



ASML

NXE resist outgas testing update

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Resist outgassing can impact scanner performance if not managed

- Carbon growth on mirrors from outgassing depends on the outgas rate and pressure and gas transport and intensity at the mirrors
- Outgas requirements have been set to maintain the system performance over the expected system lifetime productivity
- Outgassing from resist – cleanable and non-cleanable – has been given an allocation in the transmission budget
- Testing of resists for compliance with outgas requirements must mimic the scanner for environment, cleaning and contamination regime
 - Resist outgas tester requirements have been determined based on this



Resist outgassing requirements have been allocated to maintain optics reflectivity

- Cleanable contamination:
 - NXE optics cleaning system is designed to maintain high productivity over a target lifetime such that had there not been cleaning a large amount of carbon (C) would build up per mirror
 - Film thickness has been given a direct allocation from the budget
- Non cleanable contamination:
 - Total change in transmission $\leq 10\%$ for the optical column over the lifetime ($\sim 1\%$ reflection loss per mirror) is required
 - Allocations for the 1% dR/R are made for coating degradation, sputtering, cleaning residual, oxidation, cleaning by-products (eg metal from filament, outgassing from use of cleaning baths) and resist
 - For HVM the budget allocated for resist is allocated dR/R of $\leq 0.16\%$



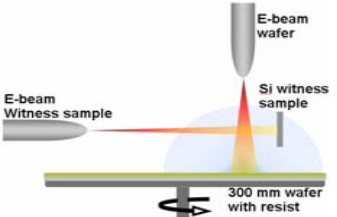
Presentation contents

- Resist outgas tool process flow, requirements, results
- Use of electrons and correlation to photons
- Tester status for NXE qualification



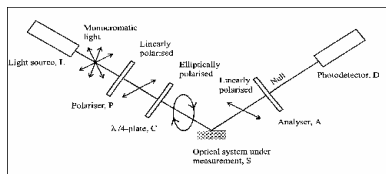
Resist Qualification has four main steps

1
Grow contamination



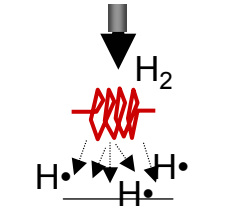
Tester

2
Measure contamination film thickness



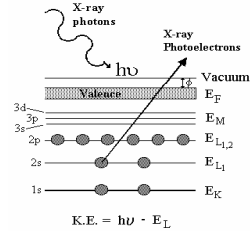
Ellipsometry

3
Clean contamination



H* Filament

4
Measure non-cleaned contamination



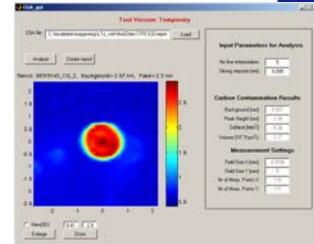
XPS

- Ellipsometry measurements allow qualification of *cleanable* contamination

- XPS measurements allow qualification of *uncleanable* contamination
- Uncleanable contamination is the biggest concern for optics lifetime

Spectroscopic ellipsometer (SE) requirements for dose to clear and total contamination measurement

- Measurements on 1" witness samples (for peak contamination measurement) and 12" wafers (dose to clear measurement)
- 2D spectroscopic ellipsometry (wavelength range 300-900nm with Cauchy model, provided by ASML, fit from 600nm – 900nm)
- 125 - 150 μm spot size
- 150 μm raster on a 5 x 5 mm^2 area
 - Spectroscopic data Psi (Y) and Delta (D) is obtained
- Detection limit/accuracy 0.1nm/ \pm 0.1nm
- Cross-calibration to ASML metrology (measure and compare) to check for 10% matching
 - ASML supplied witness sample with uniform carbon or SiO₂
 - ASML supplied witness sample with grown contamination peak



XPS requirements for non-cleanable contamination measurement

- Measurements on 1" witness samples
- Accuracy / detection limit 0.1 %_{at} and repeatability ≤ 10%
- Monochromatic Al K_α radiation source
- Spot size 500 μm or smaller
- Angle set to reach the preferred information depth of 8 - 10nm on SiO₂ (Take off angle 90 deg → 10nm; TOA 51 deg → 8nm)
- Cross-calibration with reference sample provided by ASML (measure and compare) for 1.5 at% matching (except Ru, O, N)
 - ASML supplied witness sample that has been cleaned after contamination was grown (no splitting of Ru / C peaks needed)

#176 Center Measurement Atomic Percentage (%)

Peak	S 2p	W 4d5	P 2p	Ru 3d	O 1s	N 1s	Zn 2p3	Si 2s
Other	3.4	0.2	1.0	46.7	42.0	5.8	0.1	0.6
MiPlaza	3.1	0.3	1.2	47.1	42.1	5.7	0.1	0.3



Resist outgassing specifications have been set for NXE3100 and NXE3300

- Outgassing specifications are based on
 - Cleanable contamination can be removed within the availability budget
 - Maximum transmission loss from uncleanable contamination of 10% during 30,000h EUV exposures
- The NXE3100 specifications have been revised to take into account the current tool status and expected tool lifetime

	Cleanable (C thickness)	Uncleanable (dR/R)
NXE:3100	3nm	0.23%
NXE:3300	3nm	0.16%

- All resists that pass the NXE3100 requirement can be used without wafer count restriction



With the relaxed NXE3100 specification all resists tested by ASML can be used without restriction

- All resists tested meet the cleanables requirement
- All resists meet the revised NXE 3100 non-cleanables requirement
- 9 of 26 resists tested meet the NXE3300 requirement
 - Failure mostly due to S content
- Resist suppliers have been notified as to Pass / Fail of their resists that have been tested

NXE3100		NXE3300	
	dr/r (%)		dr/r (%)
Resist 1	Green	Resist 1	Red
Resist 2	Green	Resist 2	Red
Resist 3	Green	Resist 3	Red
Resist 4	Green	Resist 4	Red
Resist 5	Green	Resist 5	Red
Resist 6	Green	Resist 6	Red
Resist 7	Green	Resist 7	Red
Resist 8	Green	Resist 8	Green
Resist 9	Green	Resist 9	Red
Resist 10	Green	Resist 10	Red
Resist 11	Green	Resist 11	Red
Resist 12	Green	Resist 12	Red
Resist 13	Green	Resist 13	Green
Resist 14	Green	Resist 14	Red
Resist 15	Green	Resist 15	Red
Resist 16	Green	Resist 16	Green
Resist 17	Green	Resist 17	Green
Resist 18	Green	Resist 18	Green
Resist 19	Green	Resist 19	Red
Resist 20	Green	Resist 20	Green
Resist 21	Green	Resist 21	Green
Resist 22	Green	Resist 22	Red
Resist 23	Green	Resist 23	Red
Resist 24	Green	Resist 24	Red
Resist 25	Green	Resist 25	Green
Resist 26	Green	Resist 26	Green

Results have been shown to be repeatable to 10%



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Tester requirements [1 of 2]

	Item	Specification
1	System performance	
a	Pumping speed	< 265 l/s
b	Vacuum quality checked multiple days	$P_{total} < 1.5 \times 10^{-7}$ mbar
c	Transfer time wafer ¹	< 15 min
d	Transfer time WS ¹	< 15 min
e	Wafer e-gun or photon stability over 2 hrs	< 5%
f	WS e-gun or photon stability over 2 hrs	< 5%
2	Dose to Clear	
a	Repeatability ²	<6%
b	Total test time	< 60 min

¹Productivity items

²Resist coating uniformity (1.5nm) and repro (60nm ± 3nm) required



Tester and cleaner requirements [2 of 2]

	Item	Requirement
3	Contamination growth ³	
a	Repeatability ⁴	<10%
b	Background contribution	<0.3 nm
c	Contamination growth regime	Contamination limited
d	Total test time ¹	< 90 min
e	Repeatability non cleanable	<25%
f	Background contribution non-cleanable (S, SOx)	≤0.1 at%
4	Cleaning	
a	Filament temperature	1800 °C < T ≤2000 °C
b	Sample temperature	≤ 60 °C
c	Background contribution to non-cleanables (S, SOx) Background contribution to non-cleanables (Sn,W, Zn)	≤ 0.6 at%±0.2 at% < 1.0 at%
d	Cleaning rate ¹	>10 nm/h
e	Cleaning time ¹	< 60 min

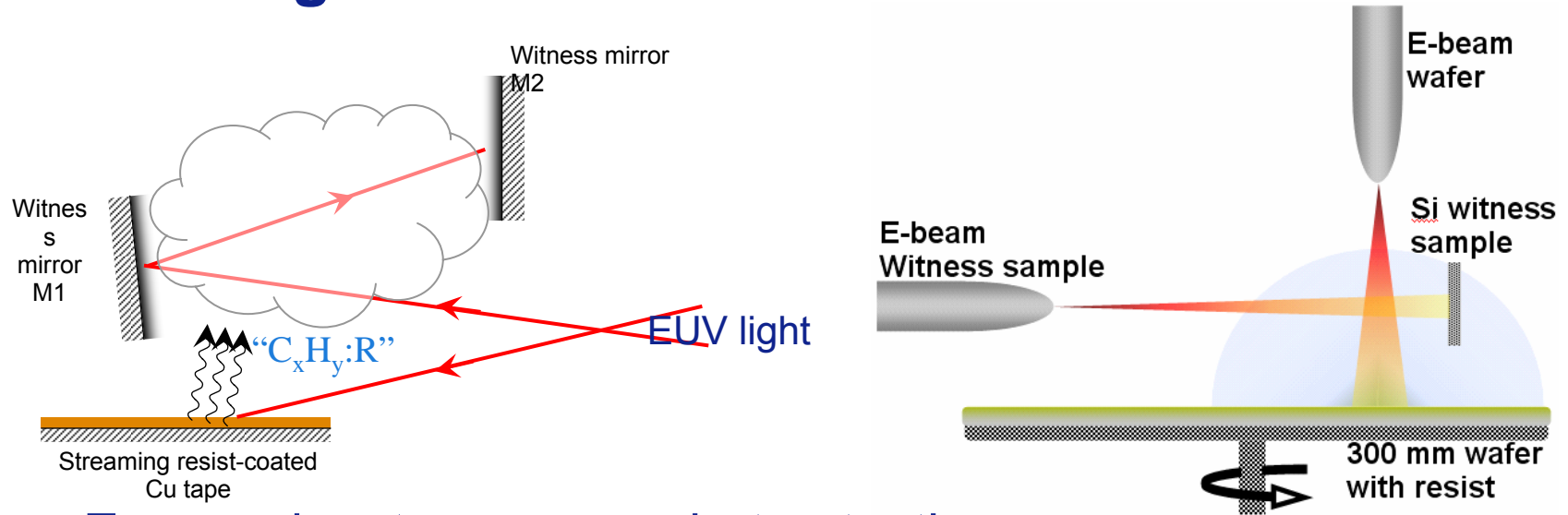
¹Productivity items

³Tested for both fast and slow resist

⁴Nominal wafer expose 60 min



E-beam test enables fast and low cost resist screening



- E-gun advantages over photon testing

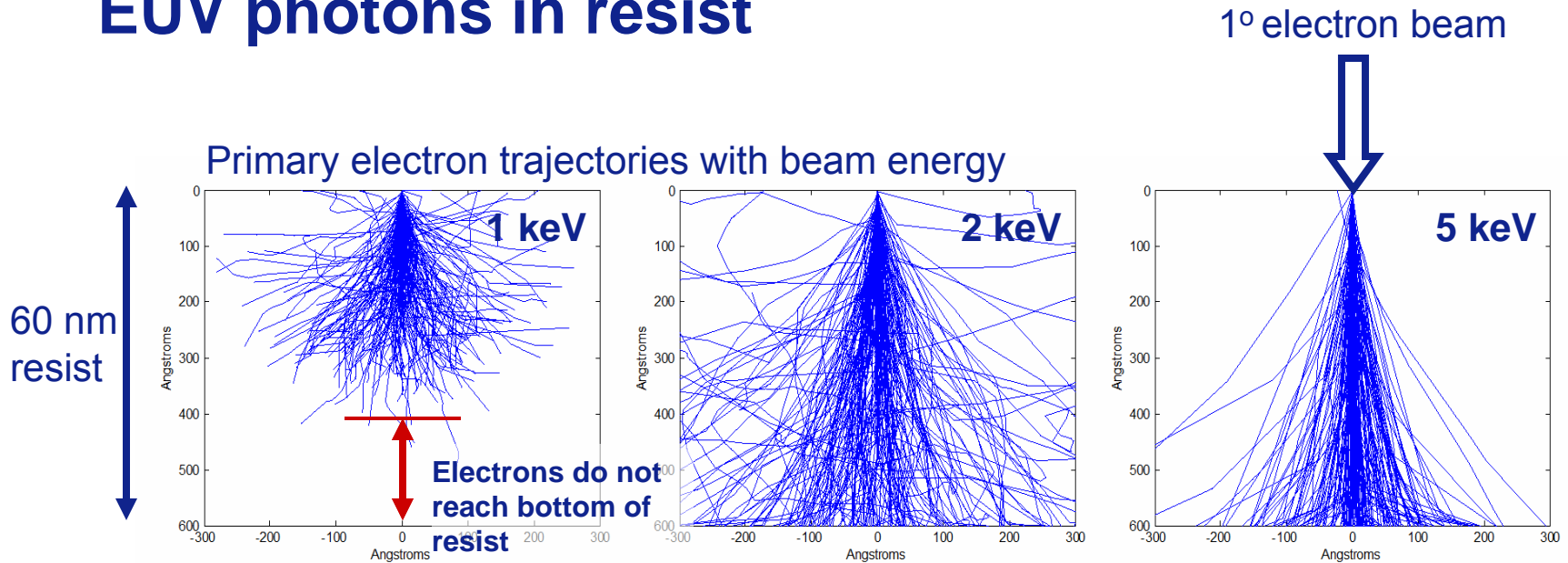
- Abundant intensity means contamination can be grown quickly
- Single wafer exposure therefore small amounts of resist is needed
- Easier maintenance (no EUV source)

Resist outgassing is caused by secondary electrons from either photons or electrons

- Photons travel through the resist, are absorbed, and create secondary electrons originating from the molecules of the substrate material
 - This triggers an avalanche of secondary electrons which in turn causes the resist decomposition and outgas
- Electrons are not absorbed but lose their energy by multiple collisions in the resist
 - This also creates an avalanche of secondary electrons which move through the resist which causes the decomposition and outgas
- Secondary electron emission has been studied extensively and the energy distribution for both photon and electron induced secondary emission from a Si substrate has the same shape and differs primarily in the number of secondary electrons produced
- Yield determines the number of secondary electrons and thus dose calibration, with electrons, is an important part of the testing to be sure that exposure is nominally at E_0
 - Dose to clear testing is done for each resist



E-beam energy at wafer is selected to match EUV photons in resist



- Electron trajectories are simulated using the screened Rutherford elastic cross section
- Energy spectrum of the secondary electrons mostly depends on the emitting material but not on the type or energy of the particles
- Only minor part of EUV photons are absorbed by resist
- *To match EUV exposure, a minimum e-beam energy of 2keV is required*

Fit for calibration resists is excellent regardless of the use of photons or electrons

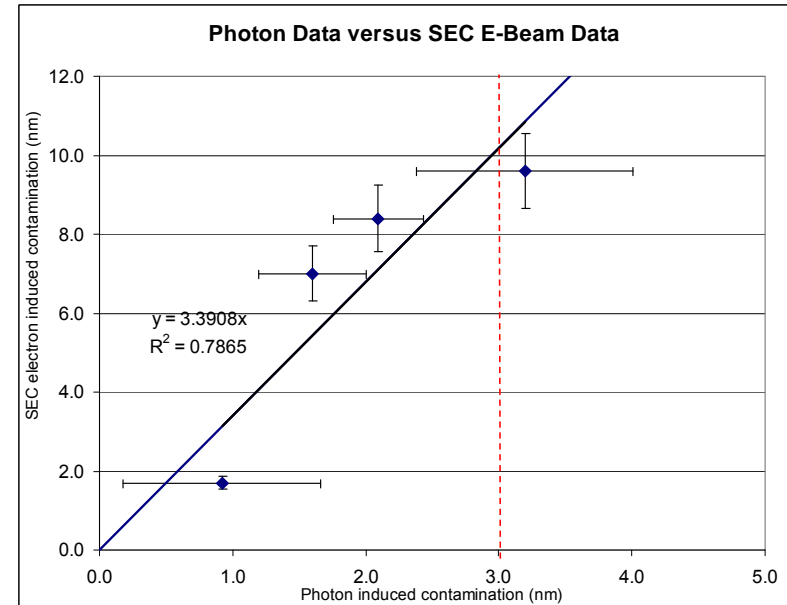
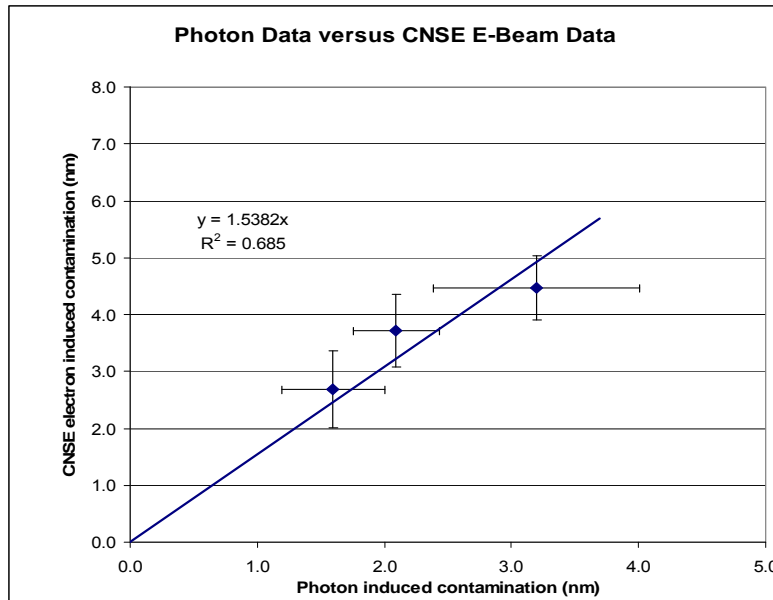
Wafer / WS	P/P	E/E	P/E	E/E
R²	NIST	LTJ SAT	CNSE	ASML
NIST	1	0.93	0.91	0.88
LTJ SAT	0.93	1	1.00	0.99
CNSE	0.91	1.00	1	1.00
ASML	0.88	0.99	1.00	1

- Both electrons and photons give similar results for resist exposure
- Key things that enable the good match are
 - Selection of e-gun energy
 - Tester cleanliness and geometry
 - Intensity at the WS
 - Good process control and metrology

P = Photons E = Electrons



Calibration curves have been made for each set up



- Linear fit for different resists is very good
- Calibration curve accounts for differences in processing, metrology and tester variation



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Summary status for resist outgas testing

- NIST, the end user of the first LTJ system, and CNSE have completed all of the qualification steps and are ready to test resists for compliance with NXE specifications
- IMEC continues to work on their plan towards completion this year and have completed several key steps
- Test report template has been shared with all who are doing testing and all who might receive test result reports, including all resist suppliers (see last sheet for points of contact at resist suppliers)



Data package check list for tester qualification

Data package	Data description
1 Facilities	a Specification resist processing (uniformity and repro)
	b Specification ellipsometer
	c Ellipsometry C or SiO ₂ on Si sample (fixed thickness cross ref)
	d Ellipsometry Si/Ru/C peak sample
	e Specification XPS
	f XPS Si / Ru / cleaned contamination ASML refence sample
2 Vacuum	a RGA spectrum of ultra clean vacuum with pressure reading
	b Pumping speed data of calibration mixture
Functionality	a Witness sample e-beam stability data
	b Wafer e-beam or photon stability data
3 Cleaning	a Cleaning process conditions
	b Sample temperature profile as a results of duty cycle
	c Cleaning background contribution
4 Qualification tests	a Contrast curve of specified resist to determine D2C
	b D2C exposure W2W reproducibility
	c D2C exposure within wafer uniformity
	d Exposed area and test timing contamination growth test
	e Reproducibility of contamination growth exposure
	f Contamination grown from background (total thickness)
	g Contamination grown from background (content)
5 Calibration	a Check outgassing limited contamination growth regime
	b Calibration exposures (3 - 4 resists)



Status of systems in qualification for NXE resist testing

Data package	Data description	LTJ SAT	CNSE	NIST	IMEC
1 Facilities	a Specification resist processing (uniformity and repro)	Done	Done	Done	Done
	b Specification ellipsometer	Done	Done	Done	Done
	c Ellipsometry C or SiO2 on Si sample (fixed thickness cross ref)	Done	Done	Done	Done
	d Ellipsometry Si/Ru/C peak sample	Done	Done	Done	Done
	e Specification XPS	Done	Done	Done	Done
	f XPS 3-layer sample (SiN/TiN/SiN)	Not applicable			
	g XPS Si / Ru / cleaned contamination ASML reference sample	Done	Done	Done	In process
2 Vacuum	a RGA spectrum of ultra clean vacuum with pressure reading	Done	Done	Done	Done
	b Pumping speed data of calibration mixture	Done	Done	Done	Done
	Functionality				
a Witness sample e-beam stability data	Done	Done	Done	Done	
b Wafer e-beam or photon stability data	Done	Done	Done	Done	
3 Cleaning	a Cleaning process conditions	Done	Done	Done	Done
	b Sample temperature profile as a result of duty cycle	Done	Done	Done	Done
	c Cleaning background contribution	Done	Done	Done	Done
4 Qualification tests	a Contrast curve of specified resist to determine D2C	Done	Done	Done	Done
	b D2C exposure W2W reproducibility	Done	Done	Done	Done
	c D2C exposure within wafer uniformity	Done	Done	Done	Done
	d Exposed area and test timing contamination growth test	Done	Done	Done	Done
	e Reproducibility of contamination growth exposure	Done	Done	Done	In process
	f Contamination grown from background (total thickness)	Done	Done	Done	Done
	g Contamination grown from background (content)	Done	Done	Done	Done
5 Calibration	a Check outgassing limited contamination growth	Japan	Done	Done	Done
	b Calibration exposures (3 - 4 resists)	Done	Done	Done	Done

Planned
 Done
 In process
 NOK



Show test report template

