EUVL

EXTREME ULTRAVIOLET LITHOGRAPHY

Overview European EUVL programme

Rob Hartman

3rd International EUVL Symposium

Miyazaki, 3 November, 2004

Agenda

- When EUV?
- European programme in risk areas
  - **Source**
  - **Tool & Optics**
  - **Reticles**
  - **Resist**
- Conclusions

When

- EUV introduction at 32 nm node
  - **production start 2009**
  - **pilot production in 2007**
  - **alpha tool in 2005**

EUV tool specification roadmap

	Process development tool	Pilot production	Volume production
EUV Tool	**AD (10)**	**EUV (30)**	**EUV (80)**
1st Shipment	2005	2007	2009
NA Range	0.15 to 0.25	0.15 to 0.25	0.15 to 0.25
Imaging - Dense Lines	50 nm (->40 nm*)	35 nm	32 nm
- Isolated Lines	40 nm (->30 nm*)	25 nm	18 nm
- iso/dense contacts	65 nm (->55 nm*)	45nm	40nm
Overlay	12 nm	8 nm	6 nm
Throughput	< 10 WPH	30 WPH	80 WPH

* with POB Upgrade

Notes:
CDU = 10 % Resolution
Throughput is at 300 mm, 16 x 32, 125 shots, 5 mj/cm

ASML

Agenda

- When EUV?
- **European programme in risk areas**
  - **Source**
  - **Tool & Optics**
  - **Reticles**
  - **Resist**
- Conclusions

Challenges EUV for high volume manufacturing * as identified in EUVL Symposium Antwerp 2003

- Source
  - **for single stage tool: power required = 115 Watt (to support > 80 wph)**
  - **lifetime condensor optics, required 5´10^{11} shots (= 5 year continuous use @ 10 kHz)**
- Optics lifetime
  - **required: 30,000hr/10yrs**
- Optics fabrication
  - **requirement: figure 0.15 nm, MSFR: 0.12 nm, HSFR: 0.15 nm**
- Mask defects
  - **requirement 0.003 defects/cm^2 (<0.5 defects/active area) of size >40 nm**
- Resist sensitivity
  - **requirement < 5mJ/cm^2 and Line Width Roughness < 2nm**

requirements are for 32nm volume production tool

European programme

2001 – 2002 – 2003 – 2004 – 2005 – 2006 –

~1700 person-years

STM, Infineon, Philips, Motorola, ASML, Zeiss, SAGEM, Xenocs, IMEC, LETI, CNRS, INFM, ASML, Clariant, Zeiss, Eldim, Sagem, Alcatel, Incam, Leica, SAGEM, Schott, SESO, Sigma-C, Sopra, Unaxis, Xenocs, IMS-chips, Lorxn, XTREME Philips, FhG, Gremi, Thales, IOE, Jenoptik, Aixuv, FOM, Innolite

~300 person-years

ASML, Zeiss, SAGEM, Xenocs, TNO-TPD, AMTC, Philips Extreme UV, Xtreme Technologies, FOM, ENEA, Phystex, EPPRA, ISAN, Imagine Optic, FhG - ISB, CNRS, Sigma-C, CEA-LETI, Uni. Bielefeld, Uni. Mainz, Focus, Uni.Delft, CLARIANT, CNRS, IMEC, IMEL, Elettra

- EUV programme in Europe started in 1997 with ESPRIT project EUCLIDES
- Since 1999 National programmes in France, Germany and the Netherlands
- Followed in 2001 with MEDEA+ project cluster and IST project SOARING
- and in 2004 with the FP6 Integrated Project “more Moore”

European EUV programs address critical issues for tool, mask, and process

Critical issues [1)]	MEDEA+ investigates	More Moore investigates
Source power and lifetime including condenser optics lifetime	**Xenon** LPP and Discharge	**Sn, maybe other materials,** solutions for 120 W
Availability of **defect free masks**	**Masks for 50-nm node**	**Masks for 22-nm node:** PSM
Reticle protection during storage, handling, and use	Development / standardisation of **reticle holder**	Particle research **in machine**
Projection and illuminator **optics lifetime**	Secure **alpha demo tool lifetime requirements**	Secure **production lifetime requirements**
Resist resolution, sensitivity, and LWR	Resist **selection study**	**Fundamental research** on resist properties
Optics quality for 32-nm node	Roughly **50-nm node** specs	**Flare reduction, active optics, illumination system**

1) Critical issues as identified in EUV workshop Antwerp 2003

Agenda

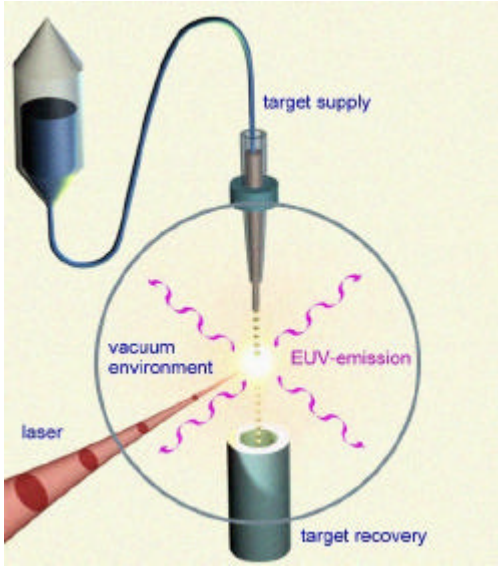
- When & wh
- European p
  - Source

	computer simulations and experimental results
SoP12	The SOARING micro plasma pulse discharge EUV source
SoP13	All-permanent magnet ECR plasma for EUV light
SoP14	Recent Improvements on AIXUV's EUV-LAMP
SoP15	Laser-induced EUV source for metrology
SoP16	Key issues for the development of a modular laser-plasma source for EUV lithography
SoP34	Modeling laser-plasma sources for EUV
SoP41	Ultra-compact and flexible noble gas filament and spray source for EUV and XUV generation
SoP44	Ionization & Excitation Rates of Multicharged Ions in Non-equilibrium Plasma of EUV Source
SoP45	A Black Box Modelling Engine for EUV Plasma sources
ReP02	Status update EXCITE, the MEDEA+ Extreme UV Consortium for Imaging Technology
MeP01	Precise at-wavelength metrology with the EUV tube
MeP02	Tools for EUVL-source characterization and optimization
MuP09	High-temperature MoSi2/Si and Mo/C/Si/C multilayer mirrors
OpP01	Collector Optics for EUV Lithography
ToP02	Radiation driven plasma
LnP01	Stopping ions, clusters and out-of-band radiation by Kr for clean EUV sources

o01	Next generatio Applications
o02	EUV Source D
o04	Update on Phil
o06	Development S Plasma Source
o08	High Power Cost Effective Laser Modules for Laser Produced Plasmas (LPP) EUV Source
o10	Power Scaling of DPP sources for EUV lithography: Xe or Sn?
o16	Modeling of the Non-equilibrium Plasmas of EUV Sources

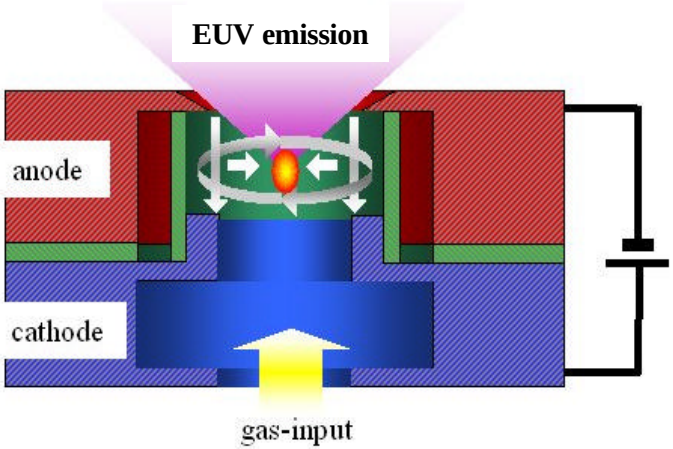
XTREME technologies: EUV Source development strategy

Laser Produced Plasma Source

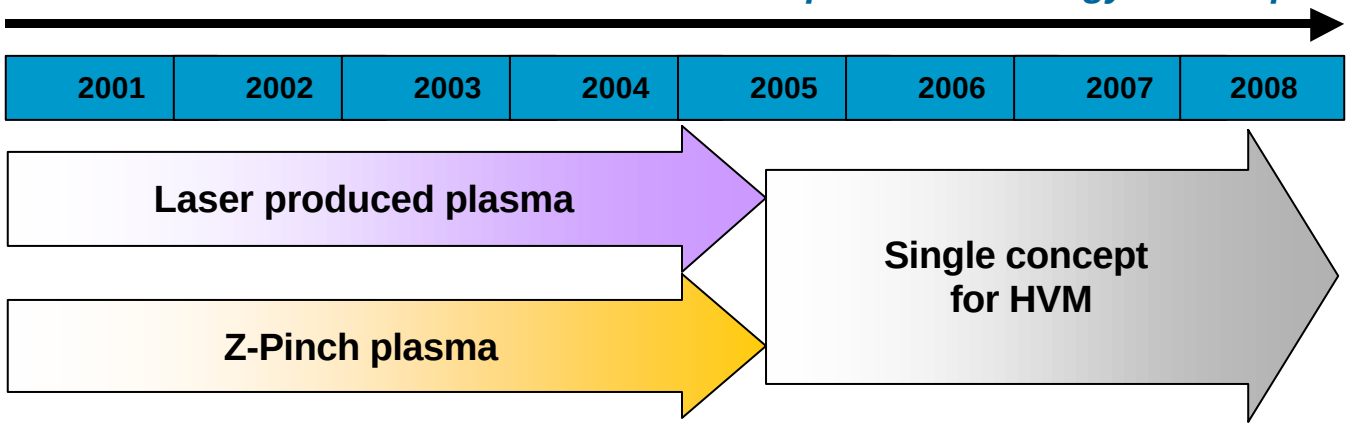


Double Technology
&
Minimize Risk

Gas Discharge Produced Plasma Source



EUV Source development technology roadmap

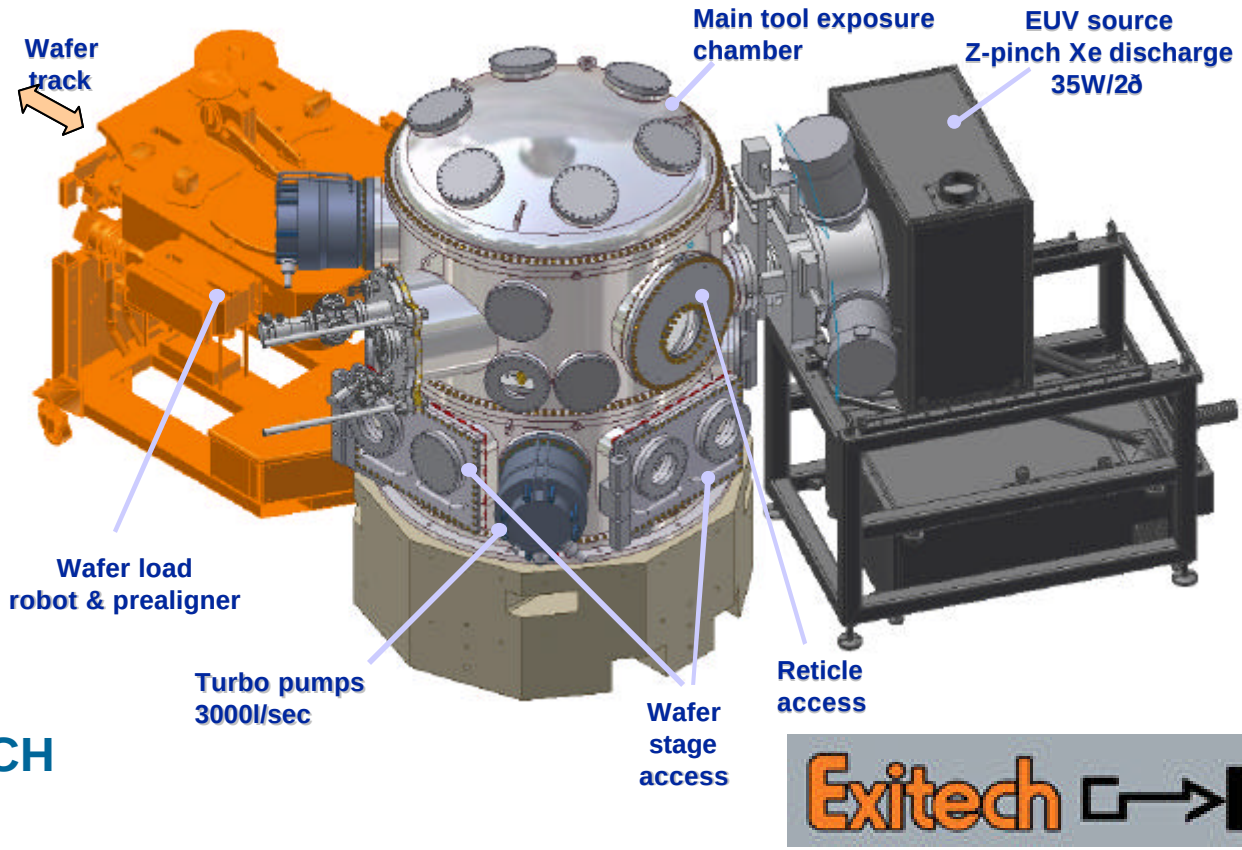


XTREME GDPP EUV Source in MS-13 EUV Microstepper

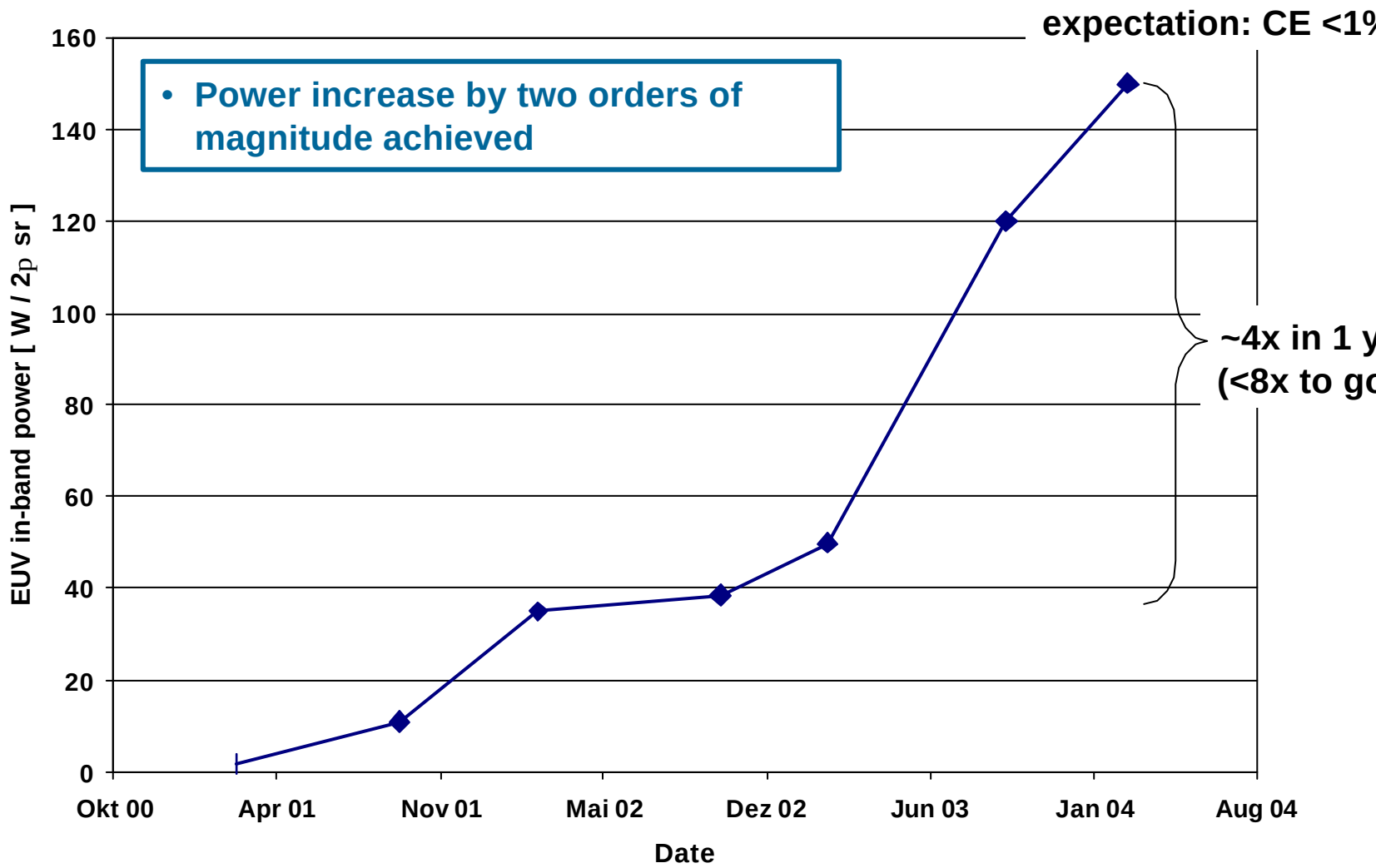
- **XTS 13-35 for EUV Microstepper:**
  - EUV sources with 35 W in 2p sr at 1000 Hz delivered and integrated
  - Optics lifetime (10 % Reflectivity decrease) with debris filter > 100 million pulses

- **Equipped with debris mitigation and integrated with collector optics from Zeiss, Germany**

- **MS-13 microstepper as pathfinder tools for semiconductor industry at intel and International SEMATECH**



Status GDPP EUV Sources: power improvement (II) - history (Xe



EXULITE Consortium within MEDEA progra

Coordinator : Alcatel

* With the financi
support of the Fren
MINE

CW diode-pumped laser module

High efficiency

High reliability

Simple and compact set-up

Process optimization

Source diagnostics

Atomic physics and plasma modeling

Optical interfaces

Debris characterization

Advanced Vacuum Technology

Xe recycling

Fluid and thermal modeling

System integration

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adixen
Alcatel Vacuum Technology

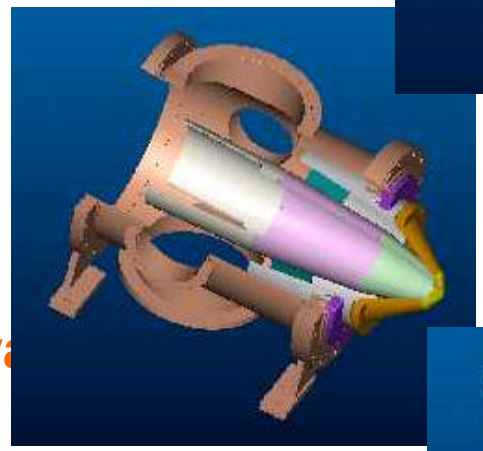
EXULITE

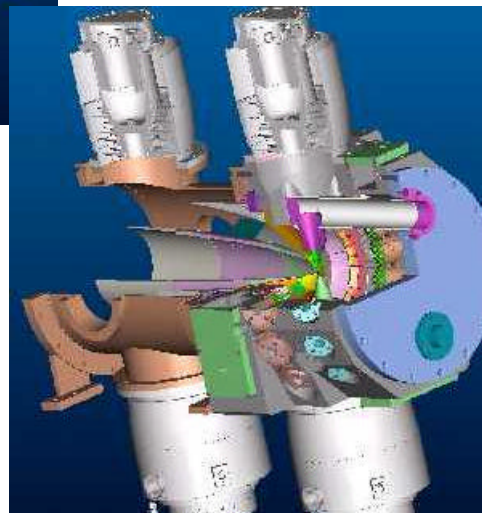
System optimization & integration ELSAC

- Design of ELSAC completed
  - **including thermal studies/pumping optimization/ new recycling system/optical interface/injector…**
- Manufacturing completed
- Optical collector design

for LPP source

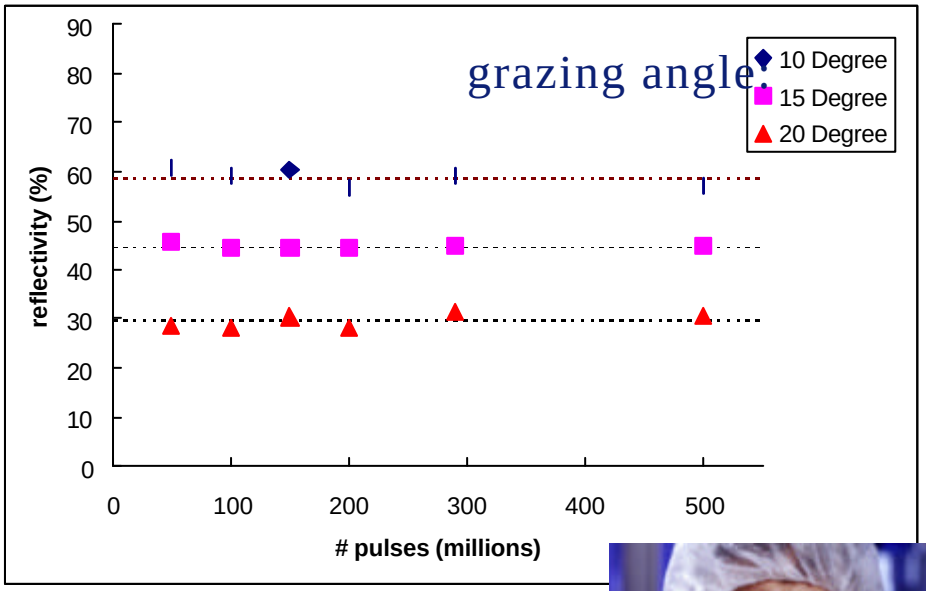
  - **grazing incidence (p sr)**
  - **collector acts as a separate va chamber**
  - **Industrial constraints (lifetime and cost)**



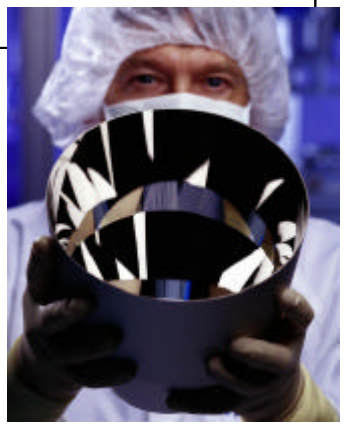


Issue #1: Integration of Xe lamp into α-tool

Source-collector-module

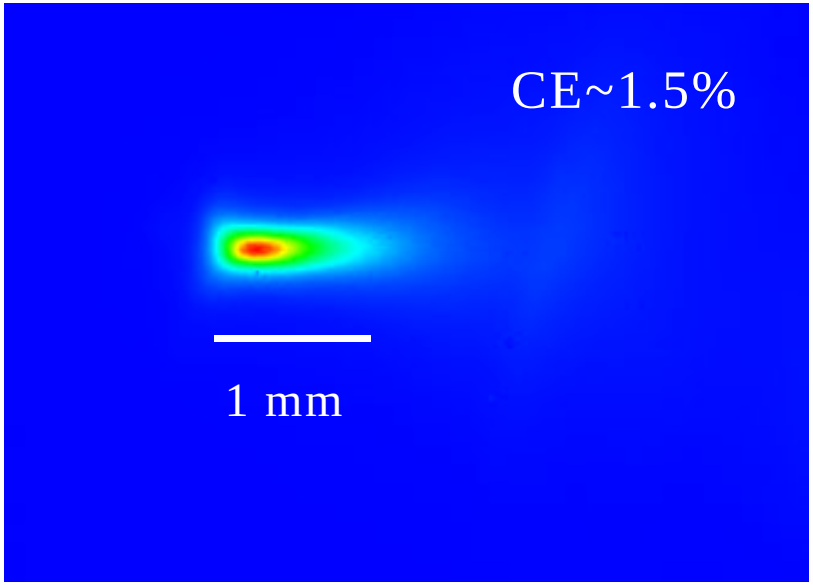


collector life time measured over 500 Mio shots

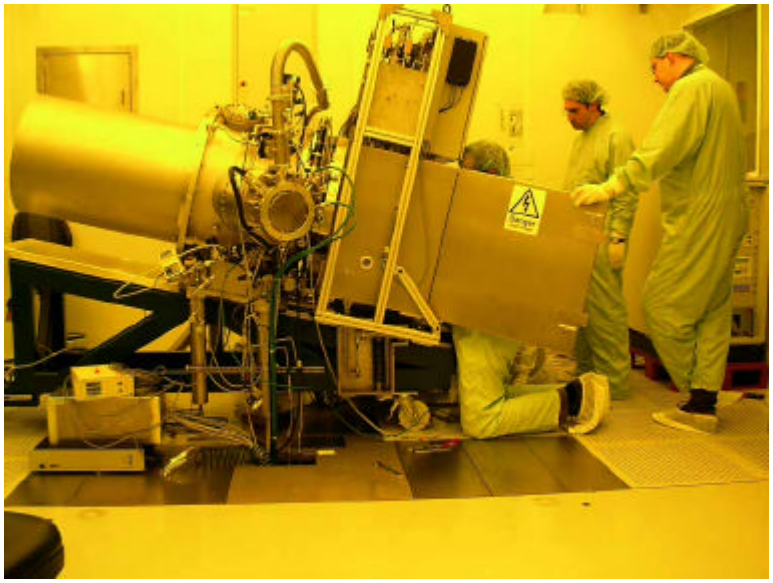


Present status: Sn source:

- 6 kW continuous operation (16 kW burst) demonstrated
- >10 W @ 2nd focus (>20 W burst)
- Electrode life time: >100 Mio shots (Xe: 500 Mshots)



very small pinch size (Sn-source)



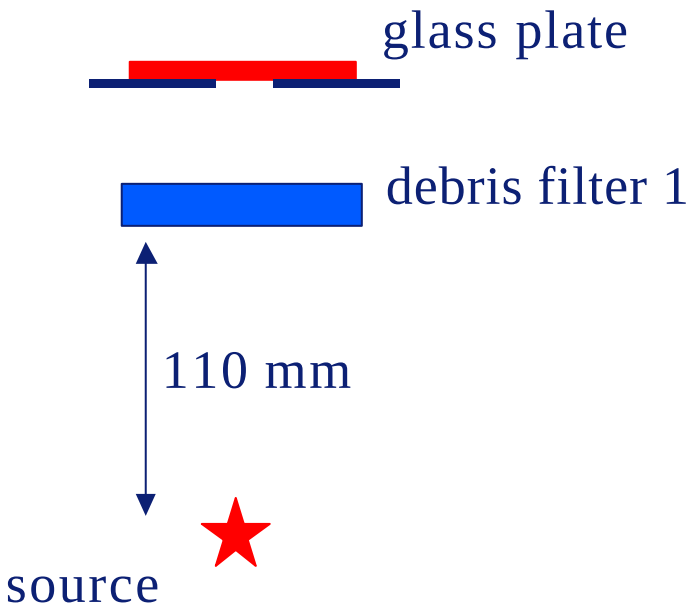
picture of (Xe-) source

Philips' source roadmap:

		2004	2005	2006	2007	2008/09
Input power	[kW]	12,0	15,0	20	30	30
conv. Efficiency	[1/2?]	1,5%	1,8%	2,0%	2,0%	2,0%
Collectable EUV	[W/2?]	180	270	400	600	600
collector opening	[sr]	1,8	1,8	1,8	1,8	3
Collection eff.	[2?]	25%	25%	25%	25%	45%
collector reflectivity	(aver.)	70%	70%	70%	70%	60%
debris system		80%	80%	80%	80%	80%
other losses		90%	90%	90%	90%	90%
EUV 2nd focus	**[W]**	**22,7**	**34,0**	**50,4**	**75,6**	**116,6**

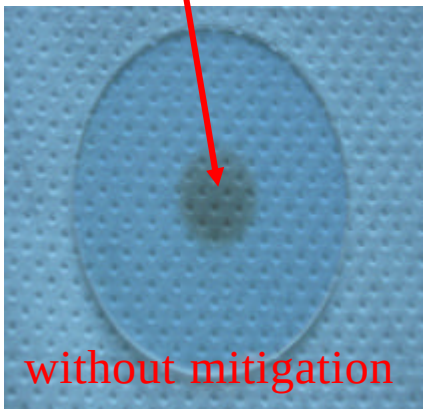
Technology for HVM: Sn based discharge lamp

Study of debris mitigation schemes



5 nm corresponding to $3*10^{15}$ atoms per shot in Pi sr

50,000 shots



10,000 shots

Est. 300x suppression

A

MeP06	High-accuracy EUV reflectometry at PTB
MeP07	Grazing incidence EUV reflectometer using a xenon pinch plasma source
OpP07	Progress in EUV Optics a SAGEM
OpP08	Networks of local minima for EUV mirror systems
ToP03	Vacuum mechatronics in the ASML EUV alpha demo tool
LnP02	Progress in the optics lifetime programme for ASML EUV Lithographic Tool
LnP05	EUVL multilayer coating development
LnP06	EUV Hartmann wavefront sensor
LnP07	AFOSUB: wavefront sensing for subnanometric metrology

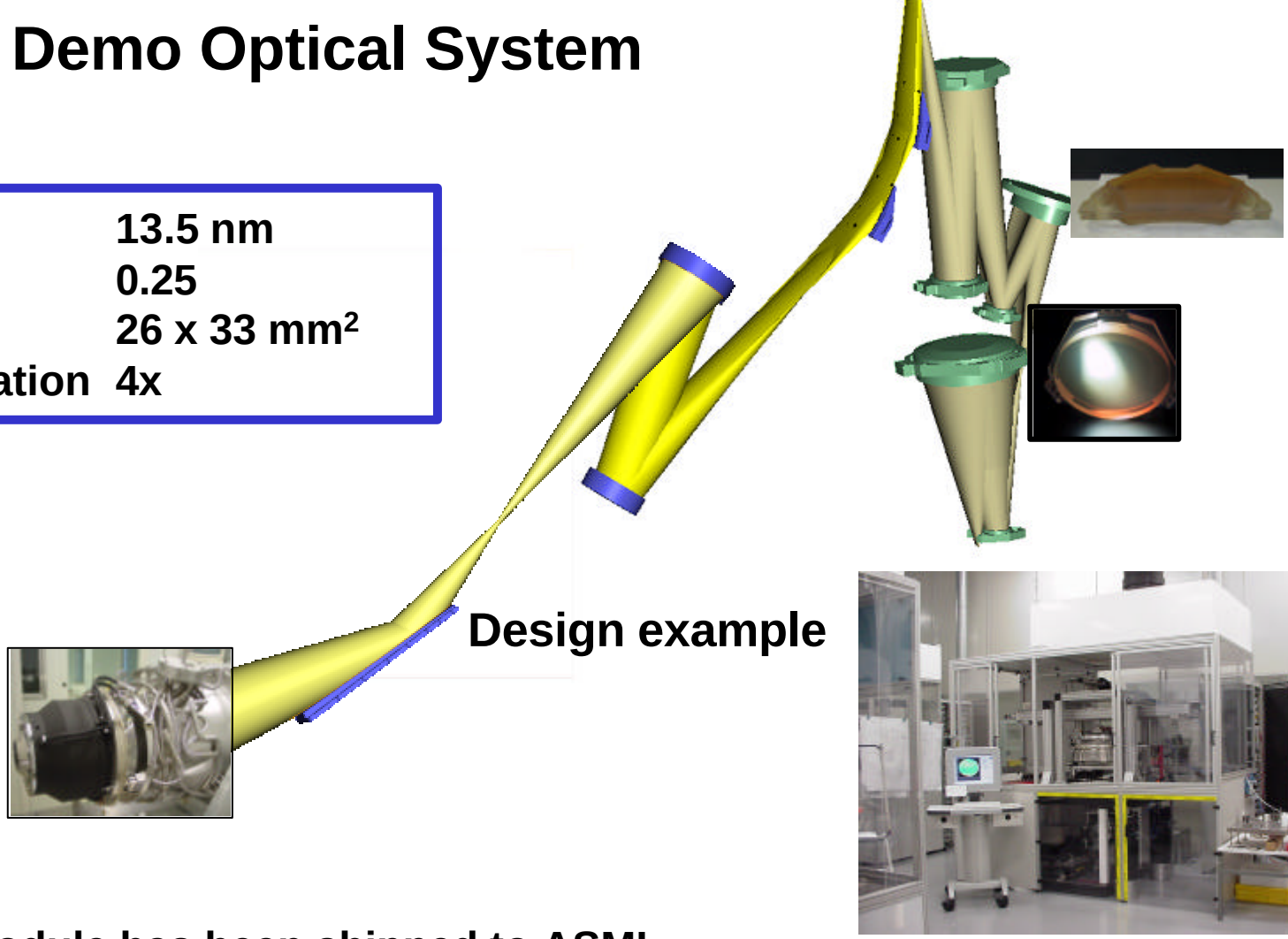
- – Tool & Optics

o02 **Progress on ASML's EUV Alpha Demo Tool**

o03 The EUV alpha demo tool program at Carl Zeiss SMT AG

Alpha Demo Optical System

- l 13.5 nm
- NA 0.25
- Field 26 x 33 mm^2
- Magnification 4x



Design example

Collector module has been shipped to ASML

all illuminator mirrors have been fabricated

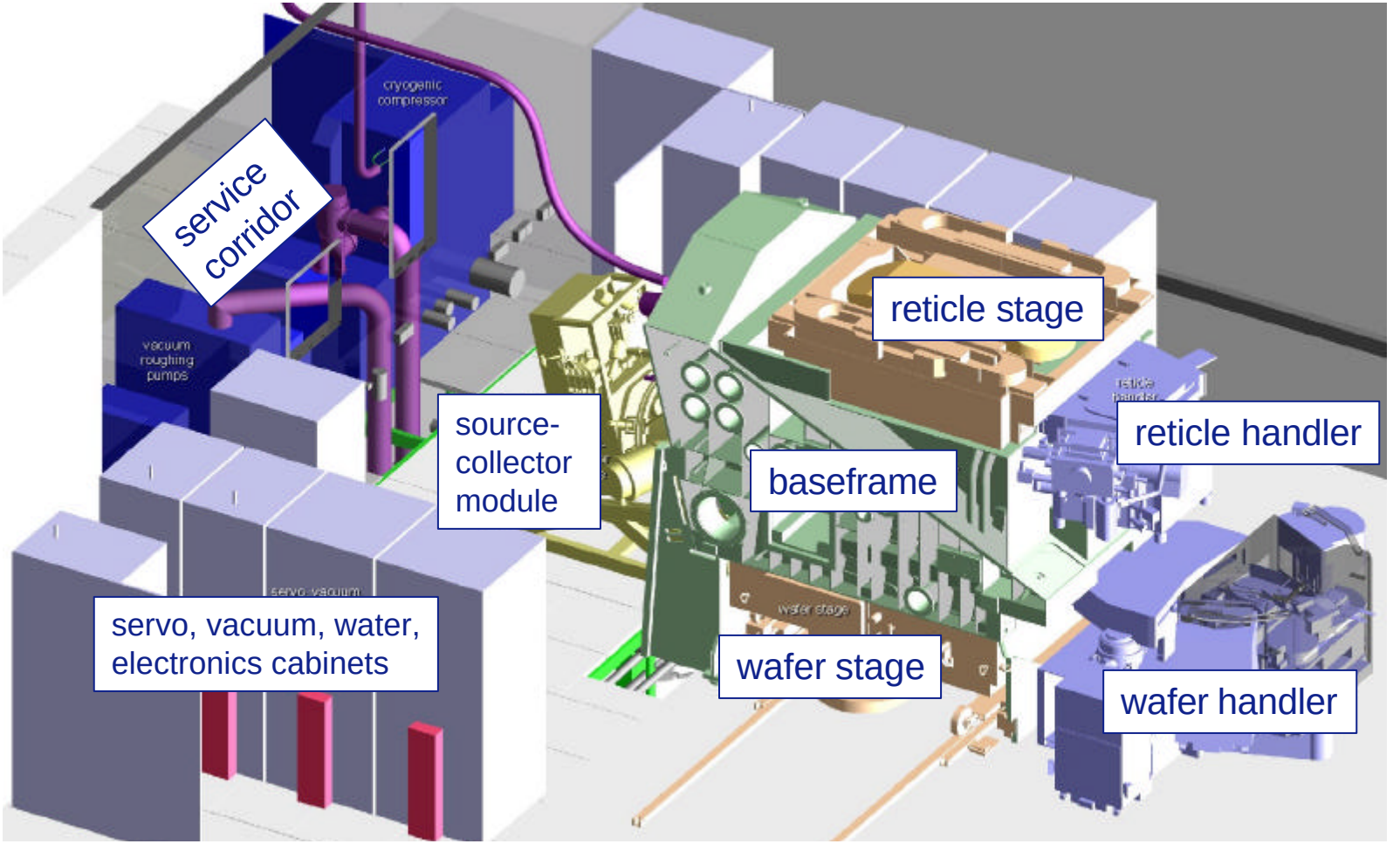
all interferometers for the projection optics are qualified,

the first two projection optics mirros have reached final specification (Figure < 0.3 nm, MSFR <0.33 nm)

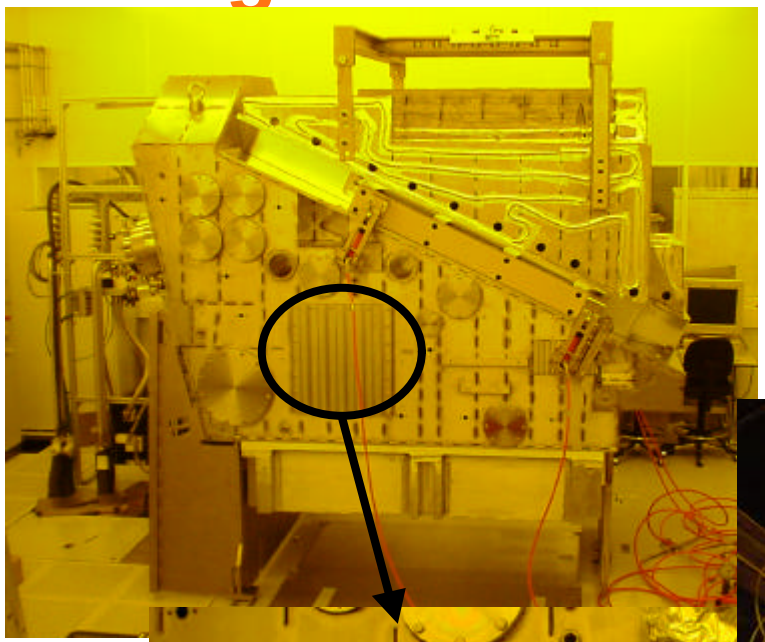
Top-level specifications Alpha Demo tool

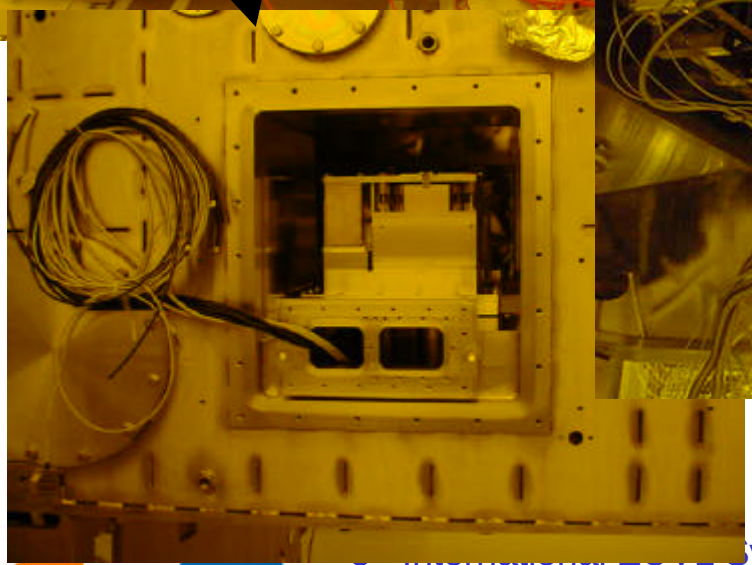
	Process development tool
NA Range	0.15 to 0.25
Imaging - Dense Lines	50 nm ->40 nm
- Isolated Lines	40 nm ->30 nm
- iso/dense contacts	65 nm ->55 nm
Overlay	12 nm
Throughput	10 WPH

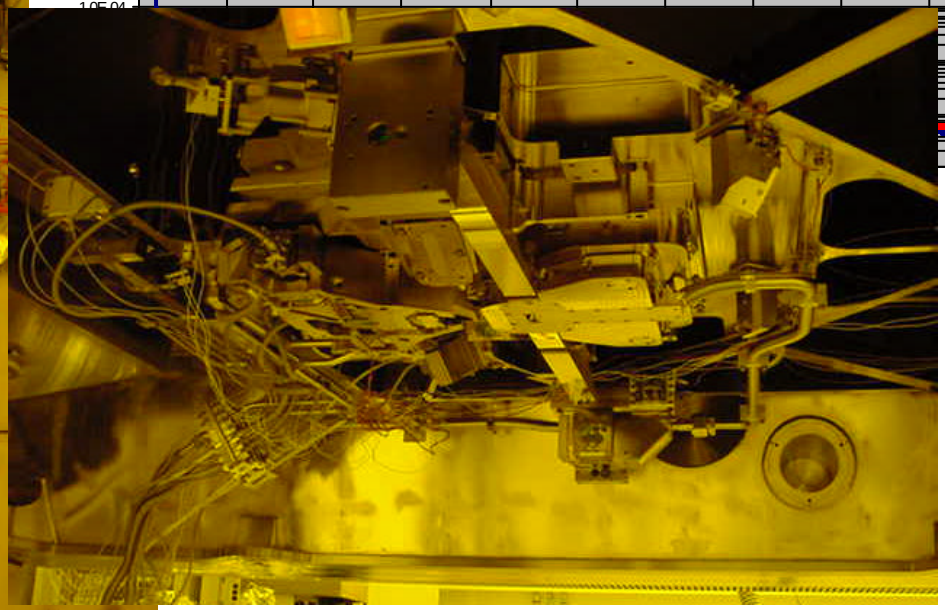
Layout of the Alpha Demo tool

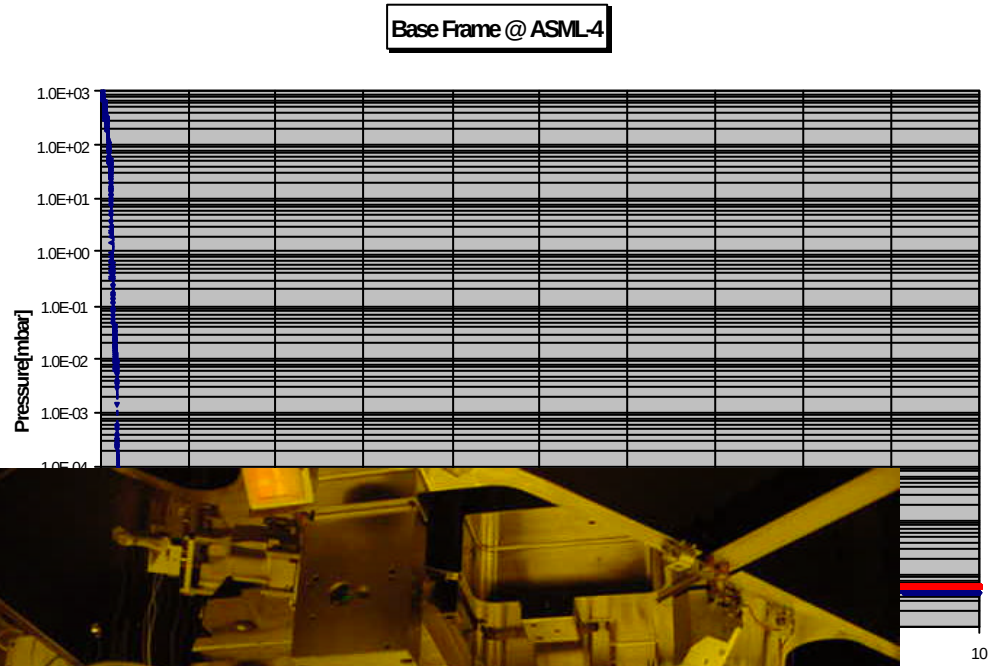


Factory ASSY: BF, airmounts, MF assy integrated!

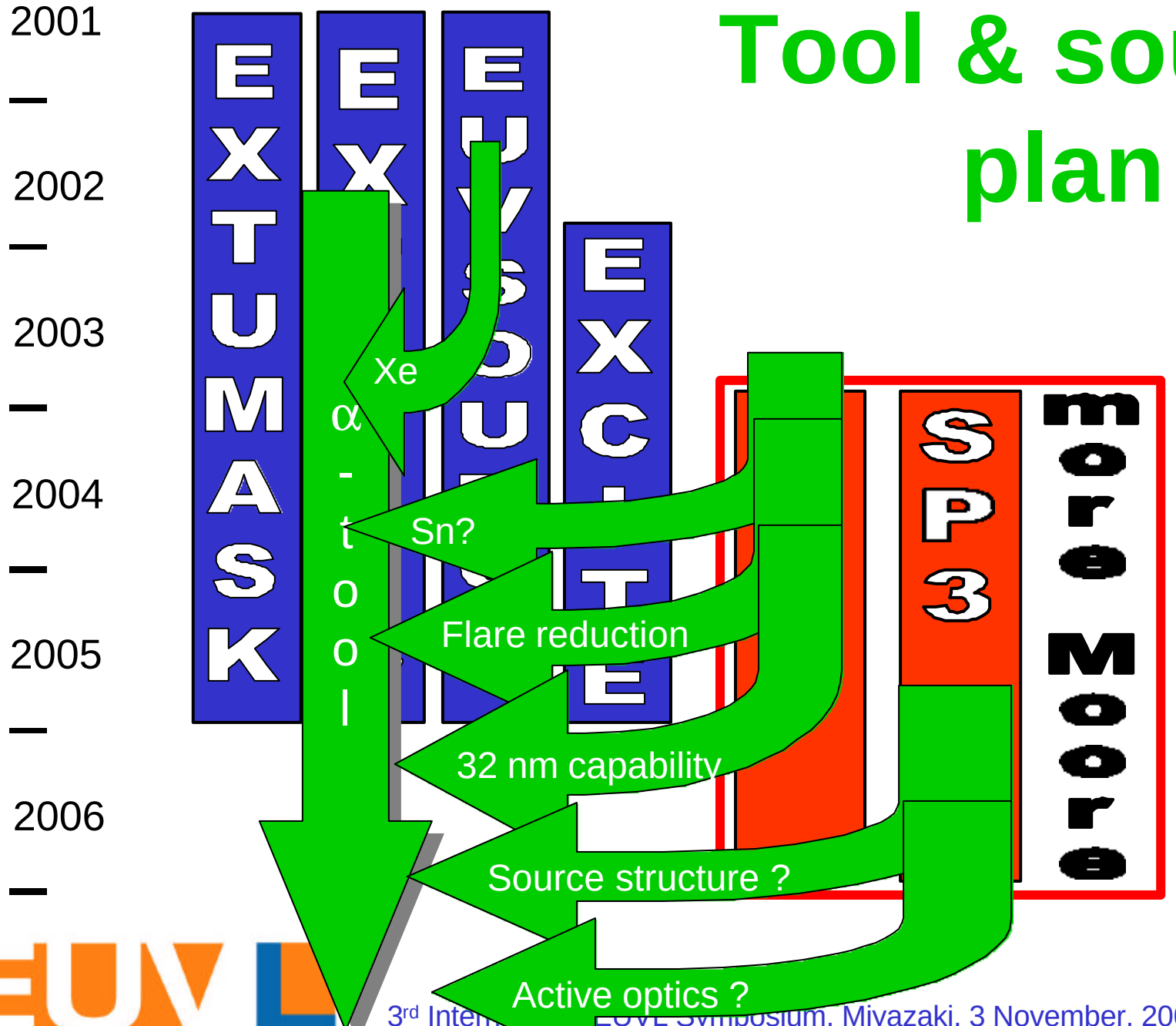








Tool & source plan

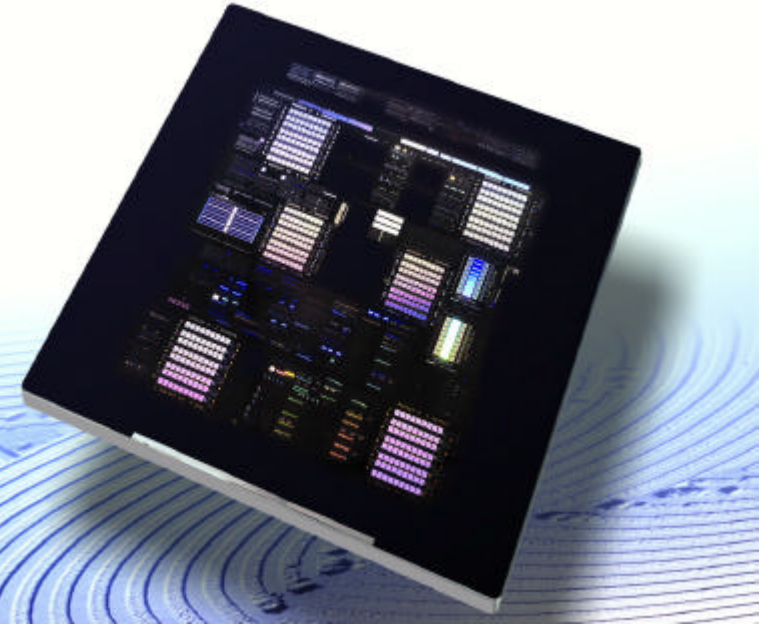


eP08 High Speed Reflectometer for EUV Mask-Blanks
uP10 A novel dual ion beam sputter deposition system for implementing low defect density and high-quality EUVL masks
aP02 Challenges to EUV mask blanks volume production
aP04 Investigation of the printability of defects in EUVL mask blank
aP08 A New Absorbing Stack for EUV Masks
aP09 Numerical and Experimental Study of EUV Mask Interface Roughness, Capping Layer Oxide Growth, and Phase Shifting Feasibility
aP12 Repair of EUV Masks using a Nanomachining Tool

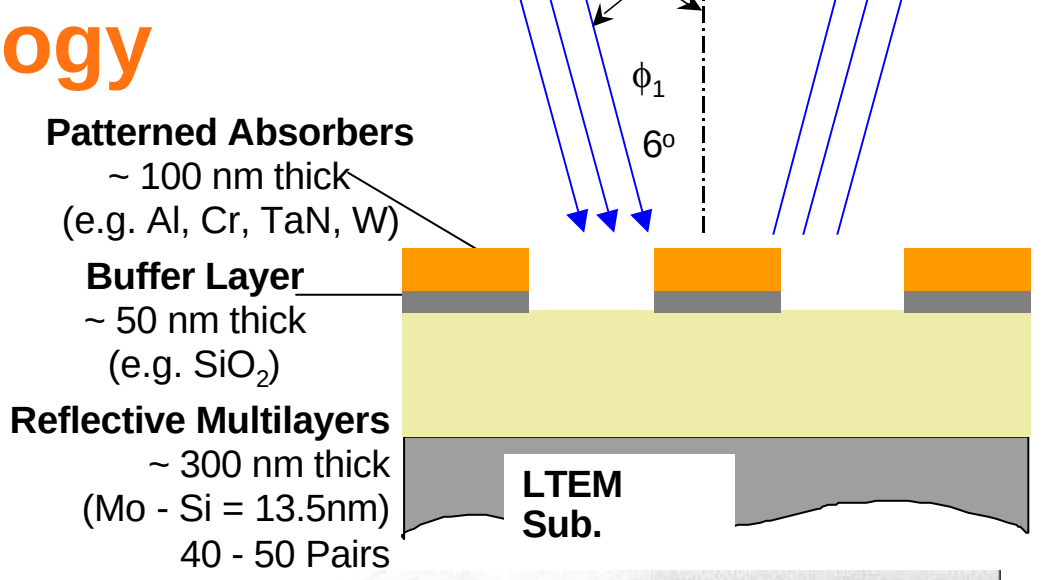
– Reticles

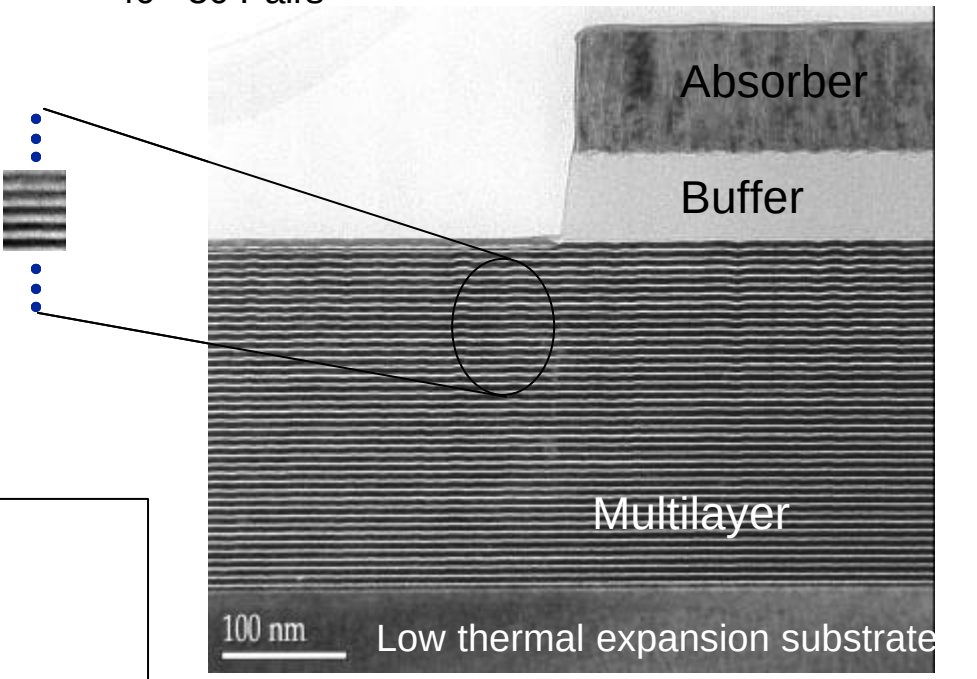
Ma06 Challenges for the Integrated Manufacturing of EUV Masks
Ha02 EUV reticles: particle-free handling and storage in the pellicle-less era

EUV Mask Technology



Full Field 6” EUV Mask with 100-nm node CMOS
Multilayers: Mo - Si
Absorber Stack: Cr/SiON
120 mm x 104 mm field size
(Courtesy of P. Mangat & S. Hector, Motorola)



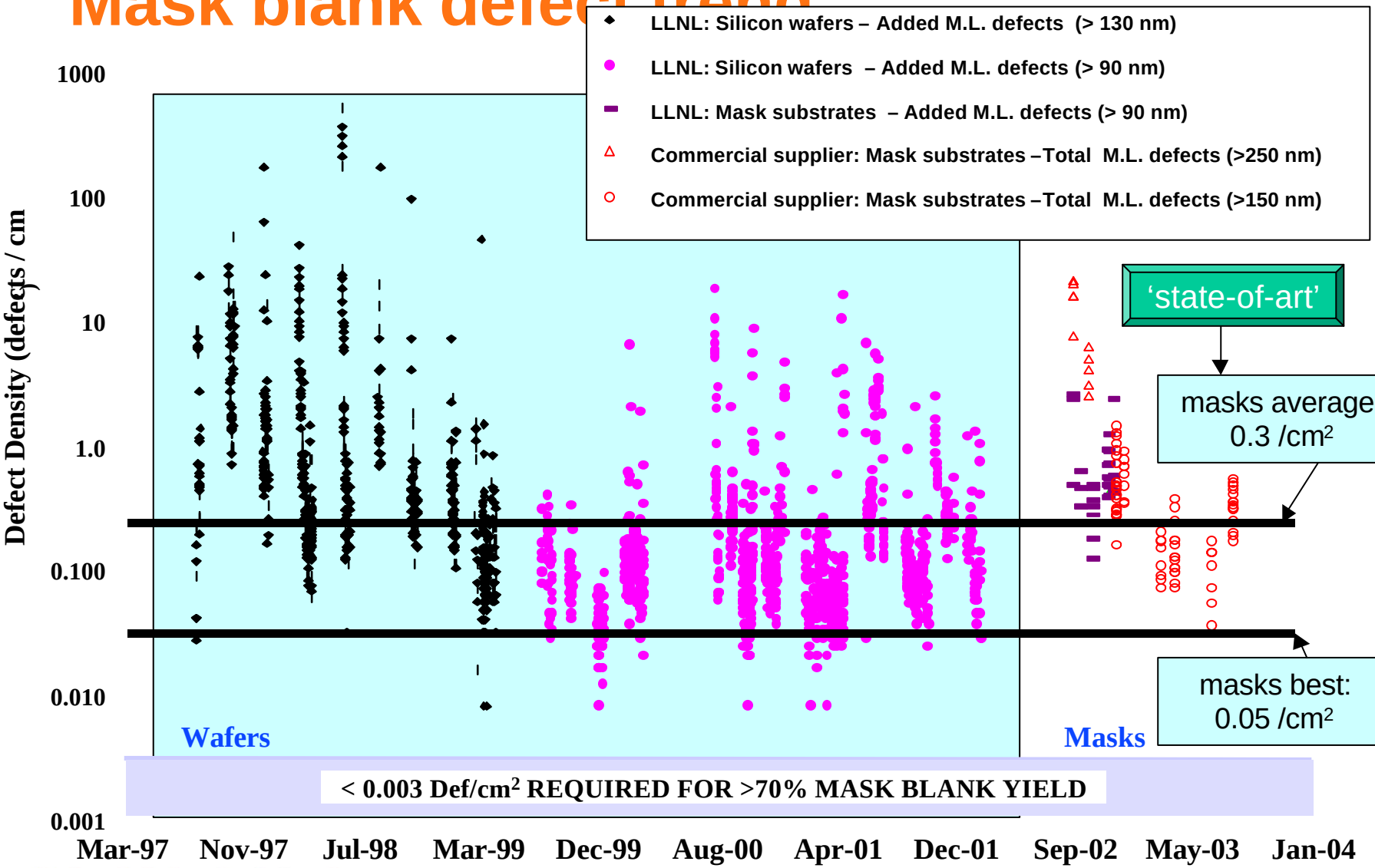


TEM courtesy of AMD

Key challenges for EUV mask multilayers

- **High uniformity of thickness**
- **No printable defects**
- **Temperature stability**

Mask blank defect trend



Actinic Defect Inspections by Photoelectron Microscopy

Ulrich Neuhäusler (University of Bielefeld, Germany)
Email: neuhaeus@physik.uni-bielefeld.de

For the EU-FP6 project ‚More Moore' SP3-WP4 team:

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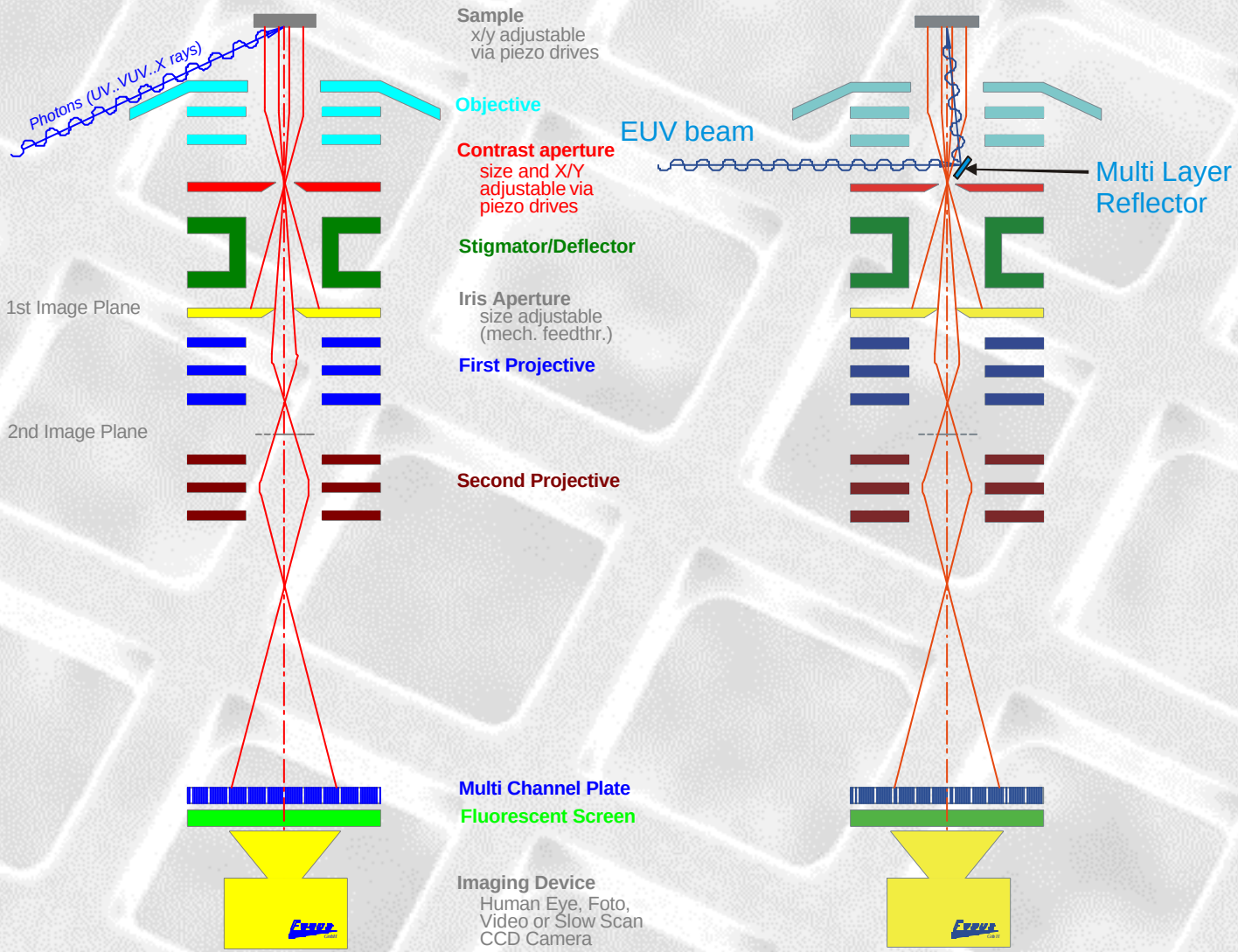
A. Oelsner, G. Schönhense (University of Mainz, Germany)
U. Neuhäusler, U. Kleineberg (University of Bielefeld, Germany)

Photo Emission Electron Microscope

www.focus-gmbh.com

PEEM

PEEM + Multi Layer Reflector



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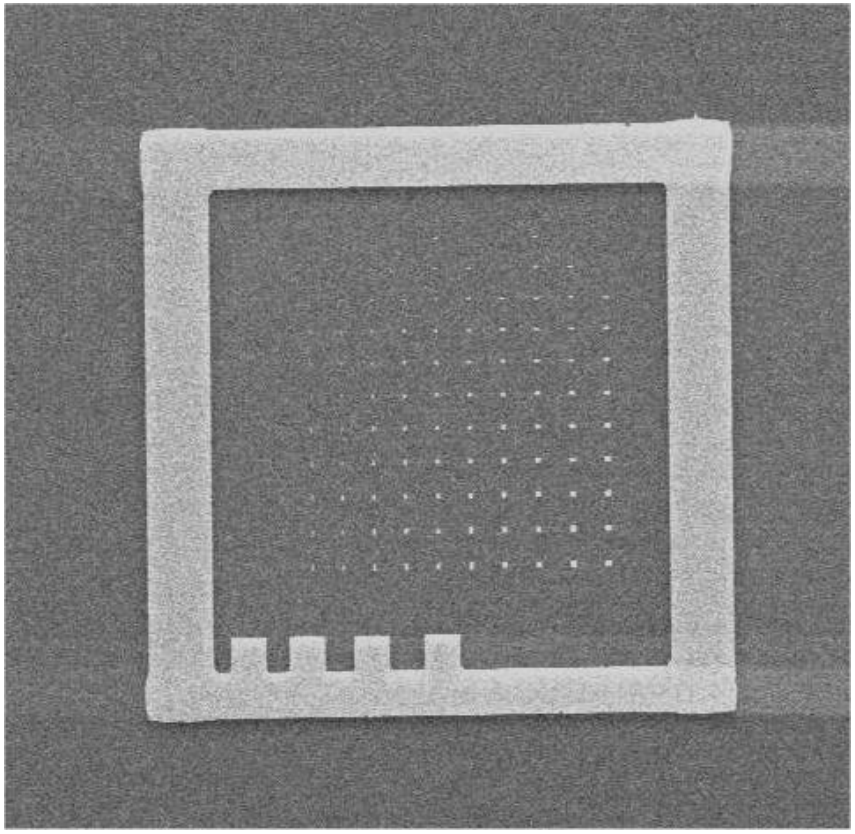
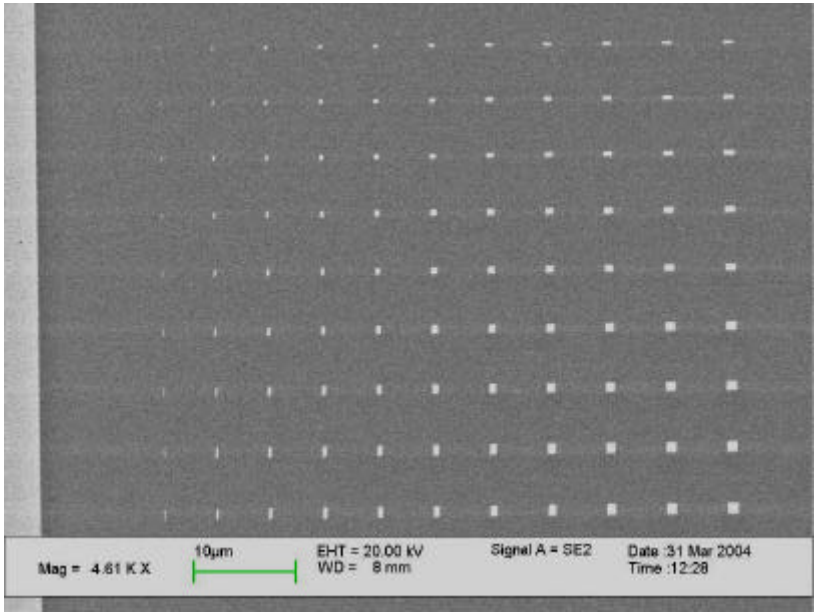
Fakultät für Physik

Programmed phase defect samples





SEM images of an array of 50 nm high Titanium nanostructures on a Si substrate with lateral sizes ranging between 50 nm and 1 µm

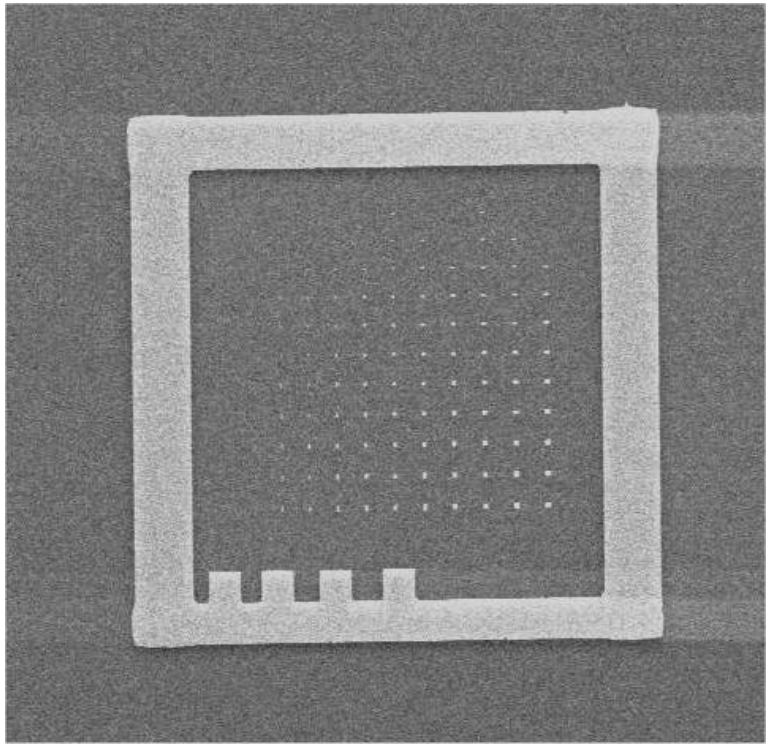
E-beam lithography in collaboration with M.Brzeska and H. Brückl (Thin film and nano structure group, Physics Department, University of Bielefeld, Germany)

FOCUS GmbH
Instruments for Electron Spectroscopy and Surface Analytics

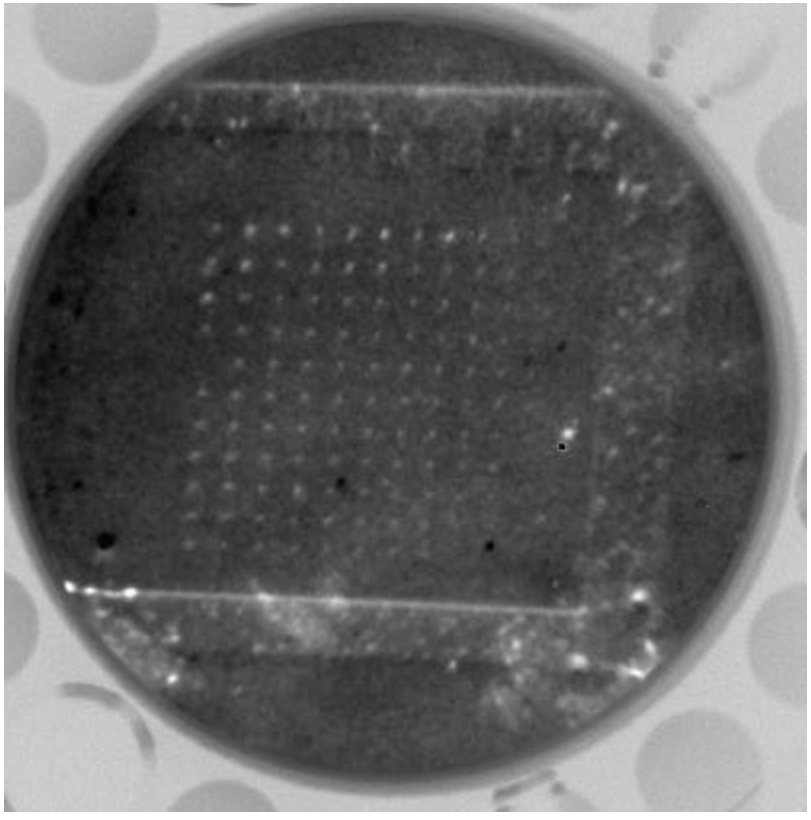
Universität Bielefeld
Fakultät für Physik

JOHANNES GUTENBERG UNIVERSITÄT MAINZ

Actinic inspection of programmed phase defects on MoSi mask blank

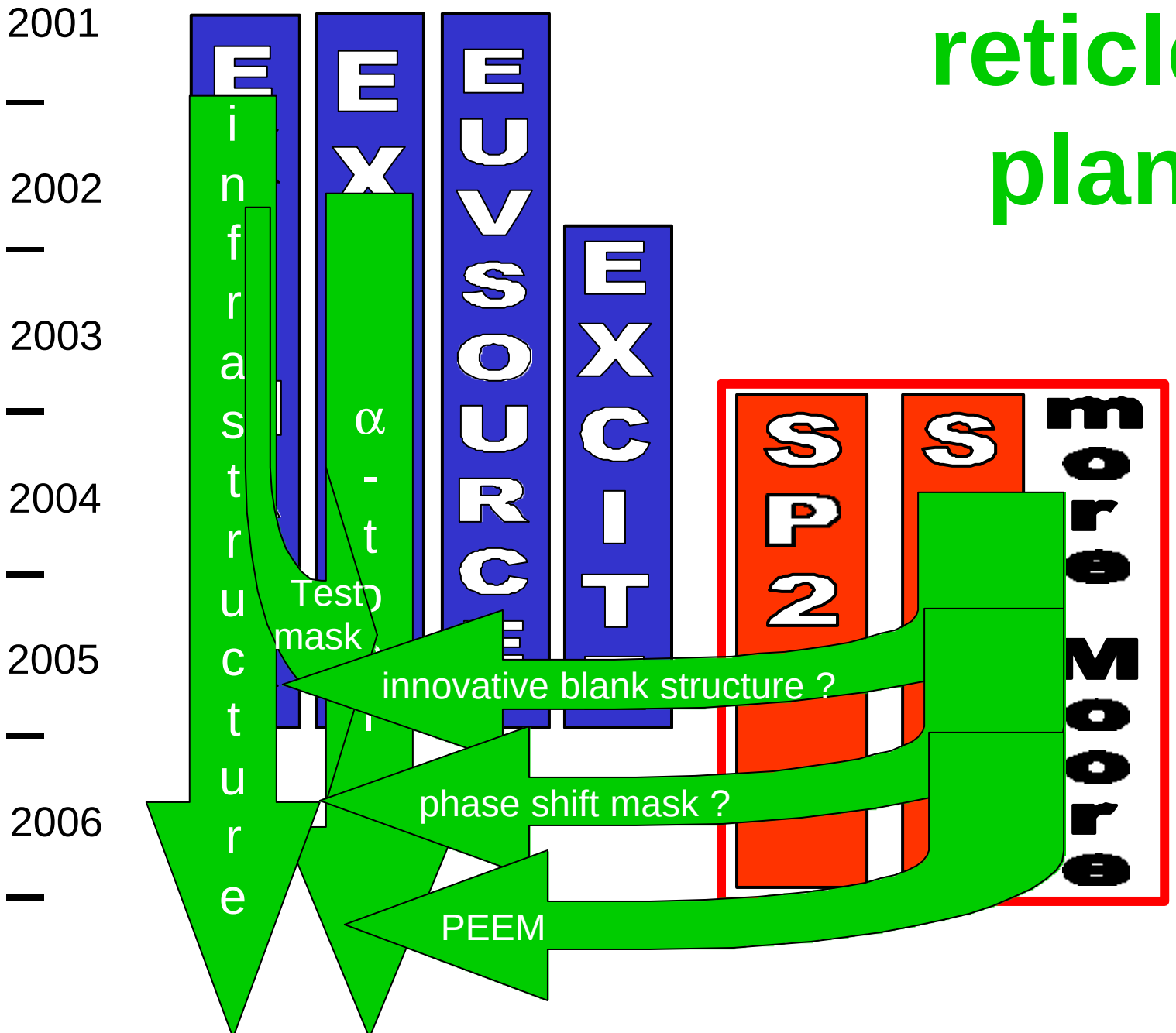


SEM images of an array of 50 nm high Titanium nanostructures on a Si substrate with lateral sizes ranging between 50 nm and 1 µm



EUV-PEEM image of programmed mask defect sample at hn =94.8 eV
FoV 110 mm.
Defects down to 50*100 nm²

reticle plan



Agenda

- When & why EUV?
- European programme in risk areas
  - Source
  - Tool & Optics
  - Reticles
  - Resist

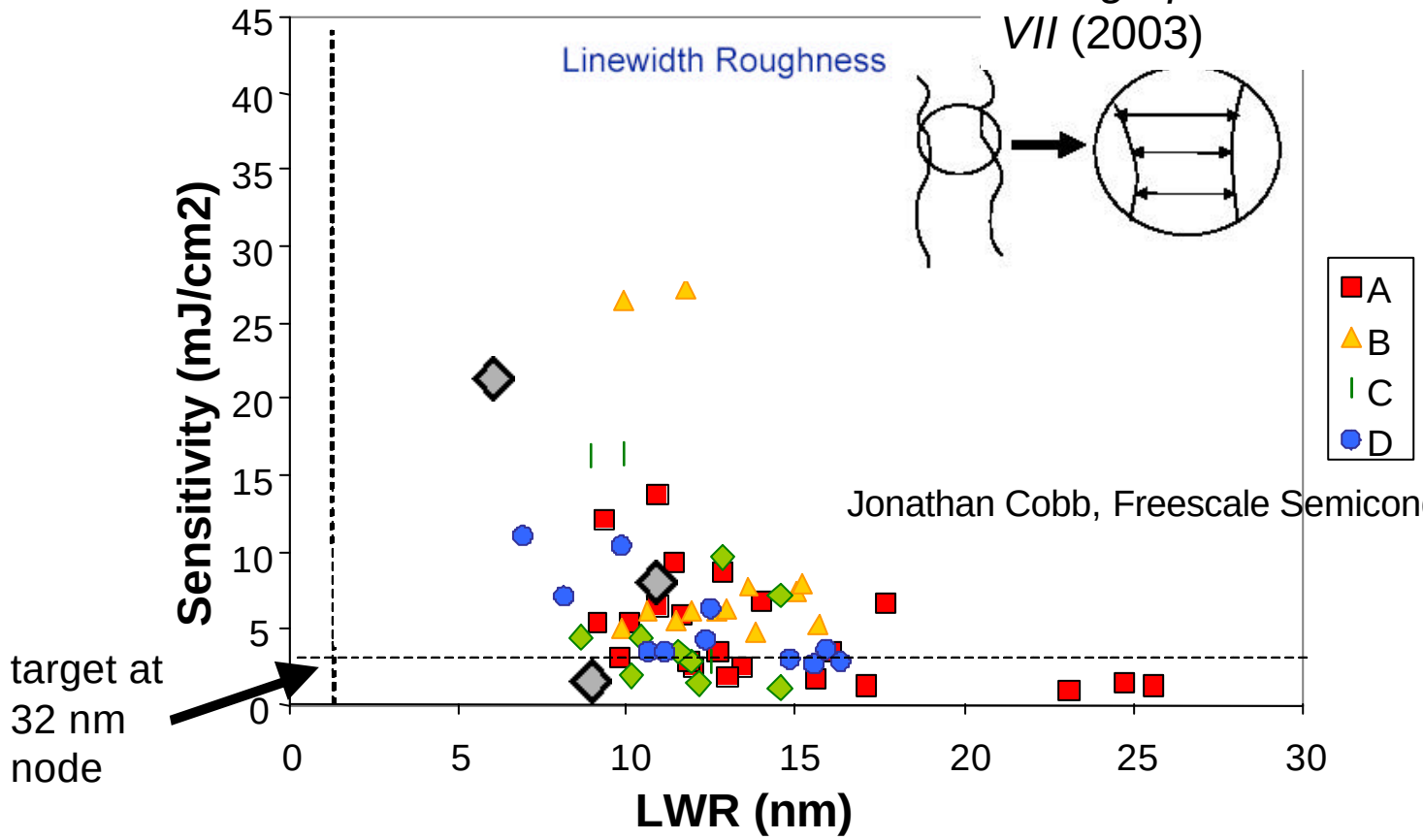
ePP11 Characterization of EUV-Ougassing of different Resist Platforms

To01 Status of the Micro Exposure Tool for EUV Microsteppers

Re03 Resist Evaluation Using EUV Interference Lithography

Status resist development

H. Cao, *SPIE Emerging Lithographic Technologies VII* (2003)



Jonathan Cobb, Freescale Semiconductor ('04

Conclusions

- presented performance needs considerable improvement for 32 nm node.
- presented data does not support unambiguously that decreasing sensitivity significantly improves LWR. High sensitivity (dose 5 mJ/cm^2 or lower) is required for throughput/CoO reasons!

Agenda

- When & why EUV?
- European programme in risk areas
  - **Source**
  - **Tool & Optics**
  - **Reticles**
  - **Resist**
- Conclusions

Conclusions

- A large cluster of EUVL projects is well underway in Europe to achieve its goals for the 32 nm node
- The Alpha Demo Tool is the stepping stone towards pilot and volume tools for the 32-nm node; its system realization is well under way
- The Alpha Demo Tool together with recently installed high NA Micro Exposure Tools will be instrumental for the timely development of the infrastructure (mask, resist), since exposure capability is too limited