High Brightness EUV Light Source for Actinic Inspection & Microscopy

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Nano-UV
EPPRA

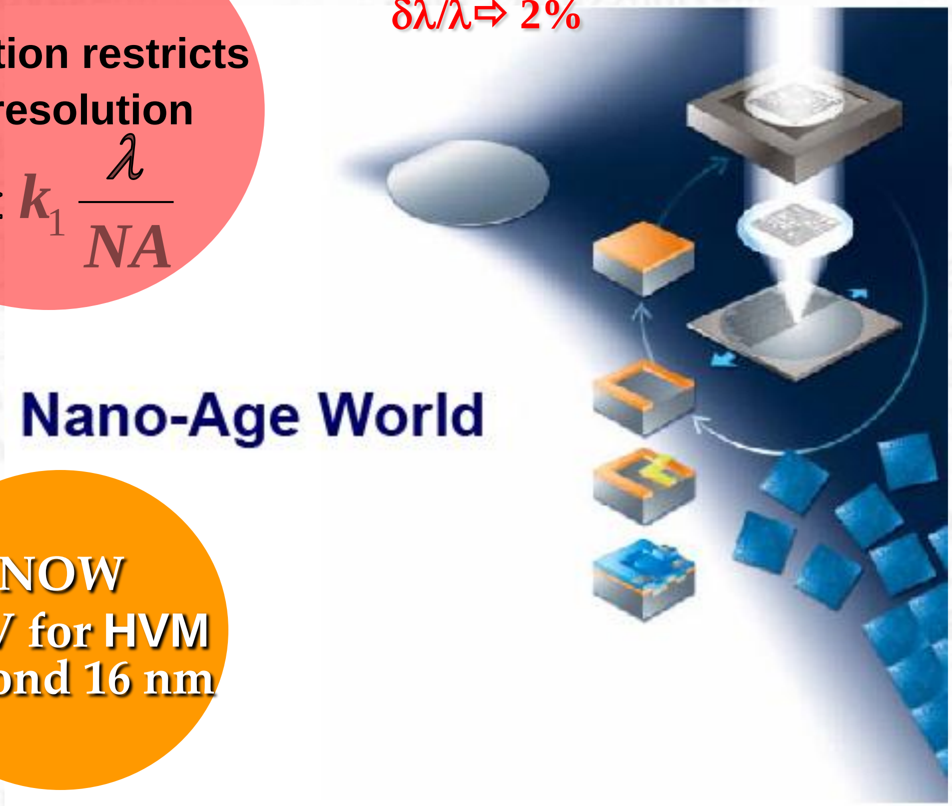
EUV Sources for EUV Lithography

Diffraction restricts the resolution

$$r \geq k_1 \frac{\lambda}{NA}$$

λ⇨ 13.5nm (hν=92eV) ⇨ 6.Xnm?

δλ/λ⇨ 2%



NOW
EUV for HVM beyond 16 nm

- For HVM: > 200 W of in-band power @ IF within < $3 mm^2 sr$ etendue
- For mask inspections ABI→AIMS→APMI : 30 → >100 $W/mm^2 \cdot sr$ within etendue of $4 \cdot 10^{-3} \rightarrow 5 \cdot 10^{-4} \rightarrow 1.5 \cdot 10^{-2}\ mm^2 \cdot sr$

LPP & DPP can produce Sn, Xe… plasma radiating at EUV range

EUV sources are still the main issue of EUVL deployment

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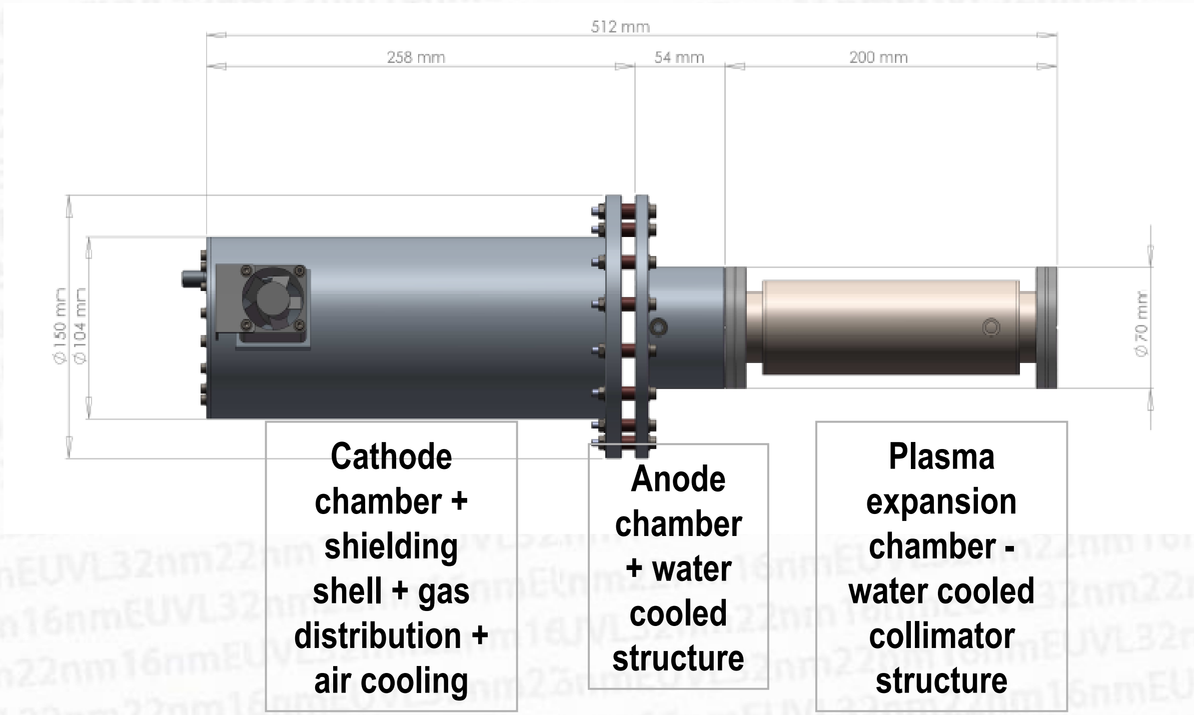
i-SoCoMo™ - GEN II cell



Physical Dimensions:

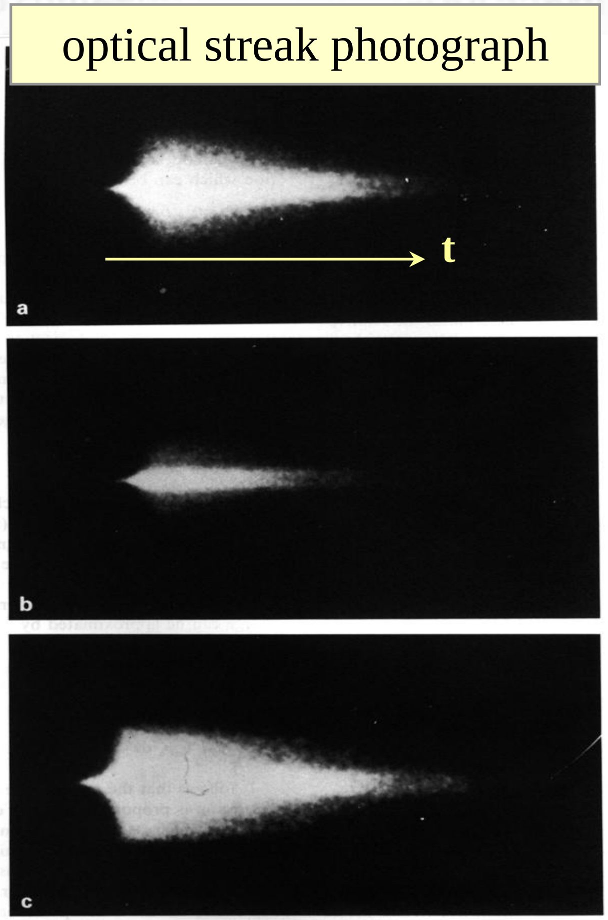
- Source : 150 mm diameter, 520 mm length, 7 kg
- Instrument rack : 1300 x 600 x 800 mm, 200 kg

Utility requirements:

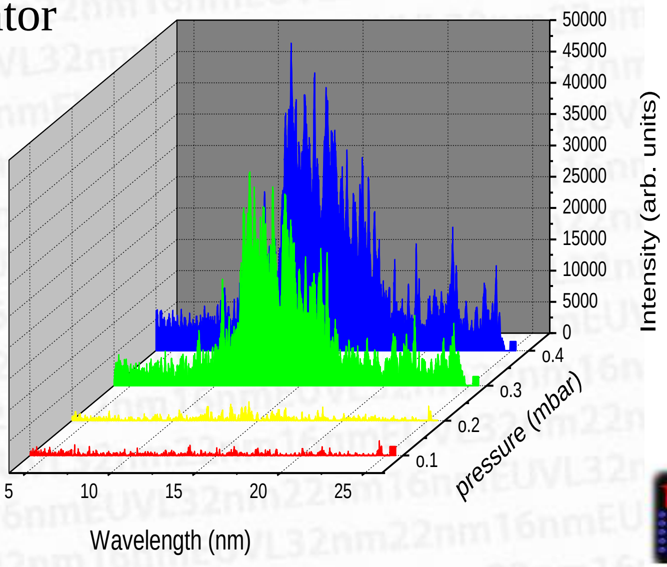
- Electrical : 200-240V, 2Ø, 50/60 Hz, 16A
- Cooling : Water cooled (2 litres per minute, 15°C - 25°C inlet)
- He, N_2 and Xe : 3 bar inlet

MPP Discharge Experiment

- plasma discharge emission from a channel produced by hollow cathode electrons



– pulse charged local energy storage
– sub-mm diameter capillary
– hollow cathode e-beam for on-axis discharge initiation
– rapid current heating
– ultra-bright high energy density radiator



- 1st EUVL Symposium, Dallas 2002 -

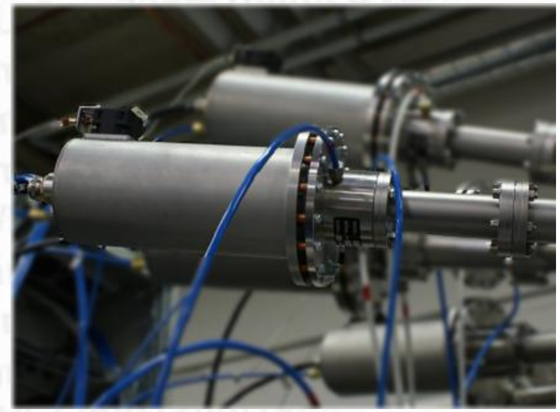
European Pulsed Power Research Applications

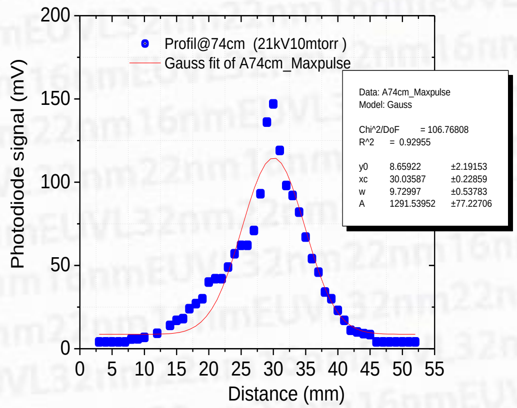
Nano-UV: EUV Source

micro - pulsed plasma

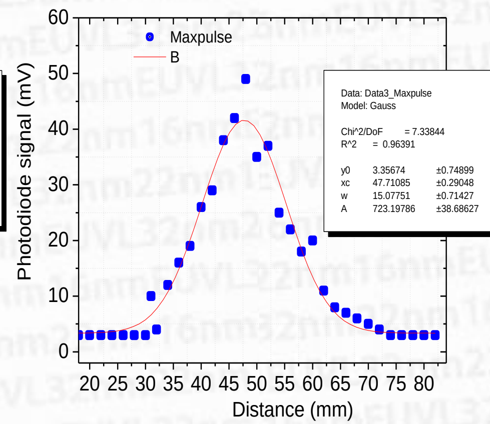
MPP Performance @ 21kV

- with SXUV20 A Mo/Si (350/500 nm) filtered diode from IRD in 3 nm EUV band (12.4 nm -15.4 nm)
- Al coated (110 nm) on Si_3N_4 (250 nm) to reject OoB
- 200μm pinhole aperture in front of the diode
- typical etendue < 10^{-3} mm^2.sr
- Discharge in He/N_2/Xe admixture, total Flow 3.2 sccm/min
- Cell capacity 1.7nF
- The low charge energy resolves heat-loading issues





Scanned signal profile @ 74cm



@ 98cm

Distance source to diode (cm)	Irrandiance @ 1kHz Ph/cm²/s	Beam HWHM (mm)	Radiation half angle divergence θ (deg)
74	8.2e17	6.13	0.8
98	1.8e17	9.65	
Radiation solid angle = 2*π (1-cosθ)= 6e-4 sr			

Estimated in-band brightness is of 31 W/mm^2 sr per kHz

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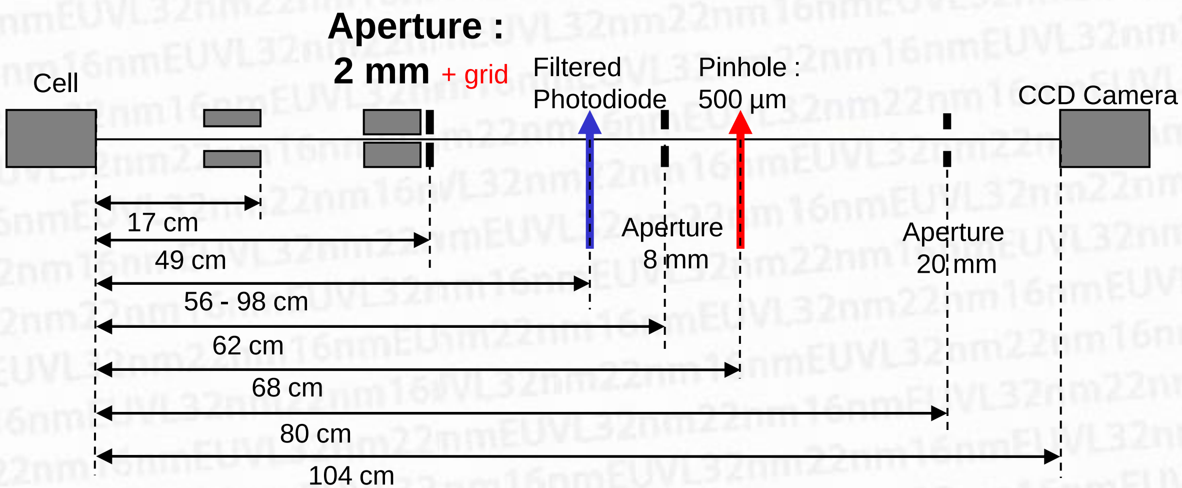
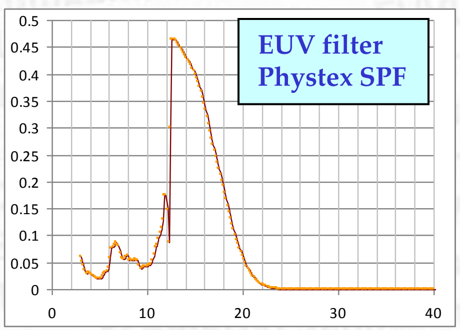
Source Characteristics
- measurement schematics

- Set up



- Pinhole scan
  - time averaged source diameter; size & stability
  - angular emission properties
  - source etendue



- Photodiode scan
  - filtered (Mo350nm/Si500nm) SXUV_20A diode with 3 nm band (12.5-15.4 nm) with Al coated Si_3N_4 to reject Oob
  - CCD with Spectral Purity Filter (SPF) or Al coated Si_3N_4 filter
  - scan diode to get radiation profile and power delivered
  - fold with pinhole scan source image data to get radiant brightness

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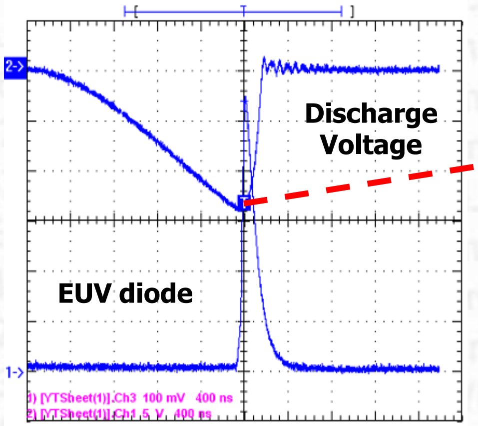
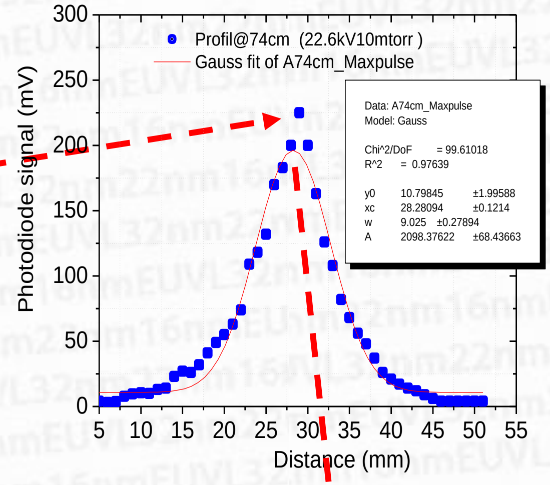
nano V

Source Characteristics I

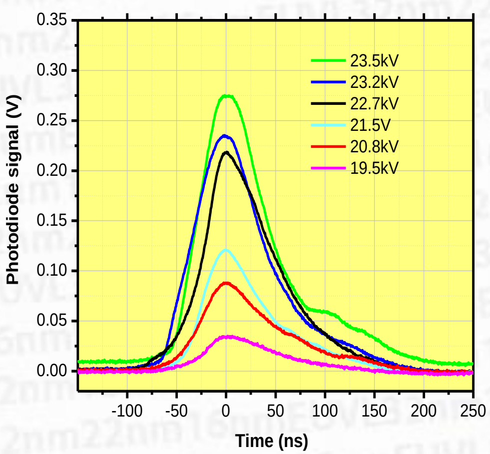
- irradiance & power vs stored energy



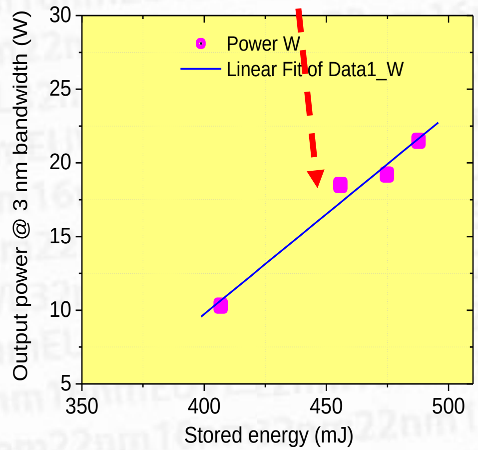


At 74 cm, 22.6 kV, 450mJ, 1 kHz, (3nm EUV band):

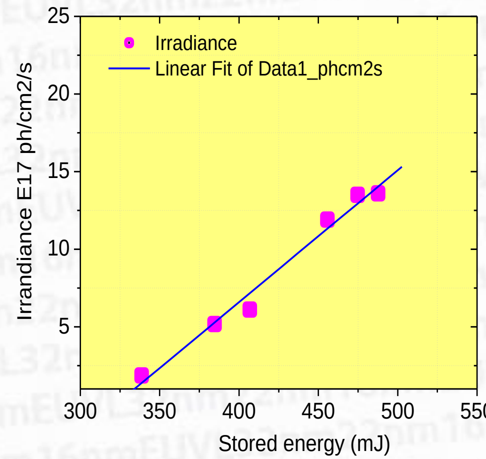
- **Peak irradiance 1.19 E18 ph/cm²/s**
- **Sigma: 4.01 mm**
- **Power: 18.5W** (3nm band)



Photodiode pulse over 16 shots



3nm EUV band power versus stored energy



Irradiance versus stored energy

Output power and irradiance increase with increasing stored energy

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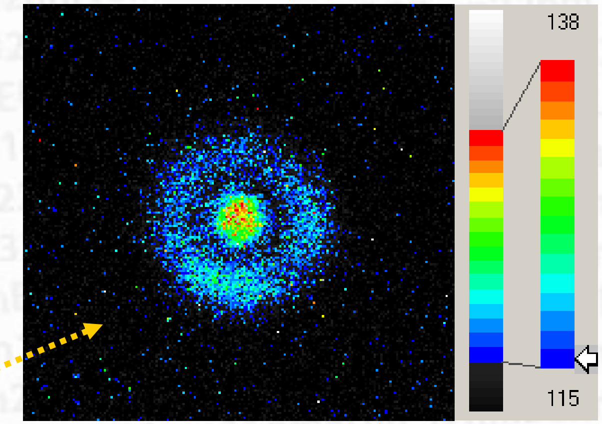
Source Characteristics
– higher resolution source projection

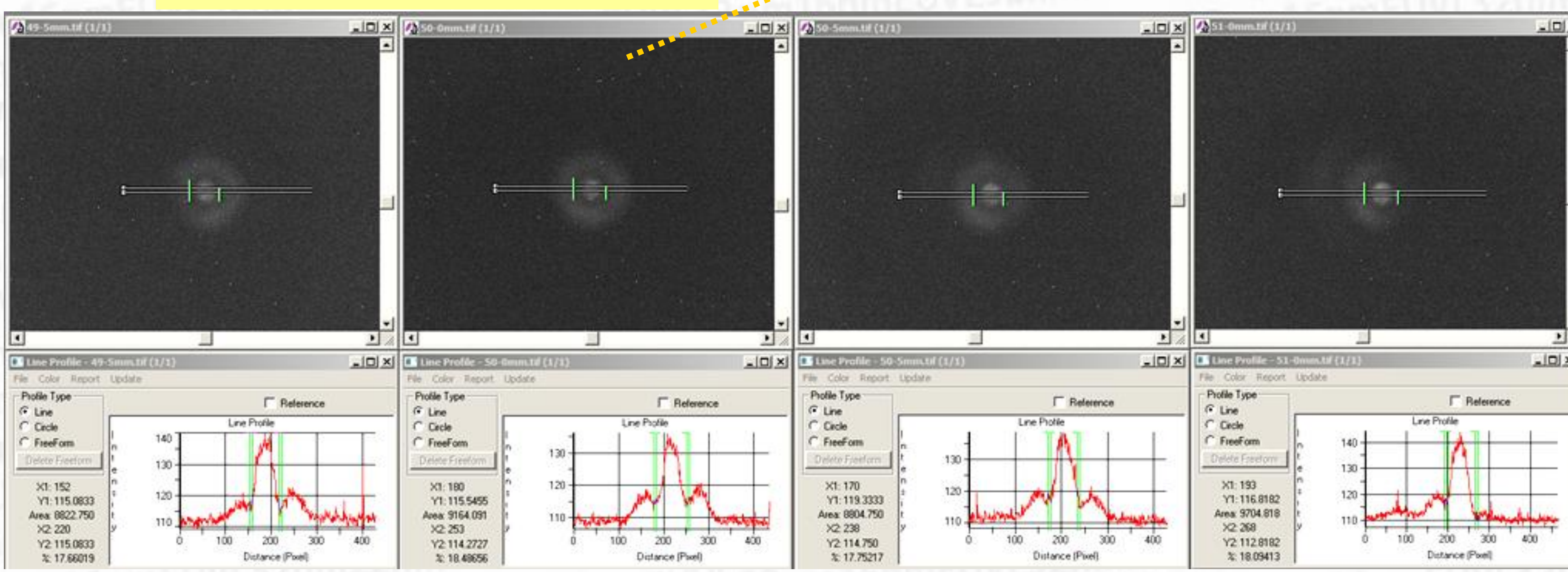
Pinhole scan – EUV SPF filter, F4 mesh grid over SEA (2mm)

- far field image showing collective features

The measured source size is less than ∅ 180um



Pseudo colour



pinhole-scan image profile - 500 μm pinhole, 0.5 mm scan step, <u>50s exposure, 2x2 bin</u> on CCD, 1 kHz EUV pulses, image sensor to source 104 cm, <u>untreated raw data</u>

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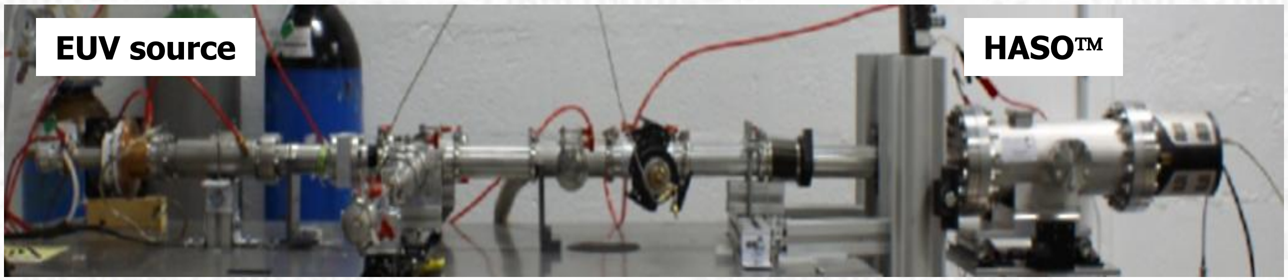
Source Characteristics II

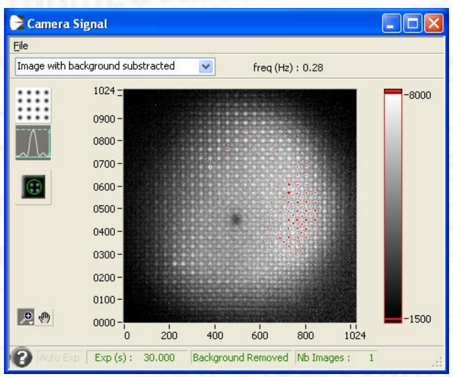
- wavefront measurement

HASO™ X-EUV Shack Hartmann wavefront sensor - (from Imagine Optic)

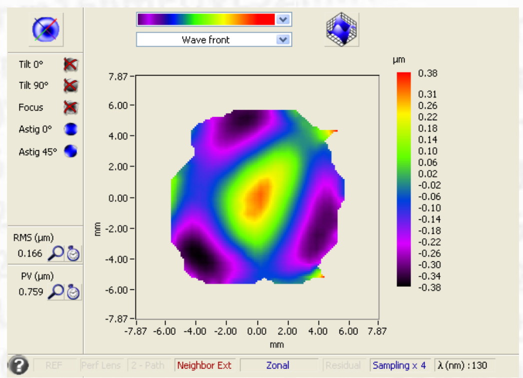


HASO X-EUV

← **1890 mm** →



Acquired image 60s exposure, source at 1 kHz



Derived wavefront
166 nm RMS (12 λ) & 760nm PV (58 λ)

- EUV beam diameter d= 9.75 mm at 1890 mm from source
- Beam divergence half angle =0.19°
- Solid angle **Ω =** 0.0345 msr
- Etendue $E = 5 \cdot 10^{-5}\ \mathrm{mm^2 sr}$

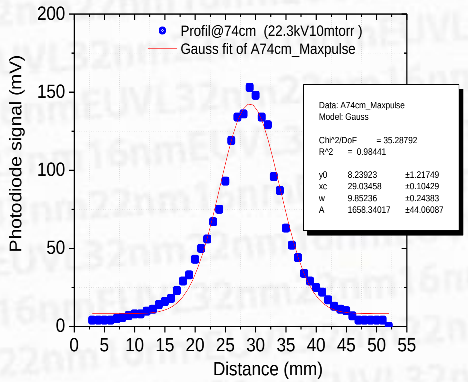
*** With support of G. Dovillaire, E. Lavergne from Imagine Optic and P. Mercere, M.Idir from SOLEIL Synchrotron**

Source Structure Tuning
- different cathode materials

Measured Parameters

SXUV20 A Mo/Si (350/500 nm) filtered diode from IRD, 3 nm EUV band (12.4 nm - 15.4 nm), Al coated (110 nm) on Si_3N_4 (250 nm) to reject OoB, typical etendue 1.7 E-2 mm^2.sr, discharge in He/N_2/Xe admixture with a total Flow 3.2 sccm/min, Cell capacity 1.7nF, Stored energy 440mJ.

Al -alloy cathode

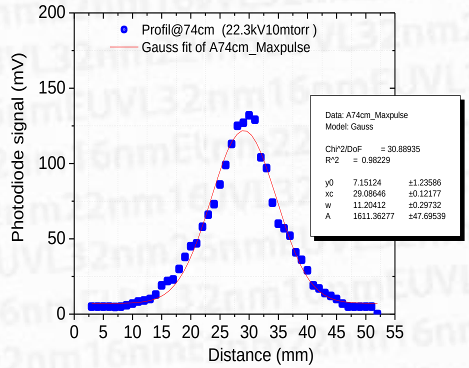


- irradiance at 74cm, 10mtorr and **<u>22.3kV</u>**- **7.4e17 ph/cm²/s at 1 kHz (3nm EUV band)**

  Power= 13.7W

  Sigma= 4.92mm

SS cathode

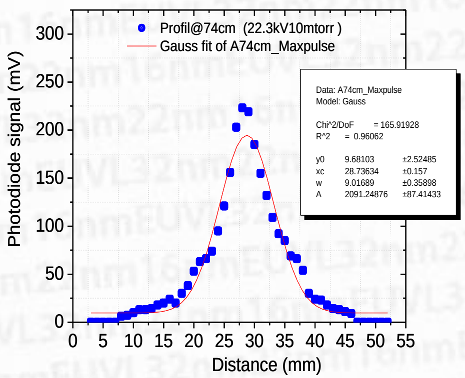


- irradiance at 74cm, 10mtorr and **<u>22.3kV-</u>** **6.9e17 ph/cm²/s at 1 kHz (3nm EUV band)**

  Power= 16.3W

  Sigma= 5.6mm

Sn-alloy cathode



- irradiance at 74cm, 10mtorr and **<u>22.3kV</u>**- **1.1e18 ph/cm²/s at 1 kHz (3nm EUV band)**

  Power= 18W

  Sigma= 4.5mm

Sn alloy cathode improves radiation output

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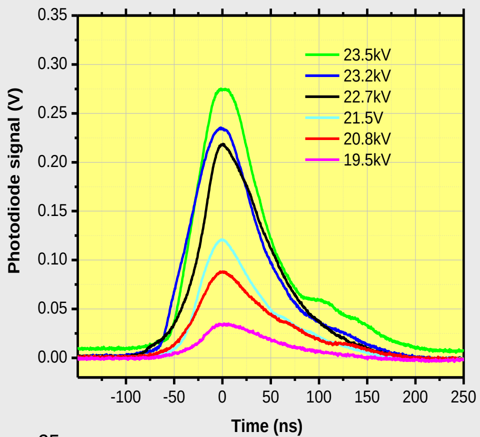
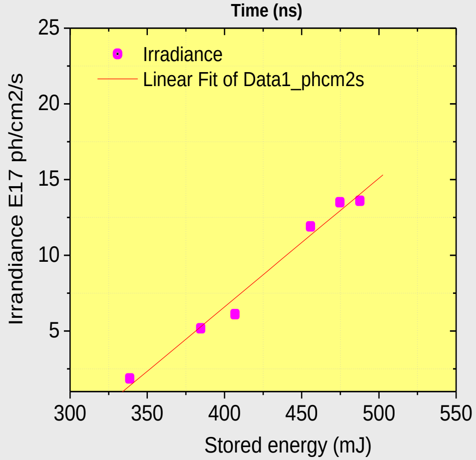
Tin addition to the gas admixture

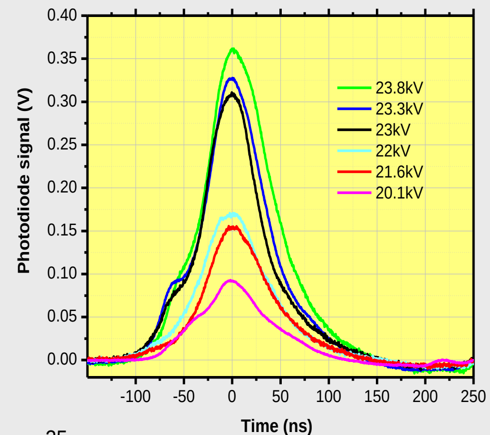
- different Tin alloy cathode

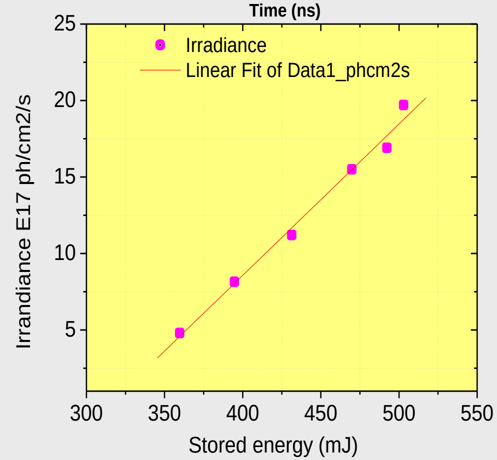
Voltage scan using Sn-alloy cathode 1





Voltage scan using Sn-alloy cathode 2 higher Sn content





At high energy, radiation output > 1.25x using Sn alloy 2 compared to Sn alloy 1

Need to assess life time issues

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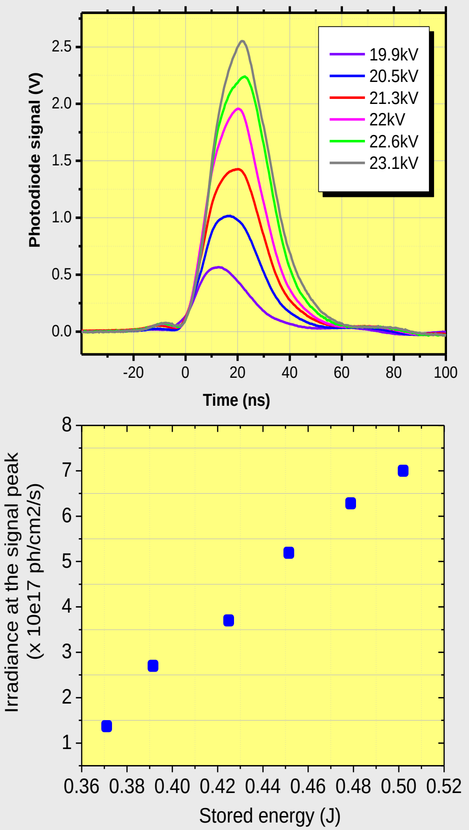
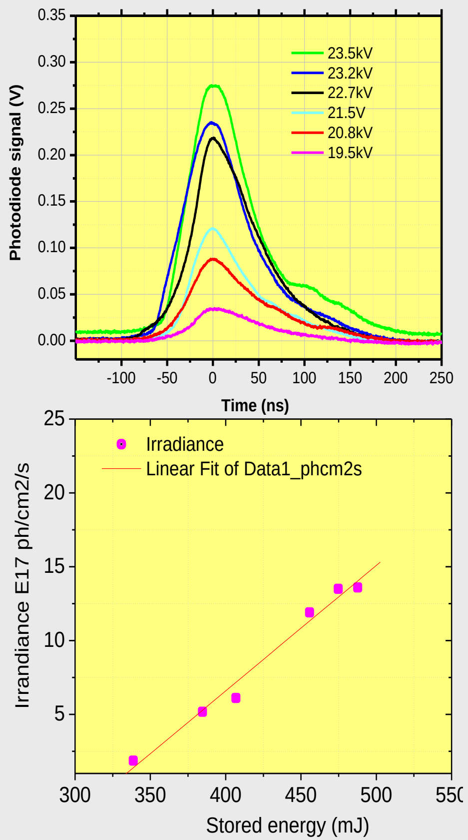
Progress in experiment

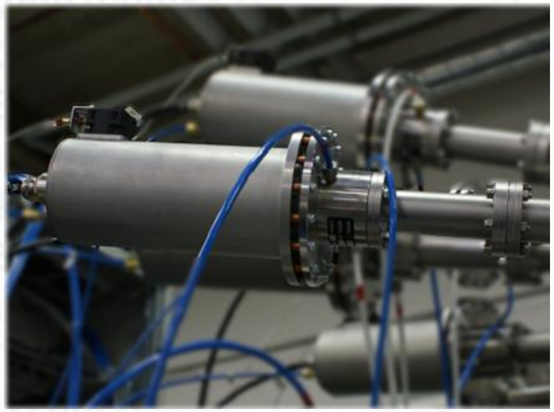
- irradiance vs stored energy

Results presented at EUVL october 2010



Current Results





At same operating voltage by optimisations made on the fuel gas mix and flow rate

- ✓ **2 fold increase in the irradiance**
- ✓ **3 fold increase on power**

Scaling to higher power demonstrated with Sn admixture

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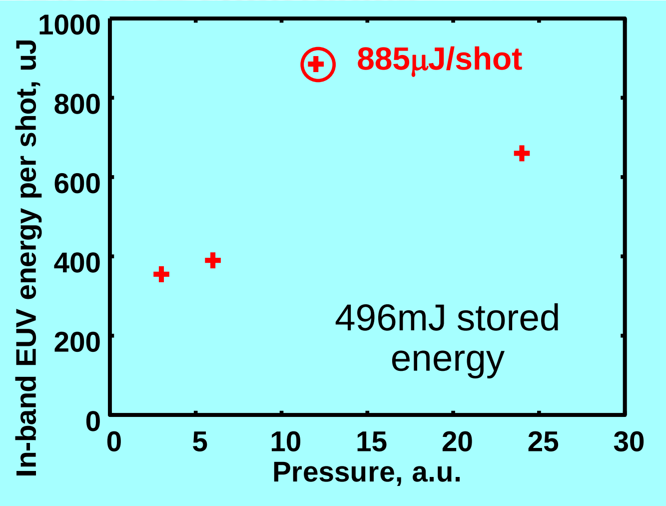
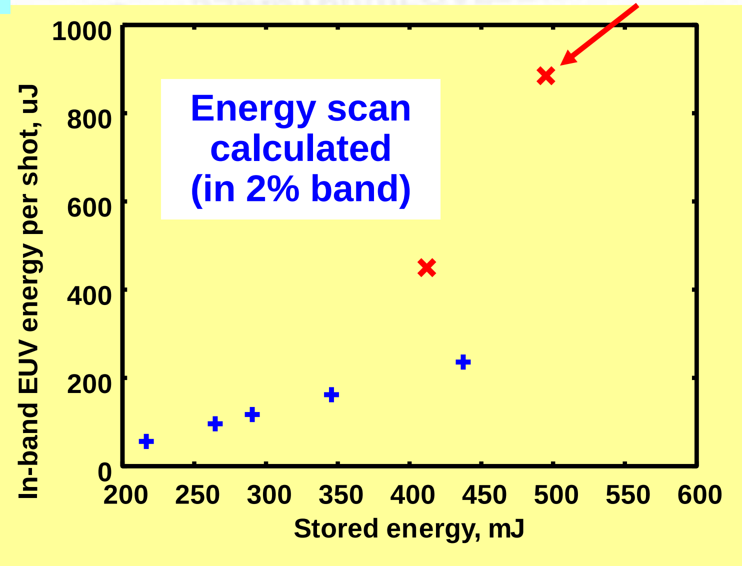
Gen II EUV Source
- characteristics & optimization from Z* modelling



Optimization
by gas mixture pressure

Resistive regime



EUV source
scan by stored electrical energy

for more details, at theoretical talk (S44): S.V.Zakharov et al

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CYCLOPS - AIMS™

- high brightness with small etendue

Aerial Image Microscope System (AIMS) tool source

- Design Specifications
  - 100 W/mm^2.sr in-band 2% EUV radiant brightness
  - 50mW within etendue - 5 10^{-4} mm^2.sr
  - IF source area < 9 mm^2
  - **optimized for aerial image measurements**
  - i-SoCoMo™ unit, 5 kHz working
  - energy stability < 10%
  - no debris / membrane filter

- Current Status
  - system characterization
  - stability optimization
  - life time components testing

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Multiplexing

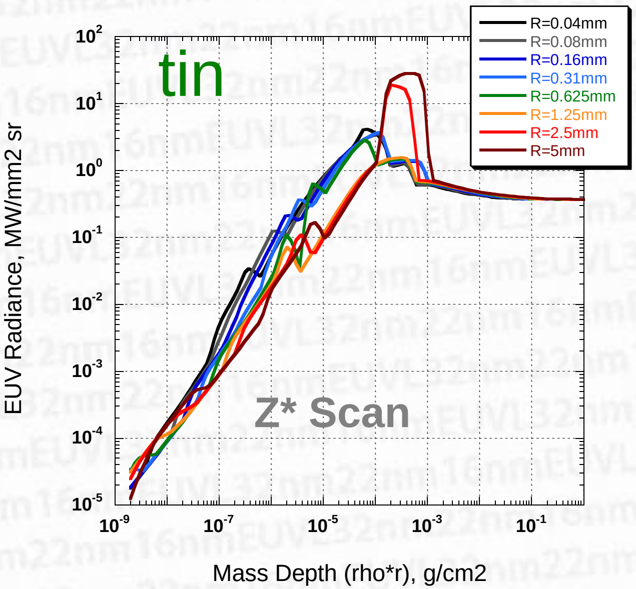
- a solution for high power & brightness

- Small size sources, with low enough etendue $E_1 = A_s\Omega << 1\ mm^2\ sr$ can be multiplexed.
- The EUV power of multiplexed N sources is

$$P_{EUV} \propto \sqrt{E \cdot N \cdot \Omega} \cdot \tau \cdot f$$

$\Rightarrow$ The EUV source power meeting the etendue requirements increases as $N^{1/2}$

- This allows efficient re-packing of radiators from 1 into N separate smaller volumes without losses in EUV power



- Spatial-temporal multiplexing: The average brightness of a source and output power can be increased by means of spatial-temporal multiplexing with active optics system, totallizing sequentially the EUV outputs from multiple sources in the same beam direction without extension of the etendue or collection solid angle

- **compact physical size of SoCoMo is required**

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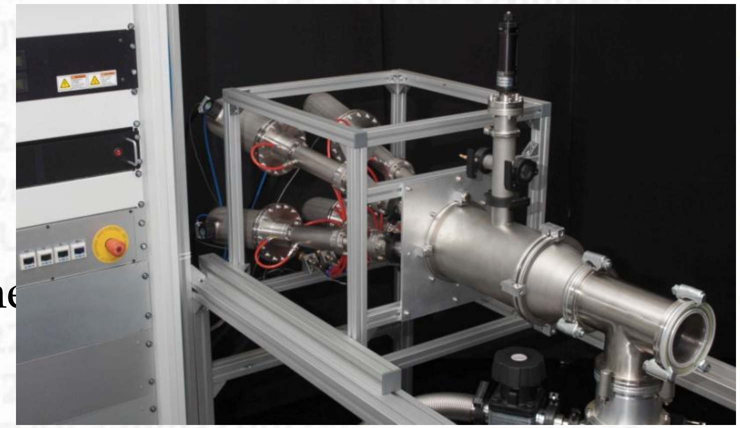
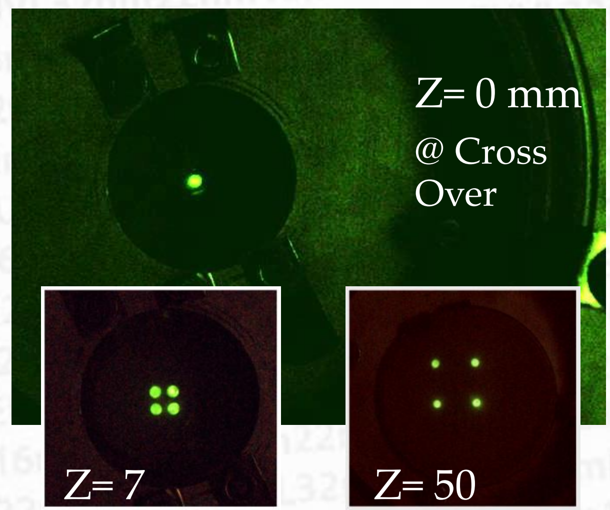
HYDRA⁴-ABI™ - spatial multiplexing for blank inspection

Actinic Blank Inspection (ABI) tool source



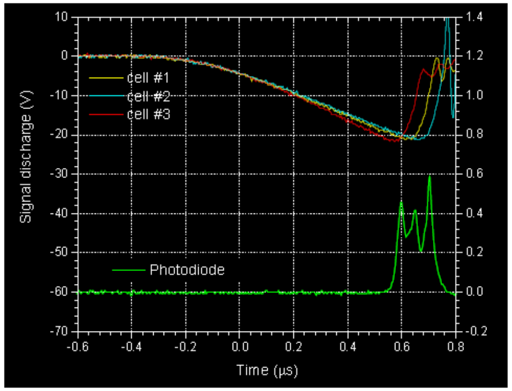
- Design Specifications
  - 60 W/mm².sr in-band 2% EUV brightne
  - 0.6 W at the IF
  - effective etendue 10^{-2} mm².sr
  - source area - 31 mm² / TBD
  - **optimized for mask blank inspection**
  - **4x** i-SoCoMo™ units working at 3 kHz each
  - no debris / membrane filter
  - **close packed pupil fill**
- Current Status
  - 4 units integration & characterization
  - single unit optimization
  - ML mirrors evaluation & modelling



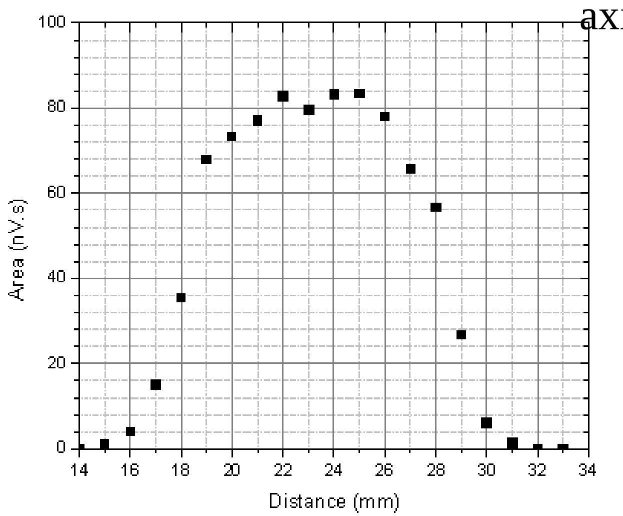
All 4 sources aligned to a point without use of any solid optical collector

HYDRA^4-ABI™
- spatial multiplexing

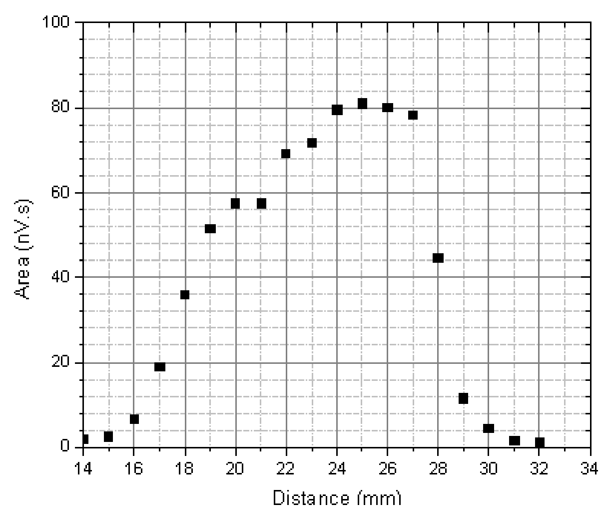
- 4 cells operating @ 1 KHz @ 22 KV
- Cells capacity : 1.2nF each
- Operating Pressure ; 30mTorr



Profile scans (3nm EUV band) @ 70 cm perpendicular to the optical beam axis



Summation of 4 single Beams



4 Beams simultaneous

9.6 10^{13} ph/pulse ➔ 1.4mJ/pulse ➔ 1.4 W @ 1 KHz

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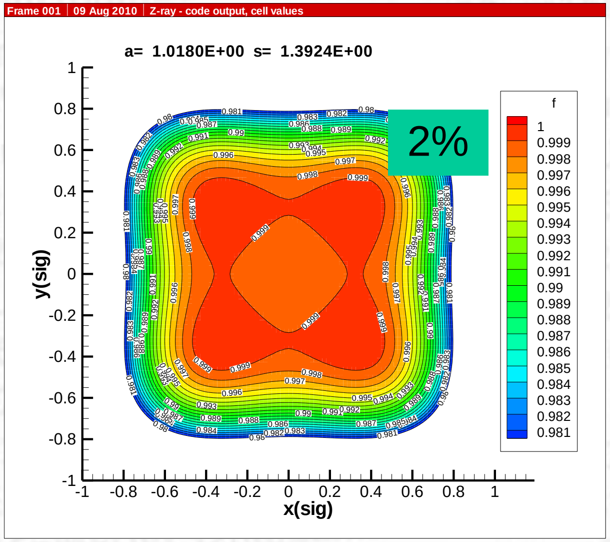
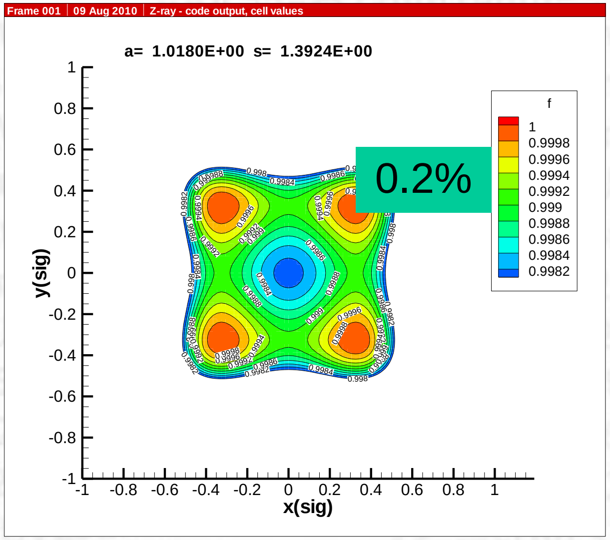
HYDRA^4-ABI™
- 4-beams flatness optimization

Overlaping of 4 suitably appertured Gaussian beam at a given flatness of 0.2%





An efficiency with flatness of 0.2% is of ***22%.***

HYDRA-APMI™

- unique temporal & spatial multiplexing

Actinic Patterned Mask Inspection (APMI) tool source

- Design Specifications
  - **60 - 120 W/mm².sr** in-band EUV brightness
  - 0.6 - 1.2 W at the IF
  - etendue – 10^{-2} mm².sr
  - IF source area - 20 mm^2
  - **optimized for patterned mask inspection**
  - **4-8x** i-SoCoMo™ units working at 3 kHz each
  - **12 - 24 kHz** temporally multiplexed
  - no debris / membrane filter
  - **Gaussian output spot**
- Current Status
  - optics design & modelling
  - single unit optimization
  - mechanical design

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Multiplexing

- Spatial & Temporal

(10) International Publication Number
WO 2009/104059 A1

Applicant *(for all designated States except US)*: **NANO-UV** [FR/FR]; 16 Avenue du Québec, F-91140 Villebon Sur Yvette (FR).

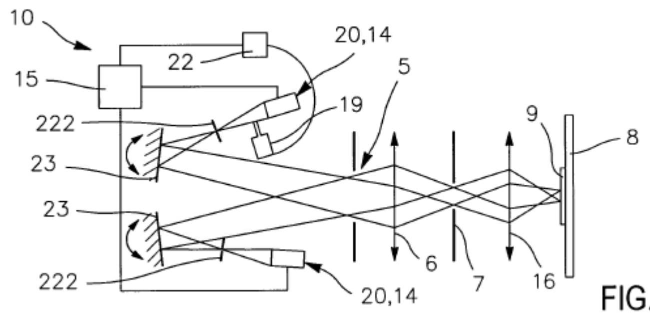
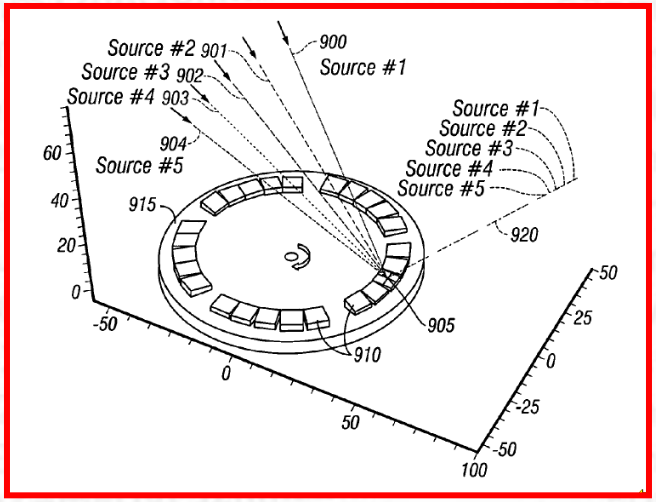
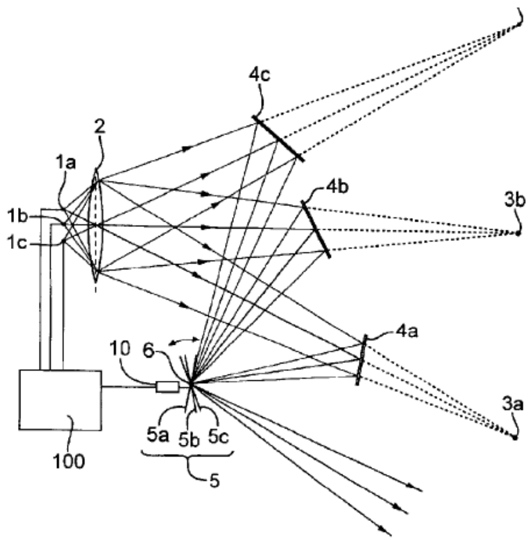


FIG. 5



United States Patent — Goldstein et al.
(10) Patent No.: US 7,183,565 B2
(45) Date of Patent: Feb. 27, 2007

United States Patent — Murakami
(10) Patent No.: US 6,861,656 B2
(45) Date of Patent: Mar. 1, 2005



Temporal Multiplexing
Technically NOT challenging
- needs development

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Acknowledgements

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  - Pontificia Universidad Catolica de Chile
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  - Keldysh Institute of Applied Mathematics RAS, Moscow, Russia
  - University College Dublin
  - King's College London
  - Imagine Optic www.imagine-optic.com
- Sponsors - EU & French Government
  - FP7 IAPP
  - OSEO-ANVAR
- Investor - RAKIA

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SEVENTH FRAMEWORK PROGRAMME

oséo soutient l'innovation et la croissance des PME

Government of Ras Al Khaimah
RAK Investment Authority

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