EUV Source Workshop

San Jose CA, Feb. 27th 2005

Lithography EUV Source Cost of Ownership Panel SEMATECH Perspective

Phil Seidel
Senior Member Technical Staff
Project Manager / EUV Strategy
(512) 356-3732   phil.seidel@SEMATECH.org

SEMATECH

Accelerating the next technology revolution.

Lithography Source Cost of Ownership Considerations SEMATECH perspective

Acknowledgements

- Scott Hector – SEMATECH / Freescale
- Vivek Bakshi – SEMATECH
- Chris Van Peski – SEMATECH
- Stefan Wurm – SEMATECH / Infineon
- Giang Dao – SEMATECH / Intel
- Kevin Kemp – SEMATECH / Freescale
- Andy Rudack – SEMATECH
- Andreas Ebert – ATDF
- Walt Trybula – SEMATECH

- **HISTORICAL: The IC Lithography Industry**

  Tool mfg, source suppliers, mask mfg., I.C. mfg., consultants

Lithography Source Cost of Ownership Considerations SEMATECH perspective

Agenda

1) CoO Overview

2) SEMATECH CoO Models Available

   - 193nm / 157nm dry exposure tool models
   - EUV system exposure tool CoO models

3) 193nm – 90nm HP node brief case study w/ ArF Source

4) SEMATECH perspective of needed common assumptions, specific source assumptions, and source parameters to be monitored

5) Summary

Cost of Ownership Overview

Cost of ownership: The overall cost of a manufacturing system to an organization including the costs associated with operating and maintaining the system, and the lifetime of operational use of the system.

Some Output Metrics:

Litho Cell Annual Cost: ($/yr) Annual total amount facility spends to operate the cell in full manufacturing.

Cost Per Wafer Level Exposed: ($/PWLE - or - $/GWLE): Cost for each “good” wafer level exposure proceed from the Litho Cell.

Cost Per Chip (or Field) Level Exposed: ($/GCLE): Cost for each “good” chip or field exposed from the Litho Cell.

1) Cost of Ownership Overview

$$\boxed{C_{pwle} = \frac{\left(C_e + C_l + C_f + C_c + C_r Q_{rw} N_c\right)}{\left(T\,U\,Y_p\right)} + \frac{C_m}{N_{wm}} + C_{other}}$$

C_{pwle} = cost per wafer level exposure

C_e = yearly cost of exposure, coating, and pattern transfer equipment (including depreciation, maintenance, and installation using 5 yr. depr.)

C_l = yearly cost of labor

C_f = yearly cost of cleanroom space

C_c = cost of other consumables (condenser, laser diodes)

C_r = cost of resist

Q_{rw} = quantity of resist used per wafer

N_c = number of wafers coated

T = throughput = raw throughput * utilization

U = Tool utilization

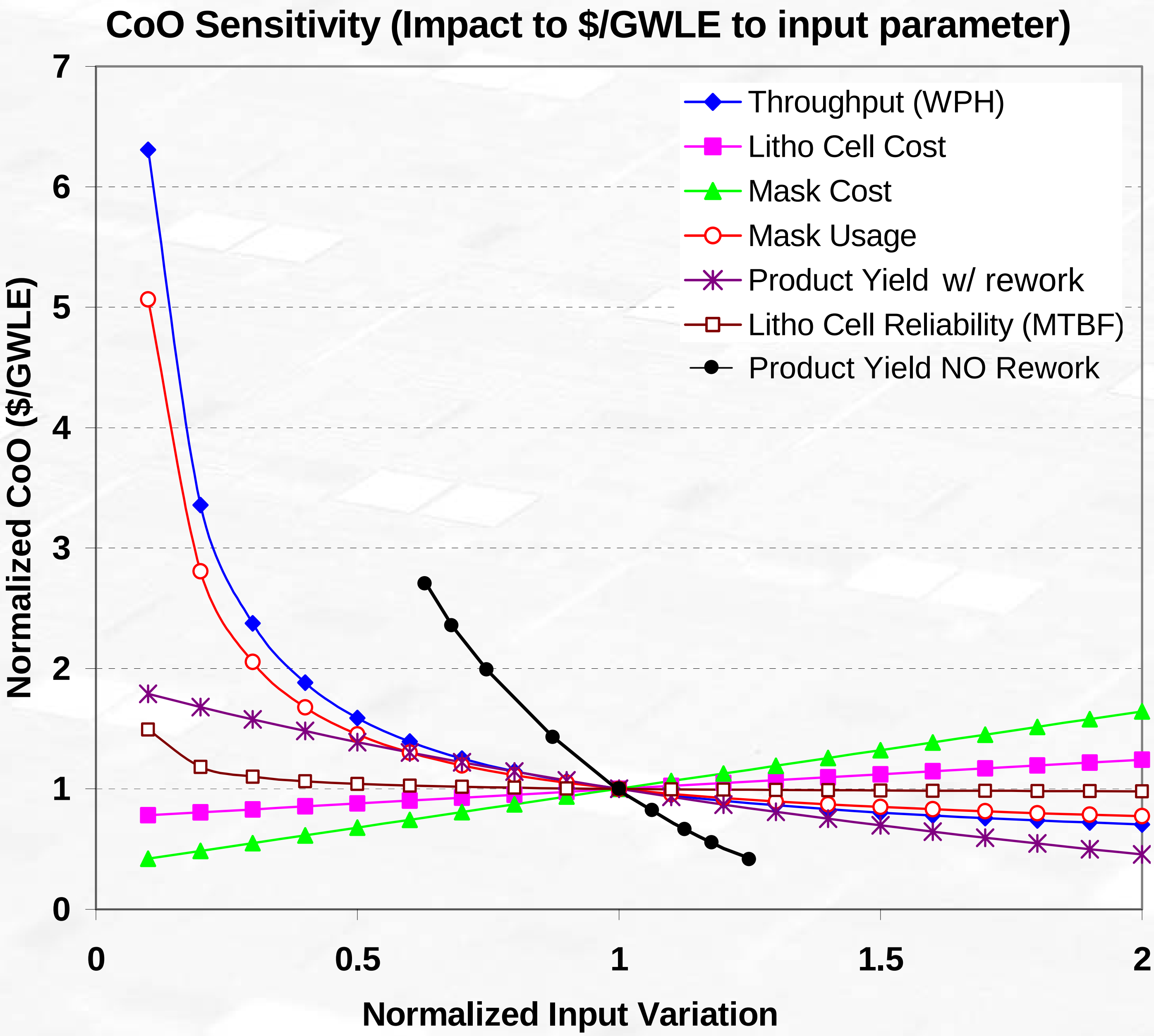
Y_p = yield of lithography step

C_m = cost of mask

N_{wm} = number of wafers exposed per mask

C_{other} = Other litho related costs (etch, cleans, etc)

1) Cost of Ownership Overview

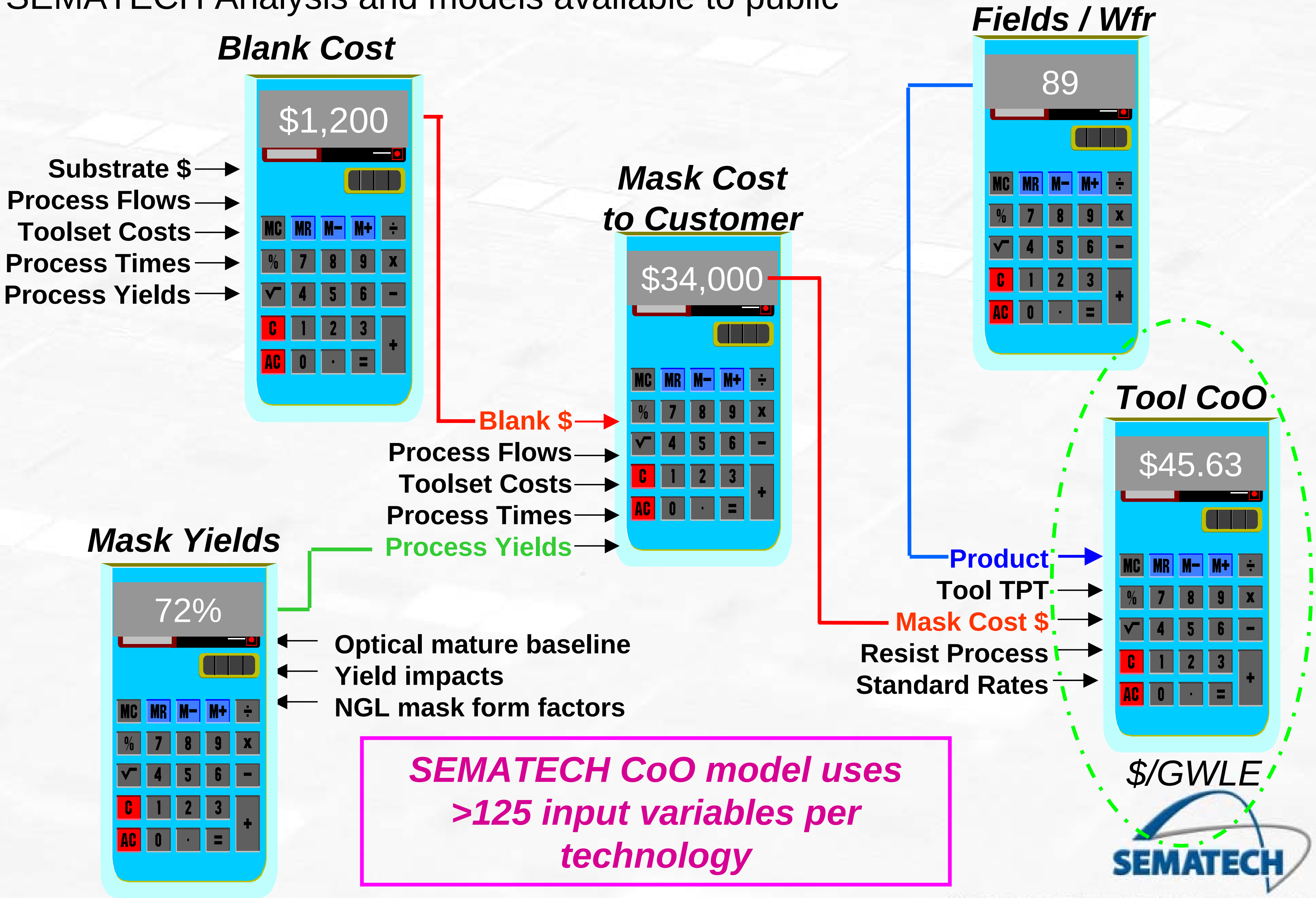


Significant CoO impacts with very low system Throughput and low Mask Usage

03/10/2005

2) SEMATECH CoO Calculation Process & Models

- Models based on SEMATECH (1990) Microsoft Excel spreadsheets
- More “User Friendly” front end input value spreadsheets added
- SEMATECH Analysis and models available to public



Blank Cost

Substrate $
Process Flows
Toolset Costs
Process Times
Process Yields

Mask Cost to Customer

Blank $
Process Flows
Toolset Costs
Process Times
Process Yields

Mask Yields

Optical mature baseline
Yield impacts
NGL mask form factors

Fields / Wfr

Tool CoO

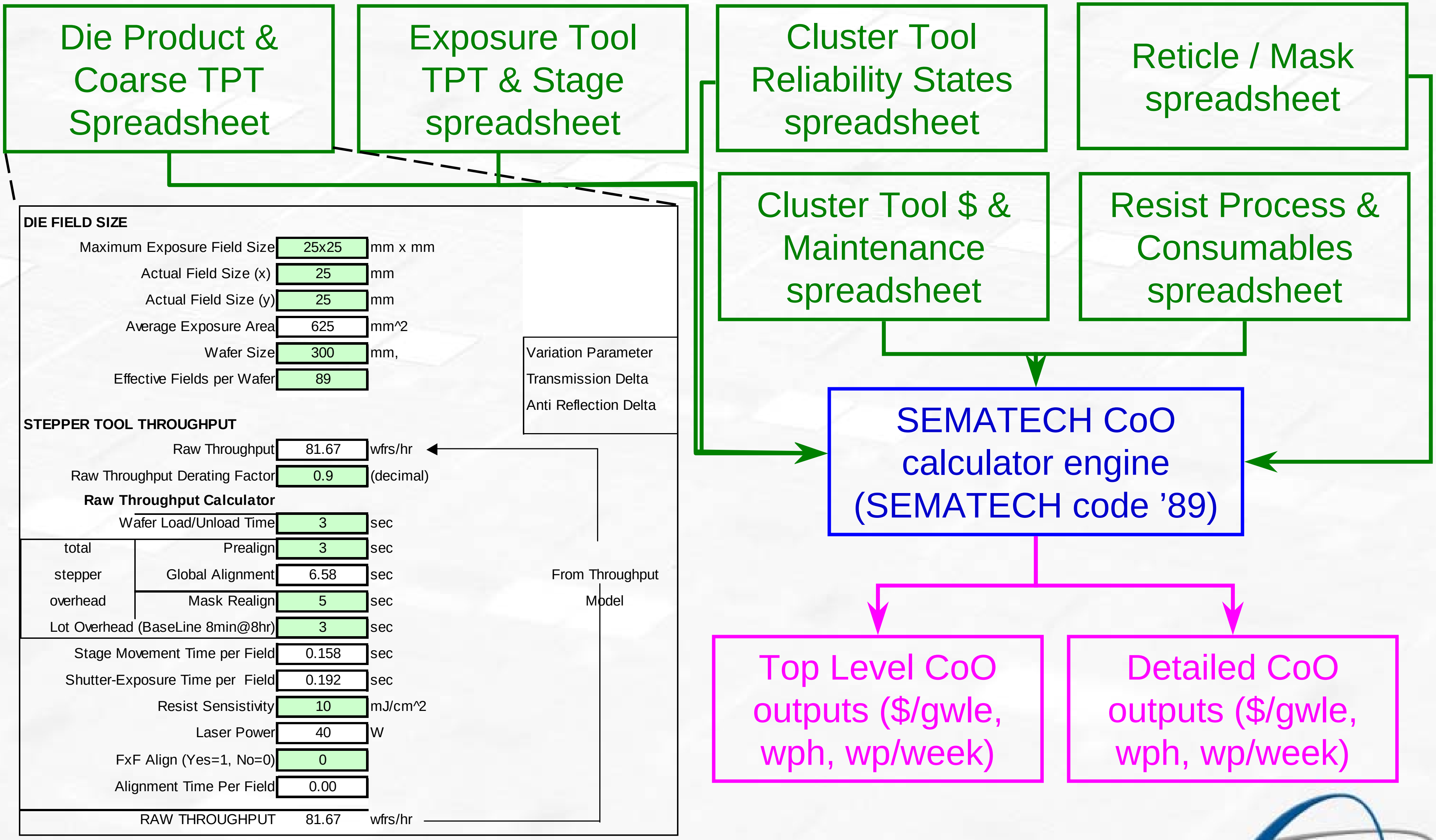
Product
Tool TPT
Mask Cost $
Resist Process
Standard Rates

$/GWLE

SEMATECH CoO model uses >125 input variables per technology

2) SEMATECH Tool CoO Model Architecture

- Models based on SEMATECH (1990) Microsoft Excel spreadsheets
- Front-end input sheets are divided into general input categories
- Output sheets provide $/gwle and annual costs with raw and net TPT's



Die Product & Coarse TPT Spreadsheet

Exposure Tool TPT & Stage spreadsheet

Cluster Tool Reliability States spreadsheet

Reticle / Mask spreadsheet

Cluster Tool $ & Maintenance spreadsheet

Resist Process & Consumables spreadsheet

SEMATECH CoO calculator engine (SEMATECH code '89)

Top Level CoO outputs ($/gwle, wph, wp/week)

Detailed CoO outputs ($/gwle, wph, wp/week)

DIE FIELD SIZE

	Maximum Exposure Field Size	25x25	mm x mm
	Actual Field Size (x)	25	mm
	Actual Field Size (y)	25	mm
	Average Exposure Area	625	mm^2
	Wafer Size	300	mm,
	Effective Fields per Wafer	89	

Variation Parameter
Transmission Delta
Anti Reflection Delta

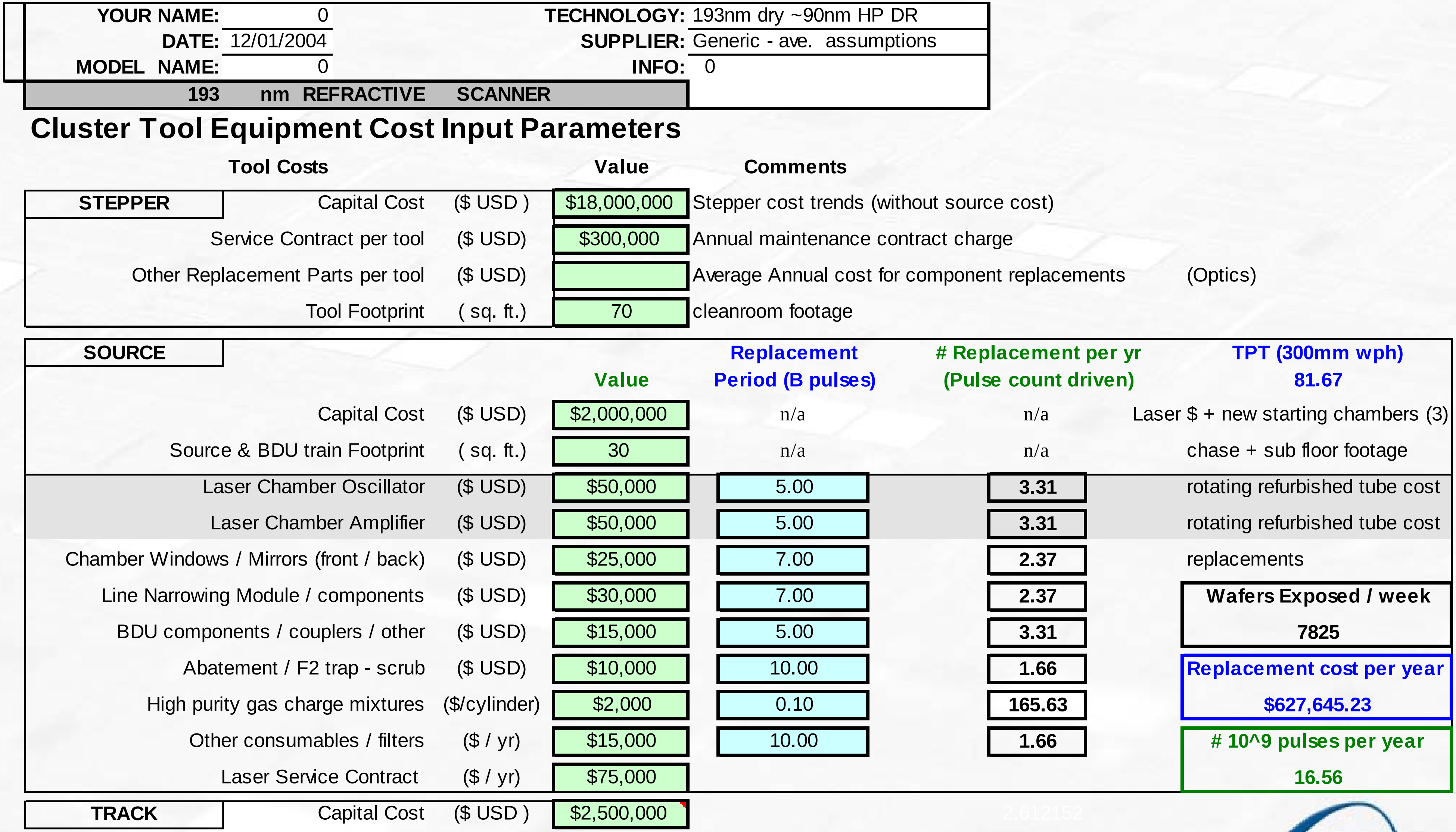
STEPPER TOOL THROUGHPUT

	Raw Throughput	81.67	wfrs/hr
	Raw Throughput Derating Factor	0.9	(decimal)
	Raw Throughput Calculator		
	Wafer Load/Unload Time	3	sec
total stepper overhead	Prealign	3	sec
	Global Alignment	6.58	sec
	Mask Realign	5	sec
	Lot Overhead (BaseLine 8min@8hr)	3	sec
	Stage Movement Time per Field	0.158	sec
	Shutter-Exposure Time per Field	0.192	sec
	Resist Sensistivity	10	mJ/cm^2
	Laser Power	40	W
	FxF Align (Yes=1, No=0)	0	
	Alignment Time Per Field	0.00	
	RAW THROUGHPUT	81.67	wfrs/hr

From Throughput Model

3) SEMATECH Tool & Source CoO Model Details

- SEMATECH 193nm & 157nm model expanded for source details in “cluster tool” input spreadsheet (2003)
- Similar source breakouts could be utilized for EUV source CoO modeling



YOUR NAME: 0
DATE: 12/01/2004
MODEL NAME: 0
TECHNOLOGY: 193nm dry ~90nm HP DR
SUPPLIER: Generic - ave. assumptions
INFO: 0

193 nm REFRACTIVE SCANNER

Cluster Tool Equipment Cost Input Parameters

	Tool Costs		Value	Comments
STEPPER	Capital Cost	($ USD)	$18,000,000	Stepper cost trends (without source cost)
	Service Contract per tool	($ USD)	$300,000	Annual maintenance contract charge
	Other Replacement Parts per tool	($ USD)		Average Annual cost for component replacements (Optics)
	Tool Footprint	(sq. ft.)	70	cleanroom footage

SOURCE			Value	Replacement Period (B pulses)	# Replacement per yr (Pulse count driven)	TPT (300mm wph) 81.67
	Capital Cost	($ USD)	$2,000,000	n/a	n/a	Laser $ + new starting chambers (3)
	Source & BDU train Footprint	(sq. ft.)	30	n/a	n/a	chase + sub floor footage
	Laser Chamber Oscillator	($ USD)	$50,000	5.00	**3.31**	rotating refurbished tube cost
	Laser Chamber Amplifier	($ USD)	$50,000	5.00	**3.31**	rotating refurbished tube cost
	Chamber Windows / Mirrors (front / back)	($ USD)	$25,000	7.00	**2.37**	replacements
	Line Narrowing Module / components	($ USD)	$30,000	7.00	**2.37**	**Wafers Exposed / week**
	BDU components / couplers / other	($ USD)	$15,000	5.00	**3.31**	**7825**
	Abatement / F2 trap - scrub	($ USD)	$10,000	10.00	**1.66**	**Replacement cost per year**
	High purity gas charge mixtures	($/cylinder)	$2,000	0.10	**165.63**	**$627,645.23**
	Other consumables / filters	($ / yr)	$15,000	10.00	**1.66**	**# 10^9 pulses per year**
	Laser Service Contract	($ / yr)	$75,000			**16.56**
TRACK	Capital Cost	($ USD)	$2,500,000		2.612152	

Accelerating the next technology revolution.

3) SEMATECH Tool & Source CoO Model Details

- Analysis of Source CoO contributions to total CoO can be assessed
- Hypothetical 193nm 90nm HP critical level exposure cost
  - Mask costs can dominate total CoO contributions (especially at low usage)
  - 193nm Source contributions > 10.0% of total CoO (at high pulse counts)

193nm Dry ~90nm HP Hypothetical Case		
Exposure Tool Cost	18	$M
Laser Tool Cost	2	$M
Source Output Power	40	Watts
Source Rep Rate	4000	Hz
Wafer Plane Power	0.741	Watts
Mask Cost / Usage	100,000 / 5000	$ / wpm
Resist Sensitivity	10	mJ/cm2
Fields per wafer	89	

Hypothetical EUV 45nm HP
30.0 - 40.0 (?)
5.0 - 10.0 (??)
115
??
0.321
100,000 (?) / 5000
5.0 (?)
89 (100 wph)

Total Wafer CoO	**52.67**	**$/gwle**	**100.0%**
CoO from Exposure Tool	14.31	$/gwle	27.2%
CoO from mask & mask usage	21.27	$/gwle	40.4%
CoO from source	4.33	$/gwle	8.2%
CoO from resist tooling & patterning	8.55	$/gwle	16.2%
CoO from other (OH, depr, etc)	4.21	$/gwle	8.0%

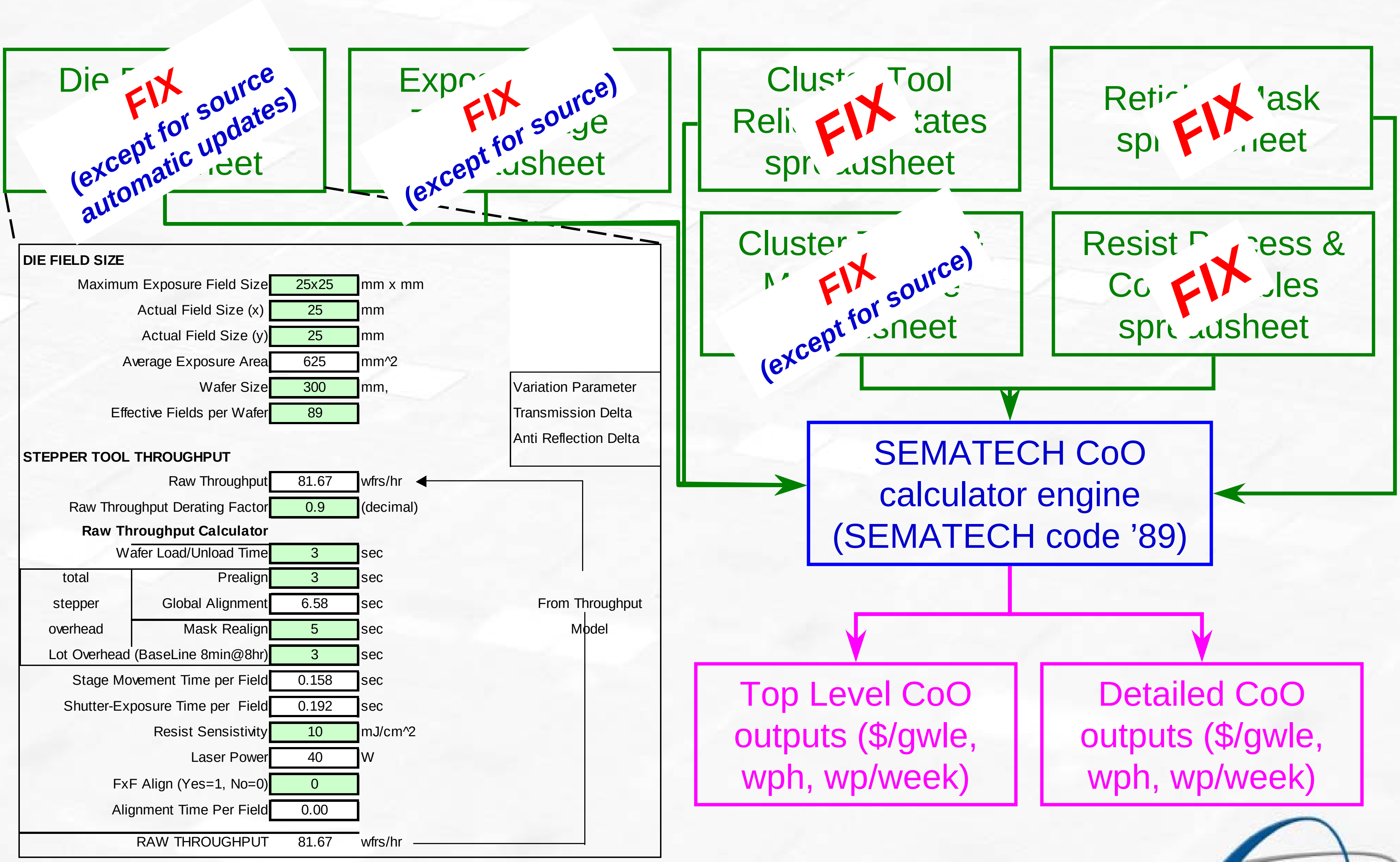
$77.96	**100.0%**
$22.61	29.0%
$23.51	30.2%
$12.95	16.6%
$12.58	16.1%
$6.31	8.1%

SEMATECH

Accelerating the next technology revolution.

4) SEMATECH Tool CoO Model Architecture

- For EUV Source CoO analysis many variables should be Fixed so that all using the model can compare equally



DIE FIELD SIZE

Maximum Exposure Field Size	25x25	mm x mm
Actual Field Size (x)	25	mm
Actual Field Size (y)	25	mm
Average Exposure Area	625	mm^2
Wafer Size	300	mm,
Effective Fields per Wafer	89	

Variation Parameter
Transmission Delta
Anti Reflection Delta

STEPPER TOOL THROUGHPUT

	Raw Throughput	81.67	wfrs/hr
	Raw Throughput Derating Factor	0.9	(decimal)
	Raw Throughput Calculator		
	Wafer Load/Unload Time	3	sec
total	Prealign	3	sec
stepper	Global Alignment	6.58	sec
overhead	Mask Realign	5	sec
	Lot Overhead (BaseLine 8min@8hr)	3	sec
	Stage Movement Time per Field	0.158	sec
	Shutter-Exposure Time per Field	0.192	sec
	Resist Sensistivity	10	mJ/cm^2
	Laser Power	40	W
	FxF Align (Yes=1, No=0)	0	
	Alignment Time Per Field	0.00	
	RAW THROUGHPUT	81.67	wfrs/hr

SEMATECH CoO calculator engine (SEMATECH code '89)

Top Level CoO outputs ($/gwle, wph, wp/week)

Detailed CoO outputs ($/gwle, wph, wp/week)

4) SEMATECH EUV Source CoO Recommendations

- SEMATECH Recommendations to EUV Source CoO activity
  - The CoO modeling approach should have consensus on all input variables NOT related specifically to source cost, operation, and maintainability.
  - CoO source modeling approach needs consensus on how far down optical train will be "source's" cost responsibility (everything up to illuminator* ??)
  - FIX Standard factory costs, tool reliability, and overheads (clean room / chase space, labor rates, etc.) SEMI E10 & SEMI E35
  - FIX all standard facility consumables / rates (gases N2, O2, CDA, DI, etc.)
  - FIX Exposure tool costs & performance not including source costs / performance
    - EUV exposure tool average (less source cost) = $35M (tool supplier consensus input*)
    - EUV tool stage performance (speed, acceler.), wafer / mask alignments & handling
    - EUV P.O. train elements & reflectivity (6 bounce system @ 67%* reflectivity per mirror)
  - FIX Wafer & chip product (89 fields/300mm*, 25mmx25mm field, etc*)
  - FIX Mask & Reticle costs and Mask Usages ($100,000* at 5000 wpm* lifetime)
  - FIX Resist process costs & performance ($2.5M* track cost, $10,000* resist/gal, speed 2.0 mJ/cm^2 ?? --> 10mJ/cm^{2*} ??, pattern develop & transfer)

*Assumptions that need agreement by EUV community

4) SEMATECH EUV Source CoO Recommendations (2)

- SEMATECH Specific EUV Source Variable Performance Inputs
  - Procurement entry cost (new system) up to the optical train cut - off point
  - Continuous operation average “in band power” collected (Main TPT input)
  - Facility standard utility consumptions for sources (electricity, CDA, N2, etc.)
  - Specialty source consumption costs
    - High purity target materials costs (Sn, Xe, H_20, other)
    - Containment / purging system gases (not covered by facility bulkhead services)
  - Source Component replacement costs & lifetimes (nozzles, electrodes, debris mitigation systems, etc.)
  - Condenser / collector replacement costs & lifetimes (time to 10% Ref. loss)
  - Source environmental containment, material recovery, or abatement maintenance costs
  - Mean Time To Repair – replacement TAT
    - Including added time for source system PM or failure recovery not covered by overall Exposure system PM – SEMI E10 states
    - Include environment recovery time (e.g. vacuum pump down) to bring tool to state of running any needed qualification wafers
- Suppliers allowed to show sensitivity analysis around parameters to highlight or recommend improvements

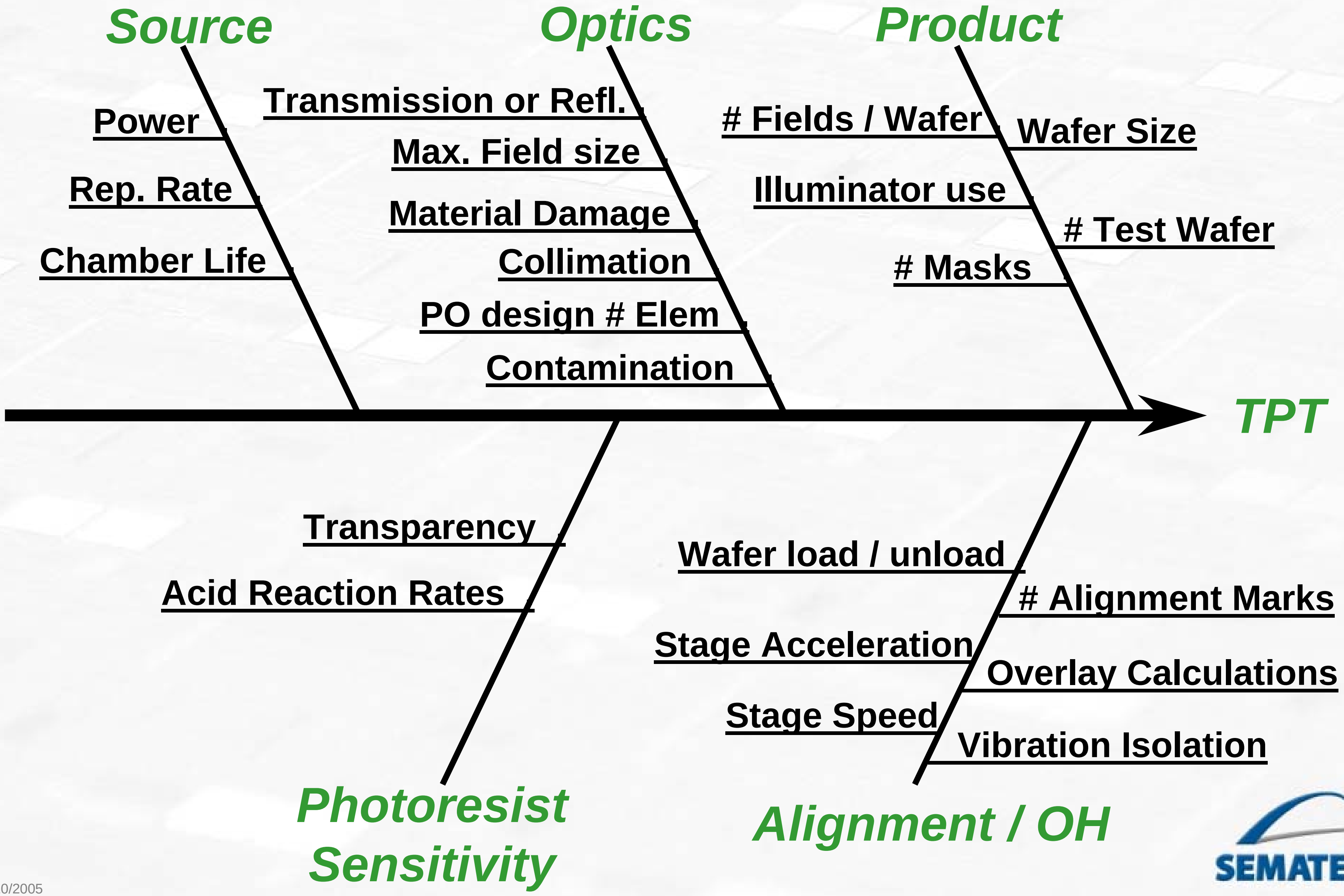
5) Summary

- SEMATECH supports this EUV Source CoO activity
  - CoO continues to be a major indicator of any technology productivity / profitability
  - EUV source implementation will be a significant departure from FAB manufacturing operation compared to optical excimer laser systems
  - Users want to know what these sources will cost and how to maintain
  - The identification and cost assessment of key EUV source CoO parameters will help identify areas of opportunity for cost improvements
  - Source CoO analysis should agree to “FIX” values for input parameters other than Source variables; agree on what source boundary condition
- Source CoO contributions should be reported as % and $/gwle values as well as the entire EUV exposure CoO costs.
  - EUV source CoO should be reported as a supplier “roadmap” performance metric (current and projected through improvement data / scaling data)
  - EUV source CoO cost targets (or ‘vision’) should be driven towards current 193nm dry baseline >10% of total CoO (current FAB cost operation scenario)
- SEMATECH has 193nm / 157nm and EUV CoO tool models that can be used as a template for a unified tool for this activity
  - Adjustments / edits to the SEMATECH model probably required with evolutionary input from EUV source community
  - Non commercial Microsoft Excel™ model “beta” software (no maintenance / warranty)

Appendix Material

Cost of Ownership System Throughput Drivers

- Interdependency of many factors that influence system exposure tool throughputs (Fish Bone Diagram). All are used in SEMATECH CoO



Source

Power

Rep. Rate

Chamber Life

Optics

Transmission or Refl.

Max. Field size

Material Damage

Collimation

PO design # Elem

Contamination

Product

Fields / Wafer

Wafer Size

Illuminator use

Test Wafer

Masks

TPT

Transparency

Acid Reaction Rates

Photoresist Sensitivity

Wafer load / unload

Alignment Marks

Stage Acceleration

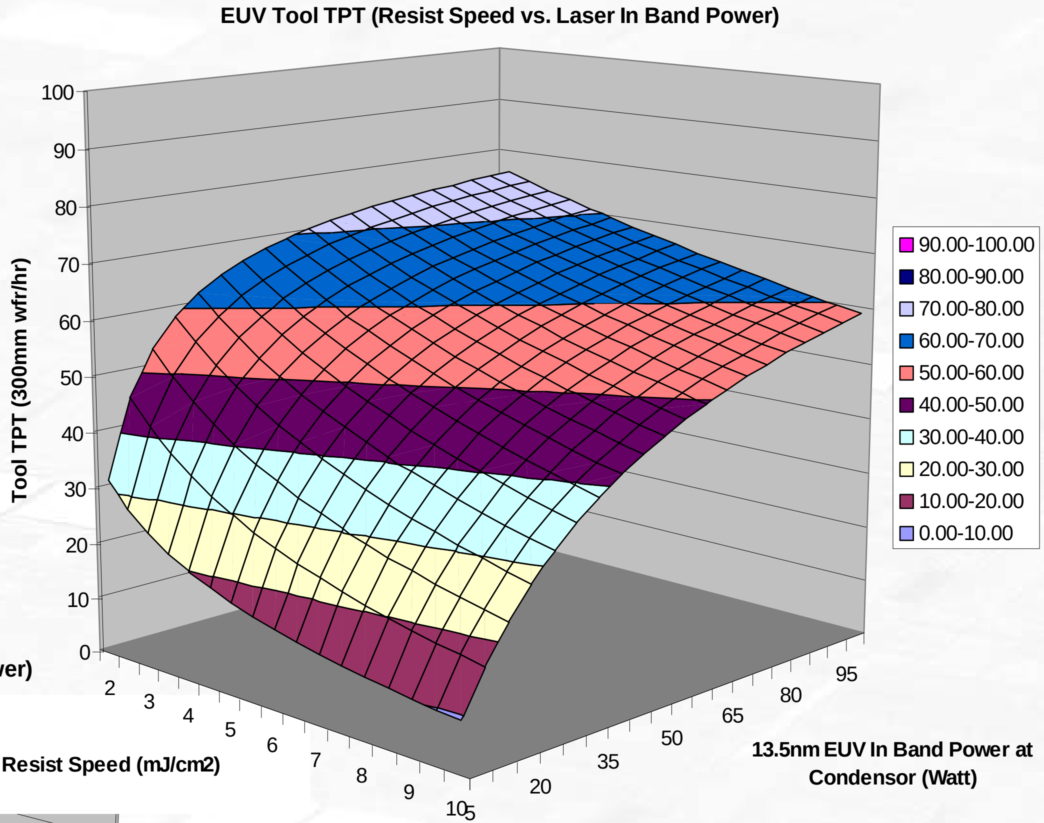
Overlay Calculations

Stage Speed

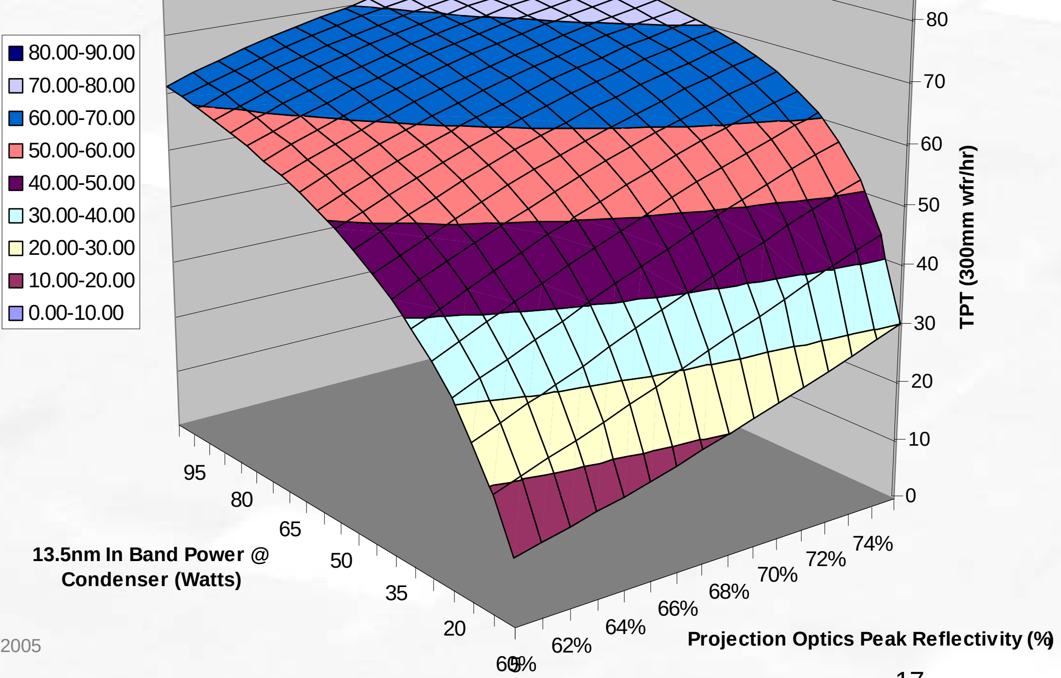
Vibration Isolation

Alignment / OH

EUV Source Cost of Ownership Sensitivity Analysis



EUV Tool TPT (Optics Reflectivity vs. In Band Power)



Cost of Ownership Standard Rates

Scheduled Production	**300 mm**
Hours / Week / Shift	42
Shifts / week	4
hours / day	24
days / year	365
supplier shifts / week	4

Labor & OH	
Engineering	111,000
Supervisor	111,000
Operator / hr.	25
Maintenance / hr.	30
Productivity	80%

FAB Space Rates ($ / sq ft / yr)	
Class 1 or ISO Class 3	$400
Class 10 or ISO Class 4	$250
Class 100 or ISO Class 5	$100
Other	$50

SEMATECH Cost of Ownership Product Input sheet (1)

YOUR NAME: 0 **TECHNOLOGY:** 193nm dry ~90nm HP DR
DATE: 12/01/2004 **SUPPLIER:** Generic - ave. assumptions
MODEL NAME: 0 **INFO:** 0

193 nm REFRACTIVE SCANNER

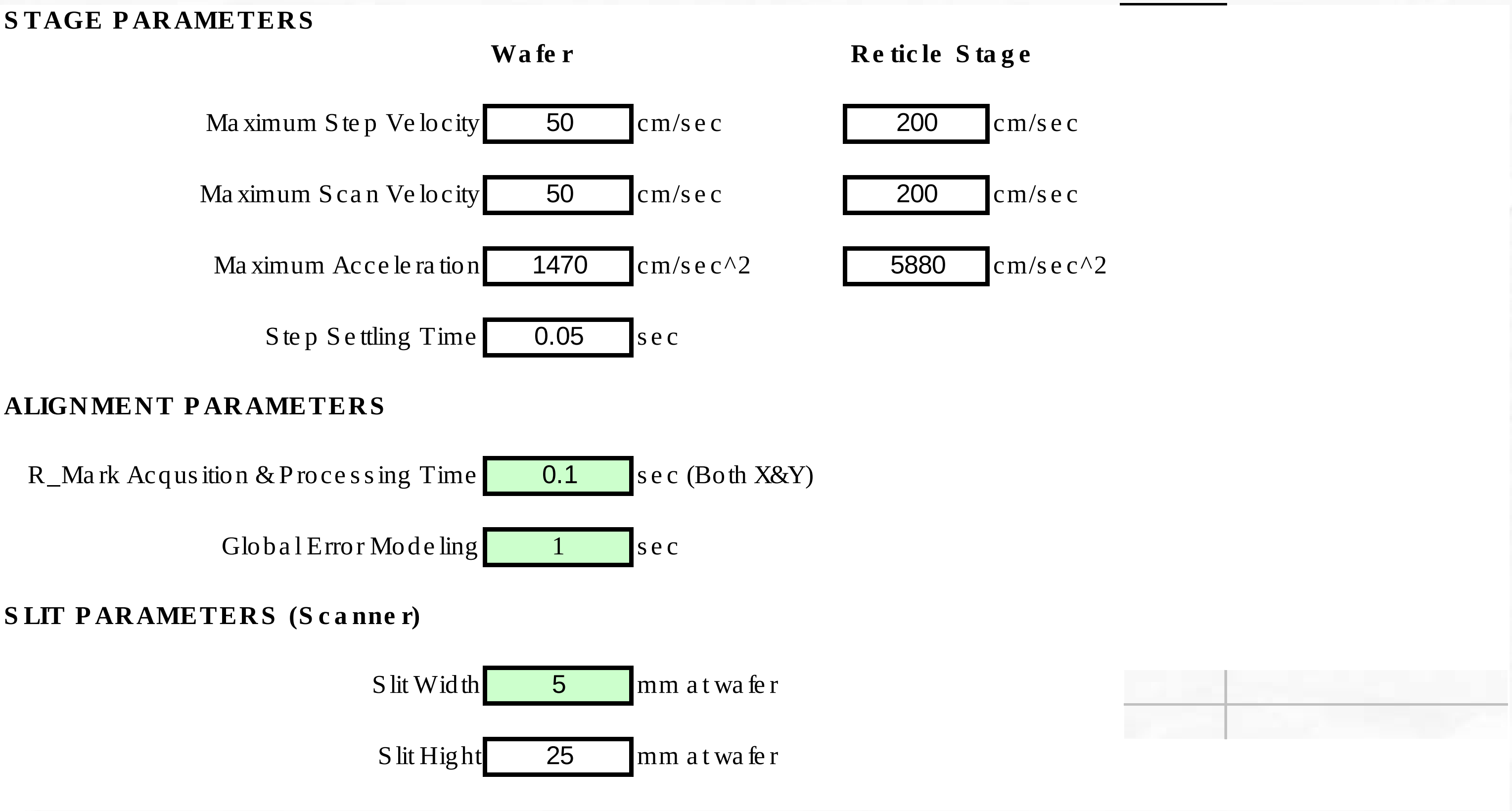
DEVICE and PROCESS PARAMETERS

Wafer Size	300	mm (From Product sheet)
Field Size (x)	25	mm (From Product sheet)
Field Size (y)	25	mm (From Product sheet)
Estimated Fields	89	(From Product sheet)
Estimated Array Size	10	Columns
Estimated Array Size	10	Rows
Resist Sensitivity	10.00	mJ/cm^2 (From Product sheet)
Stepper Shutter Open&Close	0.03	sec
Laser Repetition Rate	4000	Hz (From Product sheet)
Laser Power	40.00	W
Global Alignment Marks	9	for initial alignment
Local Alignment marks/field	6	If FxF alignment is used

Variation Parameter

1

SEMATECH Cost of Ownership Stage Input sheet



STAGE PARAMETERS

	Wafer		Reticle Stage	
Maximum Step Velocity	50	cm/sec	200	cm/sec
Maximum Scan Velocity	50	cm/sec	200	cm/sec
Maximum Acceleration	1470	cm/sec^2	5880	cm/sec^2
Step Settling Time	0.05	sec		

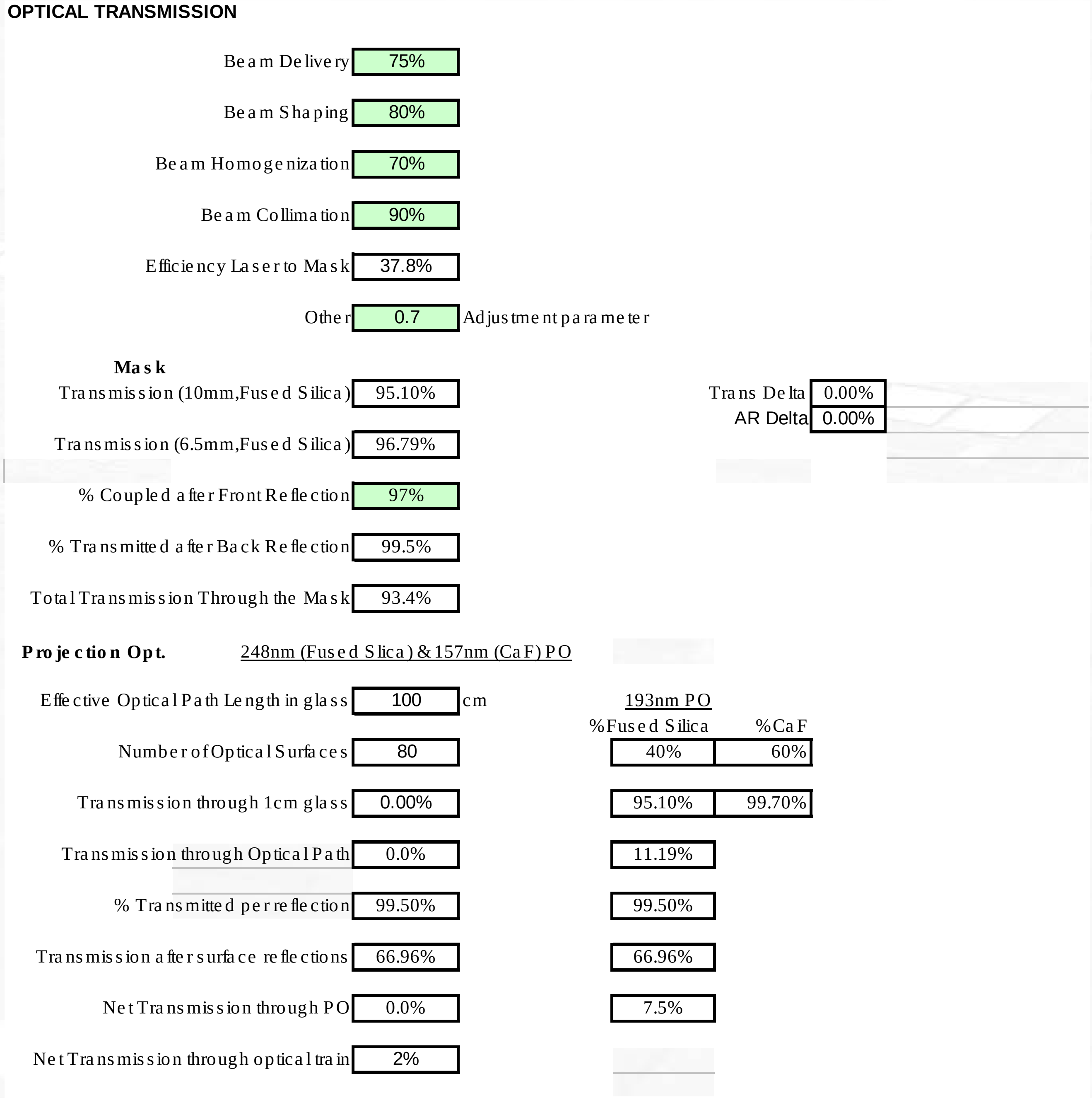
ALIGNMENT PARAMETERS

R_Mark Acqusition & Processing Time	0.1	sec (Both X&Y)
Global Error Modeling	1	sec

SLIT PARAMETERS (Scanner)

Slit Width	5	mm at wafer
Slit Hight	25	mm at wafer

SEMATECH Cost of Ownership 193nm optical train Input



OPTICAL TRANSMISSION

Beam Delivery	75%	
Beam Shaping	80%	
Beam Homogenization	70%	
Beam Collimation	90%	
Efficiency Laser to Mask	37.8%	
Other	0.7	Adjustment parameter

Mask

Transmission (10mm,Fused Silica)	95.10%	Trans Delta	0.00%
		AR Delta	0.00%
Transmission (6.5mm,Fused Silica)	96.79%		
% Coupled after Front Reflection	97%		
% Transmitted after Back Reflection	99.5%		
Total Transmission Through the Mask	93.4%		

Projection Opt. 248nm (Fused Slica) & 157nm (CaF) PO

			193nm PO %Fused Silica	 %CaF
Effective Optical Path Length in glass	100	cm		
Number of Optical Surfaces	80		40%	60%
Transmission through 1cm glass	0.00%		95.10%	99.70%
Transmission through Optical Path	0.0%		11.19%	
% Transmitted per reflection	99.50%		99.50%	
Transmission after surface reflections	66.96%		66.96%	
Net Transmission through PO	0.0%		7.5%	
Net Transmission through optical train	2%			

SEMATECH Cost of Ownership 193nm resist consumables

YOUR NAME:	0	**TECHNOLOGY:**	193nm dry ~90nm HP DR
DATE:	12/01/2004	**SUPPLIER:**	Generic - ave. assumptions
MODEL NAME:	0	**INFO:**	0

193 nm REFRACTIVE SCANNER

Patterning Consumable Cost Input Parameters

"Spin - On" Layer Consumables	**Cost ($/gal.)**	**Use (cc/wfr)**	**Comments**
Photoresist Layer #1	$10,000	2	SLR resist layer or "planarizing" layer
Photoresist Layer #2			MLR imaging layer
Bottom ARC	$2,500	2	
Top ARC			
Contrast Enhancement Layer			
Etch Stop Layer			(eg SOG for Tri-layer resist systems)
(other)		0	

Adv. Diff/Dep. Step Consumables	**Cost ($/gal.)**	**Use (cc/wfr)**	
Silyation Agent			(e.g. HMDS or DMSDEA for TSI systems)
(other)			

Dev./Etch/Strip Step Consumables	**Cost ($/gal.)**	**Use (cc/wfr)**	
Wet developer #1 (resist layer #1)	$50	90	
Wet developer #2 (resist layer #2)			
Wet stripper chemical			
Edge Bead Remover (EBR)	$27	3	Total EBR use for all layers
(other)			

SEMATECH Cost of Ownership 193nm Tool $ & maintain.

YOUR NAME:	0	**TECHNOLOGY:**	193nm dry ~90nm HP DR
DATE:	12/01/2004	**SUPPLIER:**	Generic - ave. assumptions
MODEL NAME:	0	**INFO:**	0

193 nm REFRACTIVE SCANNER

Cluster Tool Equipment Cost Input Parameters

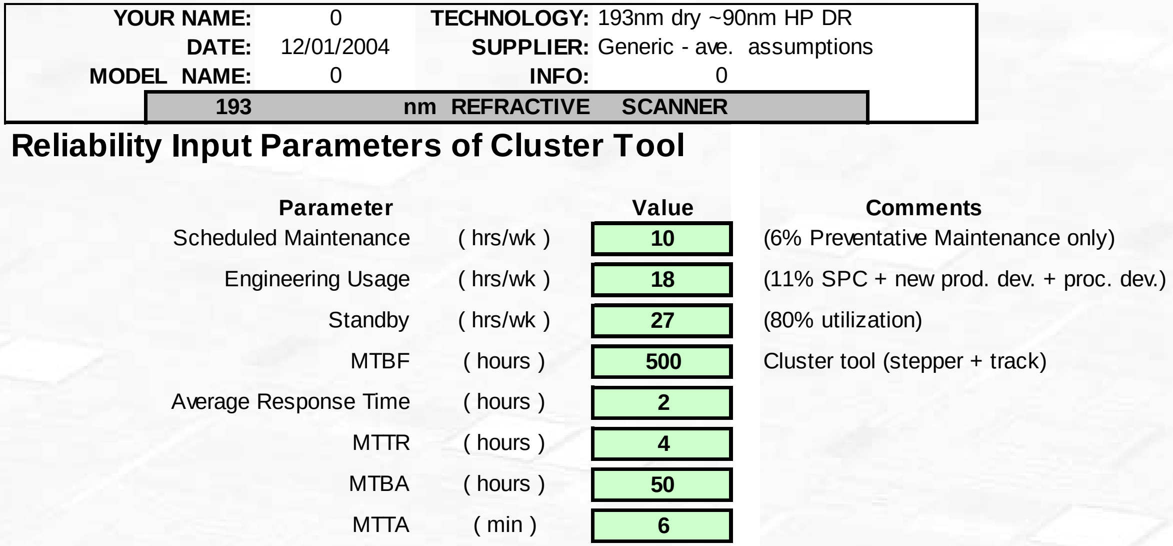
	Tool Costs		**Value**	**Comments**
STEPPER	Capital Cost	($ USD)	$18,000,000	Stepper cost trends (without source cost)
	Service Contract per tool	($ USD)	$300,000	Annual maintenance contract charge
	Other Replacement Parts per tool	($ USD)		Average Annual cost for component replacements (Optics)
	Tool Footprint	(sq. ft.)	70	cleanroom footage

SOURCE			**Value**	**Replacement Period (B pulses)**	**# Replacement per yr (Pulse count driven)**	**TPT (300mm wph)** **81.67**
	Capital Cost	($ USD)	$2,000,000	n/a	n/a	Laser $ + new starting chambers (3)
	Source & BDU train Footprint	(sq. ft.)	30	n/a	n/a	chase + sub floor footage
	Laser Chamber Oscillator	($ USD)	$50,000	5.00	3.31	rotating refurbished tube cost
	Laser Chamber Amplifier	($ USD)	$50,000	5.00	3.31	rotating refurbished tube cost
	Chamber Windows / Mirrors (front / back)	($ USD)	$25,000	7.00	2.37	replacements
	Line Narrowing Module / components	($ USD)	$30,000	7.00	2.37	**Wafers Exposed / week**
	BDU components / couplers / other	($ USD)	$15,000	5.00	3.31	**7825**
	Abatement / F2 trap - scrub	($ USD)	$10,000	10.00	1.66	**Replacement cost per year**
	High purity gas charge mixtures	($/cylinder)	$2,000	0.10	165.63	**$627,645.23**
	Other consumables / filters	($ / yr)	$15,000	10.00	1.66	**# 10^9 pulses per year**
	Laser Service Contract	($ / yr)	$75,000			**16.56**

TRACK	Capital Cost	($ USD)	$2,500,000	2.612152
	Service Contract per tool	($ USD)	$100,000	Annual maintenance contract charge
	Replacement Parts per tool	($ USD)		Average Annual cost for component replacements
	Tool Footprint	(sq. ft.)	50	
Silyation	Capital Cost	($ USD)		Tool cost for silyation processing
	Service Contract per tool	($ USD)		Annual maintenance contract charge
	Replacement Parts per tool	($ USD)		Average Annual cost for component replacements
	Tool Footprint	(sq. ft.)		
ARC Etch	CoO ($/wfr pass)		$3.66	Cost for ARC etching processing
MLR Etch	CoO ($/wfr pass)			Cost for plasma processing
(Other)	CoO ($/wfr pass)		$0.00	

SEMATECH

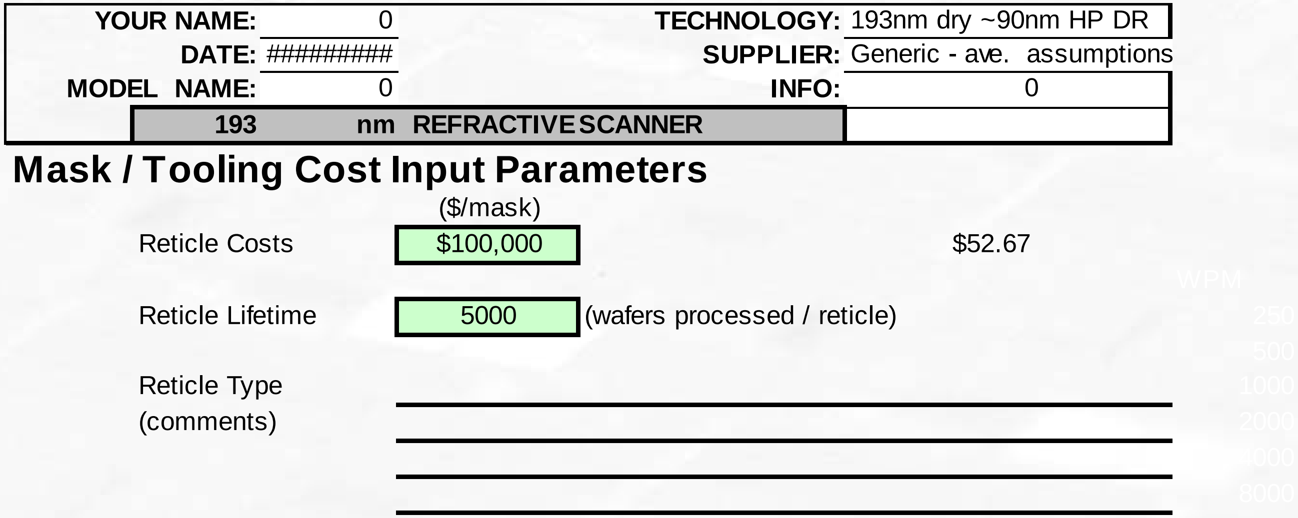
Accelerating the next technology revolution.



YOUR NAME: 0 **TECHNOLOGY:** 193nm dry ~90nm HP DR
DATE: 12/01/2004 **SUPPLIER:** Generic - ave. assumptions
MODEL NAME: 0 **INFO:** 0
193 nm REFRACTIVE SCANNER

Reliability Input Parameters of Cluster Tool

Parameter		**Value**	**Comments**
Scheduled Maintenance	(hrs/wk)	**10**	(6% Preventative Maintenance only)
Engineering Usage	(hrs/wk)	**18**	(11% SPC + new prod. dev. + proc. dev.)
Standby	(hrs/wk)	**27**	(80% utilization)
MTBF	(hours)	**500**	Cluster tool (stepper + track)
Average Response Time	(hours)	**2**	
MTTR	(hours)	**4**	
MTBA	(hours)	**50**	
MTTA	(min)	**6**	



YOUR NAME: 0 **TECHNOLOGY:** 193nm dry ~90nm HP DR
DATE: ########## **SUPPLIER:** Generic - ave. assumptions
MODEL NAME: 0 **INFO:** 0
193 nm REFRACTIVE SCANNER

Mask / Tooling Cost Input Parameters

	($/mask)			
Reticle Costs	$100,000		$52.67	
				WPM
Reticle Lifetime	5000	(wafers processed / reticle)		250
				500
Reticle Type (comments)				1000
				2000
				4000
				8000