Monitoring of the plasma generated by a gas-puff target source dedicated for SXR/EUV microscopy

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Outlines

- Motivations on development of laboratory-based SXR and EUV compact sources based on double stream gas-puff target (DSGPT)
- Feasibility of DSGPT for nanoimaging experiments and set-up descriptions
- Plasma generated by DSGPT: diagnostic by Si and SiC detectors (linearity, time evolution, signal intensity)
- Applications of DSGPT
- Conclusions

Large Facilities

Stanford Linear Accelerator (USA)
Source length: [?] 3 km

Bessy II
(Berlin, Germany)
Circumference: [?] 240 m

TOMCAT - X02DA (Switzerland)
Circumference: [?] 288 m

Advanced Light Source
(Berkeley, CA, USA)
Circumference: [?] 200 m

Advantages

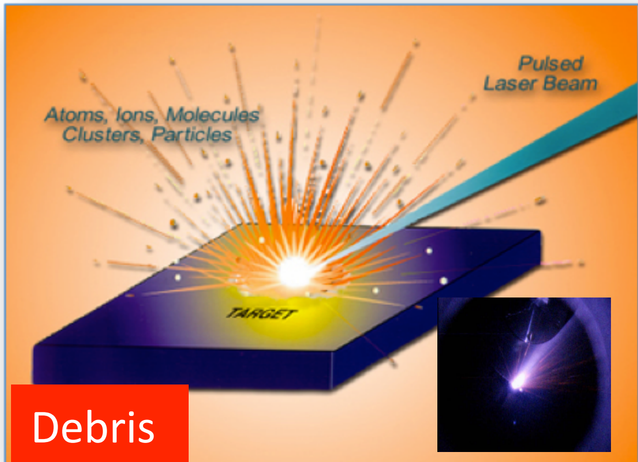
- Bright Sources
- High number of photons
- Tunable

Drawbacks

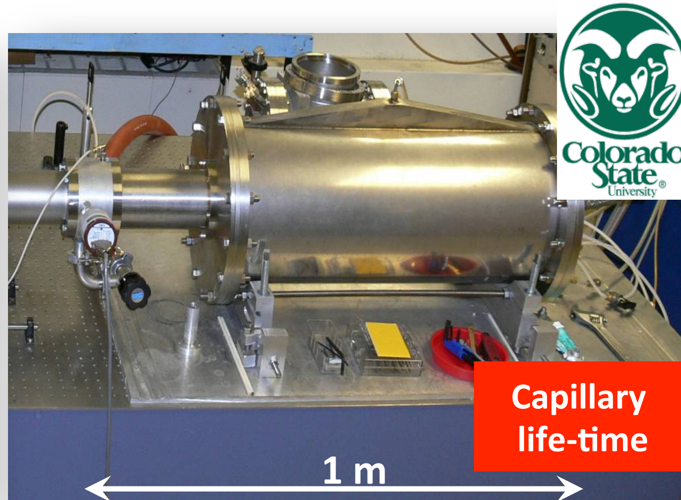
- Limited Access
- High complexity & Costs
- Expensive maintenance

Compact laser-plasma sources

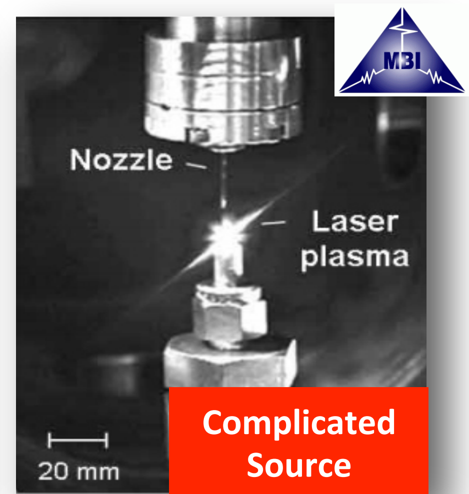
Solid target



Capillary discharge



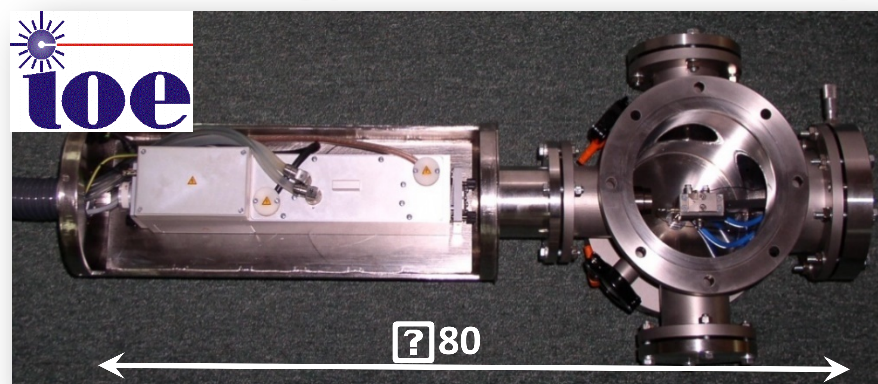
Liquid – Jet Target



Advantages

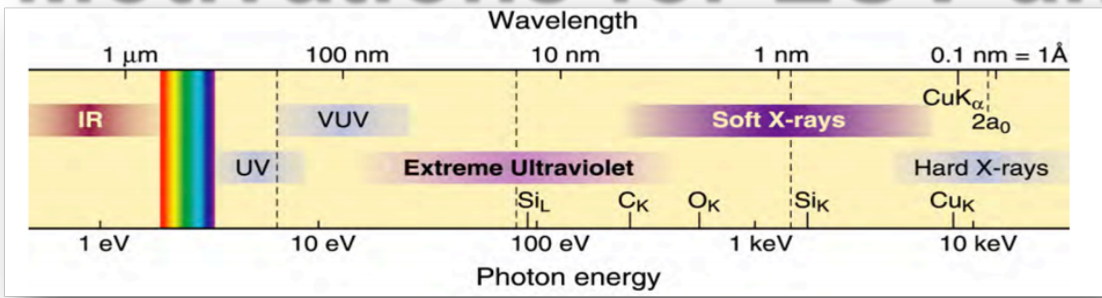
- Easily accessible
- User Friendly
- Low cost of operation
- Laboratory environment

EUV/SXR lamp for metrology and microscopy



Prof. Henryk Fiedorowicz, IOE WAT, Warsaw, Poland

Motivations for EUV and SXR imaging



$$\Delta X = \frac{k\lambda}{NA}$$

N A= n sin q

DX = Spatial Resolution
l = Illumination wavelength
NA = Numerical aperture
k = 0.61 for incoherent illumination

EUV (λ=10-120nm)

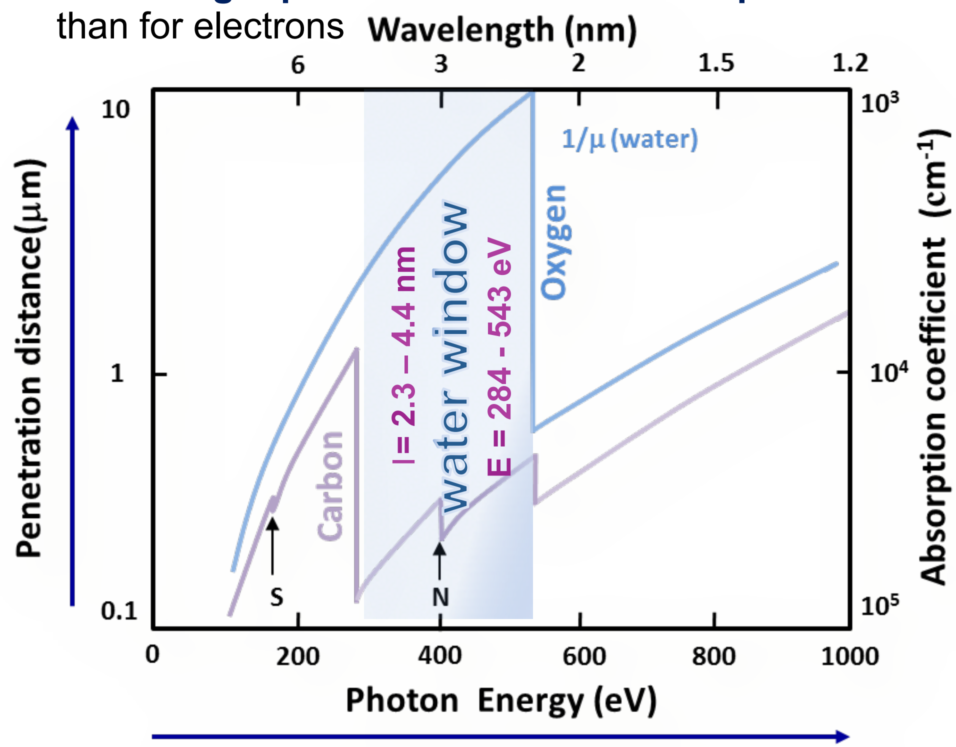
- Optical contrast
  due to the atomic resonance frequencies
- High absorption in very thin layers

SXR (λ=0.1-10nm)

- High-contrast biological imaging

good penetration in micrometer-thick specimens

much larger penetration distances for photons than for electrons



Gas-puff target EUV and SXR laser-plasma short wavelength source dedicated for imaging

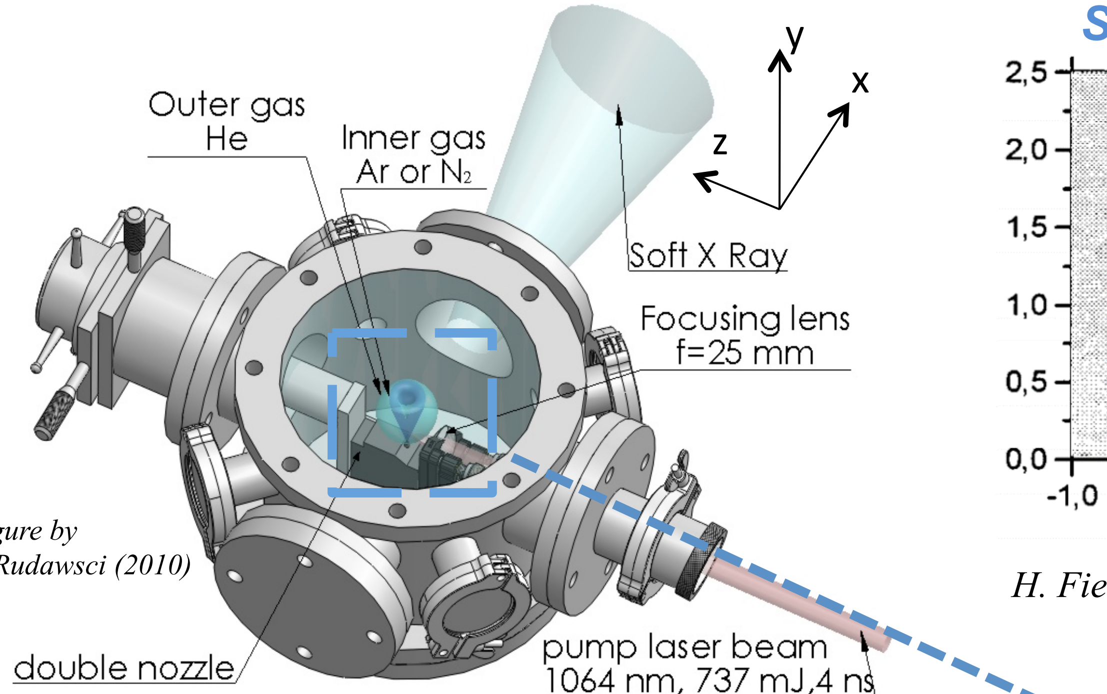
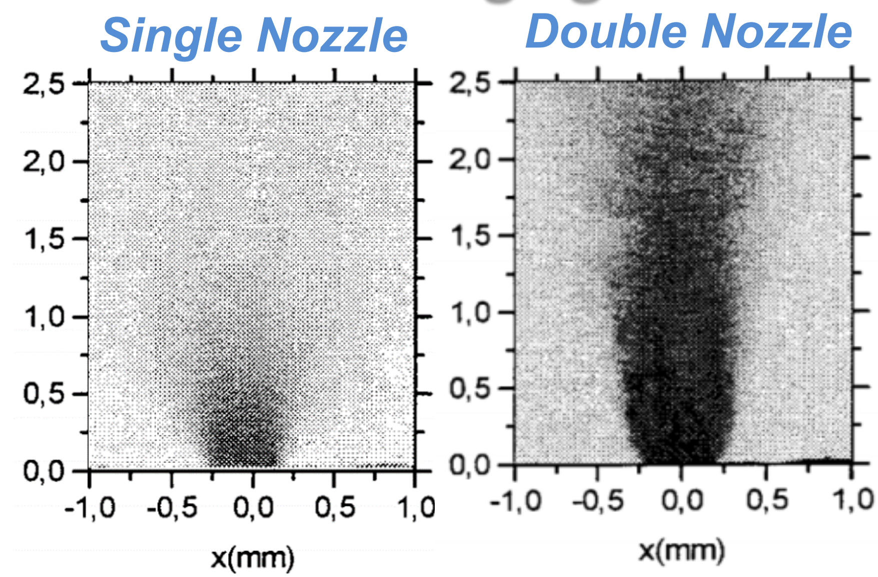
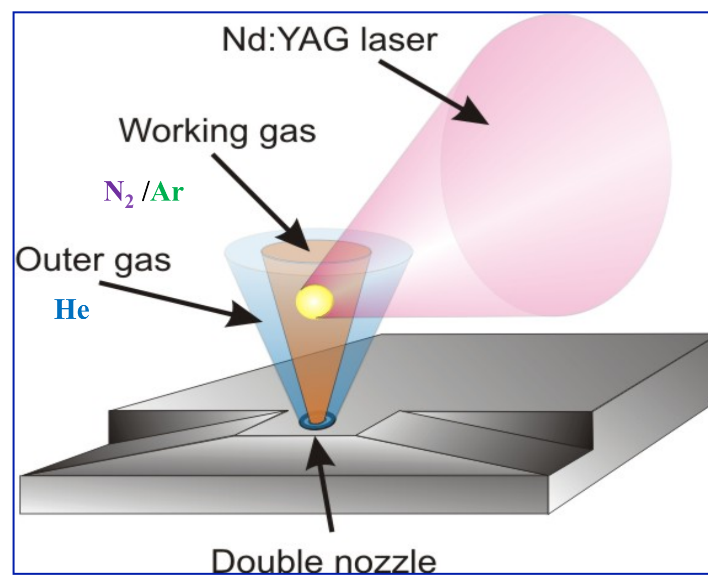


Figure by P. Rudawsci (2010)

P. W. Wachulak et al., Nucl Instrum Meth B, 268, 10, 1692-1700 (2010)



H. Fiedorowicz et al., Appl. Phys. B 70, 305–308 (2000)



- Inner noozle: circular 0.4 mm in diameter
- Outer noozle: ring 0.7 mm/1.5mm diameters

✓ **Compact construction**

✓ **Debris-free source**

✓ **High repeatability**

✓ **Optimal working gas density (~ 10^{18} at/cm^3)**

✓ **Energy stability**

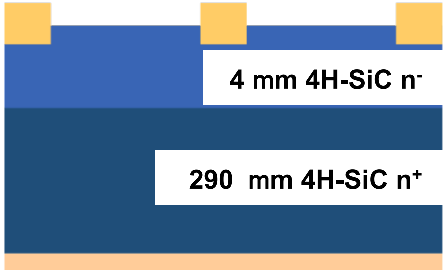
✓ **High conversion efficiency**

✓ **Thousands of shots/day**

✓ $n_{plasma} < n_{critical}$

Plasma Diagnostic and SiC detectors calibration

$$J_{SiC}=\frac{dq}{dt} = e(n_i E_i/\varepsilon)\mu_{eff}(V_d/d)$$



Shottky Contact Ni_2S

Leakage Current ~10 pA (22°C)
Bias: - 10 V
Active area: 6.35 mm^2

Collaborations with: ST Microelectronics, Catania (Italy)
Messina University (Italy), Dept. of Physics

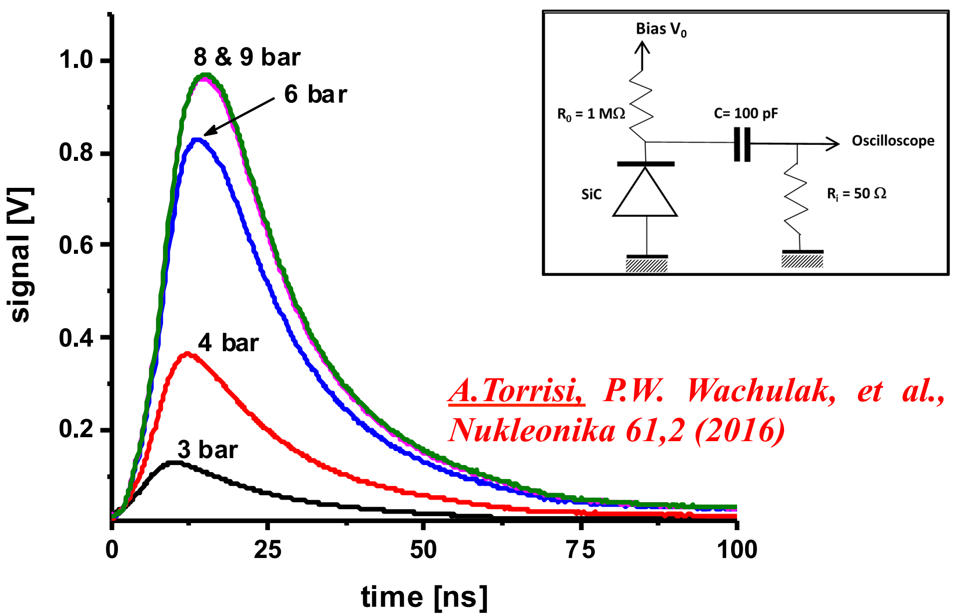
STMicroelectronics

SiC detectors cut VIS and EUV radiation emitted from plasma, enhancing the sensitivity to very fast ions.

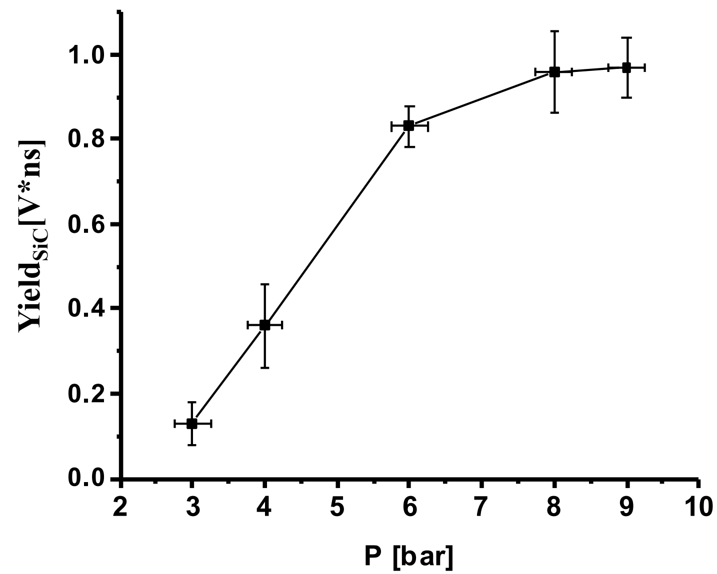
Advantages

- Higher bandgap [SiC 3.28 eV vs. Si 1.1 eV]
- Noise reduction
- Electrons and fast ions detection
- Low current at room T
- Radiation Hardness
- High electron mobility

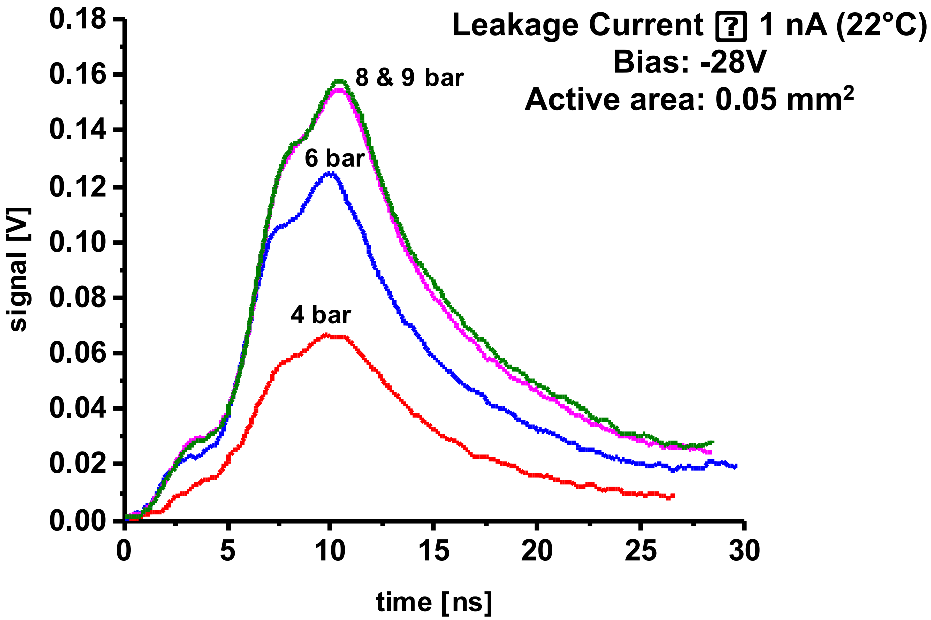
N_2 plasma @ l= 2.88 nm

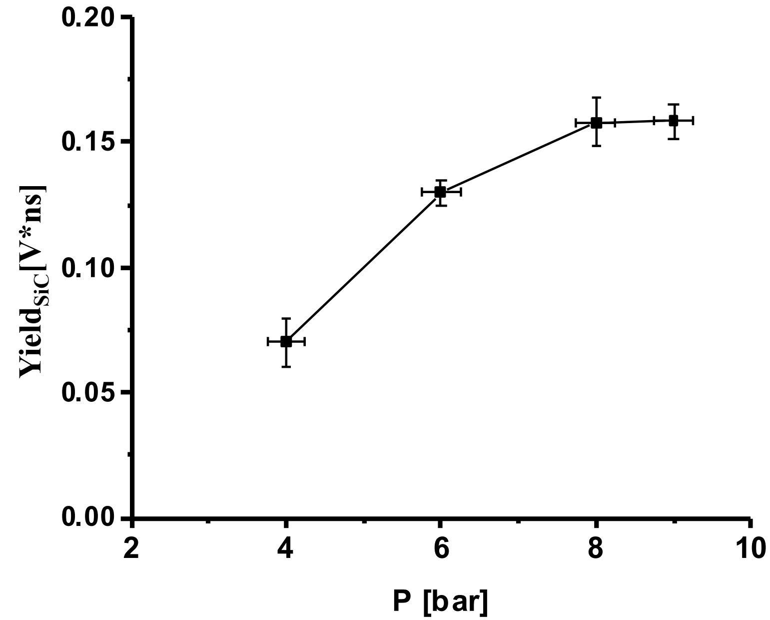


A.Torrisi, P.W. Wachulak, et al., Nukleonika 61,2 (2016)



Silicon Detector – HS1

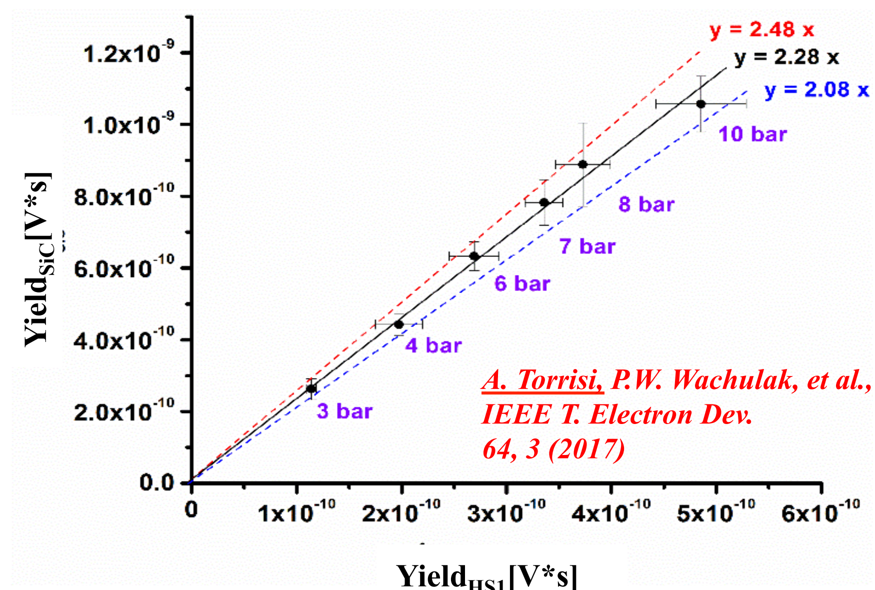




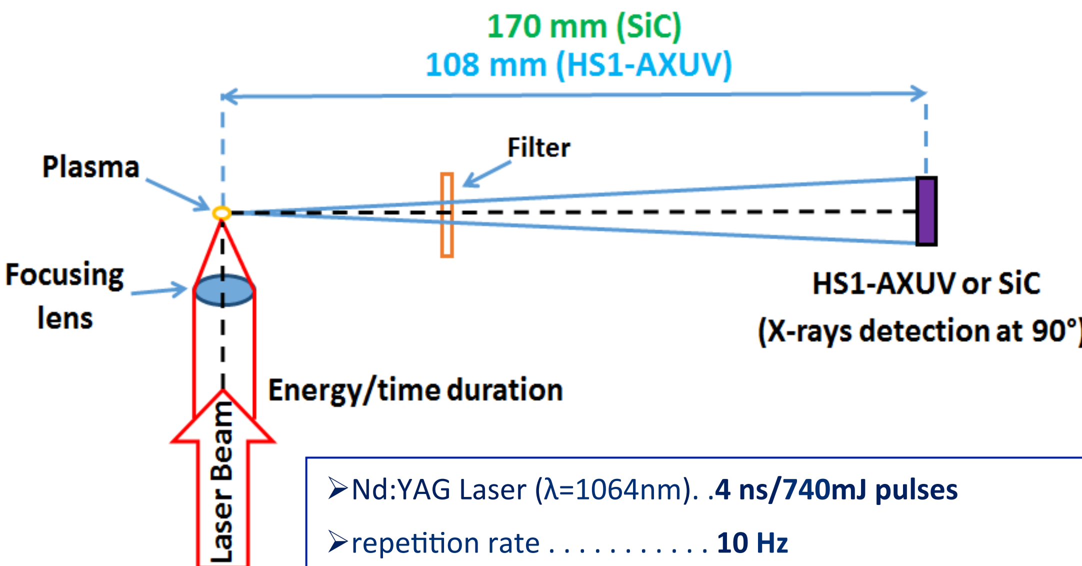
Quantum Efficiency Calculation

	AXUV/HS1 (manufacturer's data)		SiC (experimental data)	
	QE_λ [e/ph]	R_λ [mA/W]	QE_λ [e/ph]	R_λ [mA/W]
λ_{N_2} = 2.88 nm, E_{N_2} = 430.5 eV	119.49	277.5	3.41 ± 0.13	7.92
λ_{Ne} = 1.35 nm, E_{Ne} = 918.5 eV	253	275.4	7.10 ± 0.16	7.73

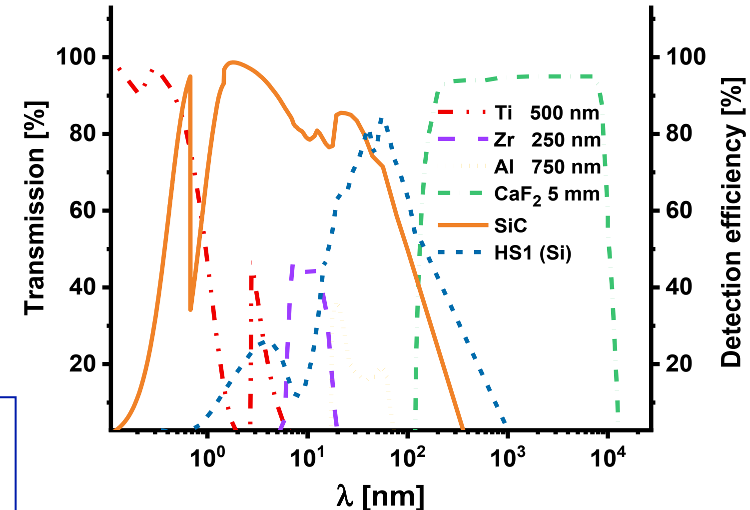
N_2 plasma @ l= 2.88 nm + 200 nm Ti filter



Plasma Diagnostic and SiC detectors calibration



- ➢Nd:YAG Laser (λ=1064nm). .**4 ns/740mJ pulses**
- ➢repetition rate . . . . **10 Hz**
- ➢Ph flux (1 EUV pulse). . . . . . **(1.36±0.07)×10^{11} photons**

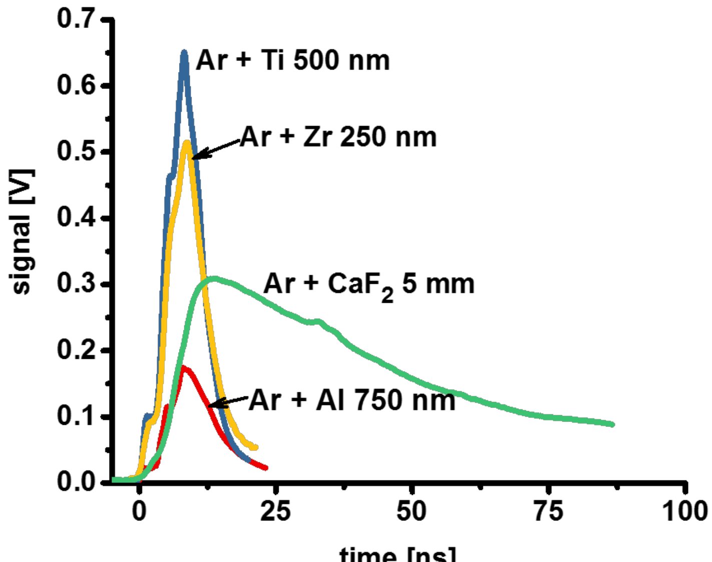


A.Torrisi et al., NIMA (2018) – under review

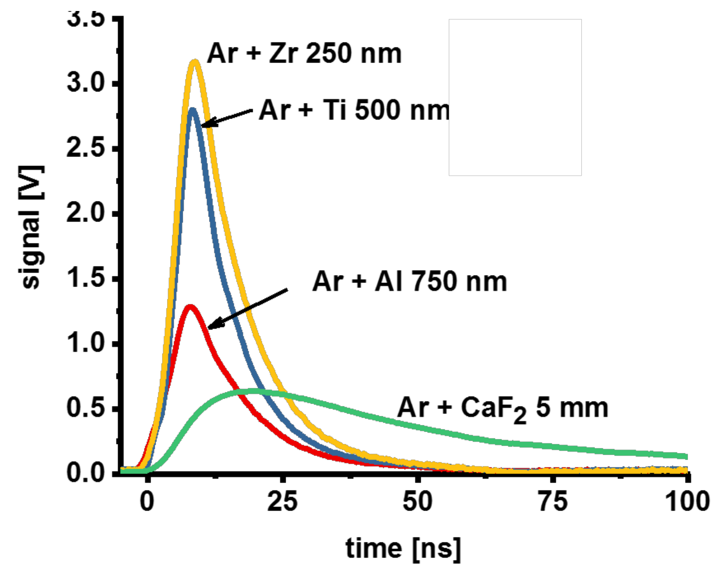
Time evolution

Ar gas (P=10 bar)

HS1 detector

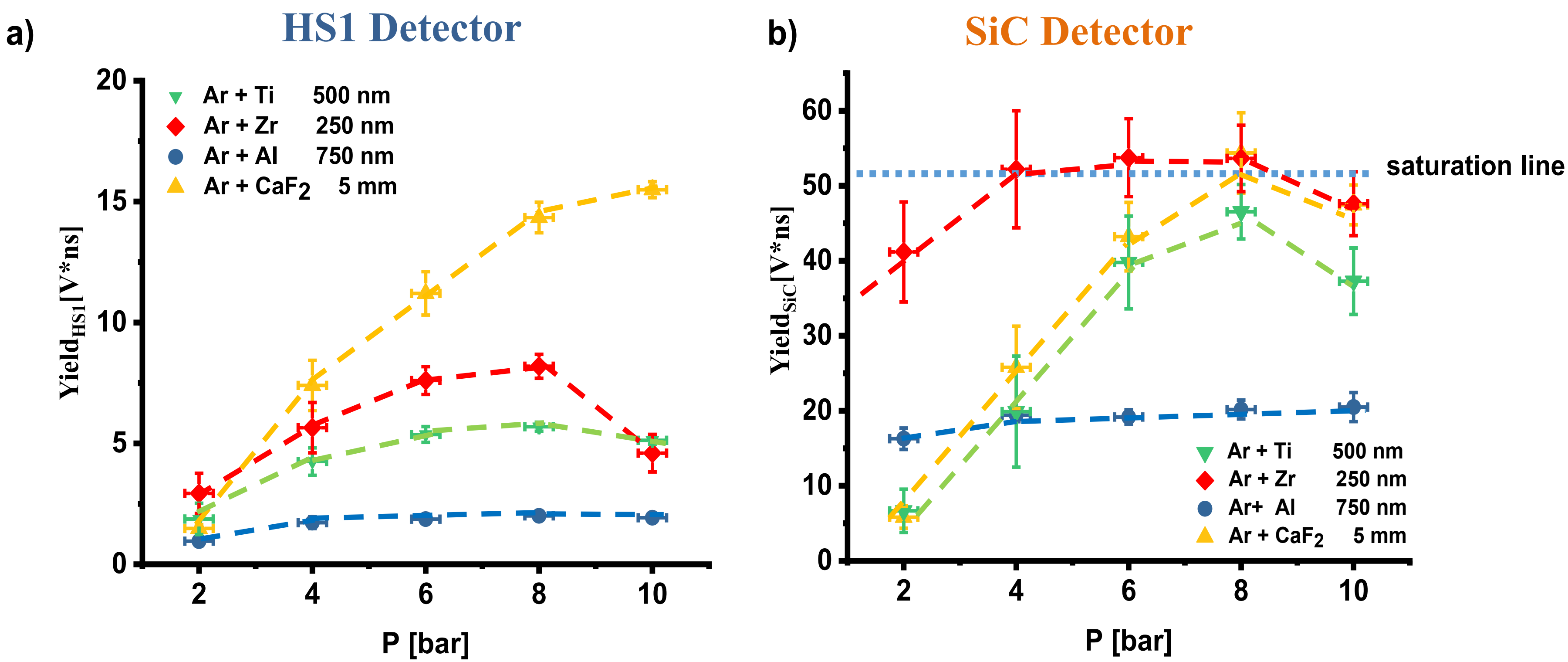


SiC detector



Plasma Diagnostic and SiC detectors calibration

Intensity signal



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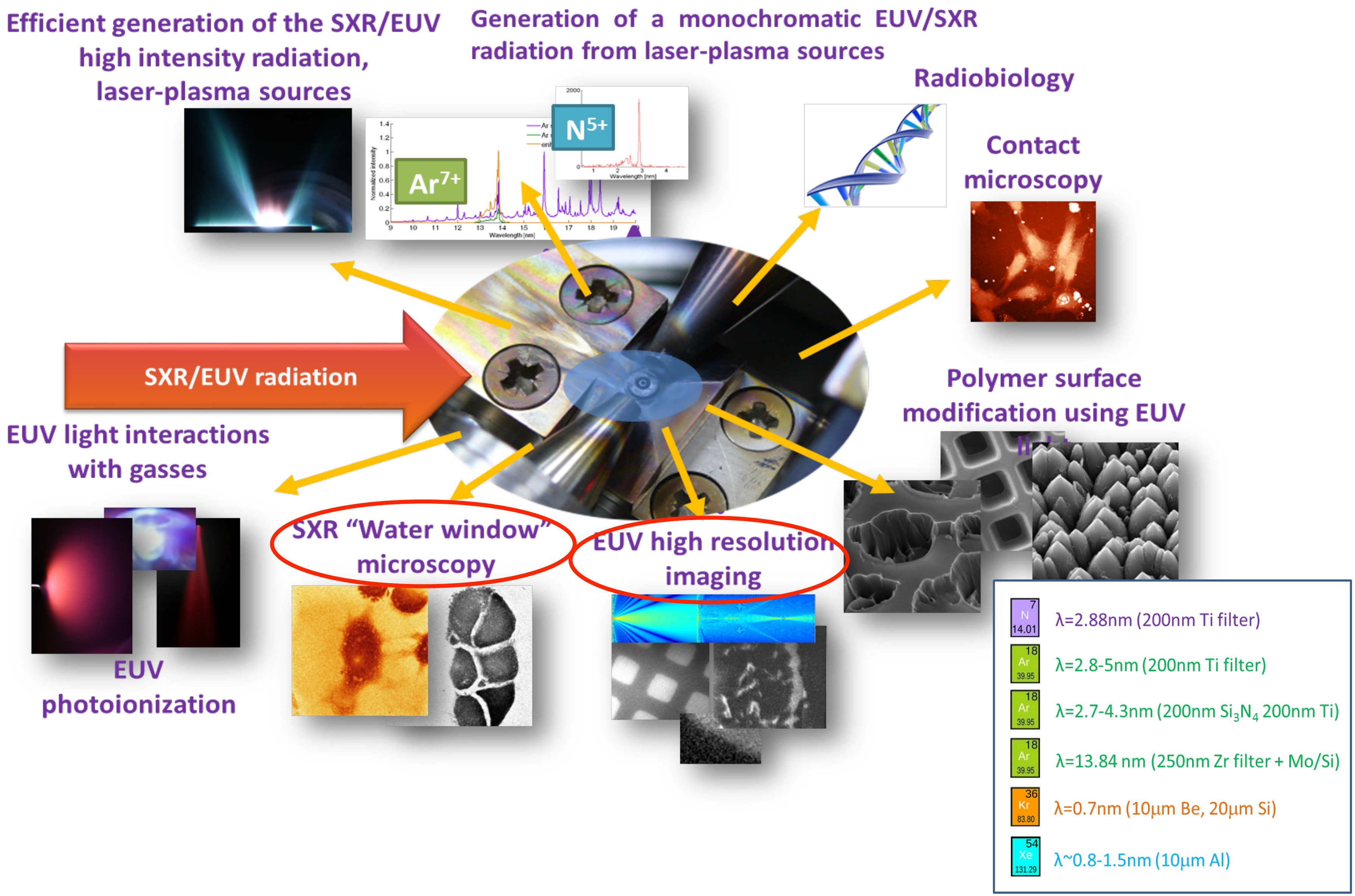
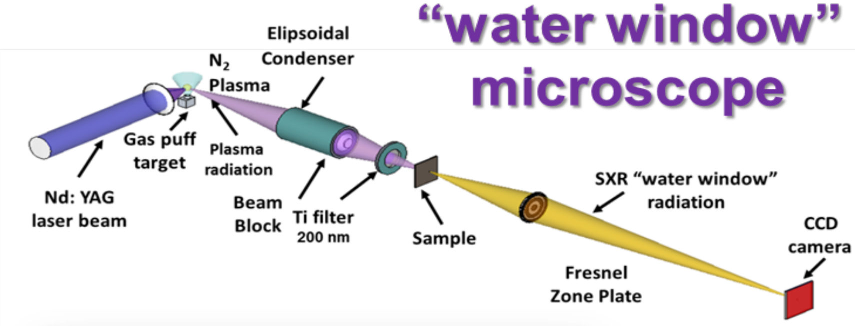
Applications

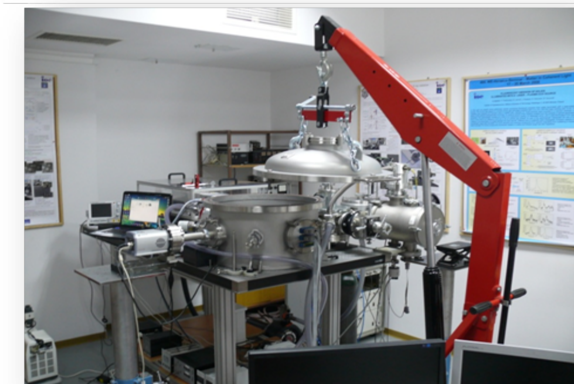
Double stream gas-puff target laser-plasma EUV/SXR source

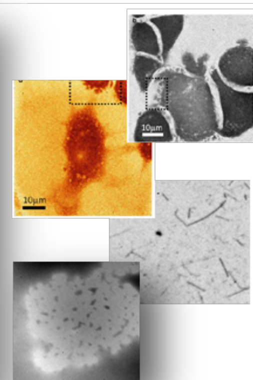


Overview of double stream gas-puff target microscopes

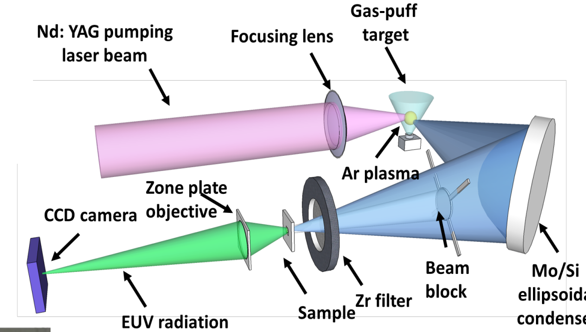
"water window" microscope

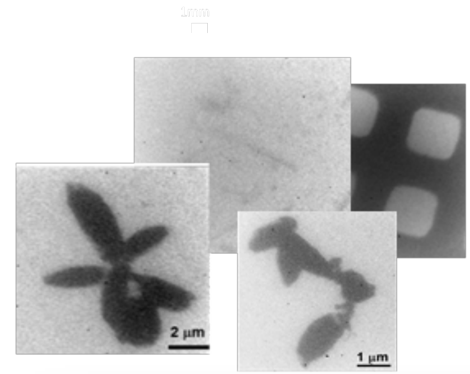






EUV microscope





Advantages

- Compactness
- Spatial resolution: ~50 – 60 nm
- Short time acquisition 3 ns – 1 min
- Applications in biology, material sciences and nanotechnology
- Possibility of commercialization

Drawbacks

- Limited number of photons and low rep. Rate compared to synchrotrons
- Possible improvement of SNR

Summary

- The presented results demonstrated that the SiC detectors have sensitivity and performance comparable to Si detectors in the diagnostics of laser-generated plasma emitting SXR up to UV radiation.
- The **low reverse current** (of about three orders of magnitude lower than in silicon), allows to employ the SiC detectors **at room temperature**, giving **higher sensitivity** with respect to silicon detectors.
- The higher energy gap of 3.3 eV in SiC, with respect to the 1.1 eV of Si, gives to the detector **insensitivity to the visible light** produced by the laser-generated plasma so that it **does not need filters** to reduce the spurious VIS radiation arriving on the detector.
- The **higher displacement energy** of the SiC (25 eV) with respect to the Si-Si crystalline structure (15 eV), permits to **reduce significantly the crystal damage** to the detector under high radiation doses and high deposited energies.
- The higher melting point and effective atomic number of the SiC, with respect to the Si, allows to use the detector with thinner active regions and to have **high efficiency for X-rays, electrons, and ions at high energy.**
- ***The obtained results are very promising to be extended to a micro-pixel CCD camera to acquire an X-ray map from applications of SiC detectors to X-ray microscopy or to detect images in the UV region.***

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ioe

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LIDER

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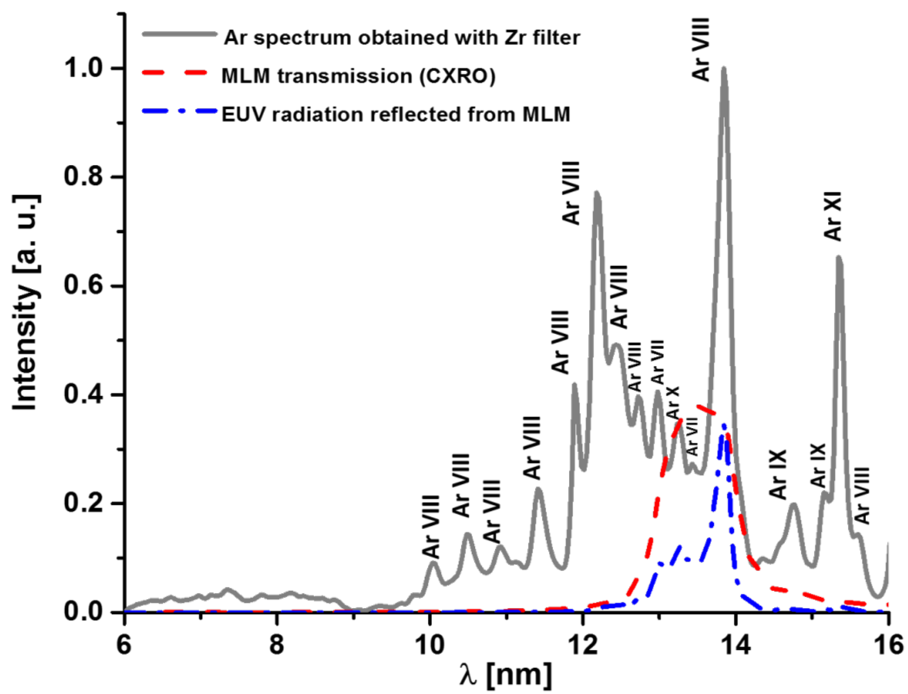
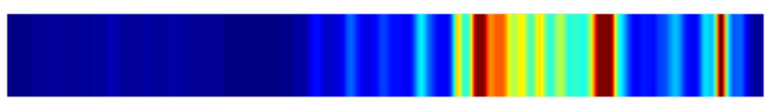
Compact EUV microscope based on Ar plasma

Source Parameters

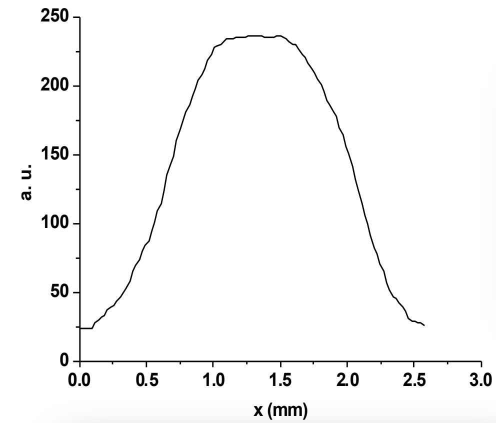
A.Torrisi et al., – Journal of Microscopy, Vol. 265, Issue 2 (2017)

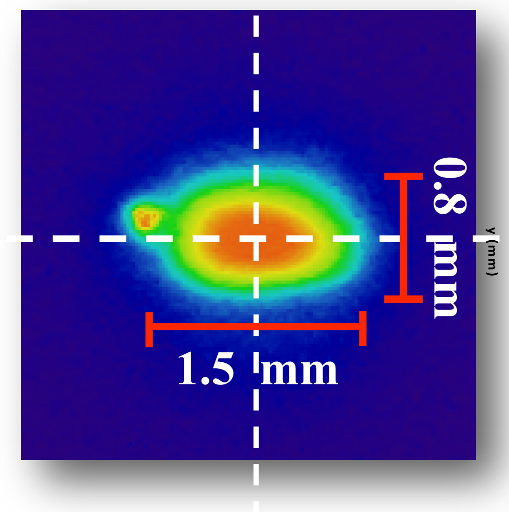


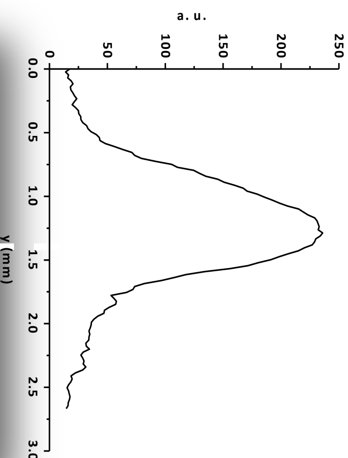


Ar Spectrum obtained with Zr filter

EUV radiation reflected from MLM







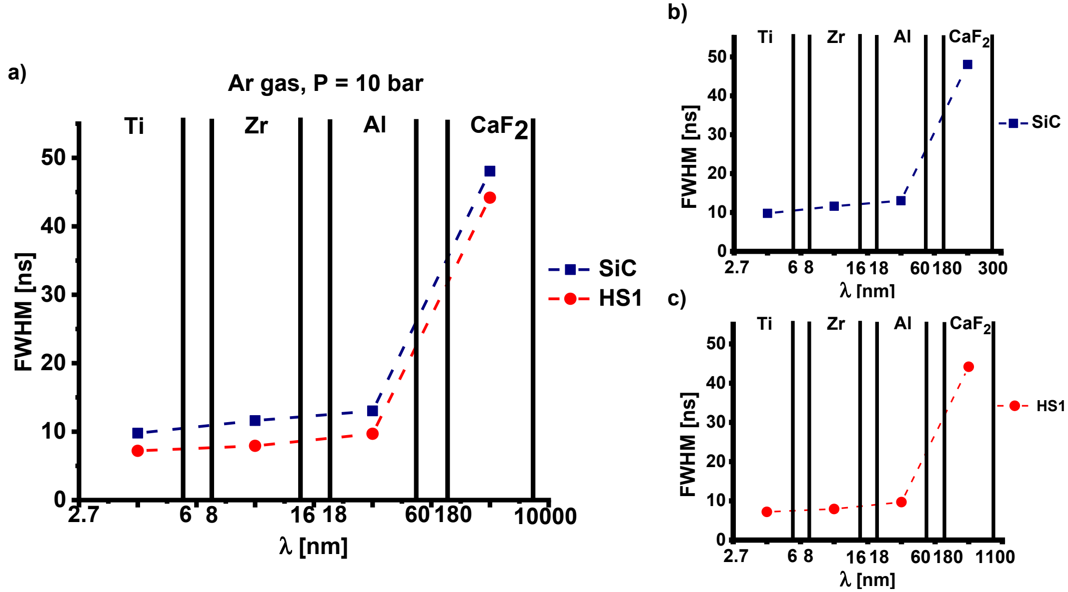
Inverse rel. bandwidth (FWHM) of emission

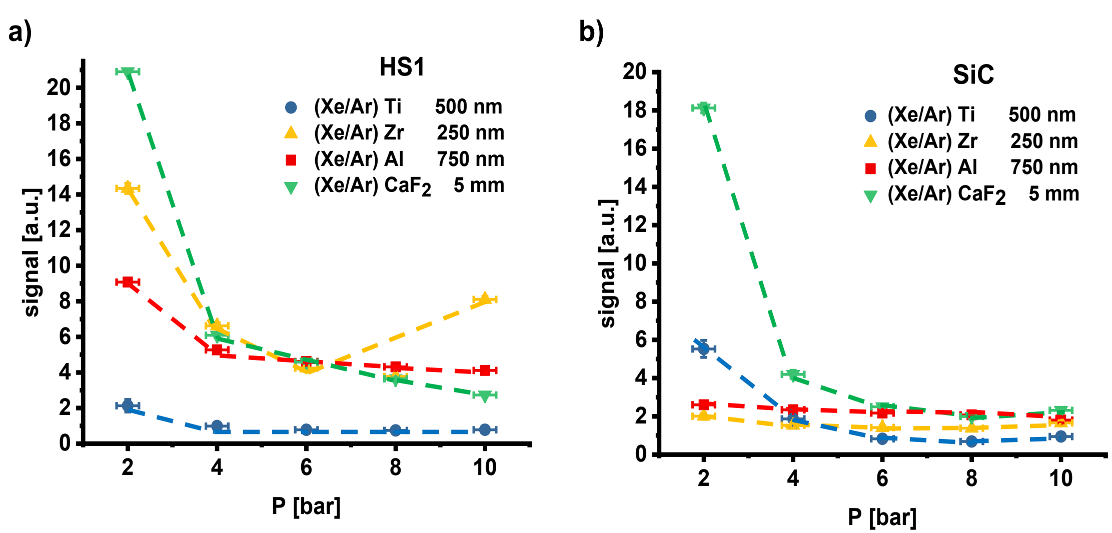
$\lambda/\Delta\lambda \sim 60$ @ l=13.84 nm

CCD camera

iKon-M (Andor), 1k x 1k pix, 13x13 μm^2

Plasma Diagnostic and SiC detectors calibration





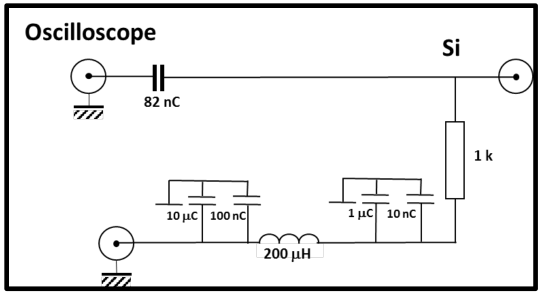
A.Torrisi et al., NIMA (2018) – under review

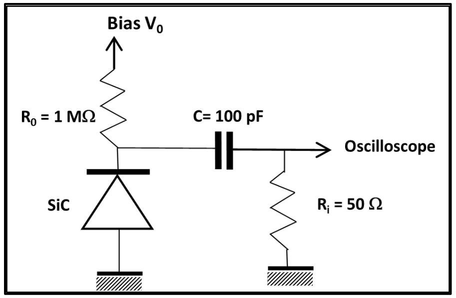
HS1 – Si Detector

Detector

Electro-optical characteristics of a HS1 - Si detector at 25°C			
PARAMETERS	TEST CONDITIONS	TYPICAL VALUES	UNITS
Active Area	0.02 mm x 0.02 mm	100	mm^2
Responsivity	@2.88 nm, V_R= 0 V	277.5	mA/W
Reverse Current	I_R = 1 mA	10	Volts
Capacitance	V_R = 0 V	10	nF
Rise Time	V_R = 0 V, RL = 50 W	10	msec

Electro-optical characteristics of a SiC detector at 25°C			
PARAMETERS	TEST CONDITIONS	TYPICAL VALUES	UNITS
Active Area	2.52 mm x 2.52 mm	16	mm^2
Responsivity	@2.88 nm, V_R= - 20 V	7.92	mA/W
Reverse Current	I_R = 6 pA	1- 10	Volts
Capacitance	V_R = - 20 V	100	pF
Rise Time	< 1	< 1	nsec





$$\psi_{\text{ph}} = \frac{\int V(t)dt}{\text{QE}_\lambda \cdot e \cdot R_i}$$

$$R_\lambda = \frac{\text{QE}_\lambda \cdot \lambda \cdot e}{\hbar \cdot c}$$