SAGEM contribution to PREUVE & trends in EUVL optics

SEMATECH Workshop - Oct 2000

Summary

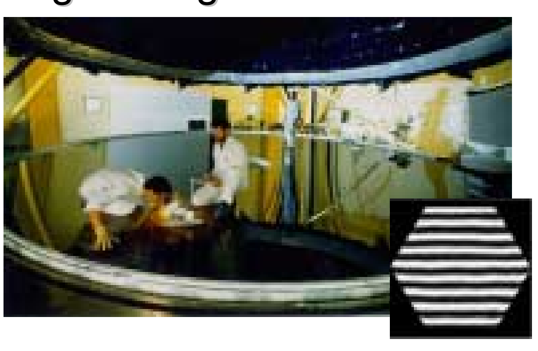
- **SAGEM Optics & Engineering & REOSC Products**
- **SAGEM Background for EUVL Optics& components**
- **The French initiative PREUVE**
- **Developments conducted within PREUVE**
    - Lens design
    - Mechanical design & demonstration
    - Polishing & demonstration
    - Metrology & demonstration
    - Coatings & demonstration
    - The optics for the B.E.L.
- **Conclusion**

☞ **Refer to CEA-LETI and SOPRA PREUVE related talks**

Optics & Engineering : REOSC Products

Space optics
Telescopes, lens assemblies

Optics for astronomy
Large & segmented mirrors



Optical equipment
Reco, UV, lithography

Precision components
Laser, UV, X Ray, ...

Coating Services
Coating, engraving, ...

SAGEM background for EUVL lithography optics

Smooth optics for X-VUV

Ultra smooth optics for grazing incidence X Rays & normal incidence VUV, EUV. Plano and aspheric mirrors of roughness below 0.1 nm are produced in size up to 1.4 meter.

High performance laser coatings.

Ringlaser gyro

Key optical elements serial production
- Cavity mirror polishing (< 0.5 Å) and coating
- Block machining
- Opto-meca-electronic assembly in Class 10

Aspherics and multi mirrors systems

High performance Three Mirror Anastigmat (TMA) optics designed, manufactured, now in space.

Full understanding of high precision multi aspheric mirror systems design, fabrication and alignment.

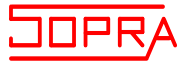
High precision large optics

Engineering & metrology of high size/figure ratio optics (EUV : 250 mm / 0,5 nm = 0,5 10^9)

VLT	8.0 m	8 nm	1,00 10^9
Sofia	2.7 m	20 nm	0,13 10^9
Military space	□	□	0,18 10^9
Themis	1.0 m	10 nm	0,10 10^9

The project PREUVE

- A French initiative (taken by CEA/LETI) federating national EUVL abilities labeled by the RMNT (Réseau Micro Nano Technologies)
- Development of know How, EUV steppers elements, metrology tools
- 24 month activity (Nov 99 - Nov 2001) financially supported by the MEFI-STCI (Ministry for Industry)
- PREUVE is focused on :
  - EUV Sources @ 13 nm for Lithography & metrology
  - Reflective Optics (illumination & projection) & ML coatings
  - Reflective masks and their metrology
  - Construction of the “Banc d’Essai Lithographie” for resist process development
- PREUVE is aimed to open on international cooperation



SAGEM contribution to PREUVE
Main drivers

Optimization of the "return to cost" effectiveness of the program

Task limited to the critical key points where know how and IP had to be leveraged to come at the EUVL requirements

- **Construct a basic EUVL optical lens design know how**
  Patent new solutions ?
- **Refine mechanical concept of mirror + fixture for EUVL application**
  Make a demonstrator
- **Leverage polishing know how**
  Aspheric - Low roughness - precise figure - mid frequ.
- **Leverage metrology know how**
  LSFE - MSFE - HSFE
- **Demonstrate ML coatings**
  Mo/Si - Reflectivity - Uniformity
- **Contribute to an EUVL micro exposure tool : supply of its optics**

Optical design (1)

Projection Optics

Explore the optical design space for a high performance, but manufacturable multi mirror optical projection system design.

=> 0.25 NA / 1/4 Reduction factor

50 nm resolution / 50 nm distortion

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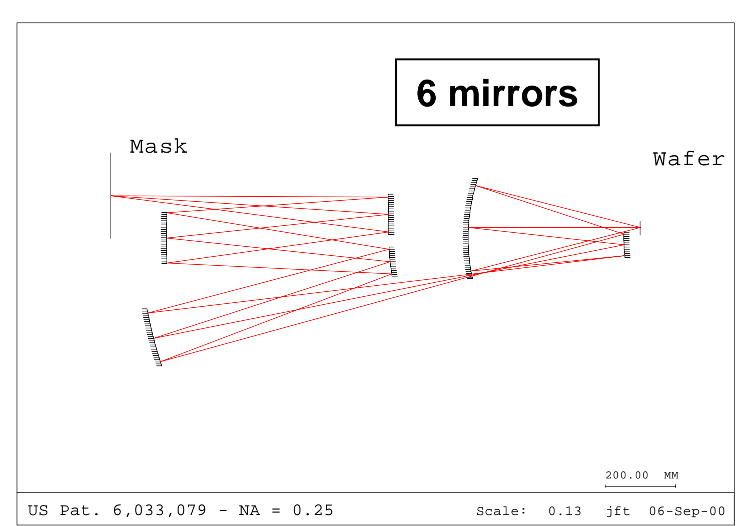
Mask

Wafer

125.00 MM

Patent WO99_42902 ~ ETS (NA 0.1) Scale: 0.20 jft 06-Sep-00



Output : extended know how - preliminary error budget

Optical design (2)

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Source
Mask (ring-field)
Paraboloïdal mirror
Complex mirror
(generalized asphere)
Projection
Optics
Aperture
Stop
Source
Mask
350.00 MM
Condenseur pour ETS
Scale: 0.07 jft 13-Oct-00

Illumination Optics

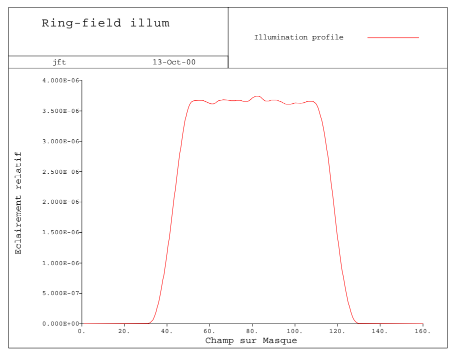
In relation with the optical source development conducted by other members of PREUVE, explore the design choices for the associated illumination optics

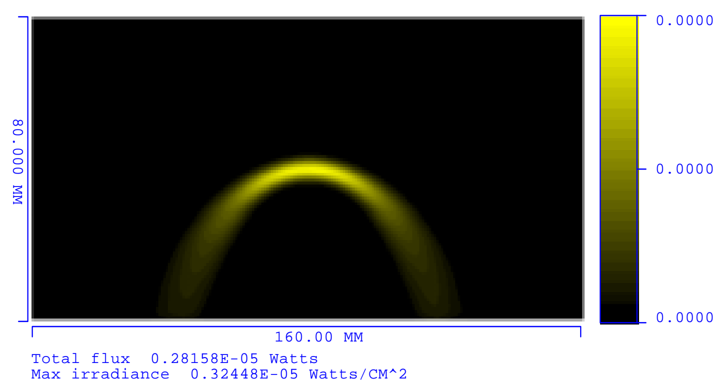
=> High collecting efficiency / Uniform illumination

=> Non conventional optics

Output :

Extended know how
Preliminary error budget





Mechanical Design

Goal : Design and optimize a mirror + fixture concept of the various optical components ensuring efficient element fixation and behavior within a structure.

=> Sub µm stability - no mirror deformation - fine adjustments - strength - stiffness

=> No contamination - low cost - etc...

Express the need

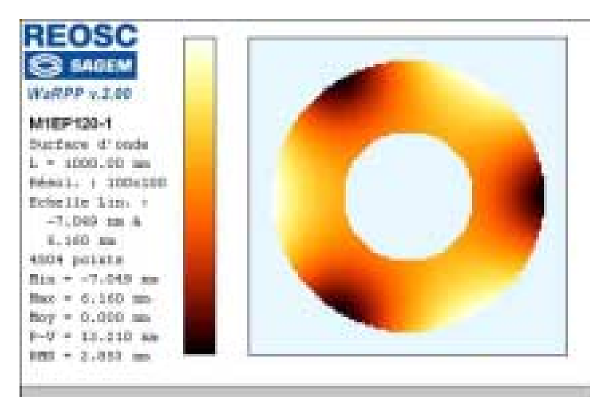
Concepts trade off

Select preferred solution

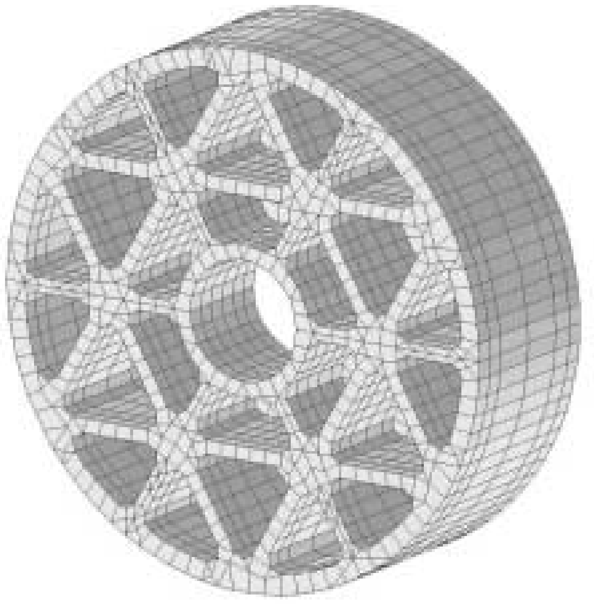
Detailed design

Demonstrator fabrication

Tests & validation



Mirror deformation analysis
Severe sag due to gravity



Typical lightweight design

Output : Demonstrator + BEL structure

Optical Fabrication Technology Development (1)

Goal : Leverage optical fabrication technology to EUVL needs.

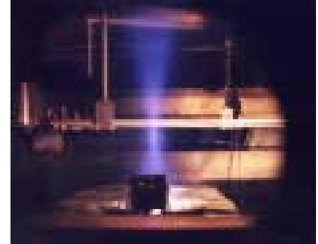
Size	: 100-350 mm
Asphericity	: up to 10 µm
Reflectivity	: 0.1 nm microroughness (HSFE)
Contrast	: 0.3 nm waviness (MSFE)
Resolution	: 0.5 nm figure (LSFE)

NC polishing

Plano polishing

A broad technology spectrum

Machine & lightweight
Aspheric generation
Plano continuous polishing
Bowl feed smoothing
CNC polishing & Ion Beam Figuring
+ other techniques



Ion beam figuring

Bowl feed smoothing

Optical Fabrication Technology Development (2)

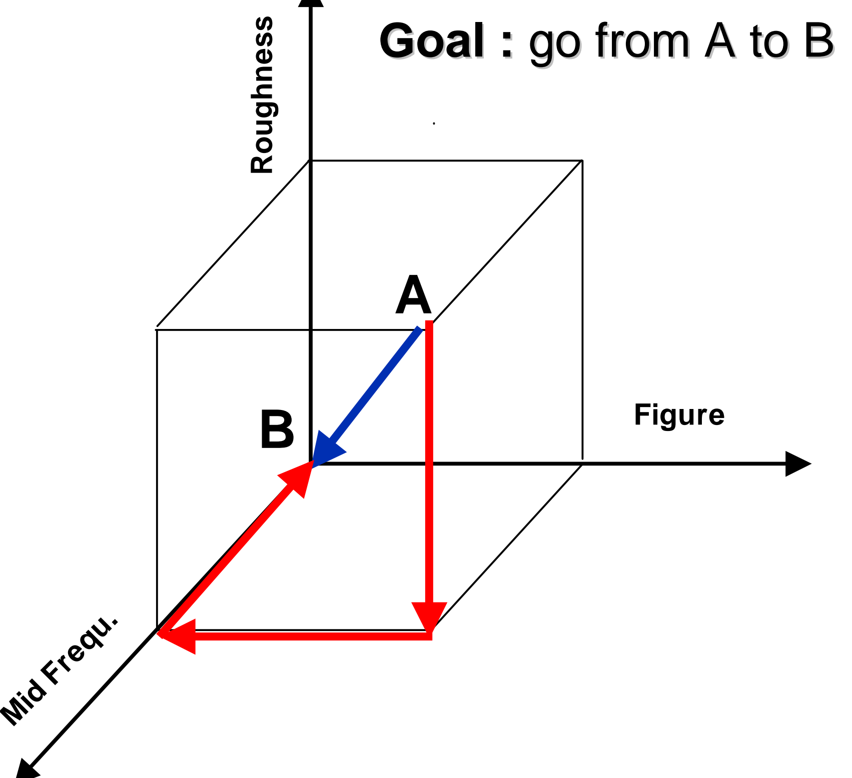
Ideal case : One process does all corrections => **Hard !**

Method : Separate per frequency range

Real case : One process per defect category
LSFE, MSFE, HSFE

Work :

- Improve each process efficiency
  Simulations and basic R&D
  Accuracy, repeatibility, linearity, speed, cost, ...
- Reduce process cross over effects
  Smoothing w/o figure loss,
  Figuring w/o MSFE,
  MSFE correction w/o figure loss,
  etc...
- Optimization of the process sequencing

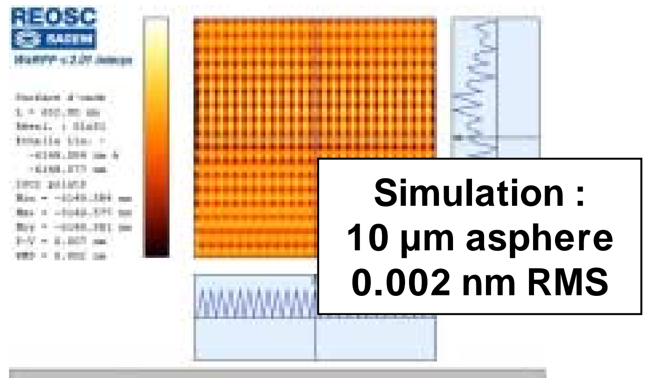


Output : Samples, BEL Optics, Aspheric demonstrator

Optical Fabrication Technology Development (3)

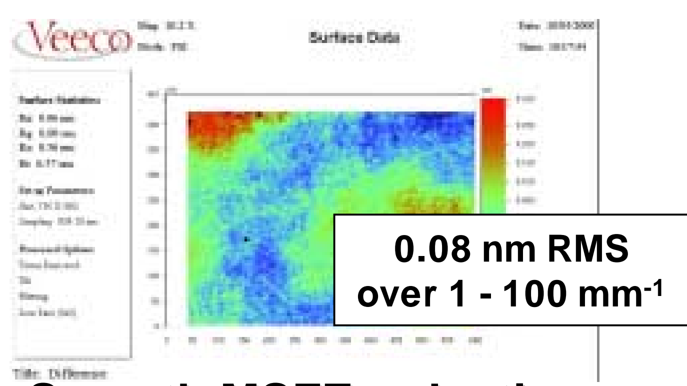
First results

Large area - Low roughness



Accurate figuring

Figuring keeps roughness



Smooth MSFE reduction

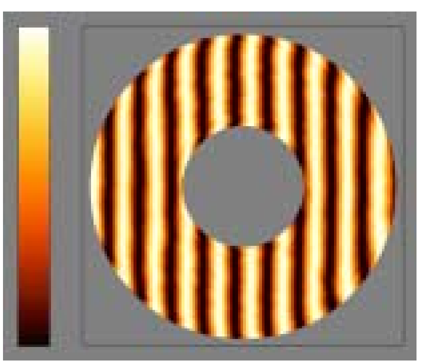
Optical Metrology development

Goal : Analyze, define and set up metrology tools and know how

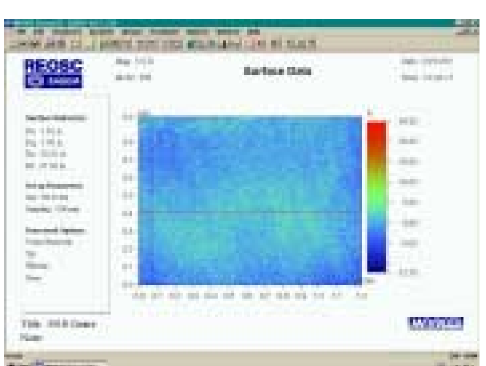
Method : Cover the full Power Spectral Density spectrum LSFE - MSFE - HSFE

Key point : Strategy for absolute calibration errors
Plano - sphere - aspheres - generalized aspheres
Interaction with global system testing
Reference plan & sphere to fabricate. **Cross checks welcome !**

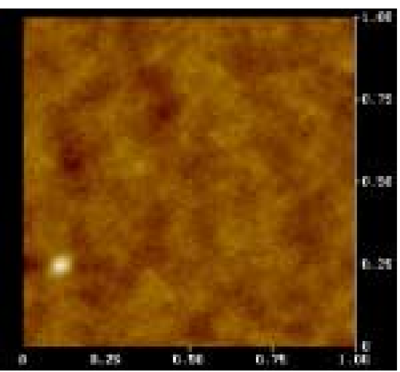
@ λ metrology considered later



Vis Interferometry



Micro -Interferometry



AFM

Output : Reference pieces & Metrology of the polished demonstrators

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Development in ML coatings (1)

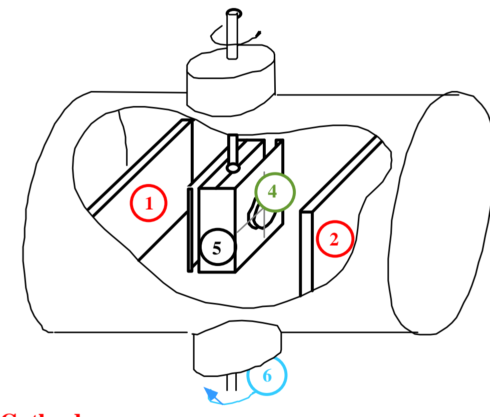
L2MP

Actor : Marseille University (B. VIDAL) ML specialist within PREUVE

Technology : Magnetron sputtering - up to 6 ' ' today

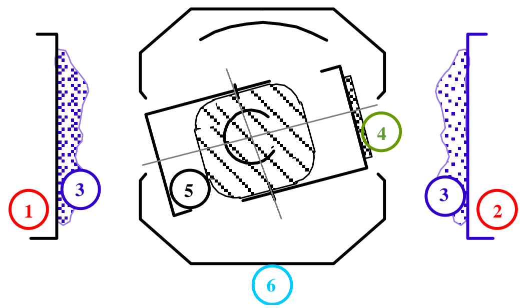
Design : 40 pairs of layers Mo/Si

The hardware



1 - 2 Cathodes
3 Argon Plasma
4 Sample
5 Rotating sample holder
6 Rotating screen

The design

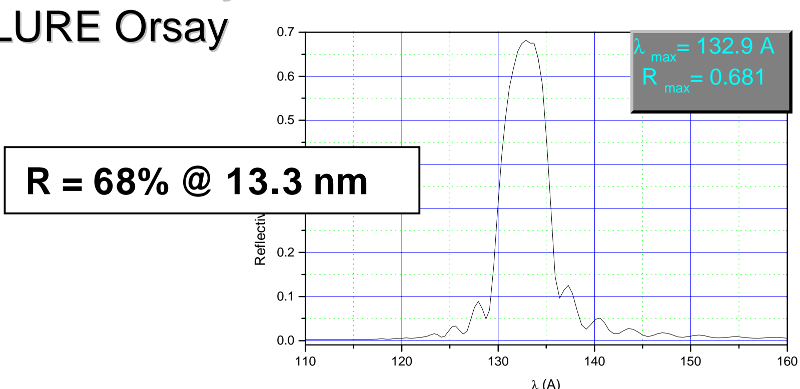


Development in ML coatings (2)

Film Characterization

Reflectivity at i ≈ 0 incidence

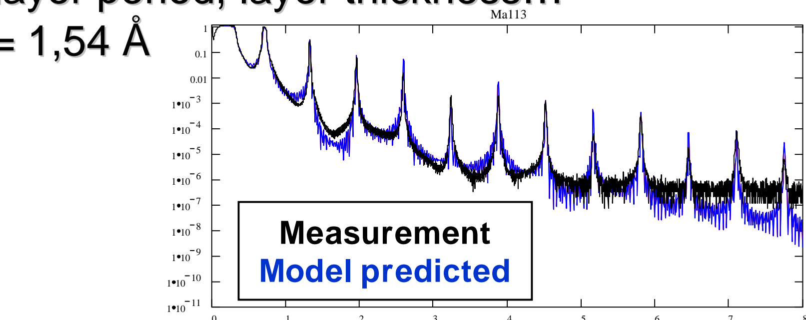
LURE Orsay



Small angle x-ray reflectivity

Bilayer period, layer thickness…

λ = 1,54 Å

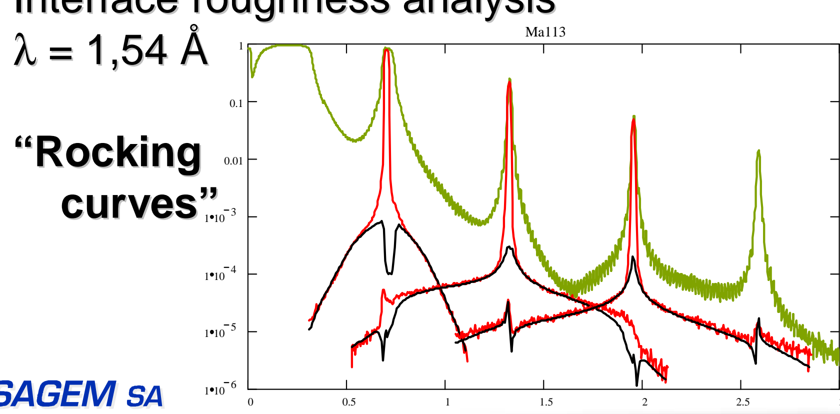


Diffuse x-ray scattering

Interface roughness analysis

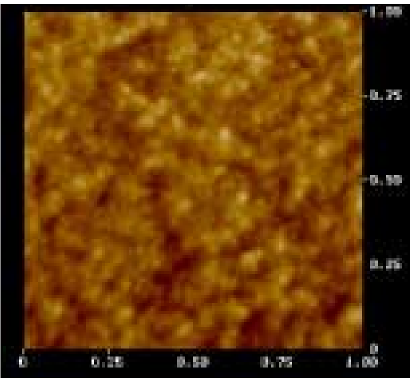
λ = 1,54 Å

"Rocking curves"



Atomic Force Microscopy

Roughness before & after deposition



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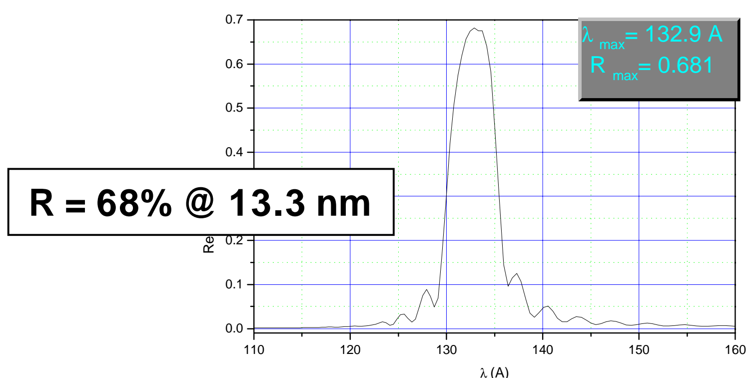
Development in ML coatings (3)

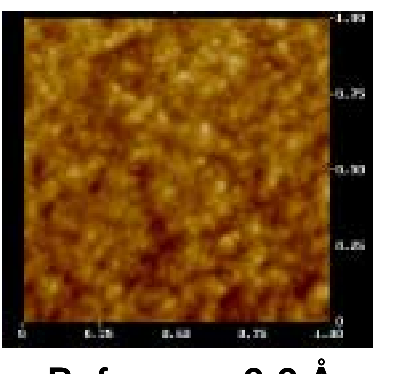
Results :

- Short process duration (1 h for 40 pairs)
- The process is stable and repetitive
- High reflectivity of 68% obtained
- Roughness of the substrate is smoothed

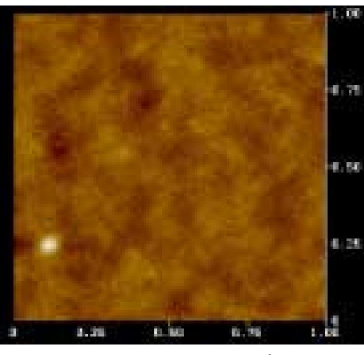


Graded layers :

Work on graded layers for BEL M1 & M2
i = 7° - 14° over 10 mm



Before σ = 2,2 Å



After σ = 1,36 Å

Comparison with other technologies :

IBS exhibits lower performances (64% only)
E Beam has much longer process time

Future : Figure correction by milling top layer

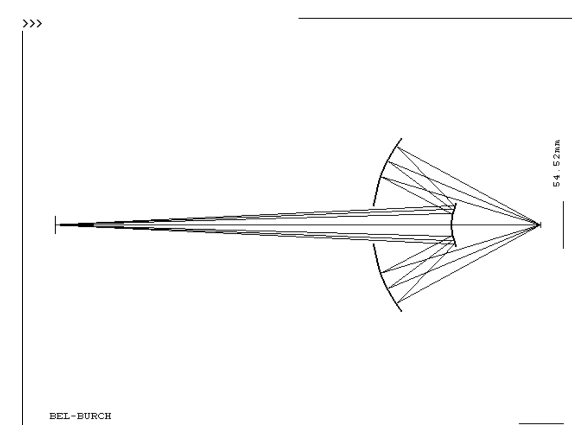
The Optics for the Banc d 'Essai Lithographie (1)

In the frame of its R&D effort in EUVL optics SAGEM will supply the optical elements of the Banc d'Essai Lithography (BEL)

Goal : Make available a lithographic tool able to conduct efficient R&D work on resists and lithography process for sub 100 nm CD.

Concept trade off (Rule 1 : simple & efficient) :

Image NA	Representative of future EUVL steppers optics ⇒ NA > 0.25
	Compatible with existing micro steppers Explore various partial coherence scheme ⇒ Subaperture with NA ≈ 0.08
Image field	100 - 200 µm sufficient
Coating	Fit within UDESAM sputtering chamber
Polarization	Avoid 45° incidence angles in beam path
Illumination	Critical illumination acceptable for BEL
	Source size ≈ 200 µm => 1 to 1 magnification to object



10X Schwartzhild - NA 0,32

The Optics for the Banc d 'Essai Lithographie (2)

14:09:32

- 10 X magnification
- NA 0.32
- M7 & M8 aspherized for perfect quality over curved field.
- M8 ∅ = 220 mm
- M7 ∅ = 50 mm

Motif 3 barres - Periode 100 nm
DIFFRACTION INTENSITY PROFILE
PARTIALLY COHERENT ILLUMINATION
N_G 26-Jun-00
WAVELENGTH 13.0 NM WEIGHT 1
DEFOCUSING 0.00000
RELATIVE INTENSITY
DISPLACEMENT ON IMAGE SURFACE (MM)

High contrast for 50 nm CD

M2
M3
M4
M6
Position de la source
M1
M5
M8
M7

Full BEL optical train

Plan de la pupille réelle
Plan image (wafer)
125.00 MM
Scale: 0.20 N_G 27-Jun-00

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The Banc d 'Essai Lithographie

Illumination Chamber

Projection Chamber

CEA/DIF/DCRE/SACE does BEL chamber design and fabrication

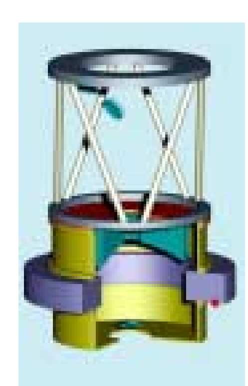
After validation, it will be transferred to CEA/LETI for resist R&D work.

cea
COMMISSARIAT A L'ENERGIE ATOMIQUE
DAM
DIRECTION DES APPLICATIONS MILITAIRES

S. HUELVAN
P. PRIGENT

Conclusion

Thanks to PREUVE, the SAGEM / REOSC high performance optics unit works hard to be recognized as a state of the art actor in EUV.



- **EUVL Optics lens design is understood**
- **Mirror + fixture concept designed -** Application to BEL
- **Polishing technology is progressing -** Key steps validated
- **Metrology skill is pushed** - Call for ref surface intercalibration
- **State of the art ML Coating demonstrated -** Graded layers
- **BEL Optics is designed -** End of fabrication by mid 2001

Results of PREUVE will be directly applicable to :

- **microsteppers optics,**
- **illumination and projection box optics,**
- **photoblank substrates.**

Thanks

Thanks to CEA/LETI, initiator of the PREUVE project in France

Thanks to all other PREUVE partners for all valuable discussions and exchanges

Thanks to the the MEFI-STCI (Ministry for Industry) partially supporting this work