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EUV Platform Readiness

Progress and Challenges

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2014 International Workshop on EUV Lithography
Maui, Hawaii June 25, 2014

Agenda

- **EUV overview**
- Source power and availability technology development

EUV overview: Progress toward production insertion

- Multiple customers are qualifying EUV for insertion at the 10 nm logic node
- For process development, customers typically require 100 wafers per day, increasing to 500 wafers per day on average for production qualification
- We have provided customers with that process development capability
- In 2016 we will provide our customers with the productivity needed for volume production


NXE:3300B

- 6 NXE:3300B systems fully qualified and shipped to customers
- 5 more NXE:3300B systems being integrated
- 4th generation NXE system (NXE:3350B) integration ongoing

NXE:3300B systems are exposing at customer sites

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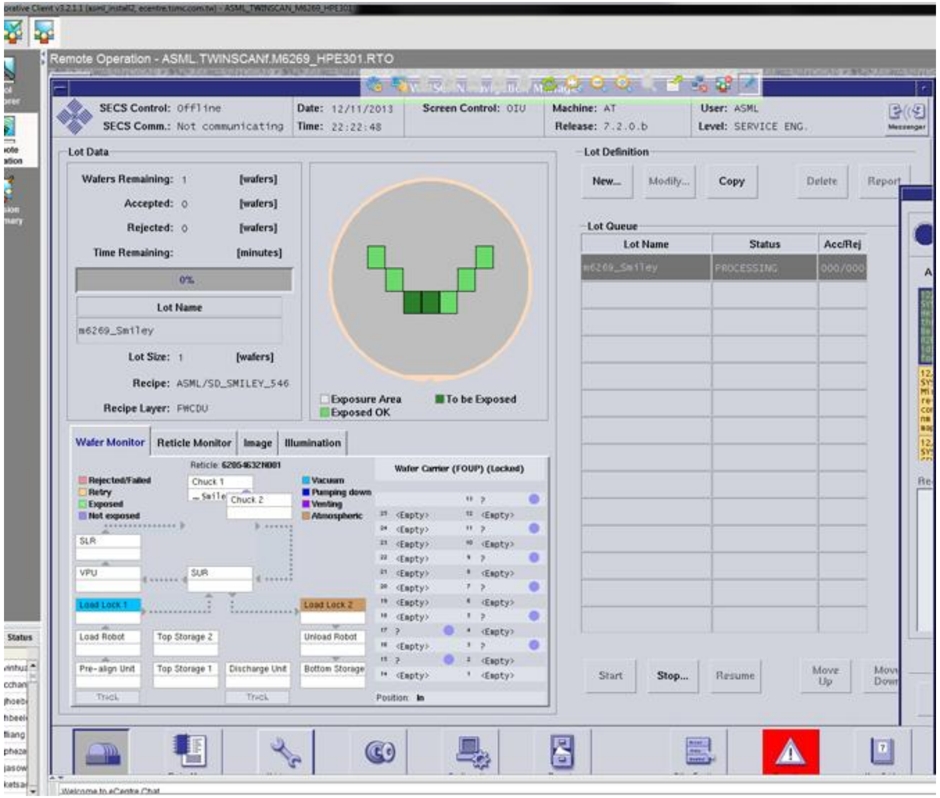
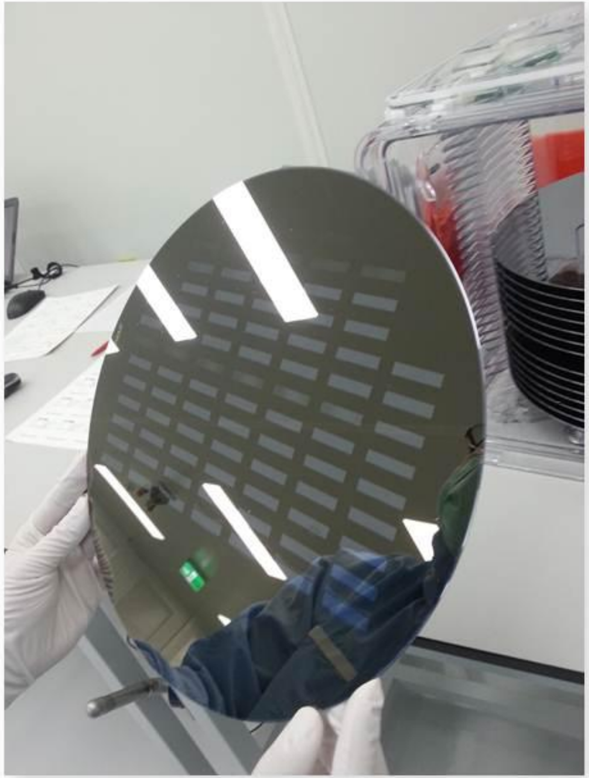
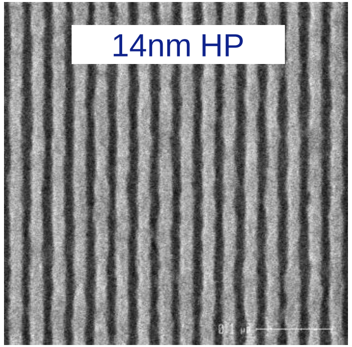
Slide 4
June 25, 2014

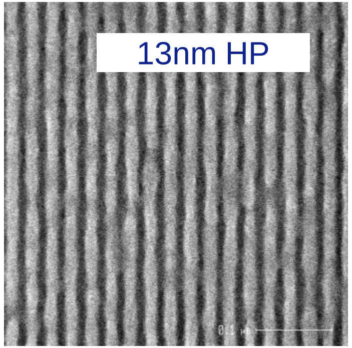




NXE:3300B resolution for single exposures

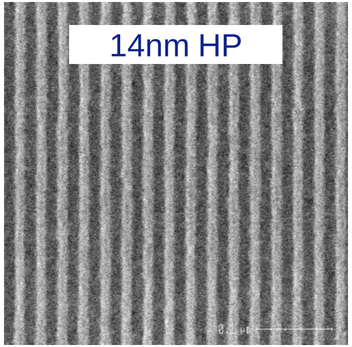
Dense line spaces, regular and staggered contact holes

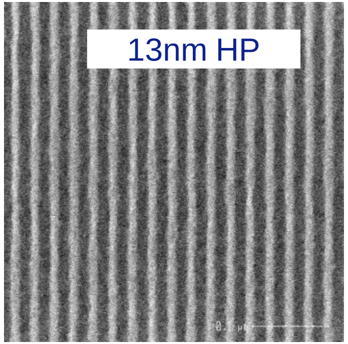




Dipole30,

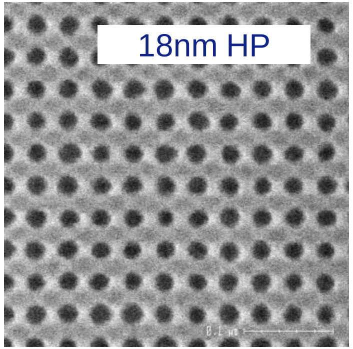
Chemically Amplified Resist (CAR)

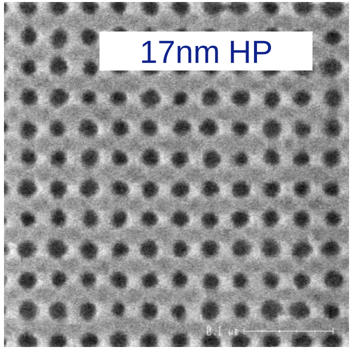




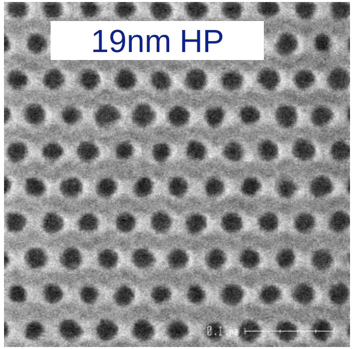
Dipole45,

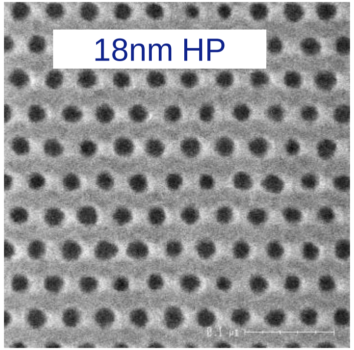
Inpria Resist





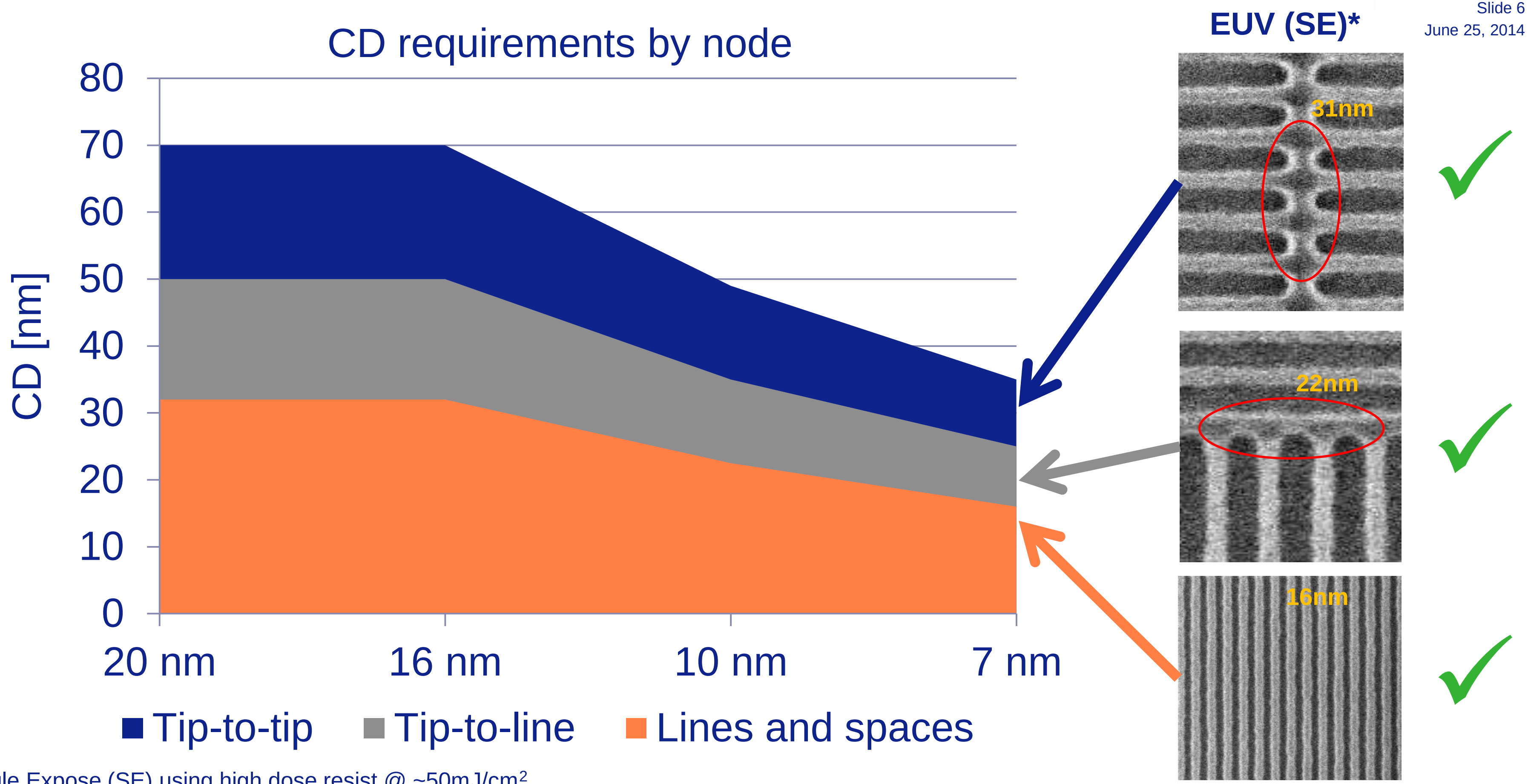
Quasar 30 (CAR)





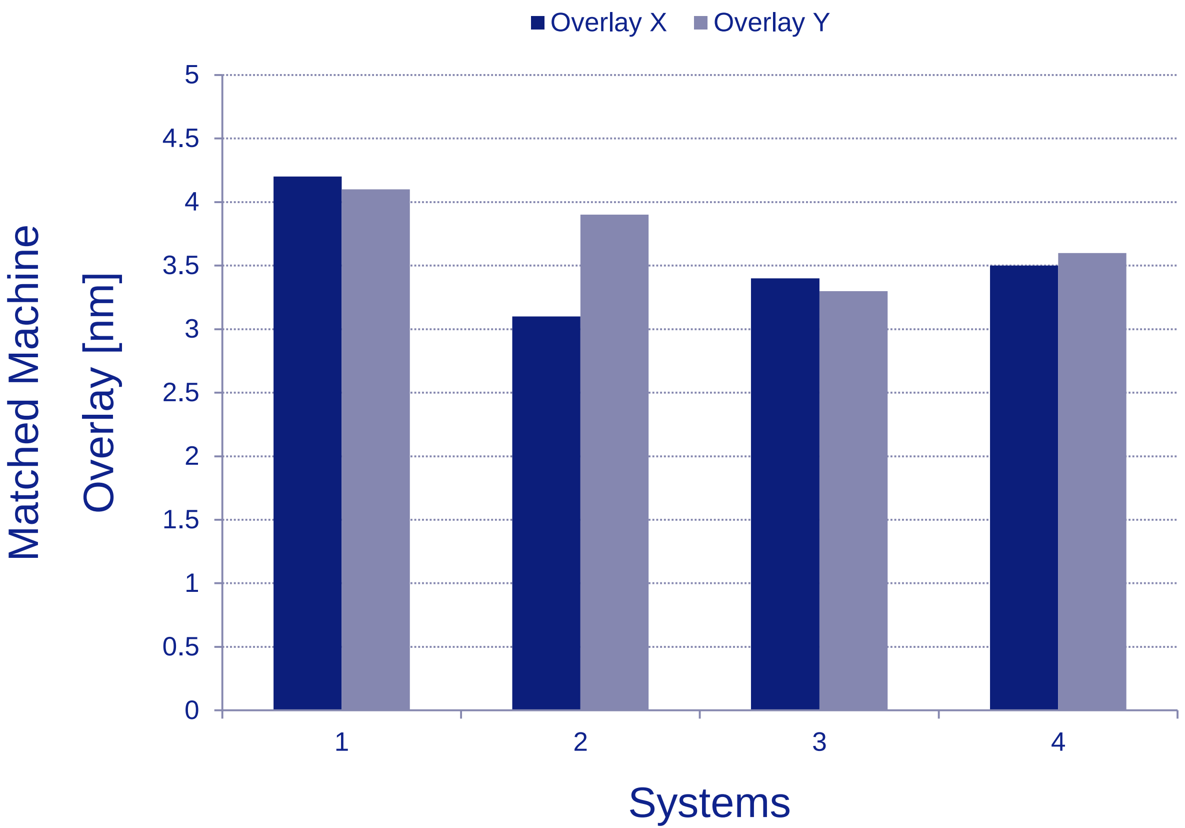
Large Annular (CAR)

EUV meets aggressive 2D logic imaging requirements



* Single Expose (SE) using high dose resist @ ~50mJ/cm^2

Good matched machine overlay performance on multiple systems (NXE:3300B to immersion)

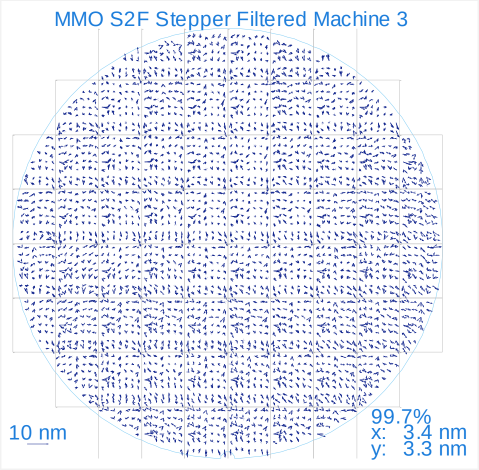


Full wafer

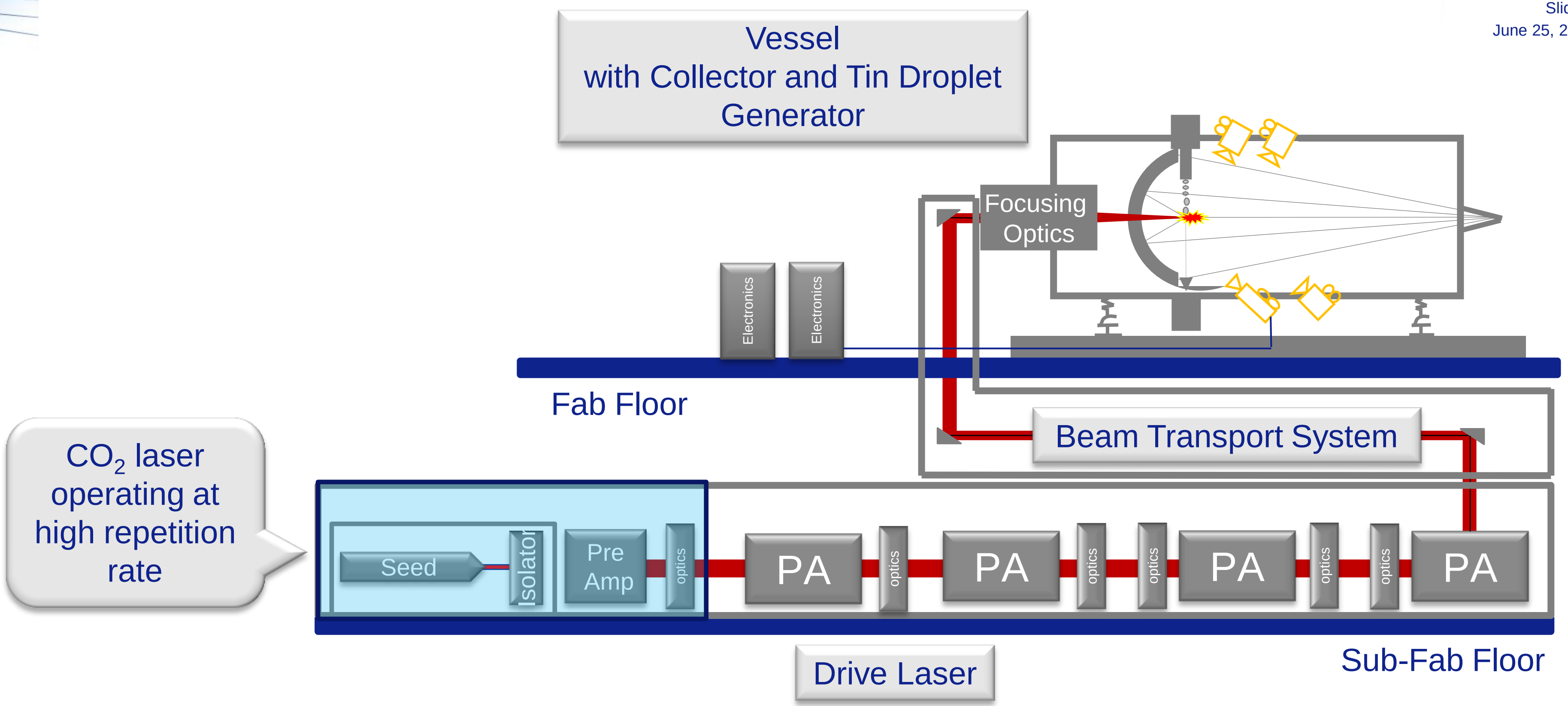
Matched Machine Overlay

NXE:3300B – NXT:1950i

No subrecipes used



Laser Produced Plasma (LPP) source architecture



Ramping source production for NXE:3300B vessels

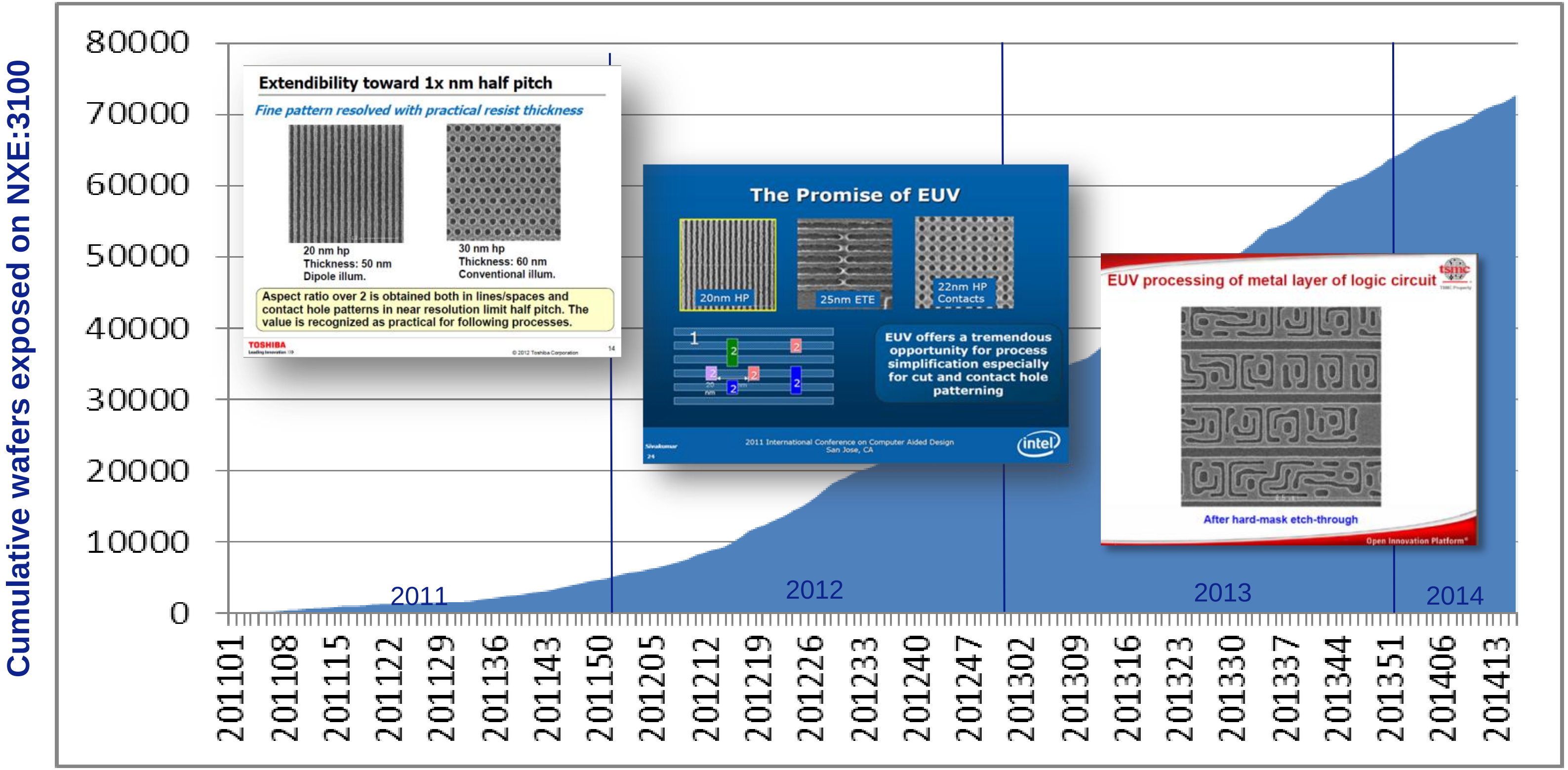
Multiple development and integration sources supporting NXE:3300B source production

NXE:3300B
Drive Laser

NXE:3300B
Source

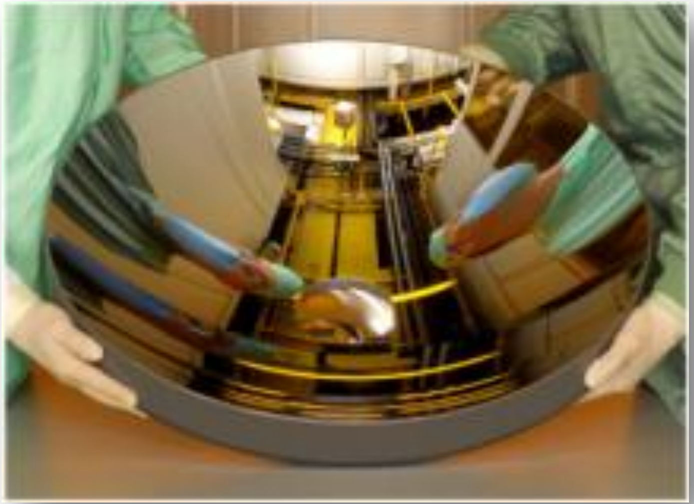
NXE:3100 continues to be used for cycles of learning

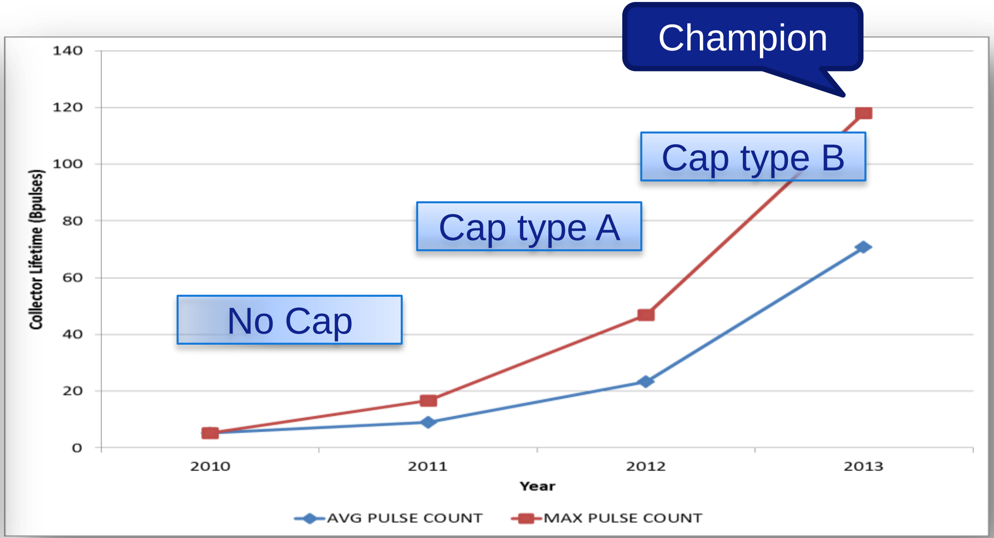
6 systems operational with source availability >70%



NXE:3100: collector lifetime is key to high availability

Field collector performance improved with changes in capping layer technology and vacuum control





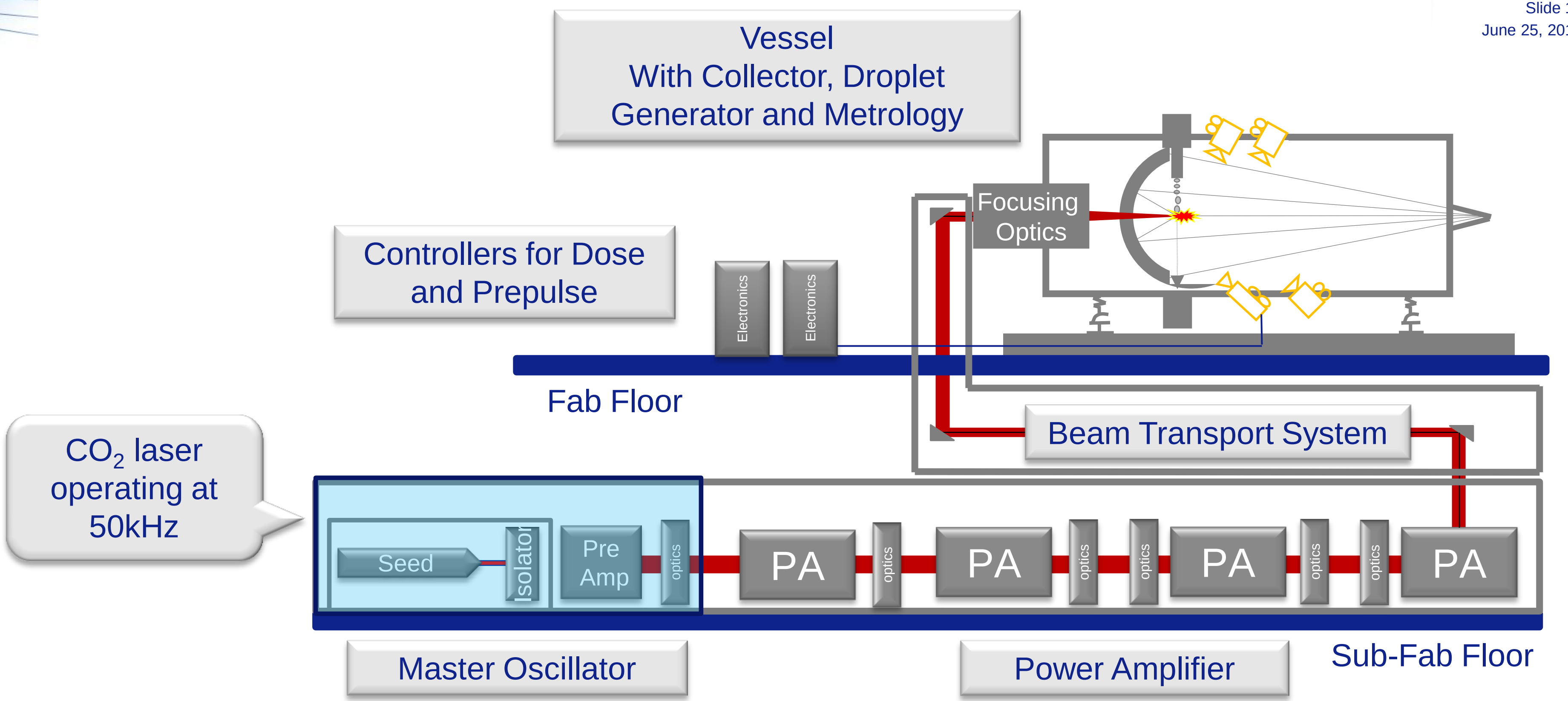
- 5steradian near-normal incidence graded multilayer coated collector
- Collector reflectivity maintained using hydrogen to prevent ion damage and tin vapor deposition

- 70 Gpulse average lifetime in 2013 for NXE:3100 field sources
- Initial usage ~10Gpulse per month
- Lifetime requirement >100Gpulse in high volume use

Agenda

- EUV overview
- **Source power and availability technology development**

MOPA Prepulse LPP source architecture for NXE:3300B



MOPA - Master Oscillator Power Amplifier

Source power and availability drive productivity

Technology development work is ongoing to improve all aspects

Source power	Drive laser power
	Conversion efficiency
	Dose margin
	Optical transmission
Source availability	Automation
	Collector protection
	Droplet generator reliability & lifetime
	Drive laser reliability

Focus of today's presentation

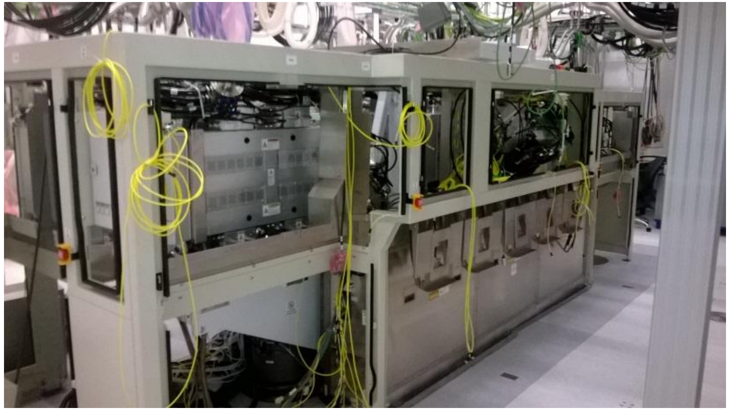
Source power scaling

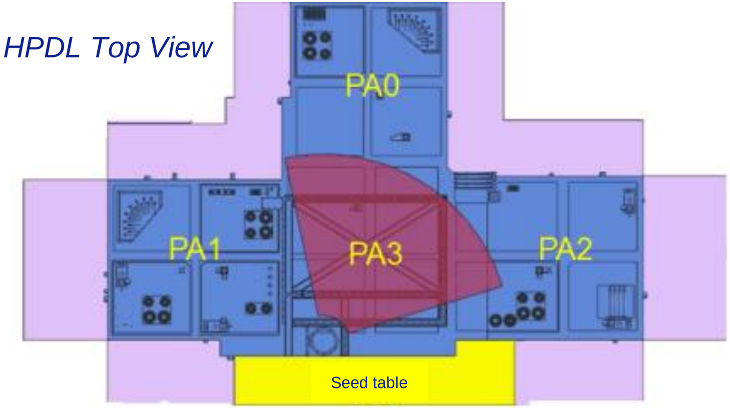
Scaling parameter			
EUV Power in Burst (W)	40	80	250
Laser Power (kW)	20	26	43
Conversion Efficiency (%)	2.5	3.5	4.5
Dose margin (%)	35	20	10

Key scaling parameters are:

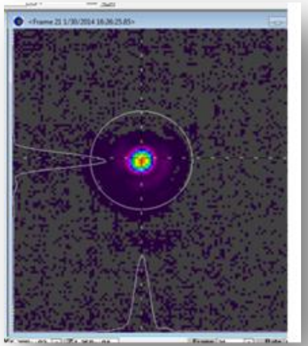
- *Laser power*
- *Conversion efficiency*
- *Dose margin*

Drive laser: High-power amplifier chain validated

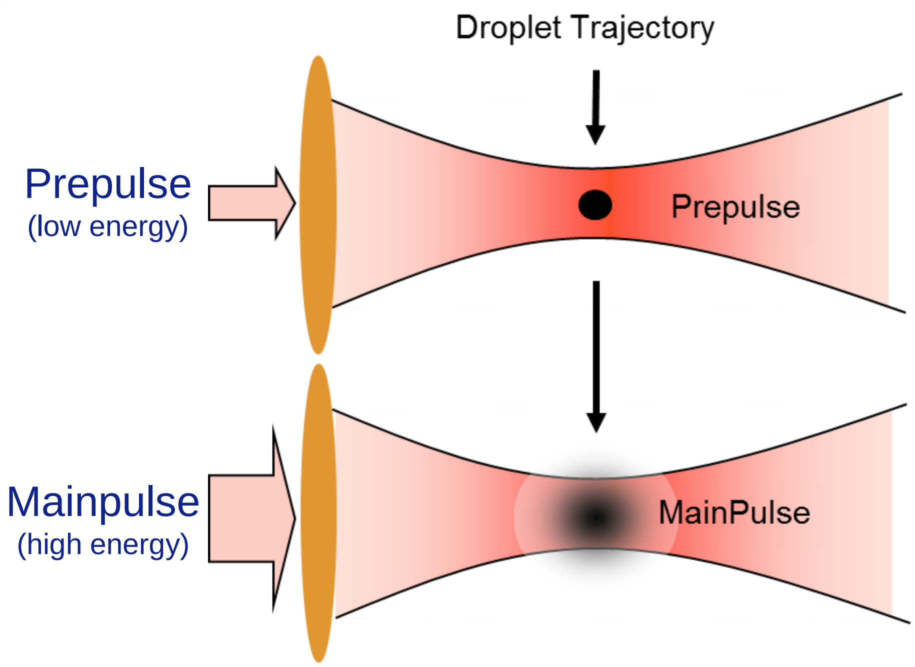




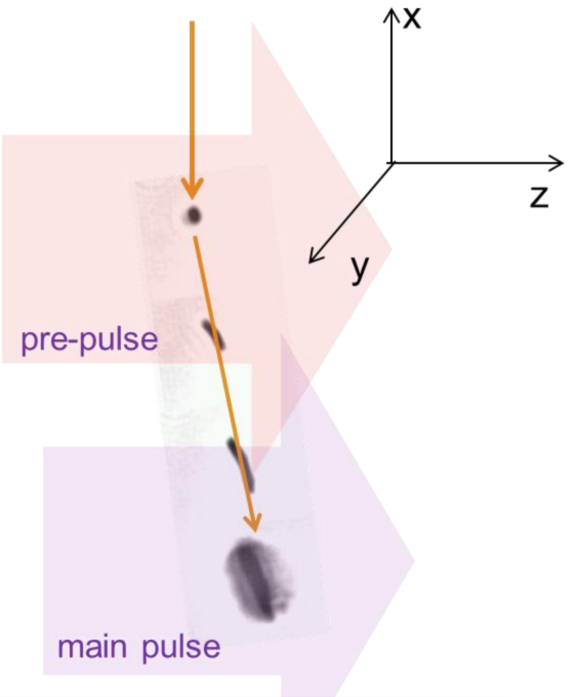
- First HPDL prototypes delivered and integrated with current seed table
  - >30kW total CO_2 power
  - Good beam quality
- Together with new seed system ➔ higher EUV power



Conversion efficiency: Optimizing pre-pulse to create a more efficient target



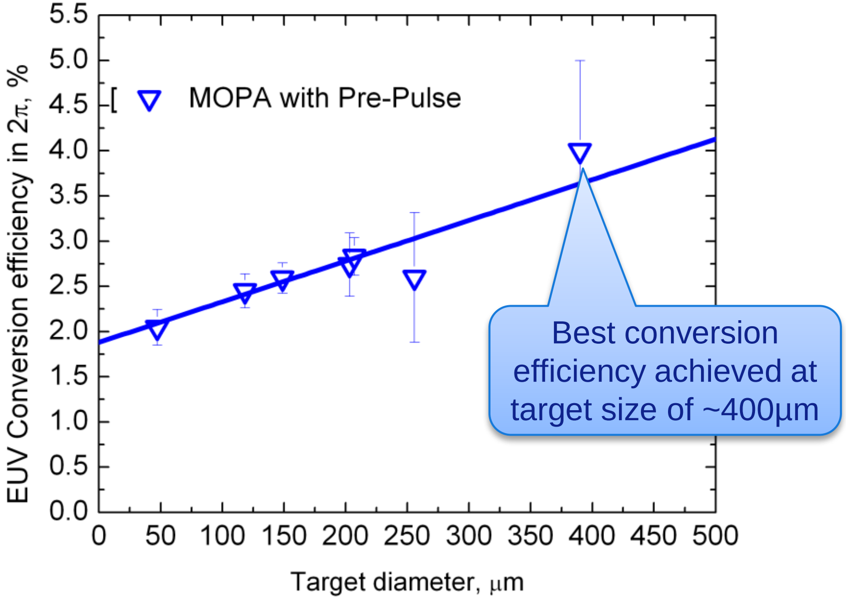
Target expansion fills main pulse beam waist

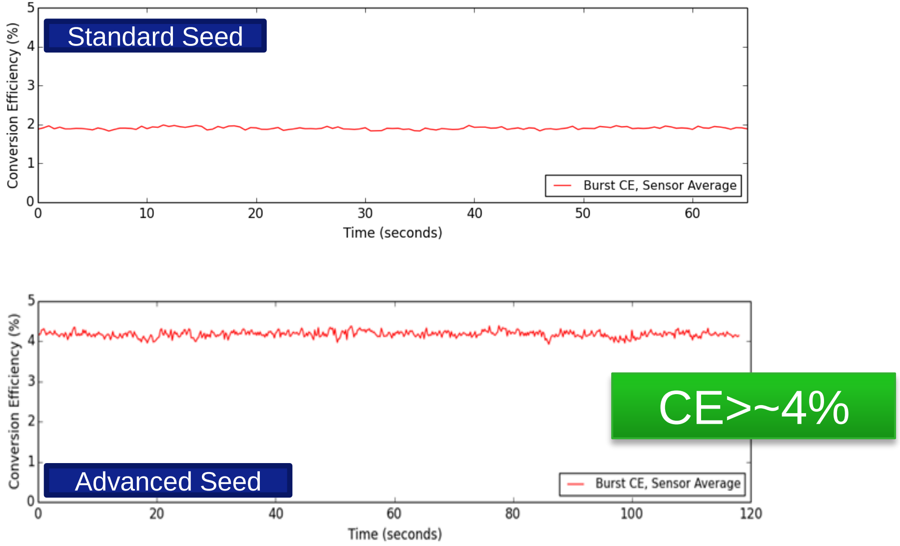


Target shape changes from droplet to disk

High CE demonstrated with optimized pre-pulse

~4% conversion efficiency achieved at high duty cycle



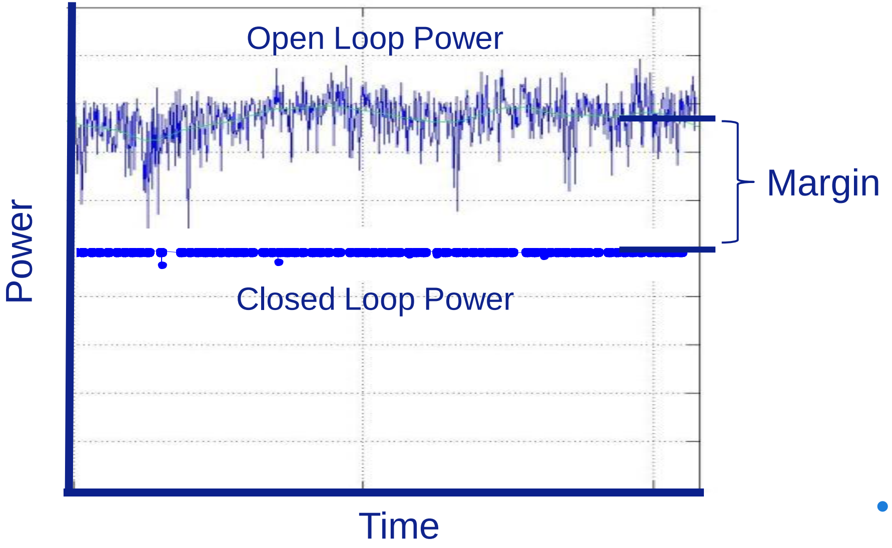


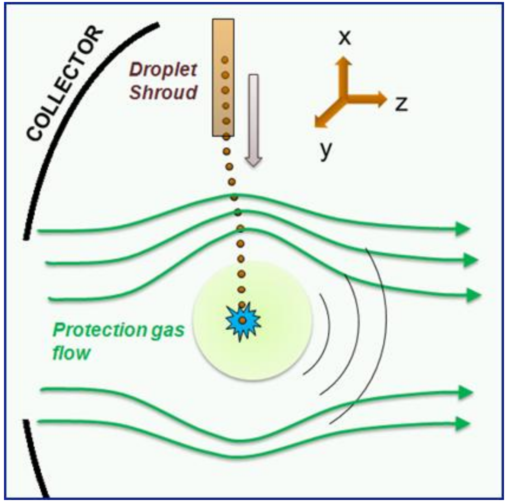
High CE requires control of:

- Target conditioning
- Targeting dynamics
- Focus control

Data taken on MOPA Prepulse development source

Dose margin: Closing the gap between 'open loop' and stabilized power





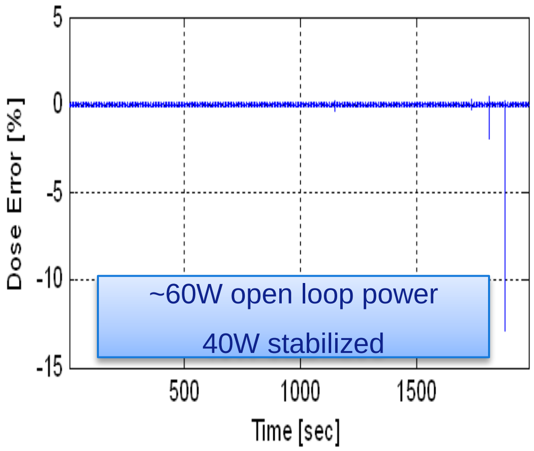
- Margin is the difference between unstabilized open loop power and stabilized closed loop power
- Required for dose control

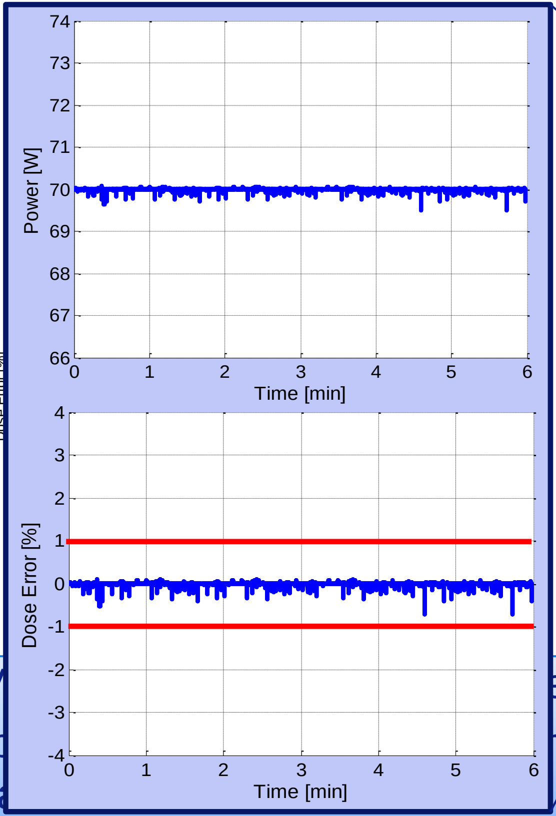
- Plasma and gas-dynamic forces distort droplet trajectories causing mis-targeting, low CE and energy instability
- Controls that compensate for these forces enable closed loop operation with reduced margin

Advanced controller demonstrated at <10% dose margin

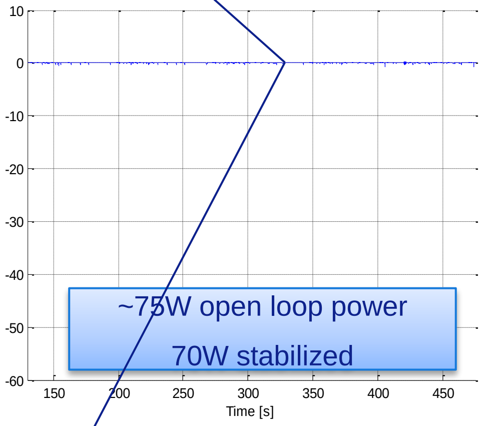
Existing controller: good performance at ~35% margin

Current controller
35% dose margin: In-spec





EUV Stabilization controller
6% dose margin: In-spec



- Comparison: EUV ... er vs current controller
- Maximizing availab ... margin using advanced dose control softwa...

Tests on MOPA/Pre-pulse development source

Source power and availability drive productivity

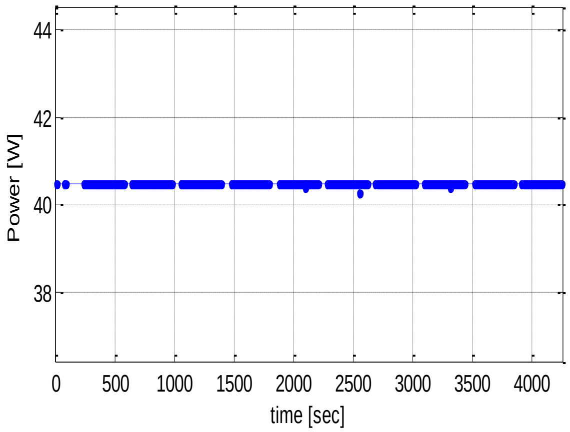
Technology development work is ongoing to improve all aspects

Source power	Drive laser power
	Conversion efficiency
	Dose margin
	Optical transmission
Source availability	Automation
	Collector protection
	Droplet generator reliability & lifetime
	Drive laser reliability

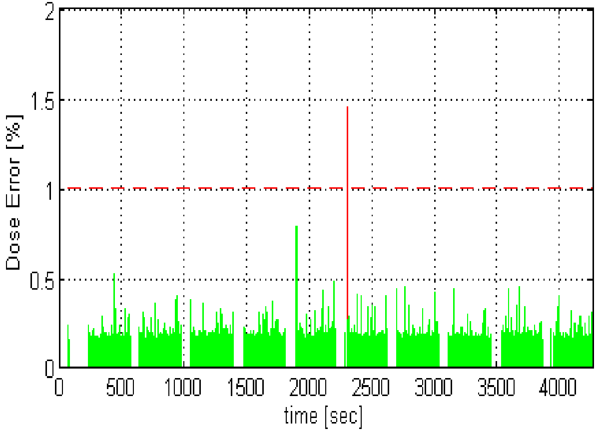
Focus of today's presentation

Automation: Stable power, good dose control

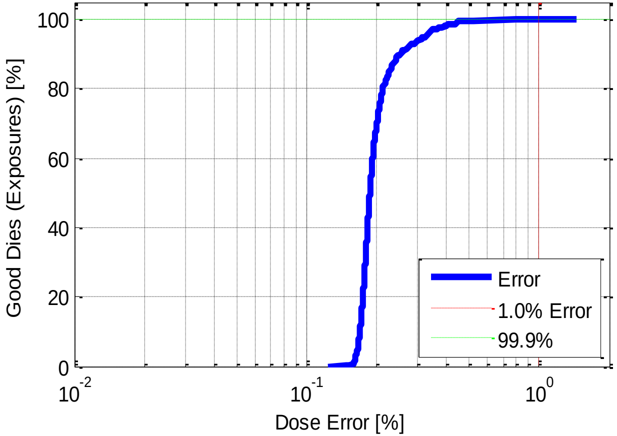
NXE:3300B stand-alone source under full automation for improved availability



~40W stable power
(x, y, z, t and E loops closed)



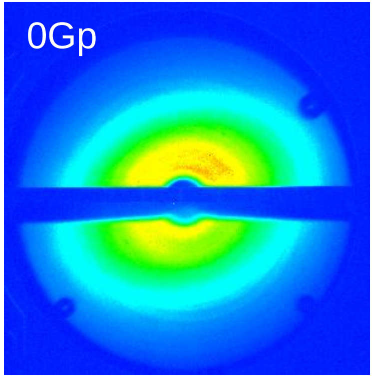
Simulated wafer lot exposures at $30mJ/cm^2$ resist dose



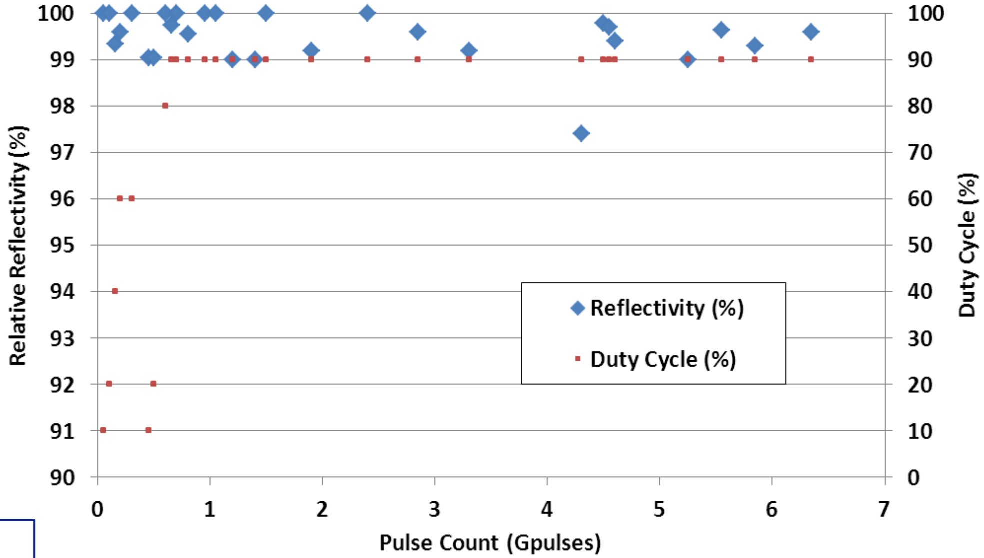
99.9% die yield
(simulated)

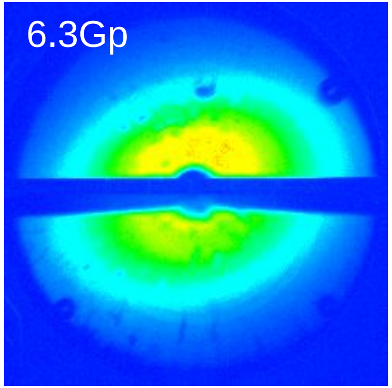
No collector reflectivity degradation after >5 Gpulses

NXE:3300B source collector protection test, all control loops closed



Far-field EUV image
Initial





Far-field EUV image
after 6.3Gp

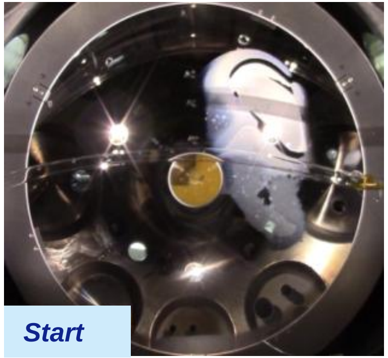
NXE:3300B stand-alone source operating in San Diego

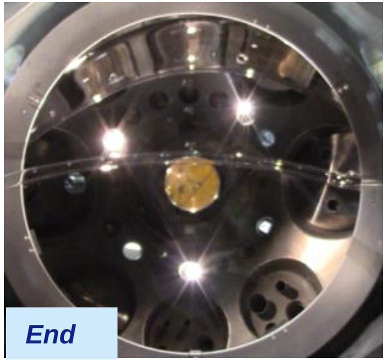
- ~40W, 90% EUV duty cycle
- All control loops closed
- Simulated wafer exposure lots at 25mJ/cm^2 dose

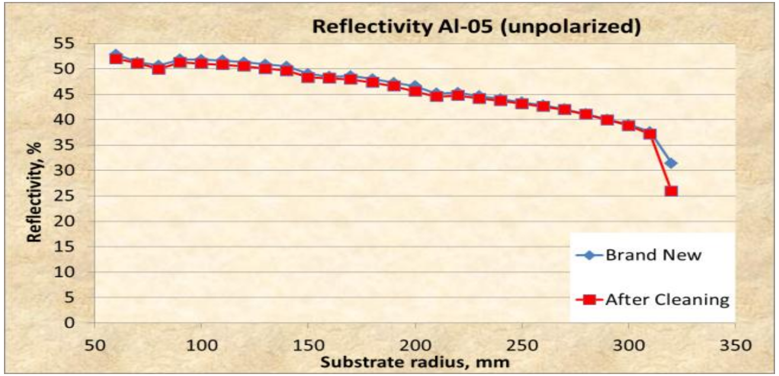
~500 simulated wafer exposures over 6.3Gpulses

In-situ collector cleaning

Effectiveness of product configuration confirmed



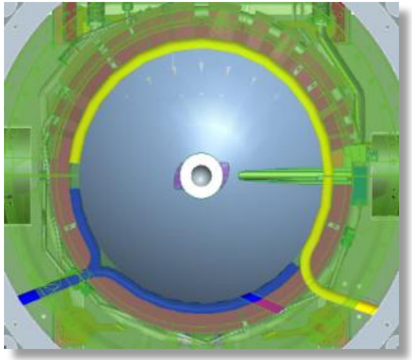


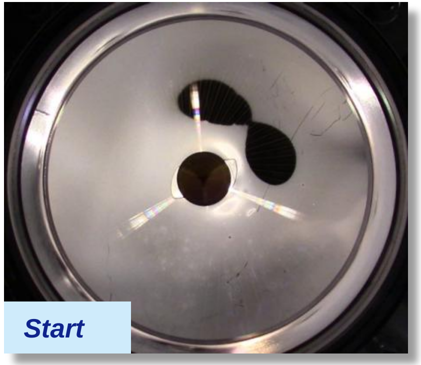


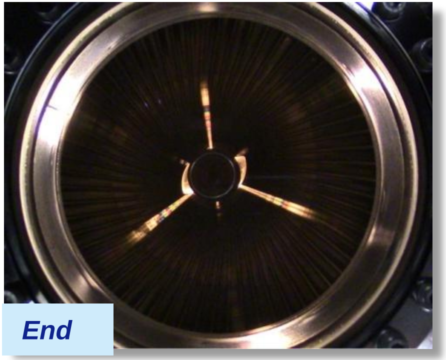
Reflectivity restored within 0.8% of original

Cleaning in off-line MOPA Prepulse development vessel

Field collector cleaned in NXE:3300 source vessel test rig







Off-line cleaning using NXE:3300B source vessel with product configuration hardware

Summary: Source power and availability technology development for improved productivity

Source power	Drive laser: high-power amplifier chain validated
	High conversion efficiency of ~4% demonstrated
	Dose margin <10% with advanced controller demonstrated
	Optical transmission
Source availability	Full automation with good dose control demonstrated
	Collector protection: protection & in-situ cleaning validated
	Droplet generator reliability & lifetime
	Drive laser reliability

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