software has been simplified in order to include only the most significant cost elements according to an analysis performed by the Cost Modeling Working Group. Specifically only those cost elements contributing more than ~1% of the final LED Package cost are included. Also, no proper account is taken regarding the order in which the process steps are undertaken which will generate a relatively small error at high process yields, but the error will increase if one or more steps have a low yield.

Structure of the Model

The model calculates the cost of each manufacturing step and adds them together to get the cumulative cost of performing the process. The cumulative value is calculated for the wafer and package depending on the number of times a process step is performed and its yield. The process sequence is fixed in the model which simplifies the calculations but will introduce a certain error. This error will become smaller as the yields increase. The user can select how many times each process step is performed (set to zero if not required) and its yield.

For each process step there is a corresponding sheet which includes a more detailed calculation of the cost of that step. For each process step it is generally possible to select the specific equipment being used from a dropdown box. The specific parameters for each piece of equipment are included in the database and can be updated. In addition, new equipment can be added. For each processing step the materials can be selected. Materials costs are included in the database which can be updated or new materials can be added. Similar databases exist for substrates and metals.

A global worksheet incorporates top level variables such as substrate type, substrate diameter, die size, overhead costs, etc. This sheet also provides access to the various databases.

Calculation Methodology

For each process step the user is able to change the process step yield and the number of times the step is repeated within the manufacturing process. If a process step is not required then simply set the number of repeats to zero. The cost of each process step is determined by the parameters chosen in the corresponding detailed worksheet. Simply click on the process step name to jump to the detailed cost calculation.

For each process step, the cost of that process step (s) is added to the cost of the incoming material from the previous step (i) and the total is divided by the process step yield (y) to obtain the final cost (f) according to the formula:

$$f = (i + s)/y$$

If the process step is repeated then this calculation is repeated for each step. In order to obtain the cumulative cost for multiple identical steps, a simple series expansion is employed as follows:

$$\begin{aligned} f &= (((i + s)/y) + s)/y + \dots + s)/y \\ f &= (i + s + sy + sy^2 + sy^3 \dots + sy^{n-1})/y^n \\ f &= i + s(1 + y + y^2 + y^3 + \dots + y^{n-1})/y^n \end{aligned}$$

Where n = number of repeats

Note that the same series expansion procedure is not employed for the packaging steps since none of the steps are normally repeated.

Inspection steps are handled slightly differently. The inspection process will add costs in the same way as before but the purpose of the inspection step is to remove non-conforming to save on process costs or to provide feedback to earlier process steps in order that process adjustments can be made to improve yield. Hence there is an overall positive impact on yield which offsets the cost. In this simple model this situation is handled by applying an adjustment to the overall yield based on the number of inspection steps. The amount of yield saving per inspection step is an adjustable variable.

Initial Set-up

1. Locate all 3 application files (LEDCOM.xls, LEDCOM.pdf, cm.mdb) in the same directory.
2. Load the Analysis ToolPak add-in¹
3. Open the excel file LEDCOM.xls to start the application.

Note: If problems are experienced accessing the back-end database, please ensure that there is a reference to the Microsoft DAO 3.6 Object Library. This is found under 'Tools', 'References' within the Visual Basic for Applications window.

¹ On the Tools menu, click Add-Ins. In the Add-Ins available list, select the Analysis ToolPak box, and then click OK.

Operating Instructions

Note: Only alter data in the yellow shaded cells on any worksheet

The spreadsheet includes a number of worksheets. The function of each worksheet is described below:

a) Global

Item	Units	Value	Comments
Substrate Type		Sapphire	Select Substrate Type
Substrate Diameter	mm	100	Select Substrate Diameter
Die Size	mm ²	1	Enter Die Size
Factory Overhead	\$/m ² /yr	\$1,500	Factory depreciation, labor, and fixed operating costs (utilities, maintenance), other indirect costs
Cleanroom Overhead	\$/m ² /yr	\$3,000	Cost of class 10 in 2005
Labor Rate	\$/hr	\$30	
Electricity Price	\$/kWh	\$0.13	

Update or Add Equipment

Update or Add Substrates

Update or Add Materials

Update or Add Metals

Important Information about this software

The 'Global' worksheet lists the global variables and provides links to the database entries for Equipment, Substrates, Raw Materials, and Metals. All database entries can be updated here, and new entries added. It also contains a link to this document.

Access to each of the 4 databases is achieved by clicking on the appropriate button. Here is an example of the 'Equipment Database' review/entry pop-up box.

EQUIPMENT DATABASE

Index: 1

Module: Epitaxy

Equipment Name: Veeco 465i

Type (Wafer/Die): Wafer

Configuration: 50 mm 75 mm 100 mm 150 mm 200 mm 300 mm

54 24 14 6 3 0

Unit: wpr Growth rate (um/hr): 2

Reagent Efficiency (%): 20

Equipment Cost (\$): 3000000 NH3 Flow (liter/hr): 60

Footprint (m2): 15 TMG Flow (sccm/um): 161

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Add Update Delete Close

Each pop-up box is similar and has the same functionality. Data can be updated by changing one or more values and clicking the 'Update' button. Click the 'Add' button to allow a completely new entry to be added. Click the 'Delete' button to completely remove an entry. Use the navigation buttons to navigate through the entries. Click 'Close' to close the pop-up box.

b) Process

Note: Only Modify Yellow Cells							
Wafer Fabrication Process							
Step	Module	Yield	Cum Yield	Cost	Repeats	Cum Cost	Type
1	Epitaxy	85%	85%	\$211.2	1	\$248.4	Epitaxy
2	Wafer Inspection	100%	85%	\$1.2	6	\$249.6	Wafer Processing
3	Dry Deno	98%	80%	\$1.30	3	\$273.1	Wafer Processing
4	Lithography	98%	71%	\$1.3	6	\$312.5	Wafer Processing
5	Dry Etch	98%	69%	\$6.2	1	\$354.9	Wafer Processing
6	Mirror Metal	98%	68%	\$0.4	1	\$362.5	Wafer Processing
7	N Metal	98%	67%	\$3.2	1	\$373.2	Wafer Processing
8	P Metal	98%	65%	\$4.3	1	\$385.2	Wafer Processing
9	Contact Metal	98%	64%	\$26.7	1	\$420.3	Wafer Processing
10	Generic Metal	100%	64%	\$0.0	0	\$420.3	Wafer Processing
11	Wafer Bonding	98%	62%	\$6.6	2	\$437.6	Wafer Processing
12	Wafer Debonding	98%	60%	\$3.7	1	\$454.0	Wafer Processing
13	Wafer LLO	90%	60%	\$0.7	0	\$454.7	Wafer Processing
14	Backgrinding	95%	57%	\$10.3	1	\$478.6	Wafer Processing
15	GaN CMP	95%	54%	\$6.7	1	\$510.9	Wafer Processing
16	Wafer Dicing	98%	53%	\$14.9	1	\$536.5	Wafer Processing
17	Wafer Probe Test	85%	45%	\$6.2	1	\$638.6	Wafer Processing
Cost/Processed Wafer						\$638.6	
Epiwafer Cost						\$465.9	
Processing Cost						\$172.7	
Yield Savings/Inspection	0.5%	Adjusted Process Yield				48%	
Adjusted Cost/Processed Wafer						\$598.9	
Adjusted Epiwafer Cost						\$436.9	
Adjusted Processing Cost						\$162.0	
Scribe Channel (um)	70	Die Yield				90%	
Edge Exclusion (mm)	5	Die/Wafer				5,647	
Cost/Die						\$0.106	
Die Cost (\$/mm2)						\$0.106	
Packaging Materials							
	Material	Cost/Die	No of Die	Cost/Pkg	Type		
	Die	\$0.106	1	\$0.106	Packaging		
	Package			\$0.014	Packaging		
Die Packaging Process							
Step	Module	Yield	Cum Yield	Cost	Repeats	Cum Cost	Type
1	Die Attach	99%	99%	\$0.003	1	\$0.003	Packaging
2	Flip Chip	99%	99%	\$0.017	0	\$0.003	Packaging
3	Die LLO	100%	99%		0	\$0.003	Packaging
4	GaN Etch	100%	99%		0	\$0.003	Packaging
5	Substrate Removal	100%	99%		0	\$0.003	Packaging
6	GaN Roughening	99%	98%	\$0.004	1	\$0.007	Packaging
7	ESD Attach	99%	97%	\$0.007	1	\$0.014	Packaging
8	Wire Bonding	99%	96%	\$0.014	1	\$0.029	Packaging
9	Phosphor Package	99%	95%	\$0.009	1	\$0.038	Phosphor
10	Encapsulation	99%	94%	\$0.048	1	\$0.087	Packaging
11	Lens Molding	99%	93%	\$0.032	1	\$0.121	Packaging
12	Lens Attach	99%	93%	\$0.075	0	\$0.121	Packaging
13	LED Test	95%	89%	\$0.010	1	\$0.137	Packaging
Packaging Cost						\$0.137	
Die Cost (yielded)						\$0.120	
Package Cost (yielded)						\$0.015	
LED Package Cost						\$0.272	

The 'Process' worksheet lists the process steps and provides links to the more detailed calculation worksheets for each process step. Click on the Module name to access the relevant detailed process step worksheet.

Yield savings due to inspection steps are entered into the 'Yield Savings/Inspection' box. The percentage entered is the improvement in absolute process yield due to each inspection step (the 'Adjusted Process Yield').

c) Process Step Worksheets

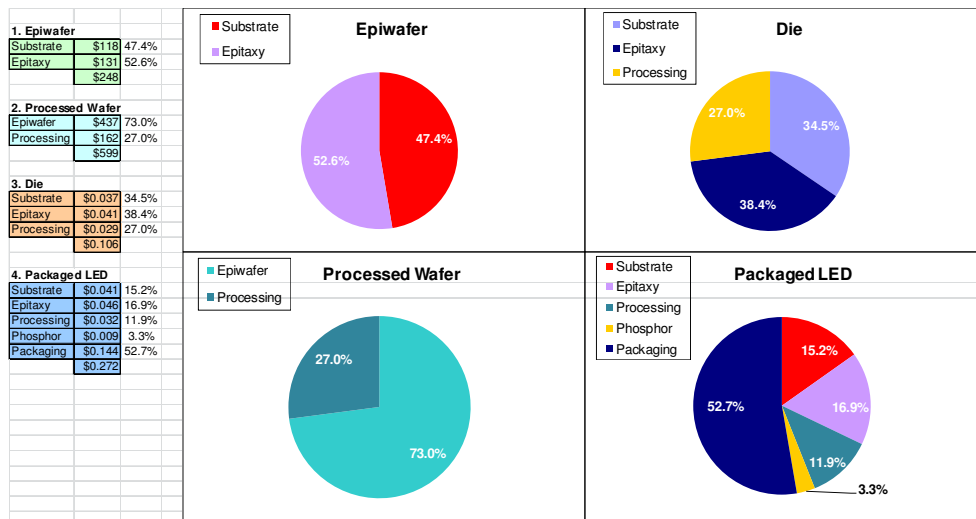
Each process step has an associated worksheet where process equipment can be selected and process parameters can be changed. The 'Epitaxy' worksheet is included here as an example.

Category	Item	Units	Value	Comments
EPITAXY				Return to Process Steps
	Substrate Type		Sapphire	
	Substrate Diameter	mm	100	
Input	Equipment		Veeco 465i	
Parameters				
	Cycle Time	hr	6	
	Thickness	um	4.5	
	Average Growth rate	um/hr	2.00	
	Reagent efficiency	%	20.0%	Amount of Ga on the wafers vs total supplied
	NH3 flow rate	slm	60	Depends on size of reactor, V/III ratio and growth rate.
Calculated				
	Substrates/run		14	
	Total Substrate Area	cm2	1100	
	Growth time	hr	2.3	Variable also? Or assume fixed heat-up/cool-down and water load/unload
	TMG Flow	sccm	322	
	TMG Flow	gm/hr	9.05	
	TMG	gm/um	4.53	Amount of TMG for a specific reactor area and efficiency (4.5 gm/um)
	TMG Total	gm	20.37	
	NH3 Total	liters	11700	1 hr extra for heat-up and cool-down
	H2 Total	liters	3600	10 slm on average (~1/5th of NH3)
	N2 Total	liters	3600	10 slm on average
	V/III ratio		1936	Highlight if gets too low, <1500
Overheads				
	Labor	Man	1.00	Effort per reactor
Equipment				
	Installed Equipment Cost	\$	\$3,000,000	
	Maintenance Cost	\$/yr	\$30,000	
	Equipment Overhead	\$/hr	\$72	
	Equipment Footprint	m2	15	
	Utilization	%	80%	
	Average Power	kW	10	
Raw Materials Costs				
	Substrate	\$	\$100.00	
	TMG	\$/gm	\$5.0000	
	NH3 HP	\$/litre	\$0.0150	
	H2	\$/litre	\$0.0006	
	N2 HP	\$/litre	\$0.0025	
Output	Substrate Costs		\$1,400	
	Materials Costs		\$289	
	Labor Costs		\$180	
	Overhead Costs		\$587.66	
	Total Cost		\$2,456.19	
	Cost/epiwafer		\$175.44	
	Total Cost (with yield)	85%	\$2,889.6	
	Cost/epiwafer		\$206.4	
	Substrate		\$117.6	57%
	Epitaxy		\$88.8	43%
	Epitaxy (\$/um.cm2)		\$0.25	

The output in terms of cost/wafer or cost/die is carried to the 'Process' worksheet.

d) Splits

The output data is displayed graphically on the 'Splits' worksheet as follows:



Version Notes

Version	Notes	Date
1.0	Initial Release	July 2012

Feedback

All feedback and suggestions are welcome, and can be emailed to: DOE.SSL.Updates@ee.doe.gov. Please reference LEDCOM in your email message.

July 2012