NXE resist outgas testing update

Noreen Harned

20 October 2011

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 reuirements 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 ≤10% for the optical column over the lifetime (~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 ≤0.16%

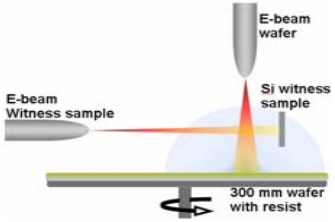
Presentation contents

- 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

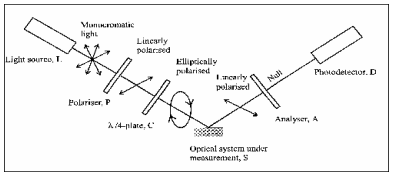
Grow contamination



Tester

2

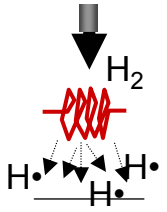
Measure contamination film thickness



Ellipsometry

3

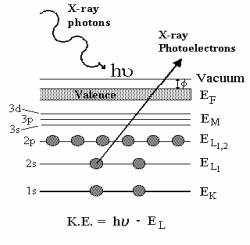
Clean contamination



H* Filament

4

Measure non-cleaned contamination



XPS

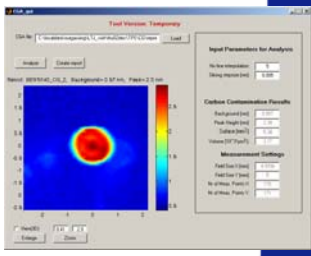
- Ellipsometry measurements allow qualification of *cleanable contamination*

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

ASML

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 mm² area
  - Spectroscopic data Psi (Y) and Delta (D) is obtained
- Detection limit/accuracy 0.1nm/±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

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

NXE3300

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

Results have been shown to be repeatable to 10%

Presentation contents

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

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 x 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

[1]Productivity items

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

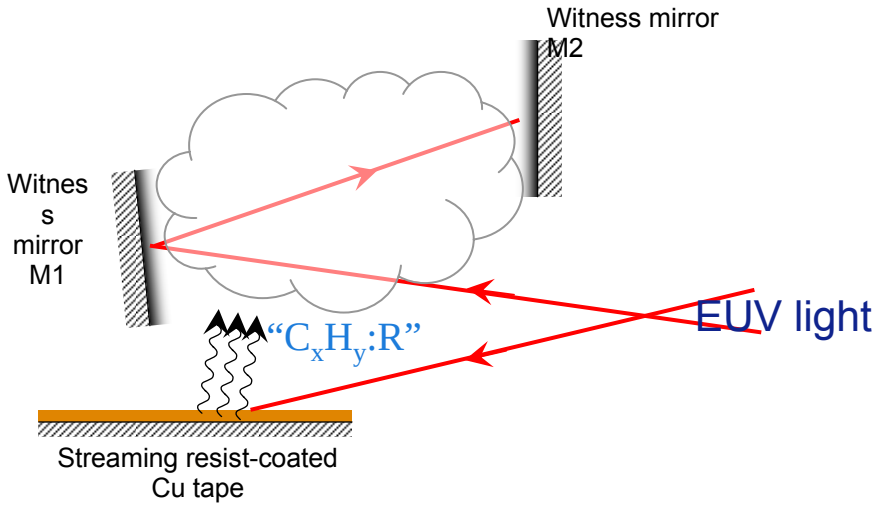
ASML

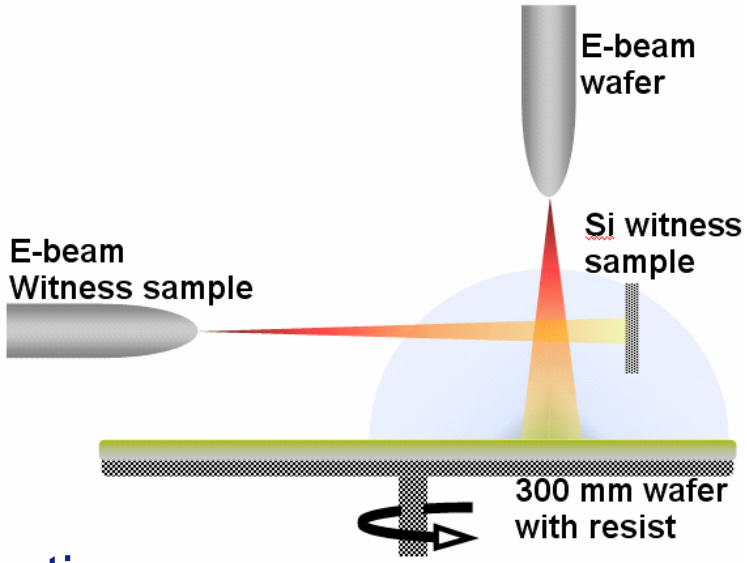
Tester and cleaner requirements [2 of 2]

	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

[1]Productivity items **[3]Tested for both fast and slow resist** **[4]Nominal wafer expose 60 min**

E-beam test enables fast and low cost resist screening



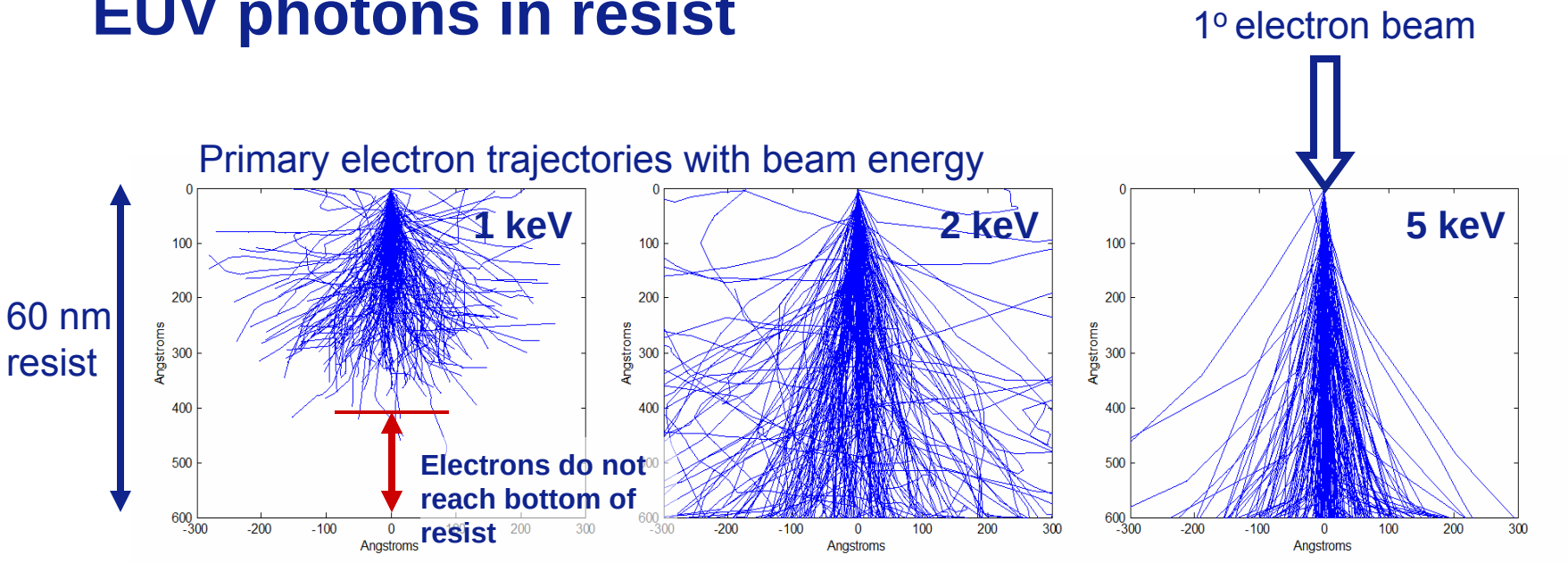


- E-gun advantages over photon testing
  - Abundant intensity means contamination can be grown quickly
  - Single wafer exposure therefore small amounts of resist is needed
  - Easier maintenance (no EUV source)

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 loose 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_o
  - 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*

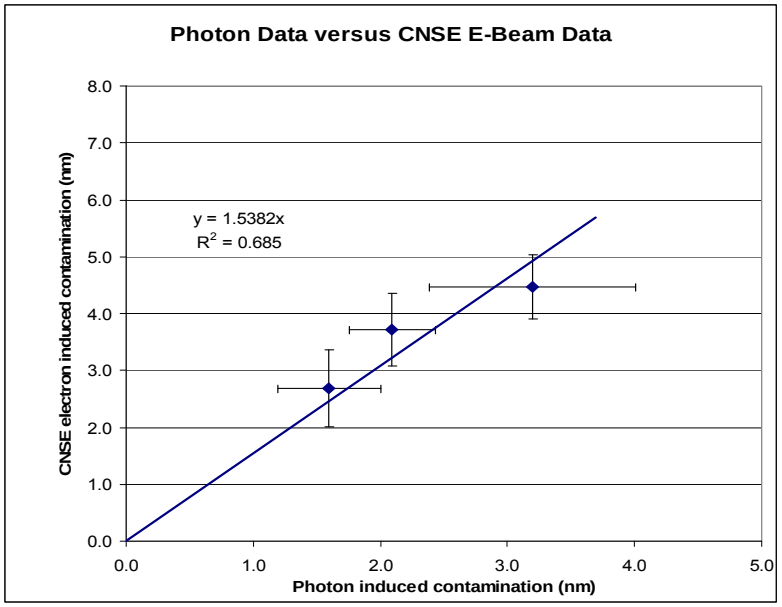
Fit for calibration resists is excellent regardless of the use of photons or electrons

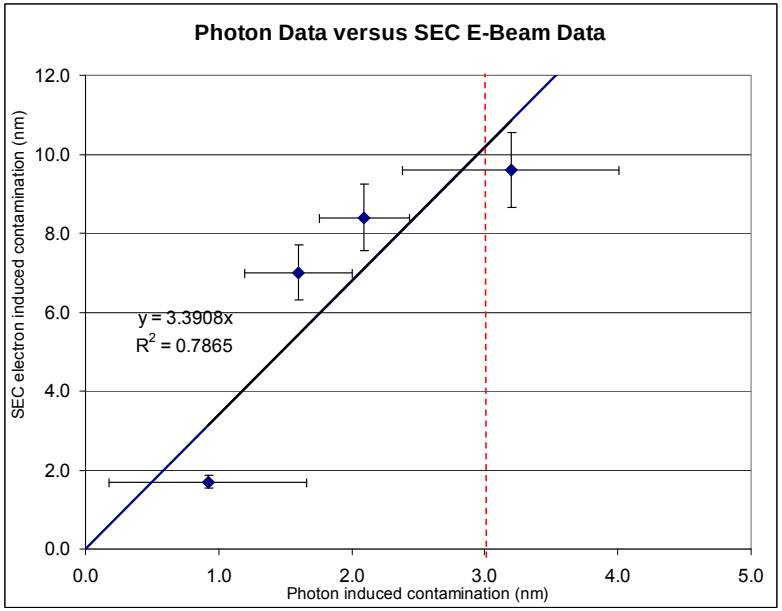
Wafer / WS	P/P	E/E	P/E	E/E
R^2	**NIST**	**LTJ SAT**	**CNSE**	**ASML**
NIST	**1**	0.93	0.91	0.88
LTJ SAT	0.93	**1**	1.00	0.99
CNSE	0.91	1.00	**1**	1.00
ASML	0.88	0.99	1.00	**1**

- 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

Presentation contents

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

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 SiO2 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	Reproducibilty 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)				
		b	Specification ellipsometer				
		c	Ellipsometry C or SiO2 on Si sample (fixed thickness cross ref)				
		d	Ellipsometry Si/Ru/C peak sample				
		e	Specification XPS				
		f	XPS 3-layer sample (SiN/TiN/SiN)	Not applicable			
		g	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 result 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	Reproducibilty 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	Japan			
		b	Calibration exposures (3 - 4 resists)				

Planned **Done** **In process** **NOK**

ASML

Show test report template