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Commercial EUV Mask Blank Readiness for 45nm Half Pitch (HP) 2009 Manufacturing

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Commercial EUV Mask Blank Readiness for 45nm Half Pitch (HP) 2009 Manufacturing

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- Chris Walton – Lawrence Livermore N.L.
- Stefan Wurm – SEMATECH / Infineon
- **Takeyuki Yamada - Hoya**

Agenda

- SEMATECH EUV blank commercial activity project overview
- Evaluation methodology and metrology / inspection tools
- SEMATECH EUV Blank Roadmap 2002 Baseline
- General project highlights
- Key performance trends
- Commercial Supplier Performances – anonymous comparison
- SEMATECH Updated EUV Blank Roadmap Q4 2004
- Areas of risk and recommendations
- Summary

SEMATECH EUV Commercial Blank Supply Overview

- Project Objectives:
  - Assess progress and identify improvement areas for blank suppliers to meet 45nm HP requirements by 2009 (SEMI P37 and P38 Standards)
  - Establish commercial supply of beta level EUV mask blanks
- Approach:
  - Engage multiple commercial suppliers to provide SEMATECH with EUV mask blanks with increasing “integrated” performance over time
  - Provide independent blank evaluations and provide feedback to suppliers to aid improvements and learning
  - Establish technical transfer of EUV mask blank metrology techniques and knowledgebase from the VNL and SEMATECH – North to suppliers
  - Distribute limited blanks to interested I.C. Mfg. in exchange for data
- Project Goals:
  - Establish “alpha” blank performance at realistic yields by YE 2004
  - Establish “beta” level performance at realistic yields by YE 2005
  - Drive towards production requirements at realistic yields by 2007

SEMATECH EUV Commercial Blank Supplier Engagement

- Procure blanks in agreement with continuously improving specification
- Obtain product mix to assess substrates, reflective multilayer, and absorbers
  - Substrate lot monitors (Fused silica and LTEM)
  - Moly / Silicon ML stack with Si cap (on Fused silica and LTEM)
  - Full blanks with buffer and absorber stacks (on Fused silica and LTEM)
- Obtain Certificate of Authenticity (COA) or 'conformance' data packages
- SEMATECH evaluation using a common metrology / inspection toolset for consistent and neutral comparisons
- Conduct metrology toolset correlations with suppliers based on COA and SEMATECH data discrepancy and supplier interest
- Review / discuss data with each supplier to aid in developments
- Utilize supplier blanks in other SEMATECH EUV projects to further assess blank 'fitness for use' (based on blank supplier interest and agreements)
  - Defect repair demonstrations (just underway)
  - Cleaning demonstrations (near future)
  - Defect inspection (actinic vs. optical correlations) – (near future)
  - … other activities as they develop…

SEMATECH Metrology or Sponsored Metrology Toolset

Performance parameter & measurement	Sponsored Metrology (LLNL / LBNL) - Q3'02 – Q1'04 -	SEMATECH & SEMATECH-North Metrology - Q1'04 – Q4'04 -
• substrate & blank flatness	• Sommargren PSDI & Zygo GPI™	• Zygo Verifier™ (Austin TX & Albany NY)
• substrate & blank roughness	• DI 5000™	• Veeco DI 9000™
• substrate & blank total defects	• KLA – Tencor Starlight™ (NIST / ATP) – 80nm PSL substrate – 120nm PSL ML	• Lasertec M1350™ (SEMATECH – North) – 60nm PSL substrate – 80nm PSL ML
• multilayer & absorber reflectivity and wavelength control	• LBNL ALS reflectometer (BL 6.3.2)	• EUV Technology Reflectometer (periodic correlation w/ LBNL ALS 6.3.2)

SEMATECH EUV Blank Commercial Roadmap (Q3 2002)

- SEMATECH developed roadmap based on production needs that resulted from many supplier individual discussions
- SEMATECH uses roadmap as guideline for multi-phased activity

Year	2003		2004		2005		2006		2007		Production
Half	H1	H2	H1	H2	H1	H2	H1	H2	H1	H2	45nm
Parameter	Pre-a	Pre-a	alpha	alpha	beta	beta	beta	beta	beta	beta	gamma
Mask Substrate											
Material	LTEM	LTEM	LTEM	LTEM	LTEM	LTEM	LTEM	LTEM	LTEM	LTEM	LTEM
Mean CTE (± ppb/ deg K)	30	30	25	25	20	20	15	15	10	10	± 5
CTE Spatial Variation (± ppb/ deg K TIR)	10	10	10	10	8	8	8	6	6	6	6
Flatness Front (μm) (P–V)	0.6	0.6	0.5	0.4	0.3	0.3	0.2	0.2	0.1	0.05	0.03
Flatness Back (μm) (P–V)	1.0	1.0	0.8	0.8	0.6	0.5	0.4	0.3	0.2	0.1	0.05
Maximum Wedge Angle (μradians)	200	200	200	200	150	150	150	150	100	100	100
Surface Finish											
MSFR (nm rms)	< 2.0	< 2.0	< 1.5	< 1.0	< 1.0	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
HSFR (nm rms)	0.25	0.25	0.25	0.20	0.20	0.20	0.20	0.15	0.15	0.15	< 0.15
Local Slope of Front Surface (mrad)	N.A.	N.A.	≤ 2.0	≤ 2.0	≤ 1.5	≤ 1.5	≤ 1.5	≤ 1.5	≤ 1.0	≤ 1.0	≤ 1.0
Total Blank Defects											
Total ML Defect Density (defects/cm^2)	2.0	1.0	0.8	0.6	0.4	0.20	0.12	0.08	0.03	0.01	0.003
Cut-off Size (PSL equivalent, nm)	150	150	120	120	90	90	60	60	40	40	25
Multilayer Performance											
Peak Reflectivity (%)	>58	>58	>60	>60	>62	>62	>64	>64	>66	>66	> 67
Peak Reflectivity Unif. (%P-V) Absol.	0.80	0.80	0.70	0.60	0.60	0.55	0.55	0.50	0.50	0.50	0.50
Mean Centroid λ of Reflectivity (nm)	13.40	13.50	13.50	13.50	13.50	13.50	13.50	13.50	13.50	13.50	TBD
Centroid Reflected λ Uniformity (nm P-V)	0.08	0.08	0.08	0.08	0.07	0.07	0.07	0.07	0.06	0.06	0.06

Q3 2002 version

- Supplier Performance Capability (Q3 '02)
- Meet w/ upgraded tooling & process
- New tooling / process needed
- New Tooling & Process innovation needed

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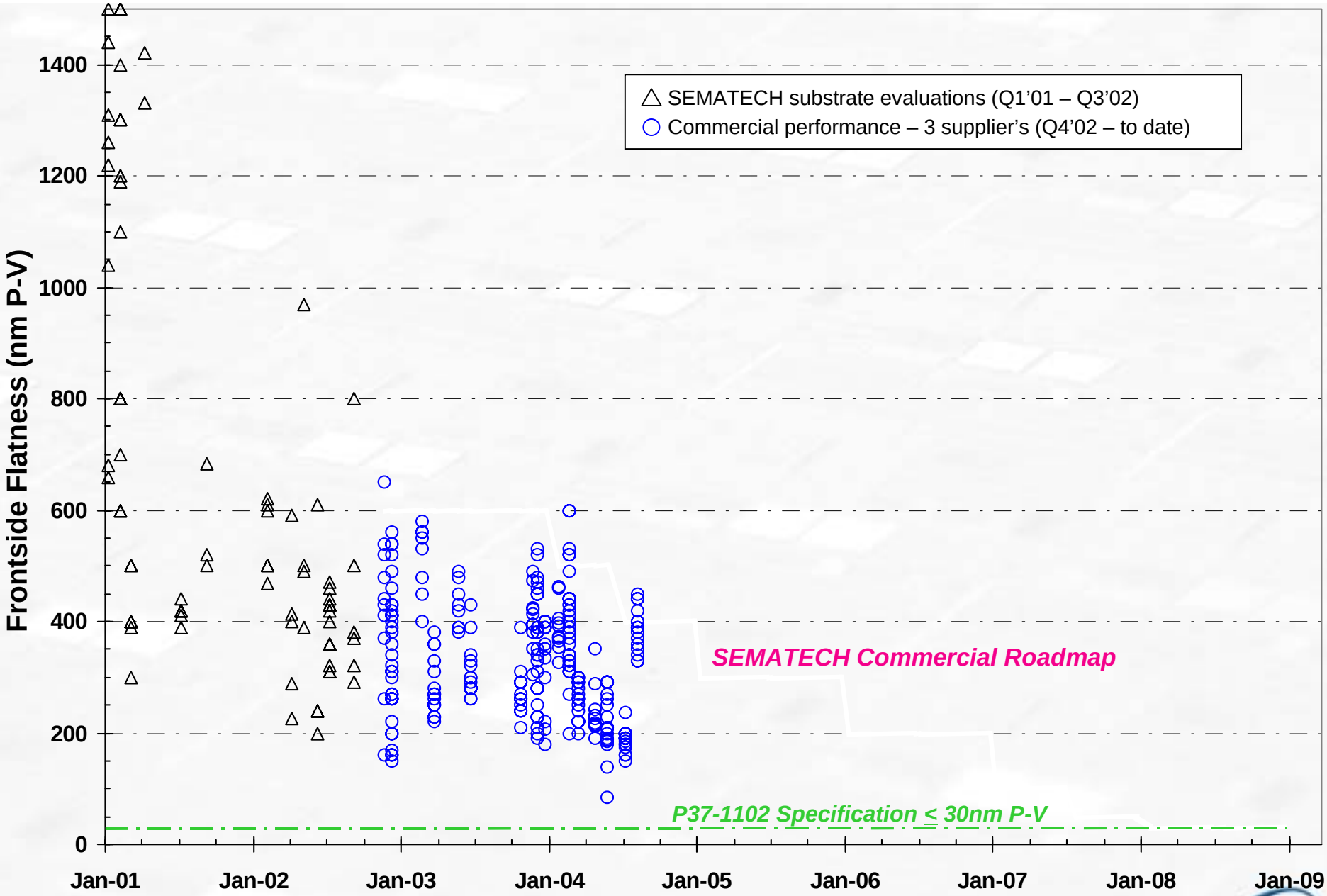
SEMATECH EUV Commercial Blank Supply

ACCOMPLISHMENTS TO DATE (HIGHLIGHTS):

- SEMATECH began receiving blanks from the first supplier since Oct of '02
- Three planned commercial suppliers have been engaged since Sept 2003
  - > 270 blanks have been received to date (COA data on 260 received)
  - > 60 substrates provided for lot monitor surface quality evaluation
- Each supplier has completed all shipments under current agreements
- EUV blank supplier involvement with evaluation data and metrology correlation is generally good and is showing benefits
- Inspection and metrology evaluation transition to the SEMATECH-North Albany NY facility is 100% complete
- Lawrence Livermore and Berkeley National Labs (LLNL & LBNL) completed assessment of substrate "local slope" methodology for SEMI P37-1102
- Developed "EUV Mask Blank Exchange" Program for interested Integrated Circuit (IC) Manufactures. Blanks in exchange for returning evaluation data (www.SEMATECH.org/resources/litho/maskblank/index.htm)

EUV Mask Blank Supply: Frontside Flatness Performance



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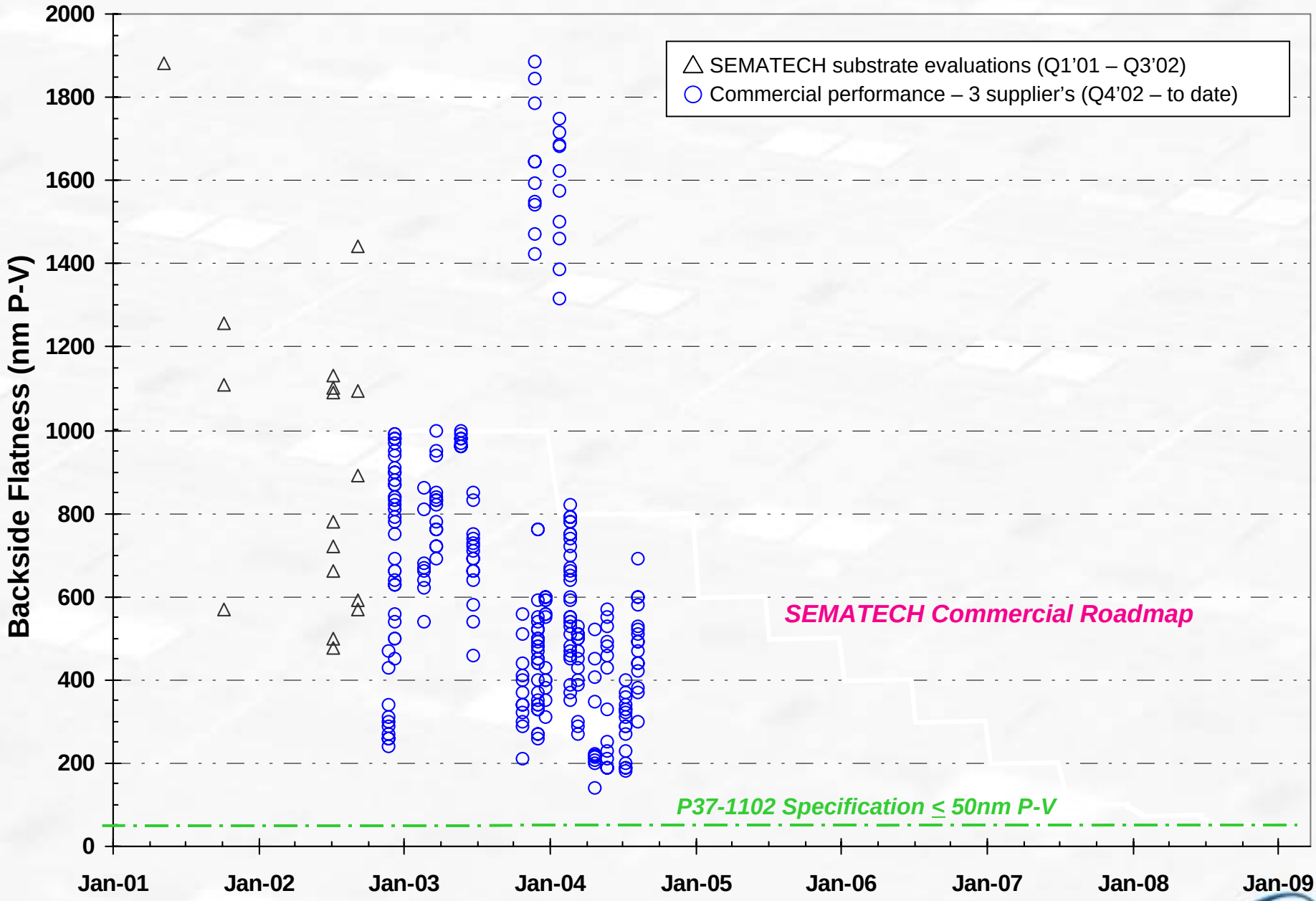
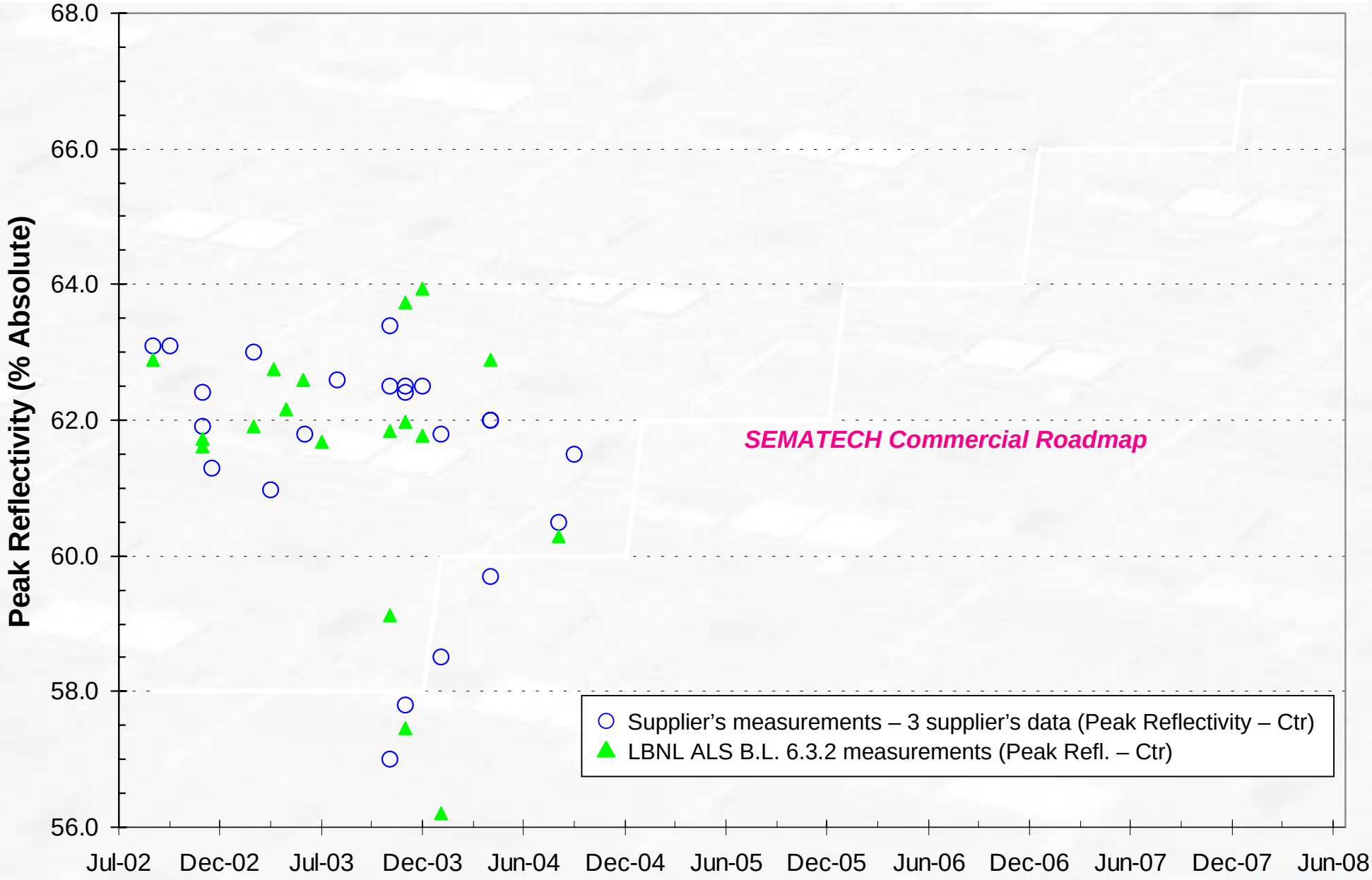
EUV Mask Blank Supply: Backside Flatness Performance



EUV Mask Blank Supply: Peak Reflectivity Performance



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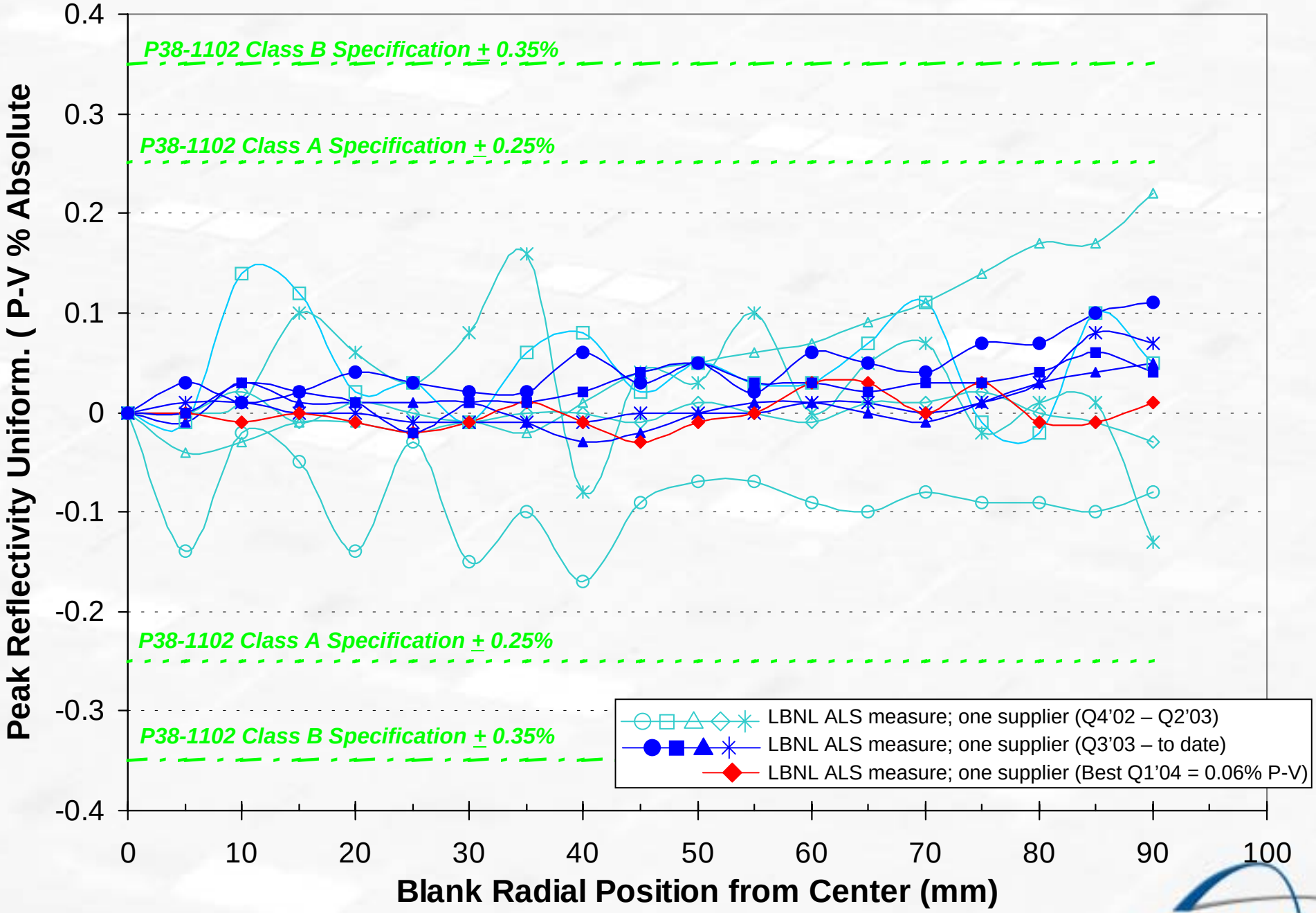
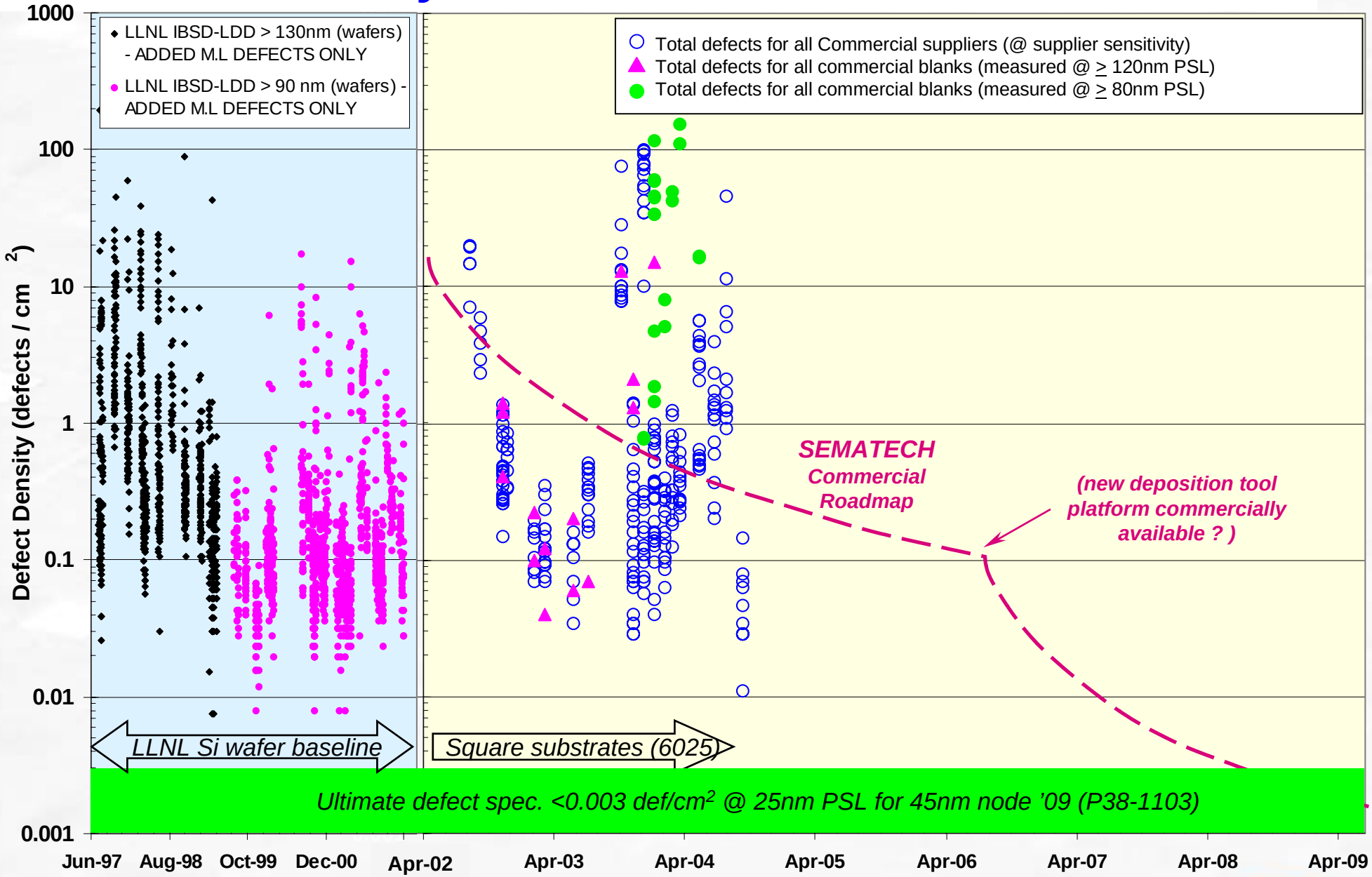
EUV Mask Blank Supply: Peak Reflectivity Uniformity Per.



EUV Blank Multilayer Defect Levels Trends



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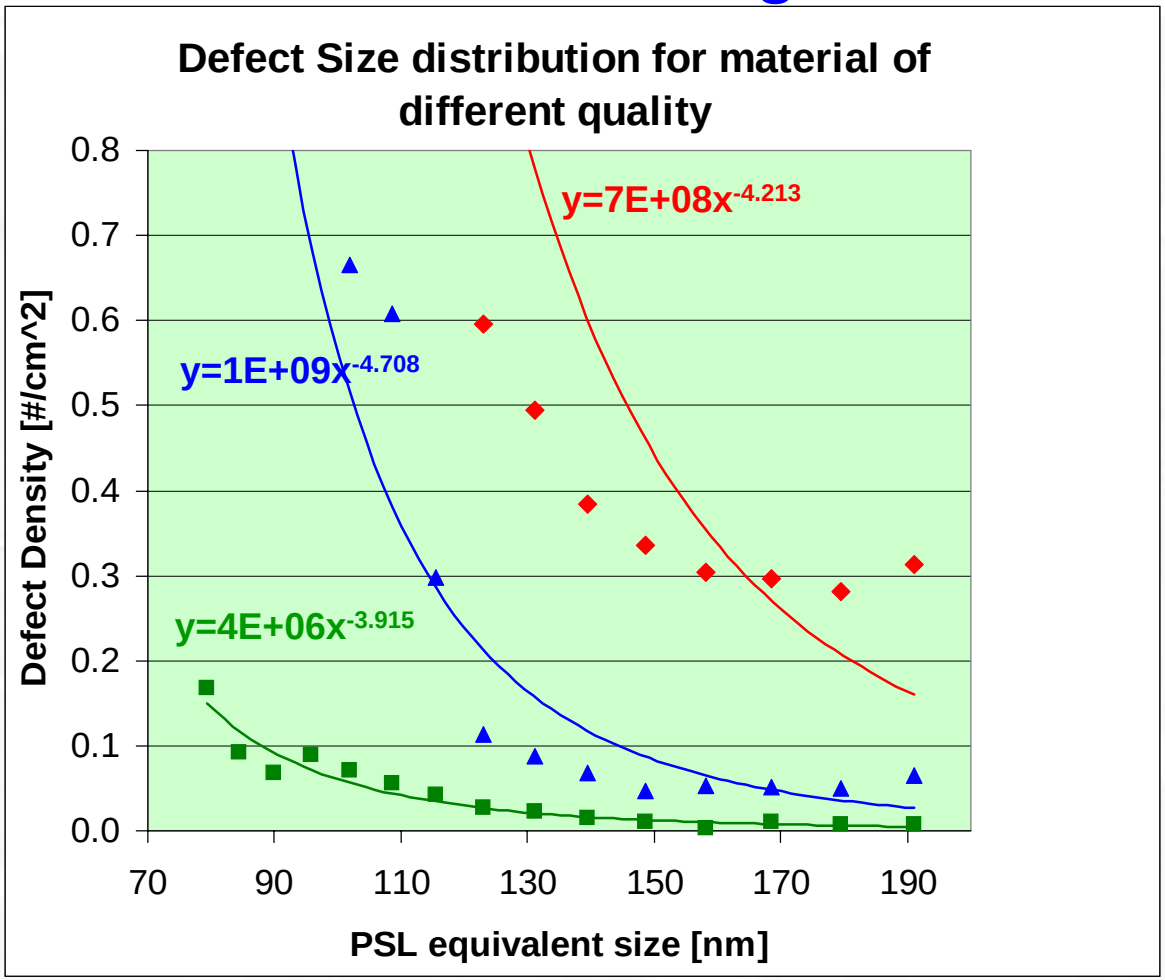
EUV Blank Defect Scaling Based on 40nm / 32nm PSL



Defectivity Range	Defect Density * 40nm	Defect Density * 32nm	Req. Improvement ** 40nm	Req. Improvement ** 32nm
LOW	2.2E+00	5.2E+00	7.3E+01	8.7E+02
MID	4.2E+01	1.2E+02	1.4E+03	2.0E+04
HIGH	1.2E+02	3.0E+02	3.9E+03	4.9E+04
Specification	3.0E-02	6.0E-03		

* fit data [defects / cm2]

** improvement required compared to 80nm performance

- Present SEMATECH defect size sensitivity is ~80nm
- Defect density scaling varies greatly within each blank
- For defect density of 0.03 cm^{-2}, significant defect density reduction is required even for leader
  - 40nm PSL: factor 73*
  - 32nm PSL: factor 870*

* Based on trends of observed total defect density (substrates and multilayers)

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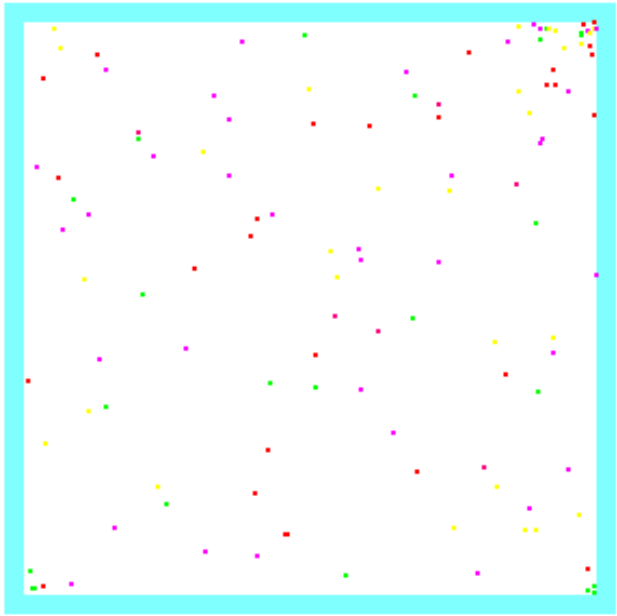
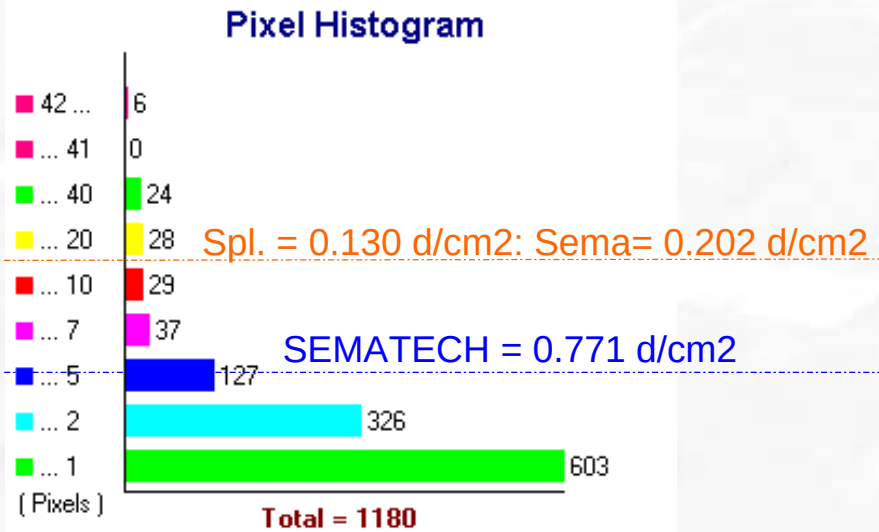
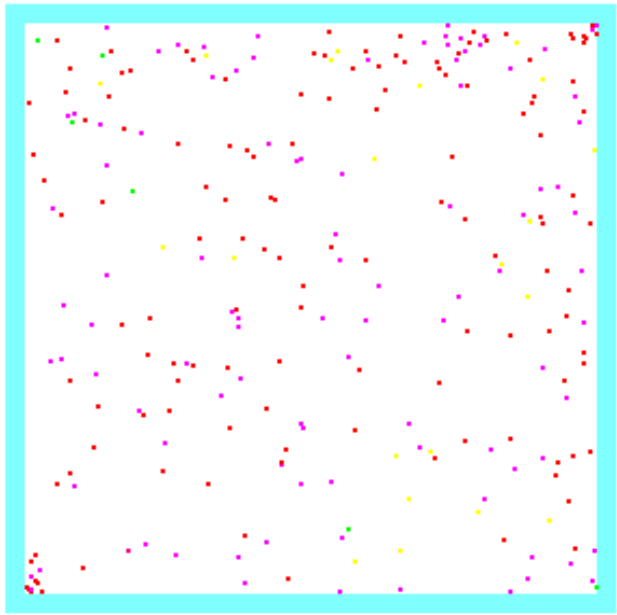
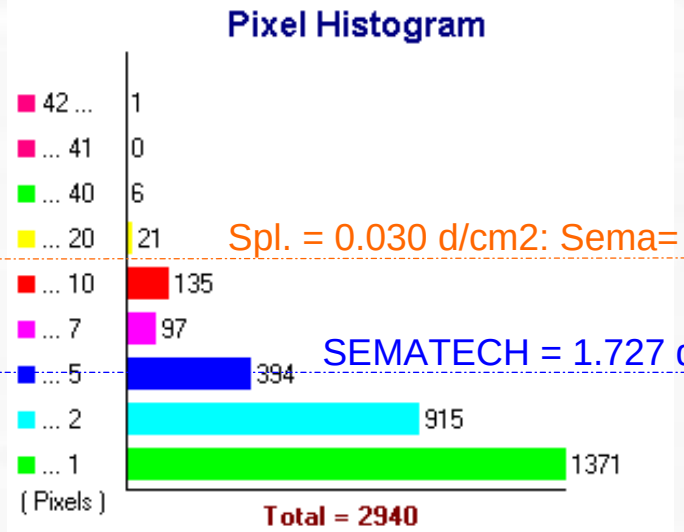
EUV Blank Multilayer Defect Density Scaling Variations





Supplier blank
Q3 '03





Supplier blank
Q1 '04

@ Supplier PSL cut-off

80nm PSL

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EUV Mask Blanks Commercial Supplier Performance

PARAMETER	Product. Spec (γ)	Best Integrated Blank	Supplier A		Supplier B		Supplier C	
SUBSTRATE & SURFACE FINISH	**Routine**	**Splr. C**	**Best**	**Ave.**	**Best**	**Ave.**	**Best**	**Ave.**
Front Flatness (nm, P–V)	≤ 30	230	85	252	190	340	150	362
Back Flatness (nm, P–V)	≤ 50	400	180	388	139	1100	240	649
MSFR (nm rms)	NA	0.41	0.62	0.50	0.80	0.80	0.39	0.513
HSFR (nm rms)	≤ 0.15	0.21	0.11	0.12	0.35	0.40	0.141	0.24
Local Slope (mrad)	≤ 1.0	4.5	2.4	2.9	7.1	8.6	3.4	5.2
Substrate Defects @ Supplier PSL (def/cm^2)	≤0.003 / 50	0.008	0.032	0.101	0.006	0.150	0	0.2
TOTAL BLANK DEFECTS								
Max. Defect Density @ Supplier PSL (def/cm^2)	≤0.003 / 25	0.029	0.124	14.5	0.189	0.562	0.011	0.248
Max. Defect Density (def/cm^2) @ 80nm PSL	≤0.003 / 25	0.771	16.45	50.88	34.2	56.30	0.771	2.44
MULTILAYER PERFORMANCE								
Peak Reflectivity Absolute (%)	≥ 67.0	62.4	61.5	58.5	63.9	62.6	63.1	62.0
Peak Reflectivity Uniformity Absolute (% P-V)	≤ 0.50	0.60	0.24	1.50	0.26	0.57	0.06	0.40
Median Central λ offset (nm)	± 0.06	+ 0.06	+ 0.050	+ 0.150	- 0.04	+ 0.058	± 0.00	- 0.006
Full Width Half Max (nm)	> 0.500	0.556	0.530	0.530	0.520	0.508	0.556	0.544
Central Reflected λ Uniformity (nm P-V)	≤ 0.06	0.038	0.13	0.13	0.04	0.058	0.022	0.052
Absorber Reflectivity absolute (%)	≤ 0.50 %	na	0.08	0.09	0.64	0.64	0.70	0.73
Absorber contrast (%) (calculated P38 draft)	>~ 97%	na	99.7	99.0	97.8	97.8	97.7	97.0
Mulitlayer Film Stress (MPa)	+ / - 200	- 480	- 283	- 1100	- 350	- 400	- 400	- 444

SEMATECH EUV Blank Commercial Roadmap (Q3 2002)

- SEMATECH developed roadmap based on production needs that resulted from many supplier individual discussions
- SEMATECH uses roadmap as guideline for multi-phased activity

Year	2003		2004		2005		2006		2007		Production
Half	H1	H2	H1	H2	H1	H2	H1	H2	H1	H2	45nm
Parameter	Pre-a	Pre-a	alpha	alpha	beta	beta	beta	beta	beta	beta	gamma
Mask Substrate											
Material	LTEM	LTEM	LTEM	LTEM	LTEM	LTEM	LTEM	LTEM	LTEM	LTEM	LTEM
Mean CTE (± ppb/ deg K)	30	30	25	25	20	20	15	15	10	10	± 5
CTE Spatial Variation (± ppb/ deg K TIR)	10	10	10	10	8	8	8	6	6	6	6
Flatness Front (μm) (P–V)	0.6	0.6	0.5	0.4	0.3	0.3	0.2	0.2	0.1	0.05	0.03
Flatness Back (μm) (P–V)	1.0	1.0	0.8	0.8	0.6	0.5	0.4	0.3	0.2	0.1	0.05
Maximum Wedge Angle (μradians)	200	200	200	200	150	150	150	150	100	100	100
Surface Finish											
MSFR (nm rms)	< 2.0	< 2.0	< 1.5	< 1.0	< 1.0	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
HSFR (nm rms)	0.25	0.25	0.25	0.20	0.20	0.20	0.20	0.15	0.15	0.15	< 0.15
Local Slope of Front Surface (mrad)	N.A.	N.A.	≤ 2.0	≤ 2.0	≤ 1.5	≤ 1.5	≤ 1.5	≤ 1.5	≤ 1.0	≤ 1.0	≤ 1.0
Total Blank Defects											
Total ML Defect Density (defects/cm^2)	2.0	1.0	0.8	0.6	0.4	0.20	0.12	0.08	0.03	0.01	0.003
Cut-off Size (PSL equivalent, nm)	150	150	120	120	90	90	60	60	40	40	25
Multilayer Performance											
Peak Reflectivity (%)	>58	>58	>60	>60	>62	>62	>64	>64	>66	>66	> 67
Peak Reflectivity Unif. (%P-V) Absol.	0.80	0.80	0.70	0.60	0.60	0.55	0.55	0.50	0.50	0.50	0.50
Mean Centroid λ of Reflectivity (nm)	13.40	13.50	13.50	13.50	13.50	13.50	13.50	13.50	13.50	13.50	TBD
Centroid Reflected λ Uniformity (nm P-V)	0.08	0.08	0.08	0.08	0.07	0.07	0.07	0.07	0.06	0.06	0.06

Q3 2002 version

- Supplier Performance Capability (Q3 '02)
- Meet w/ upgraded tooling & process
- New tooling / process needed
- New Tooling & Process innovation needed

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SEMATECH EUV Blank Commercial Roadmap Update (Q4'04)

- Updates made due to supplier performance and understanding issues better
- Supplier performance areas of excellence are diverse

Year	2003		2004		2005		2006		2007		Production
Half	H1	H2	H1	H2	H1	H2	H1	H2	H1	H2	45nm
Parameter	Pre-a	Pre-a	alpha	alpha	beta	beta	beta	beta	beta	beta	gamma
Mask Substrate											
Material	LTEM	LTEM	LTEM	LTEM	LTEM	LTEM	LTEM	LTEM	LTEM	LTEM	LTEM
Mean CTE (± ppb/ deg K)	30	30	25	25	20	20	15	15	10	10	± 5
CTE Spatial Variation (± ppb/ deg K TIR)	10	10	10	10	8	8	7	7	7	7	6
Flatness Front (μm) (P–V)	0.6	0.6	0.5	0.4	0.3	0.2	0.2	0.1	0.075	0.05	0.03
Flatness Back (μm) (P–V)	1.0	0.8	0.8	0.6	0.5	0.4	0.3	0.2	0.15	0.1	0.05
Surface Finish											
MSFR (nm rms)	< 2.0	< 2.0	< 1.5	< 1.0	< 1.0	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
HSFR (nm rms)	0.25	0.25	0.25	0.20	0.20	0.20	0.20	0.15	0.15	0.15	< 0.15
Local Slope of Front Surface (mrad)	N.A.	N.A.	≤ 5.0	≤ 5.0	≤ 4.0	≤ 4.0	≤ 3.0	≤ 3.0	≤ 2.0	≤ 2.0	≤ 1.0
Total Blank Defects											
Total ML Defect Density (defects/cm^2)	2.0	1.0	0.8	0.6	0.4	0.20	0.12	0.08	0.03	0.01	0.003
Cut-off Size (PSL equivalent, nm)	150	150	120	120	90	90	60	60	40	40	25
Multilayer Performance											
Peak Reflectivity (%)	>60	>60	>62	>62	>63	>64	>65	>65	>66	>66	> 67
Peak Reflectivity Unif. (%P-V) Absol.	0.80	0.80	0.70	0.60	0.60	0.55	0.55	0.50	0.50	0.50	0.50
Median Central λ of Reflectivity (nm)	13.40	13.50	13.50	13.50	13.50	13.50	13.50	13.50	13.50	13.50	TBD
Median Central λ Offset (nm)	± 0.12	± 0.10	± 0.08	± 0.08	± 0.07	± 0.07	± 0.07	± 0.07	± 0.06	± 0.06	≤ ± 0.06
Centroid Reflected λ Uniformity (nm P-V)	0.08	0.08	0.08	0.08	0.07	0.07	0.07	0.07	0.06	0.06	0.06

Q4 2004 Update

- 3 Suppliers w/ good yield performance (Q4 '04)
- 2 Suppliers w/ good yield performance (Q4 '04)
- 1 Supplier w/ good yield performance (Q4 '04)
- Meet w/ upgraded tooling & process
- New tooling / process needed
- New Tooling & Process innovation needed

SEMATECH EUV Blank Commercial Roadmap Update (Q4'04)

- Updates made due to supplier performance and understanding issues better
- Supplier performance areas of excellence are diverse

Q4 2004 Update

Year	2003		2004		2005		2006		2007		Production
Half	H1	H2	H1	H2	H1	H2	H1	H2	H1	H2	45nm
Parameter	Pre-a	Pre-a	alpha	alpha	beta	beta	beta	beta	beta	beta	gamma
Mask Substrate											
Material	LTEM	LTEM	LTEM	LTEM	LTEM	LTEM	LTEM	LTEM	LTEM	LTEM	LTEM
Mean CTE (± ppb/ deg K)	30	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	10	10	± 5
CTE Spatial Variation (± ppb/ deg K TIR)	10	10	10	10	8	8	7	7	7	7	6
Flatness Front (μm) (P–V)	[illegible]	[illegible]	[illegible]	0.4	0.3	0.2	0.2	0.1	0.075	0.05	0.03
Flatness Back (μm) (P–V)	[illegible]	[illegible]	[illegible]	0.6	0.5	0.4	0.3	0.2	0.15	0.1	0.05
Surface Finish											
MSFR (nm rms)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	N.A.	N.A.	N.A.	N.A.	N.A.
HSFR (nm rms)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.20	0.15	0.15	0.15	< 0.15
Local Slope of Front Surface (mrad)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	≤ 3.0	≤ 3.0	≤ 2.0	≤ 2.0	≤ 1.0
Total Blank Defects											
Total ML Defect Density (defects/cm^2)	2.0	1.0	0.8	0.6	0.4	0.20	0.12	0.08	0.03	0.01	0.003
Cut-off Size (PSL equivalent, nm)	150	150	120	120	90	90	60	60	40	40	25
Multilayer Performance											
Peak Reflectivity (%)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	>65	>66	>66	> 67
Peak Reflectivity Unif. (%P-V) Absol.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.50	0.50	0.50	0.50
Median Central λ of Reflectivity (nm)	13.40	13.50	13.50	13.50	13.50	13.50	13.50	13.50	13.50	13.50	TBD
Median Central λ Offset (nm)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.06	± 0.06	≤ ± 0.06
Centroid Reflected λ Uniformity (nm P-V)	0.08	0.08	0.08	0.08	0.07	0.07	0.07	0.07	0.06	0.06	0.06

Figure correction improvements

Figure correction intro.

Veeco / SEMATECH IBSD development

SEMATECH cleaning development

Lasertec / SEMATECH development

SEMATECH MBDC – supplier collaborations

- 3 Suppliers w/ good yield performance (Q4 '04)
- 2 Suppliers w/ good yield performance (Q4 '04)
- 1 Supplier w/ good yield performance (Q4 '04)
- Meet w/ upgraded tooling & process
- New tooling / process needed
- New Tooling & Process innovation needed

SEMATECH
Accelerating the next technology revolution.

SEMATECH EUV Blank Specific Supplier Summary

Supplier A:

- Has shown to be leader in substrate performance (flatness, finish, and defects)
- Has shown significant learning in defect reduction in last 12 months and is encouraged to continue defect improvements
  - 10X improvements at Supplier PSL cut off and 4X improvement at 80nm PSL cut off
- Shown reasonable improvements in Peak reflectivity with ~4% absolute increase
- Supplier encouraged to improve reflectivity uniformity, wavelength control, and peak reflectivity in '05

Supplier B:

- Offers a competitive EUV blank in many performance areas
- Has the highest peak reflectivity of all three suppliers with good reflectivity uniformity
- Has shown good improvement and is competitive in frontside and backside flatness control with recent shipments
- Supplier encouraged to improve defect performance as well as understanding better the inspection tools correlations and mismatches in '05
- Supplier encouraged to assess substrate roughness performance with respect to HSFR and local slope contributions in '05

Supplier C:

- Offers the best integrated performing EUV blank of three suppliers
- Defect performance leader of 0.77 def/cm^2 @ 80nm (large % < 0.2 def/cm^2 @ Supplier PSL) with highest defect inspection sensitivity of commercial blank suppliers; encouraged to continue defect improvements
- Offers very uniform reflectivity and very good wavelength control
- Competitive in areas where not leader (i.e. HSFR, flatness, peak reflectivity)
- Supplier is encouraged to improve flatness and peak reflectivity in '05

SEMATECH EUV Blank General Summary

- SEMATECH believes the supplier evaluation results are consistent using standard toolset and methodologies
- Achieving integrated blank performance is and will continue to be very difficult
- Supplier current performance is at “early” alpha level which should support most small field micro-exposure systems and some limited full field exposure requirements
- Frontside and backside flatness has shown significant improvements over 2 – 3 years and is near to achieving sub 100nm P-V at modest yields
- Preliminary local slope performance appears less than anticipated (~ 5 mrad ave). More data probably needed to fully understand current performance
- Several suppliers have shown defectivity improvements of 4x - 10x in this activity yet matching the performance at 80nm PSL can be difficult to predict
- Only one blank supplier appears to be on SEMATECH roadmap for defects from data and correlation results
- Needed defect improvements is still a high risk item, will be very challenging, and need critical timing of new key elements by early ’06 (deposition, inspection, etc.)
  - Achieving reduction as defect inspection sensitivity increases will be difficult. Some suppliers have procurement plans for improved defect inspection in ’05
  - ~100x improvement needed for 0.03 def/cm2 @ 40nm PSL performance will be challenging to meet within 3 years for beta level requirements
  - Use of defect smoothing, repair, and potential defect avoidance is strongly encouraged
  - Commercial supplier adoption of new tooling developments that include acquiring outputs can take +1 yr(s) after successful development program completion

Thank You