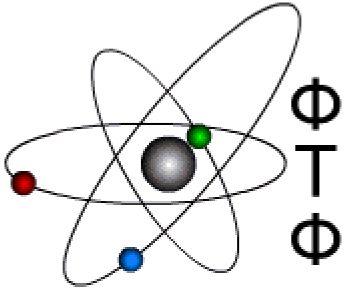
V.N. KARAZIN KHARKIV
NATIONAL UNIVERSITY



2005 Фізико-математичний ліцей при ХНУ ім. В.Н.Каразіна

2009 Бакалавр в прикладній фізиці

2011 Мастер в прикладній фізиці

2011-2014 аспірантура

26/02/2016 кандидат фіз.-мат наук з фізики плазми,

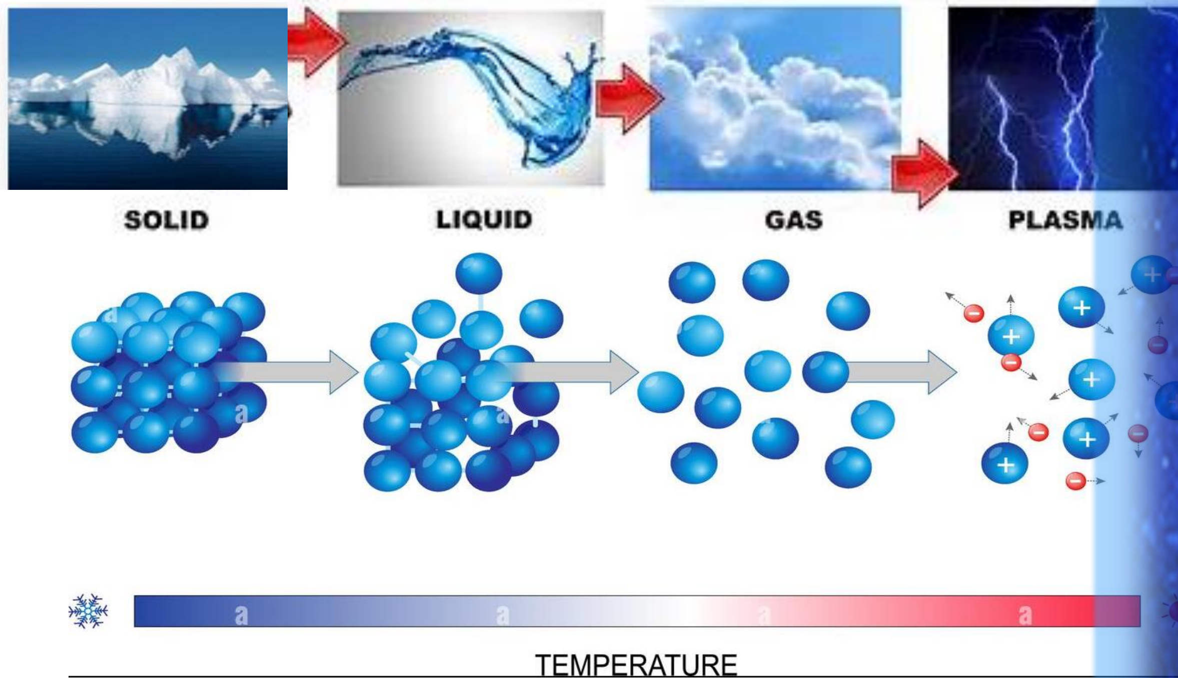
the thesis: "**Extreme ultraviolet radiation from plasma of the high-current pulse diode**"

2020-2022 науковий співробітник ННІ «Фізико-технічний факультет», старший викладач на КШІКФ ФКН

2022-... Post-Doc in EUV plasma source group at ARCNL

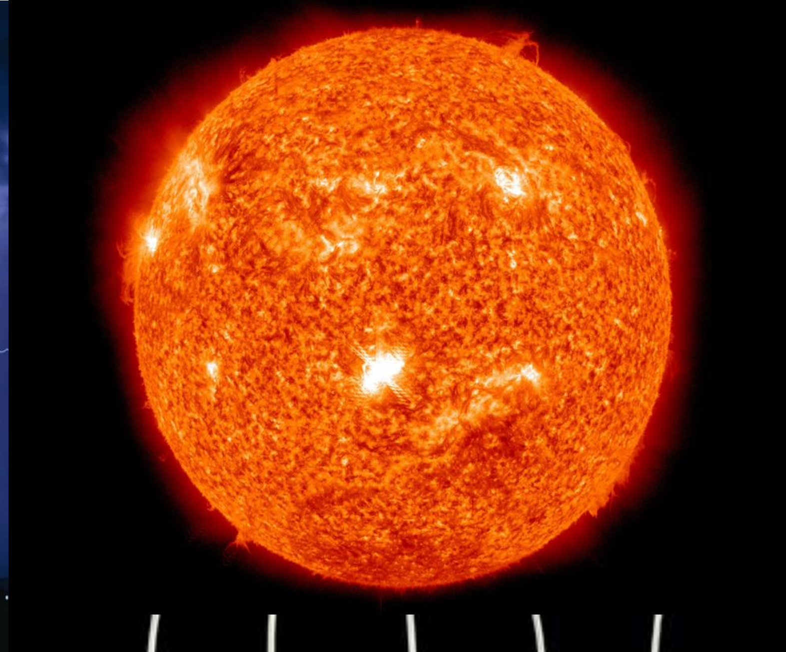
Плазма
як джерело світла

Що таке плазма???



99% нашого Всесвіту – це ПЛАЗМА!!!

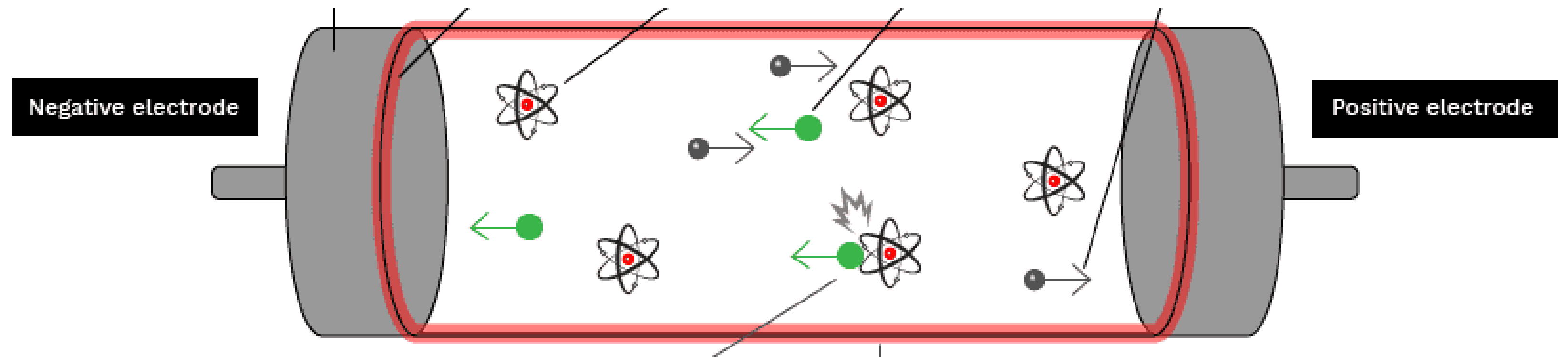
Випромінювання з плазми

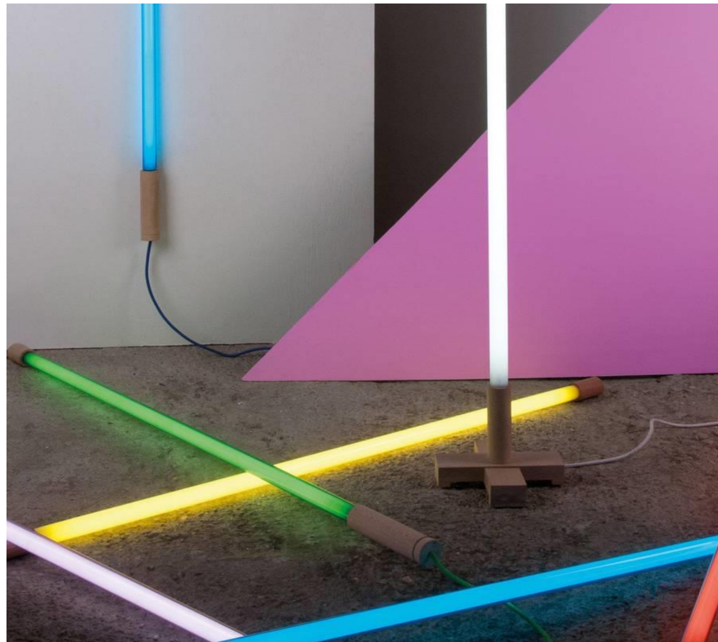


Газорозрядні лампи

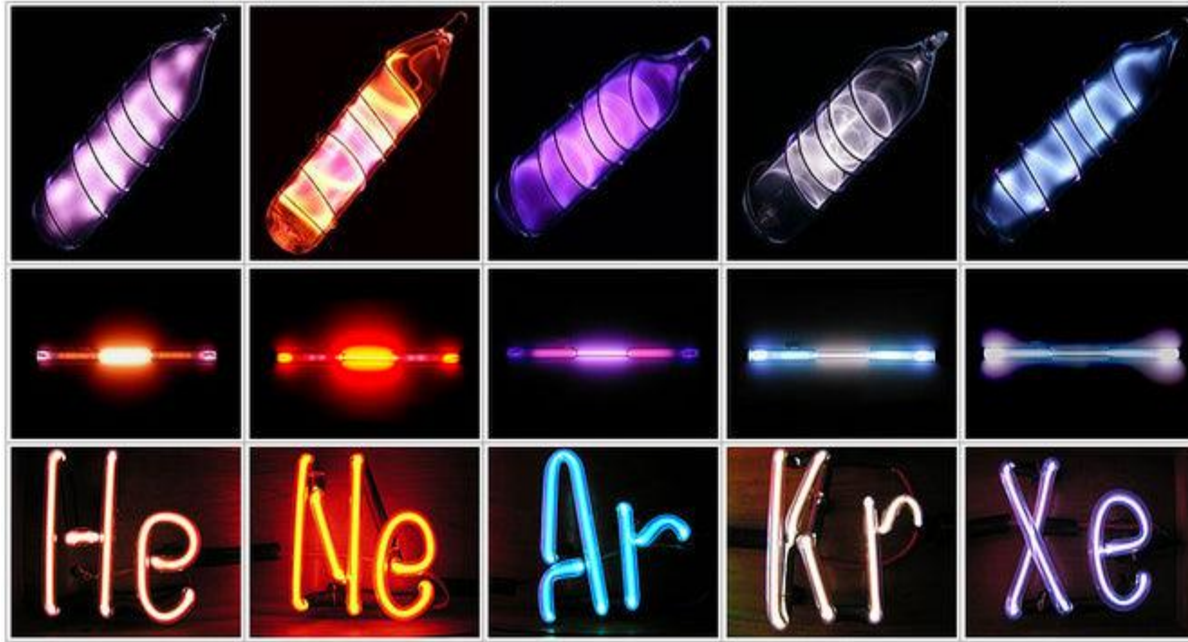
Люмінесце́нтни (флуоресцентни) ла́мпа

Генріх Гайслер
1856

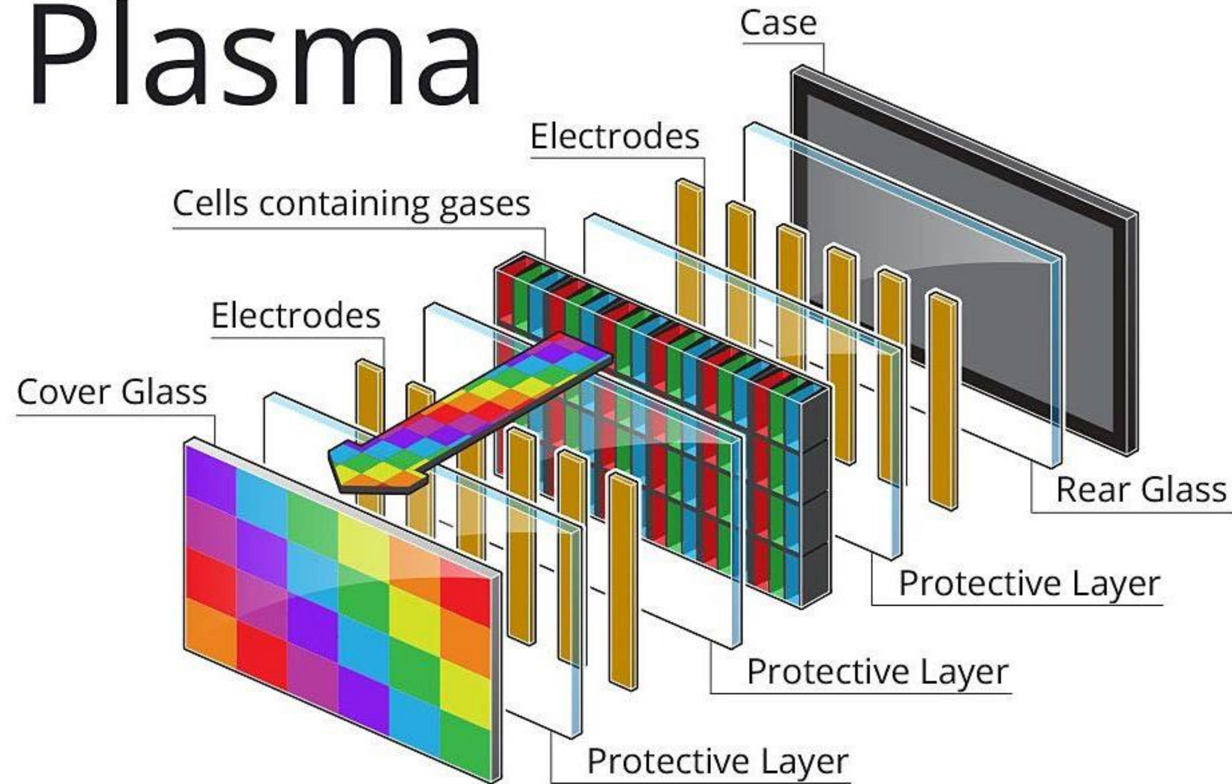




«Благородні» лампи



Плазмові монітори

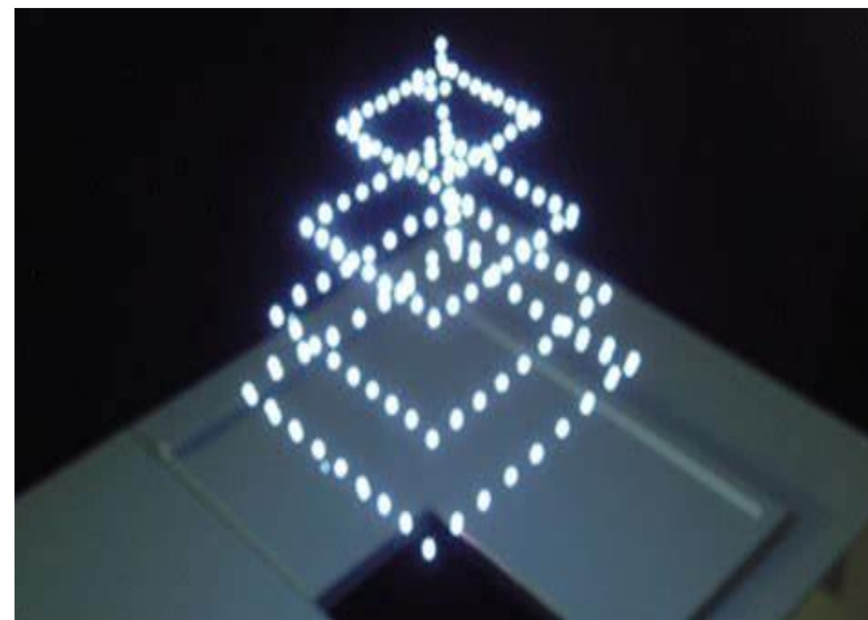


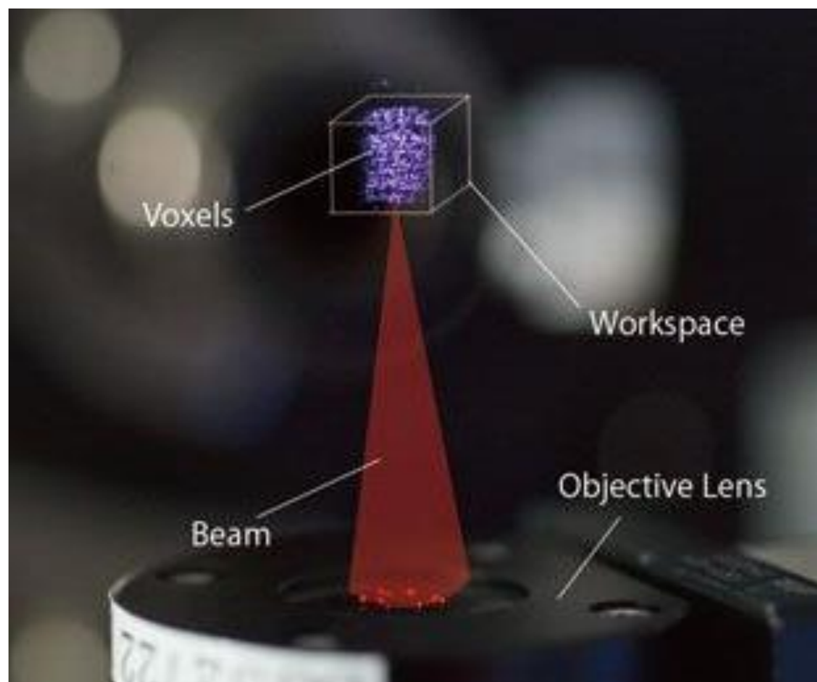
3D Плазмовий дісплей

"Aerial Burton" technology

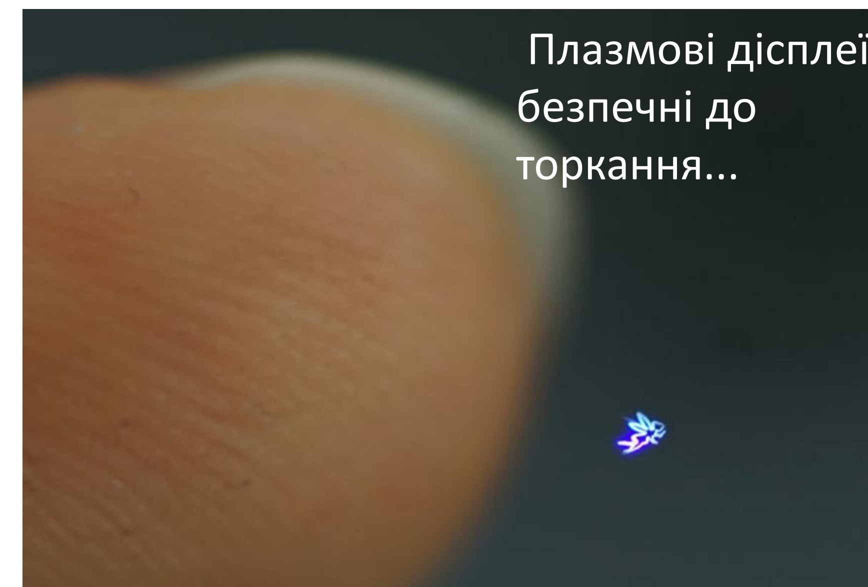
[laser-induced plasma displays]

1kW інфракрасний лазерний імпульс, який фокусується в точку простору через 3D сканер. Та цій точці молекула іонізується, тобто створюється плазма на короткий час.

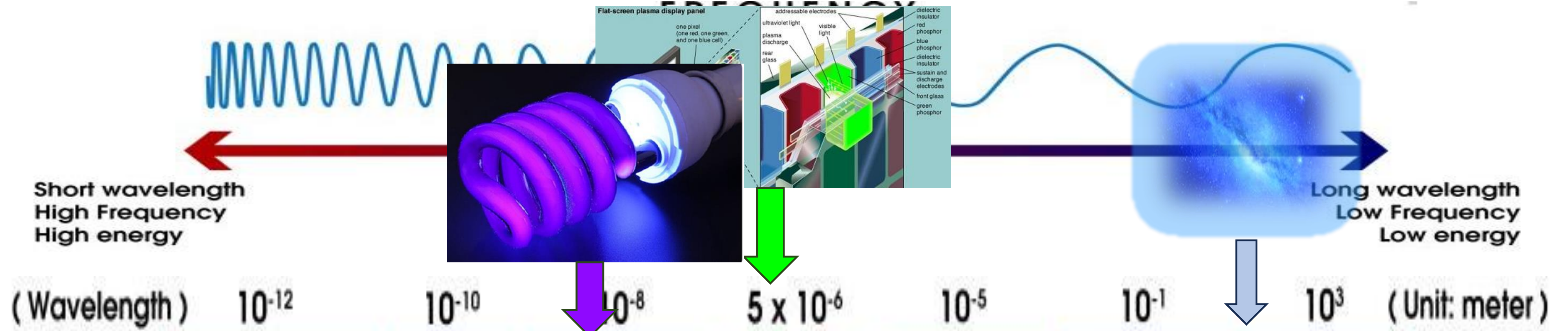


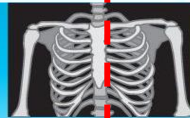
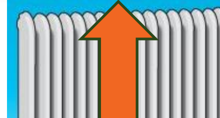


Фемтосекундні лазери створюють тривимірні плазмові дисплеї, до яких можна торкатися.



Спектр випромінювання



Soft x-ray Extreme UV

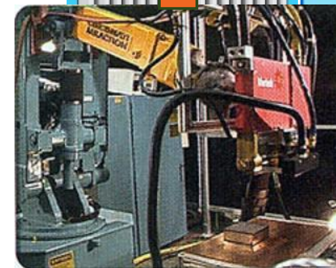
used in medicine for killing cancer cells

used to view inside of bodies and objects

used in cooking, radar, telephone and other signals

used to broadcast radio and television

***Найактуальніші** та **найсучасніші** технології, які базуються на плазмовому джерелі світла*



Інфрачервоні технологія нанесення покриття на основі плазмової лампи at Oak Ridge Laboratory

Soft x-ray та EUV технології

- Nanoscale EUV laser ablation mass spectrometry

EUV Microscopy: A Unique Appr
characteristics

- Nanoscale imaging
- Nanoscale defect-free pattern
- Time Resolved Fourier transfo

Table-top soft X-ray laser in th

- Diagnostics of Dense Plasmas
- Nanolithography

Ion implantation

Stripping

Deposition

Etching

Development

Application of photoresist

Illumination

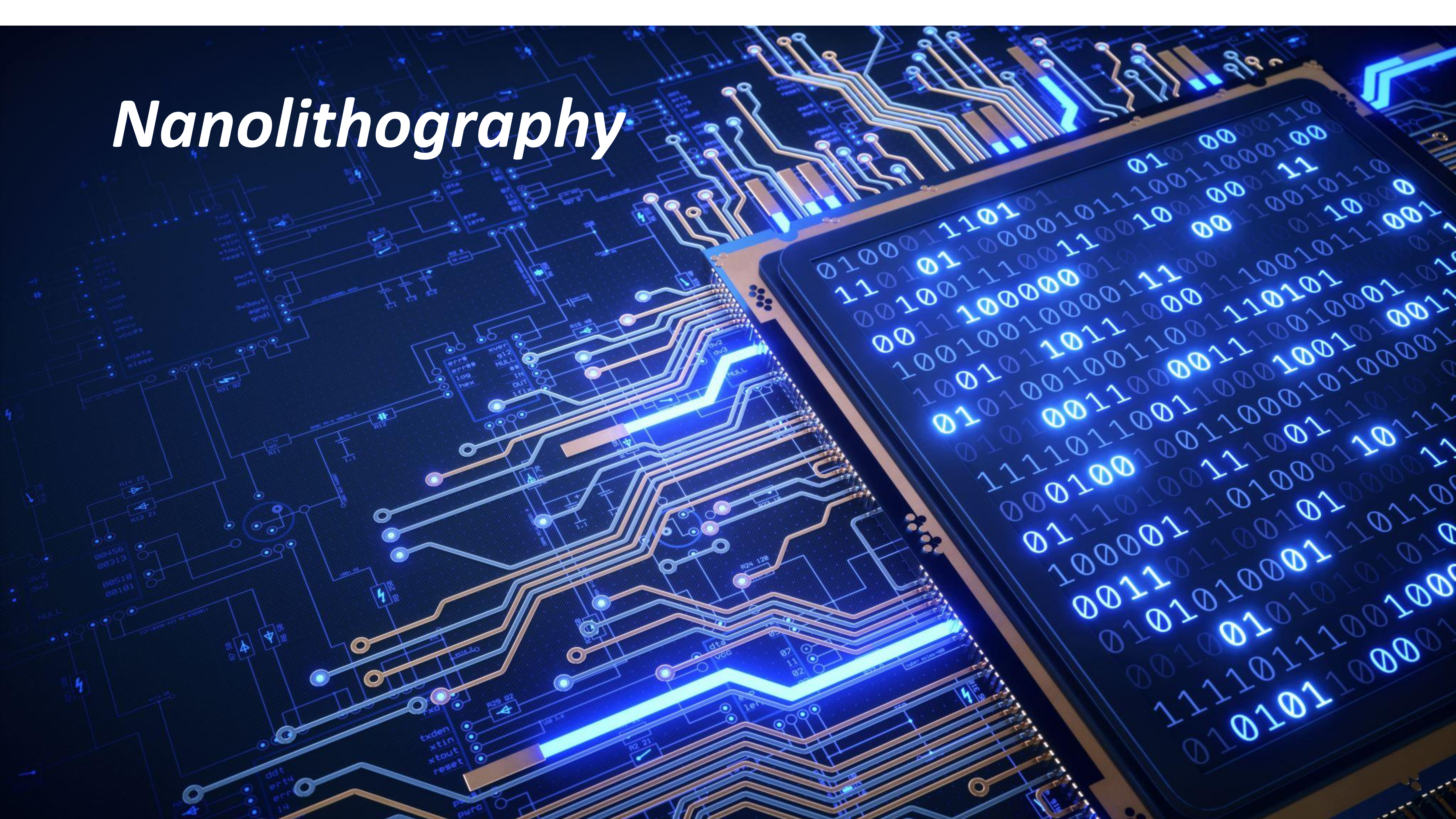
Fig. 5 Schematic of the light path of a typical CDI system that enables acquisition of a series of diffraction patterns from the sample that are reconstructed to produce the image. (Image courtesy of Kapteyn-Murnane Group, JILA, U. Colorado [2])

10 μm

www.photonics...ws.com © 2019 WILEY-VCH Verlag GmbH & Co. KGaA, Wein...

λ = 46.9nm промінь фокусується в точку діаметром 120nm

1um


Nanolithography

Закон Мура (Moore`s law)

Moore's Law: The number of transistors on microchips doubles every two years

Moore's law describes the empirical regularity that the number of transistors on integrated circuits doubles approximately every two years. This advancement is important for other aspects of technological progress in computing – such as processing speed or the price of computers.

Our World in Data

Transistor count

- IBM will announce a *new breakthrough* in semiconductor scaling, **the world's first chip with 2nm technology.**

perpendicular view

75nm

40nm

44nm

L_g=12nm

S/D Epi

S/D Epi

T_{Si}=5nm

Inner Spacers

Bottom Dielectric Isolation

- This new technology combines:
  - An industry-first *Bottom Dielectric Isolation* to enable 12nm gate length
  - A 2nd generation *Inner Spacer dry process* for precise gate control
  - *EUV patterning* to produce variable Nanosheet widths from 15nm to 70nm
  - A novel *Multi-Vt scheme* for both SoC and HPC applications
- Expected to offer 45% performance improvement or 75% power reduction compared to 7nm

IBM Research / M.Khare/ © 2021 IBM Corporation

IBM NDA/Embargo

Intel

1971th

WHAT IS "NM" IN PROCESSOR?

FinFET 10nm

FinFET 7nm

FinFET 5nm

VYRIAN

Lithography Scaling

Wafer size

50 mm
100 mm
150 mm
200 mm
300 mm
450 mm

6.1 µm (Nodes)
Lamp
KrF
ArF
Plasma
3 µm
2 µm
1.5 µm
1 µm
0.8 µm
0.7 µm
0.5 µm
0.35 µm
0.25 µm
180 nm
130 nm
90 nm
65 nm
45 nm
32 nm
22 nm
15 nm

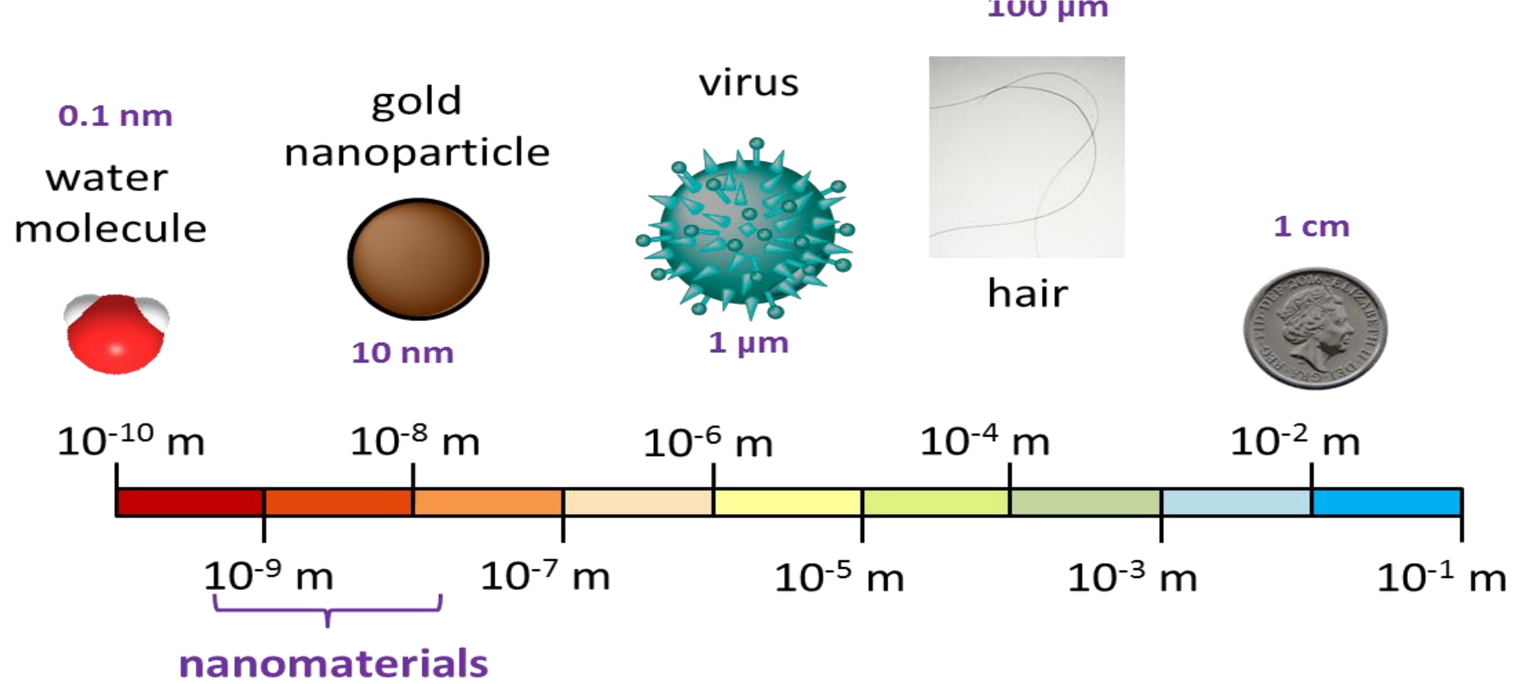
400 – 440 nm
436 nm
356 nm
248 nm
193 nm
193 nm wet
13.5 nm

De-magnification
1:1
10:1
5:1
4:1

Microns
10
1
0.1
0.01

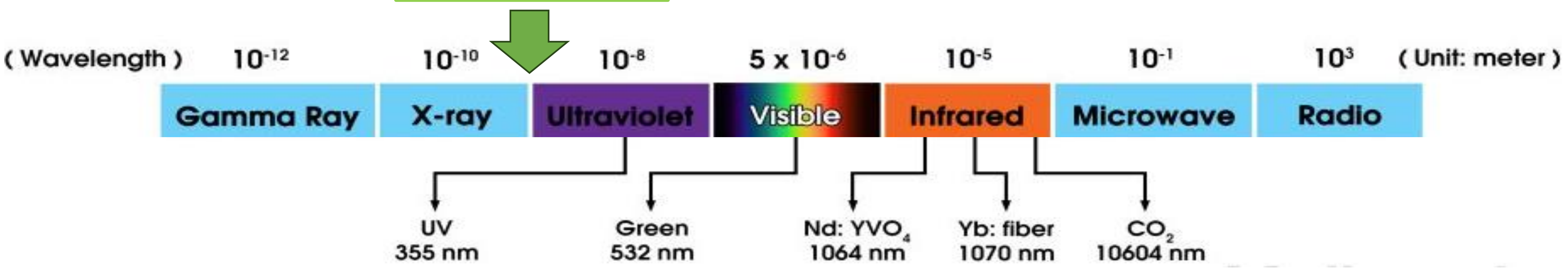
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020

Year



Критерій Реллея

$$\Delta x \sim \lambda / NA$$



Джерела
ЕУФ та м'якого рентгену
100нм….0.1нм

Когерентні
Синхротроні кільцеві прискорювачі

Теватрон, радіусом 6,3 км, штат Іллінойс.

Некогерентні
(всі інші)
Плазмові
Рекомбінація іонів
Ar^{+9}, Xe^{+10}, Sn^{+8}–Sn^{+14}, Mo^{+8}

Laser Produced Plasma

Discharge Produced Plasma:
- Капілярні розряди (Capillary discharge)

- Сильнострумові діодні розряди (High-current Diode discharge)

Laser Produced Plasma

Laser Produced Plasma EUV Source

ASML

NXE:3350B

3м

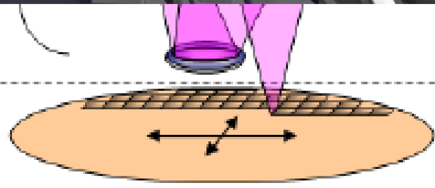
‘Джерело’

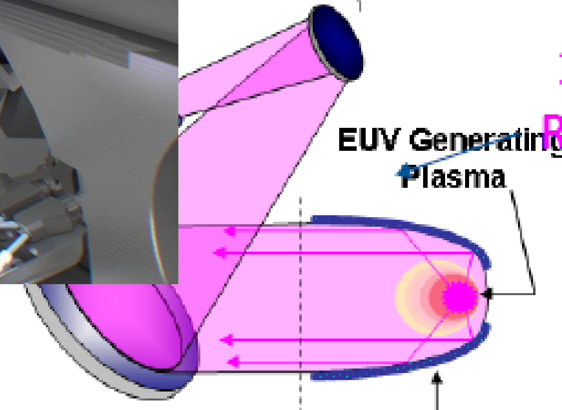
6 м

EUV Generation For Nanolithography

tem

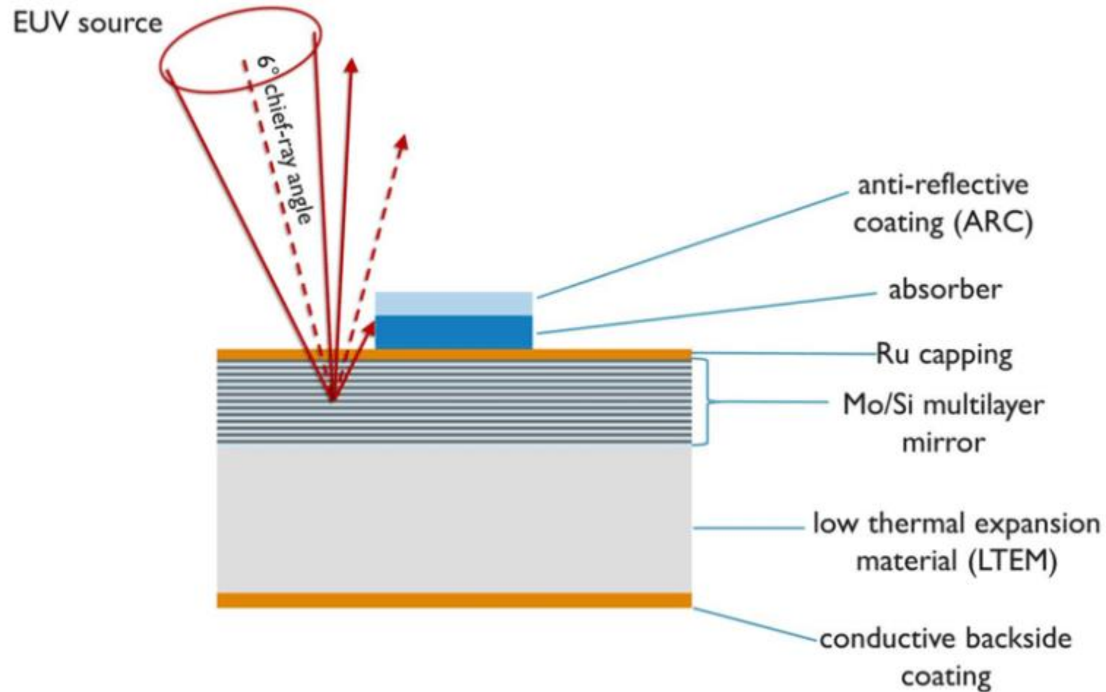
on:
ics /
ator Optics





- All Reflective Optics
- Optical train is in a vacuum

Яка довжина хвилі?



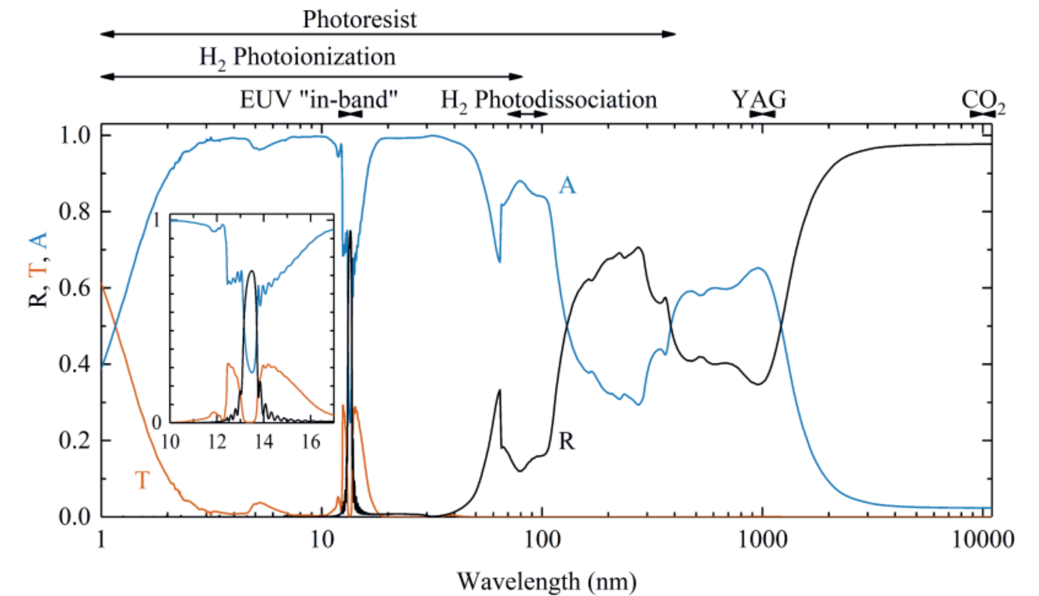


Figure 1.1: Calculated reflectance (R), transmission (T), and absorbance (A) of a 50-period Mo/Si multilayer mirror. The relevant physical phenomena at different wavelength bands are also indicated at the top (see main text).

13нм ±2%

Xe^{+10}

Sn^{+8}….Sn^{+14}

ARCNL

Science with mission...

EUV plasma source group

SOURCE *Oscar Versolato*	METROLOGY *Stefan Witte*	MATERIALS *R. Bliem a.i.*
EUV Plasma Processes *Oscar Versolato*	EUV Generation & Imaging *Stefan Witte & Kjeld Eikema*	Materials & Surface Science for EUV Lithography *Roland Bliem*
Plasma Theory & Modeling *John Sheil*	Light-Matter Interaction *Paul Planken*	Contact Dynamics *Steve Franklin & Bart Weber*
Ions Interaction *Ronnie Hoekstra*	Computational Imaging *Arie den Boef*	Materials Theory & Modeling *Emilia Olsson*
	High-Harmonic Generation and EUV Science *Peter Kraus*	
	Nanoscale Imaging & Metrology *Lyuba Amitonova*	

INTEGRATION

Wim van der Zande a.i. (ARCNL), Marjan Fretz (ARCNL), Maarten Voncken (ASML)

ARCNL | Mission | Research | Career | More | Directory

Group Members

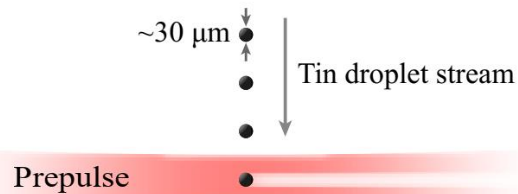
- prof.dr. Ronnie Hoekstra — Group leader
- dr. Oscar Versolato — Group leader
- dr. Laurens van Buuren — Technician
- dr. Edcel Salumbides — Technician
- dr. Jane Babenko — Postdoc
- Hugo França — Postdoc
- Mikheil Kharbedia — Postdoc
- Luc Assink — PhD student
- Dion Engels — PhD student
- Youssef Ezzo — PhD student
- Yahia Mostafa — PhD student
- Karl Schubert — PhD student
- Xyoisan Danser — Intern
- prof. Wim Ubachs — Guest researcher

Latest Publications

- L.P. Behnke, *Efficient EUV Light Plasma Sources Driven by a 2-μm-Wavelength Laser*, VU University Amsterdam, 2023-10-02
- J. Sheil, J. Colgan and O.O. Versolato: *Atomic Origins of EUV Light* In: Photon Sources for Lithography and Metrology, V. Bakshi, Ed., SPIE Press, Bellingham, Washington, SPIE., 2023. - pp. 111-148
- Y. Mostafa, Z. Bouza, J. Byers, I. Babenko, W.M.G. Ubachs, O.O. Versolato and M. Bayraktar, *Extreme ultraviolet broadband imaging spectrometer using dispersion-matched zone plates*, Opt. Lett. 48, (16), 4316-4318 (2023)
- L. Poirier, A. Lassise, R. Hoekstra, J. Sheil and O.O. Versolato, *Dependence of ion charge-energy emission from Nd:YAG-laser-produced plasma on laser intensity in the 0.4–40×10^10 W/cm2 range*, Phys. Plasmas 30, (8), 083505 : 1-10 (2023)

View more publications

ARCNL Source Research: physics challenges

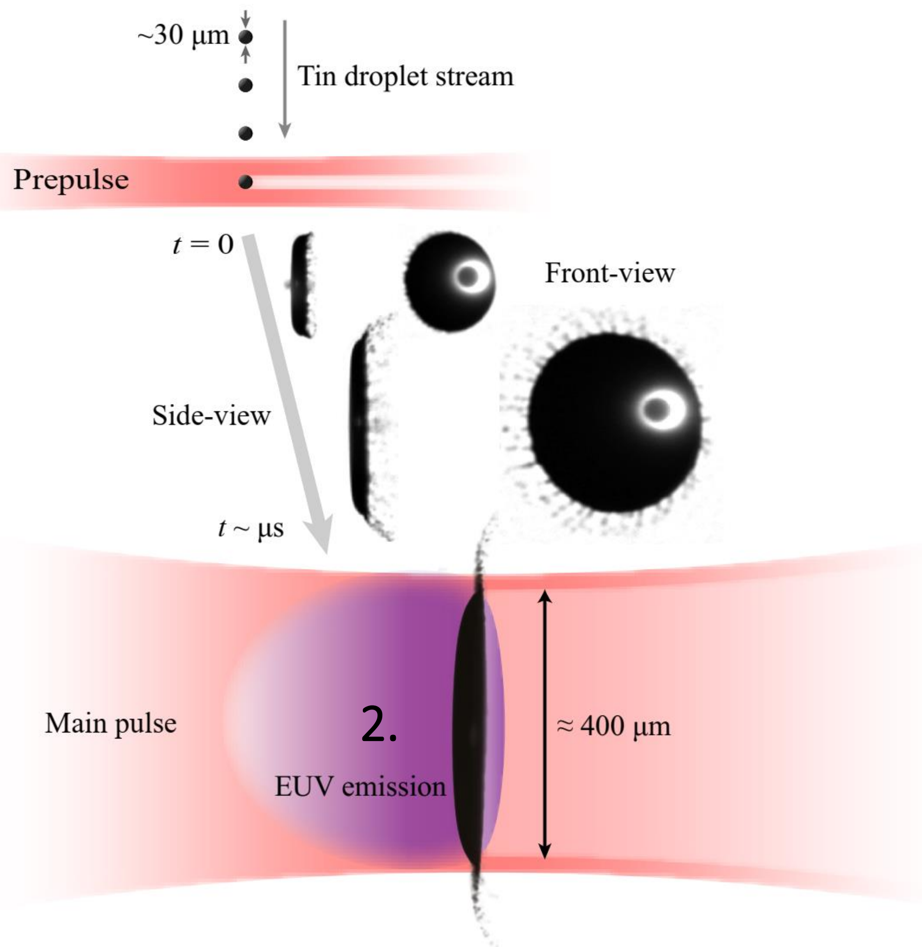


1.

1. Understand exploding tin microdroplets
   - What determines deformation and fragmentation?
2. Key insights to enable source predictive modeling
   - What emits that EUV light?
3. Push the fundamental limits of the conversion efficiency
   - What sets the fundamental limit?
4. Control expansion dynamics of laser-produced plasma
   - What is the cause of the ion energy distribution, how can it be controlled, and what does it cause?

A.L. Klein, J. Fluid Mech. **893**, 1 (2020); B. Liu, et al., Phys. Rev. Applied **13**, 024035 (2020) and Phys. Rev. Fluids **13**, 024035 (2022)
B. Liu and R. Meijer, et al., JAP **129**, 053302 (2021); T. de Faria Pinto et al., Appl. Phys. A **127** (2021);
R. Meijer et al., Phys. Rev. Applied **16**, 024026 (2021) ; J. Hernandez-Rueda et al., Phys. Rev. Res. **4**, 013142 (2022)

ARCNL Source Research: physics challenges



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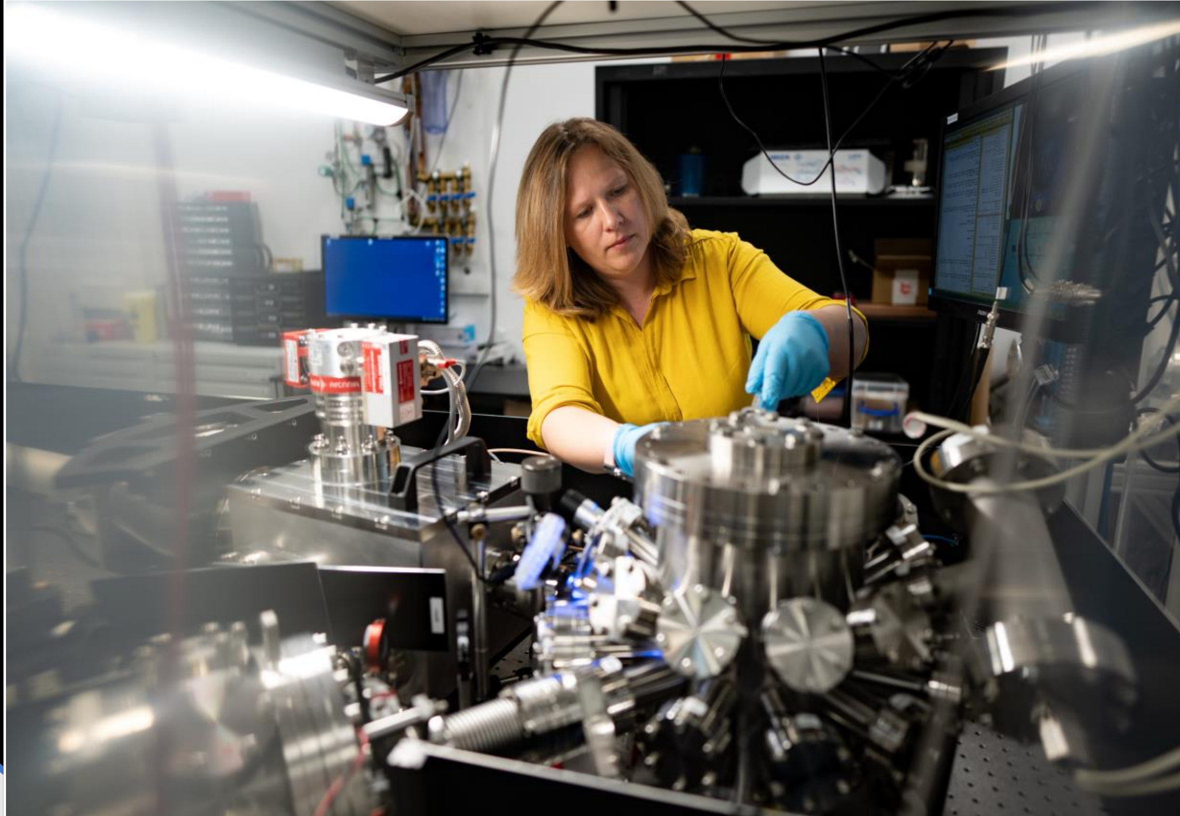
J. Scheers, et al., PRE **102**, 012304 (2020); J. Scheers, et al., PRA **101**, 062511 (2020);
Z. Bouza and J. Scheers, et al., J. Phys. B **53**, 195001 (2020); F. Torretti, J. Sheil, et al., Nature Communications **11**, 2334 (2020);
J. Sheil, et al., J. Phys. B. **54**, 035002 (2021); Z. Bouza et al., AIP Advances **11**, 125003 (2021)

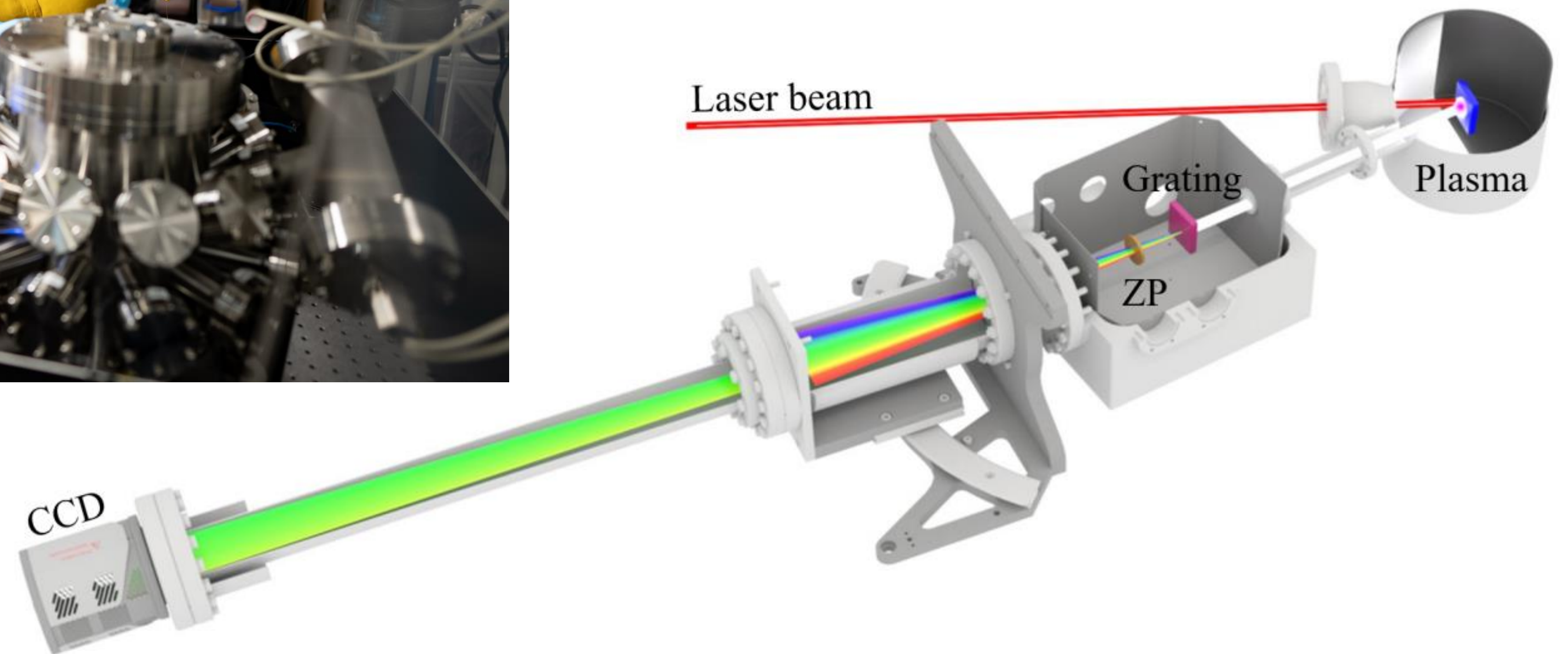
Мій вклад...



ImSpec STAR

Imaging Spectroscopy

Sn Target A Radiation



Laser beam

Grating

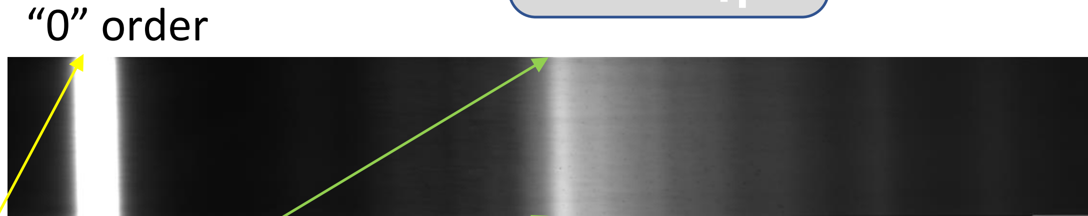
Plasma

ZP

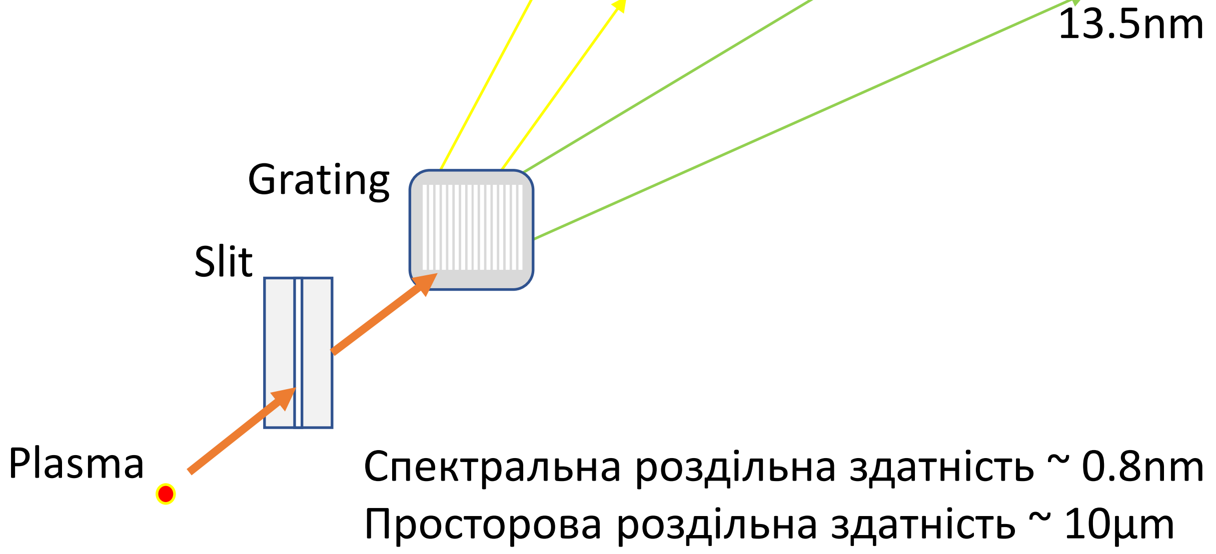
CCD

Zone Plate

“0” order

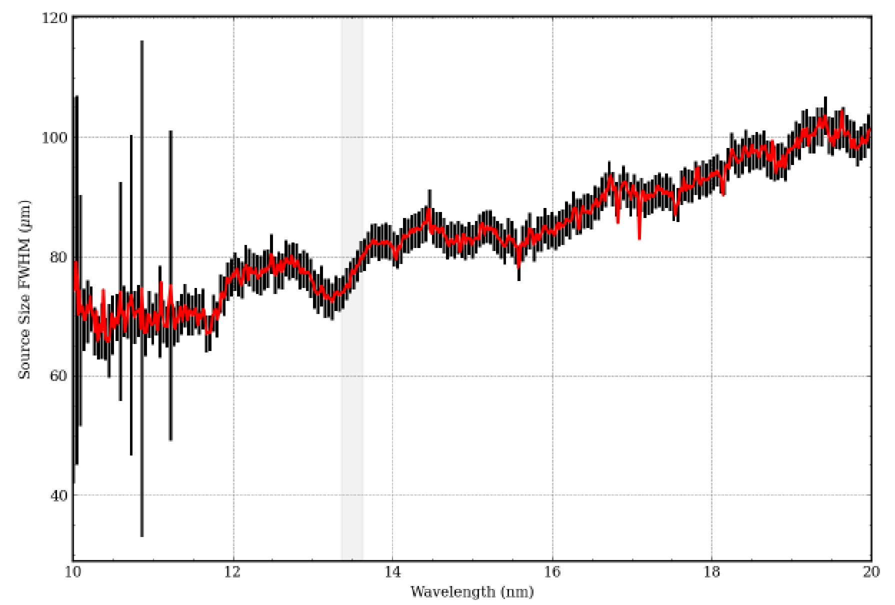


13.5nm



Спектральна роздільна здатність ~ 0.8nm

Просторова роздільна здатність ~ 10µm

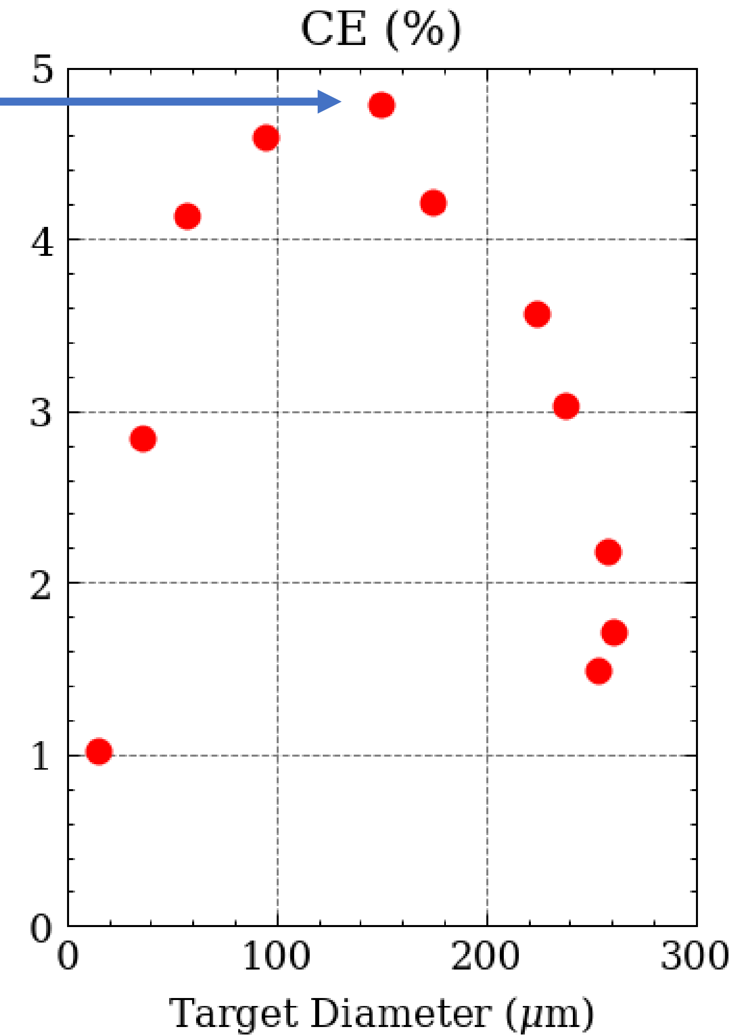


Results – Record CE for 2 µm Main-pulse [flat-top]

$$\mathrm{CE} = \frac{E_{2\%EUV,2\pi}}{E_{laser}} =$$

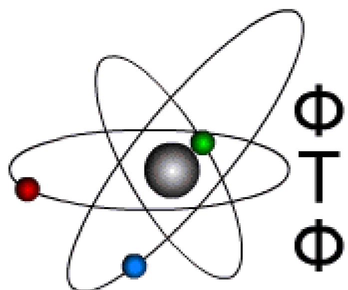
Maximum $\boldsymbol{CE} = \mathbf{4.9}$ %
(@ τ = 10 ns)

Main-pulse (Laser)	CO_2	Tm:YLF (BAT)	Nd:YAG
Wavelength	10.6 µm	1.9 µm	1 µm
max. CE	>5%[2]	**5%**	3%
Wall-plug efficiency	~3%	~15-20%	~15-20%



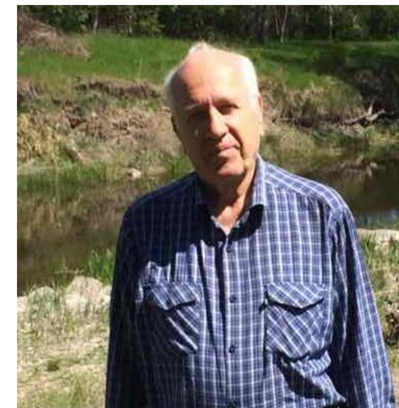
Сильнострумові діодні розряди (High-current Diode discharge)

ЕУФ Джерело на базі розрядної плазми

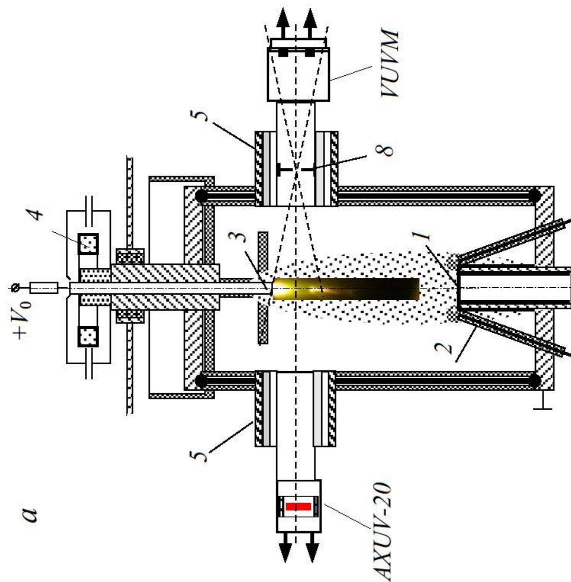


Целуйко О.Ф.

Бабєнко Є.В.

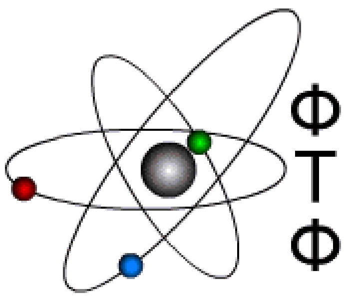

Рябчіков Д.Л.

High-current Diode discharge EUV source



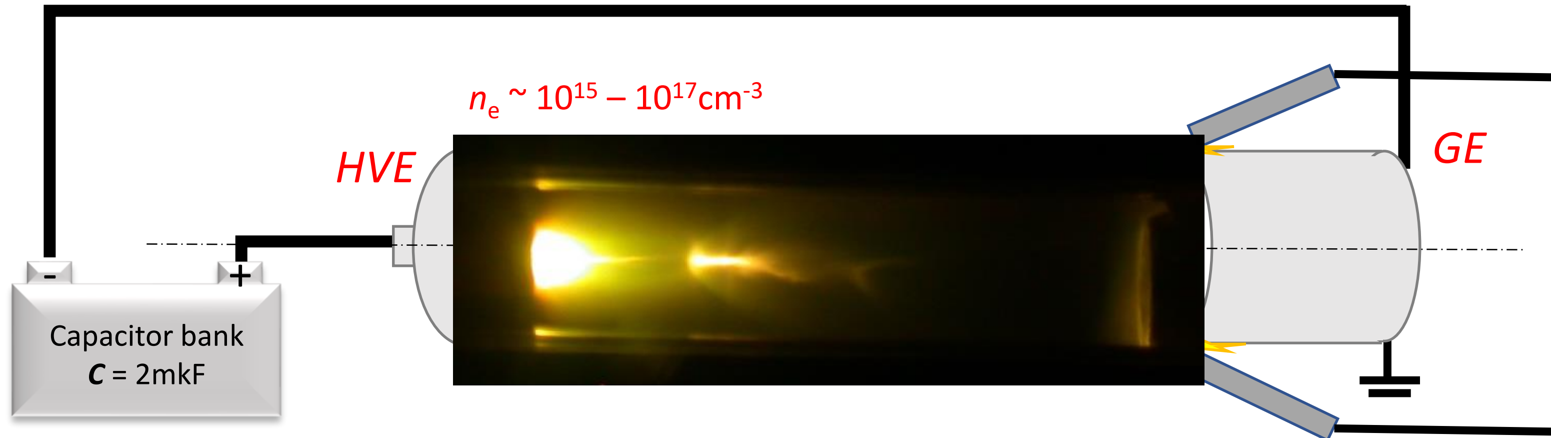
Гречко Я.О.

Середа І.М.



ЕУФ з сильнострумового діодного розряду

(High-current Diode discharge EUV source)



$U_p \sim 5 - 13$kV

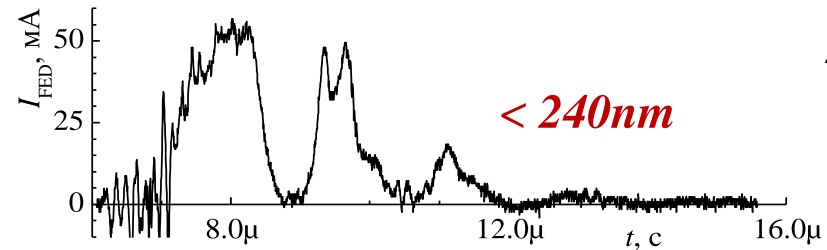
$I_{dis} \sim 10 - 35kA$

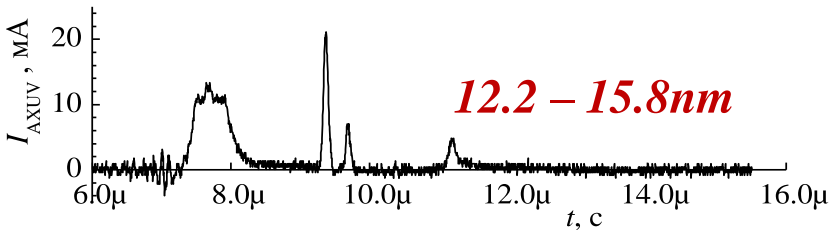
$j_{dis} \sim 0.2 - 2MA/cm^2$

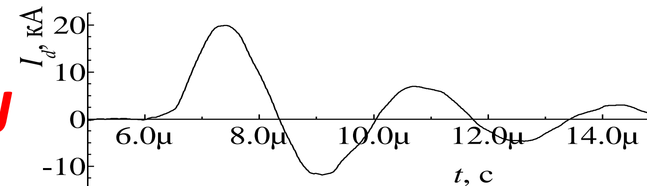
$t \sim 2$ - 7mks

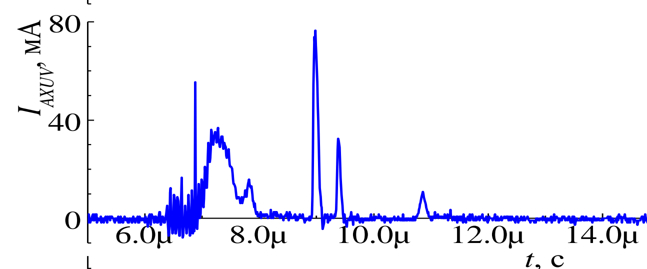
P_λ ~ **1MW!!!**

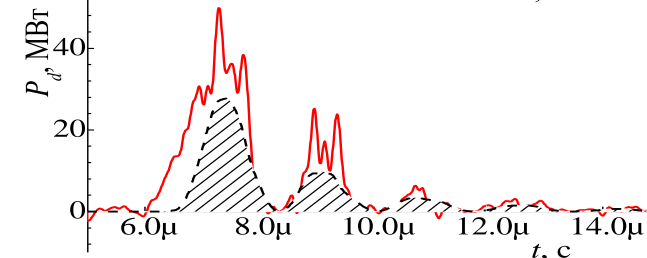
At stored W_0 ~ **100 J**





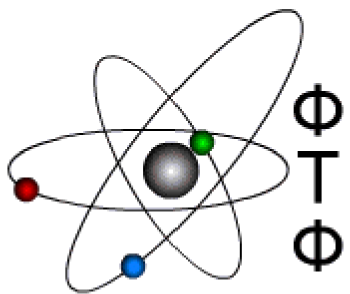






$CE_w^{1h.p.} = 0.26$ %

$CE_{peak}^{2h.p.} = 1.36$ %

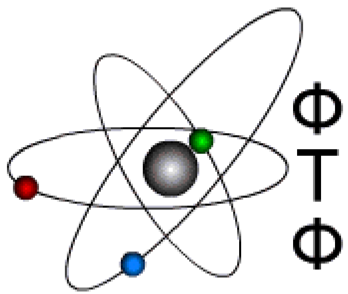


УФ матриця

Time resolution **4 ns**

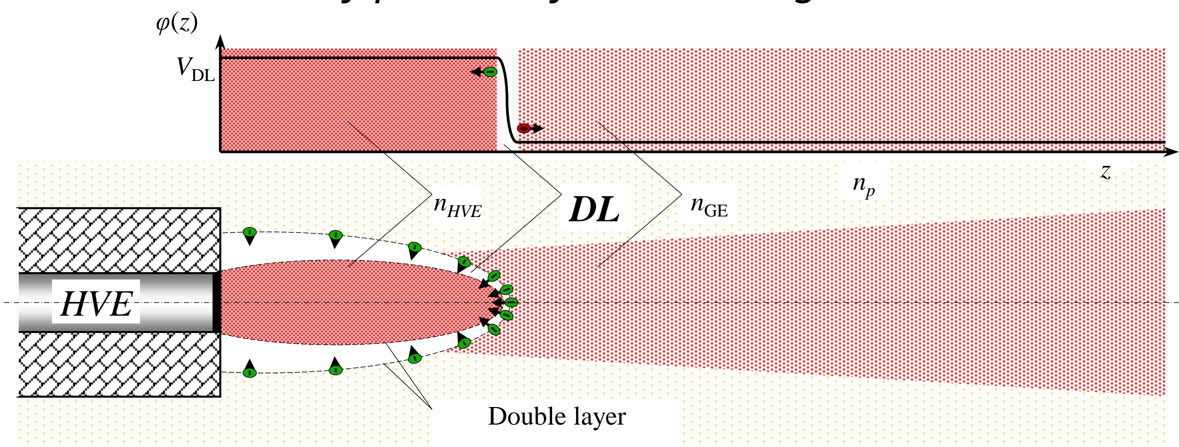
VUV intensity

9.0μ
10.0μ
11.0μ
Time, s
12.0μ
13.0μ

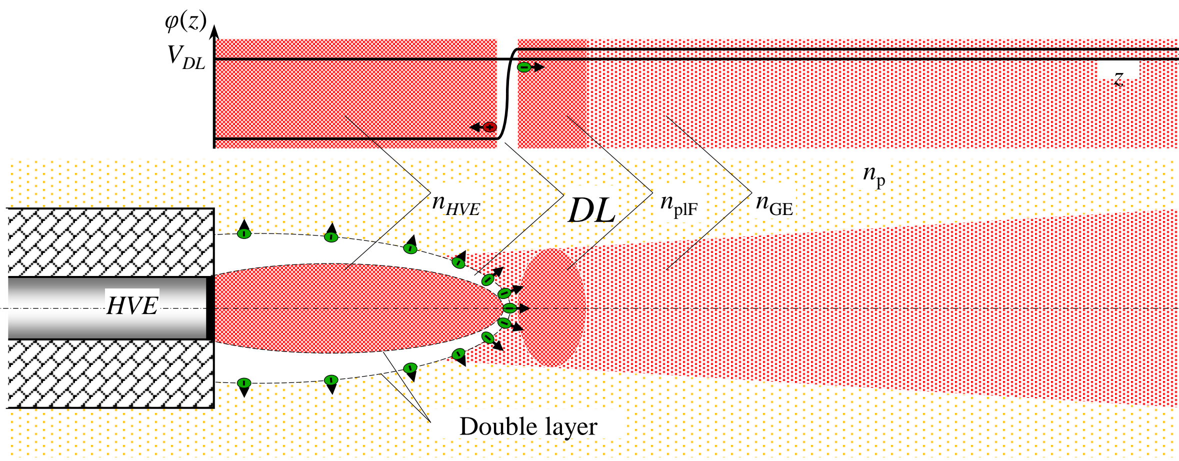


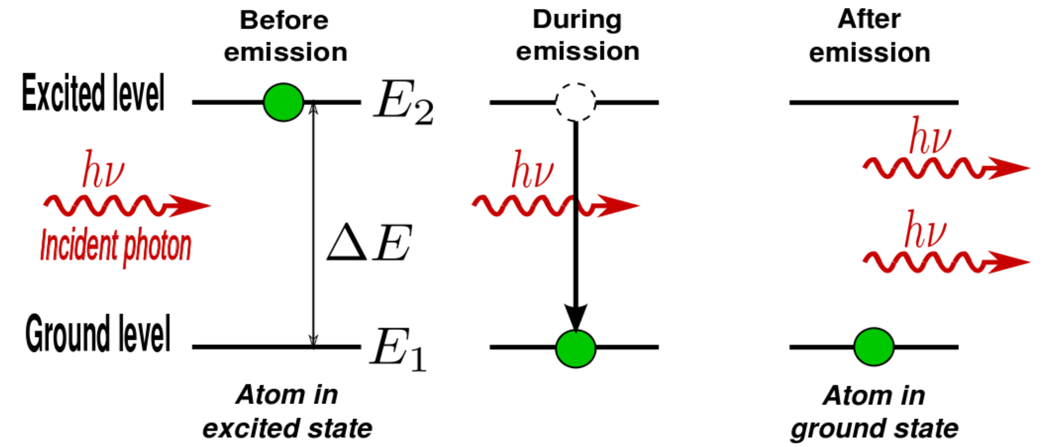
Подвійний шар об'ємного заряду

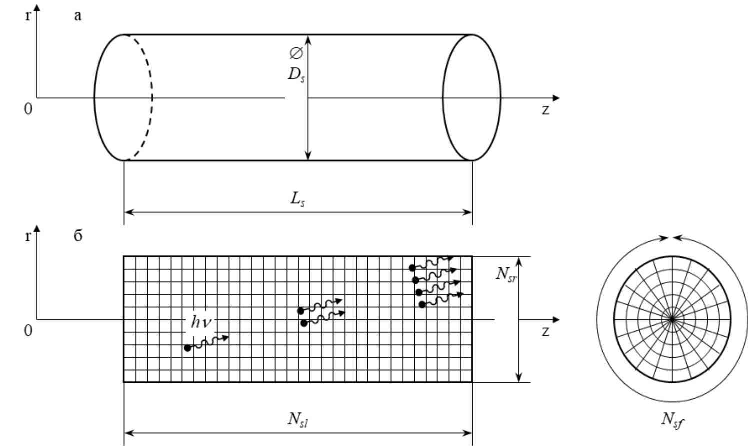
1st and 3rd half-periods of the discharge current oscillation



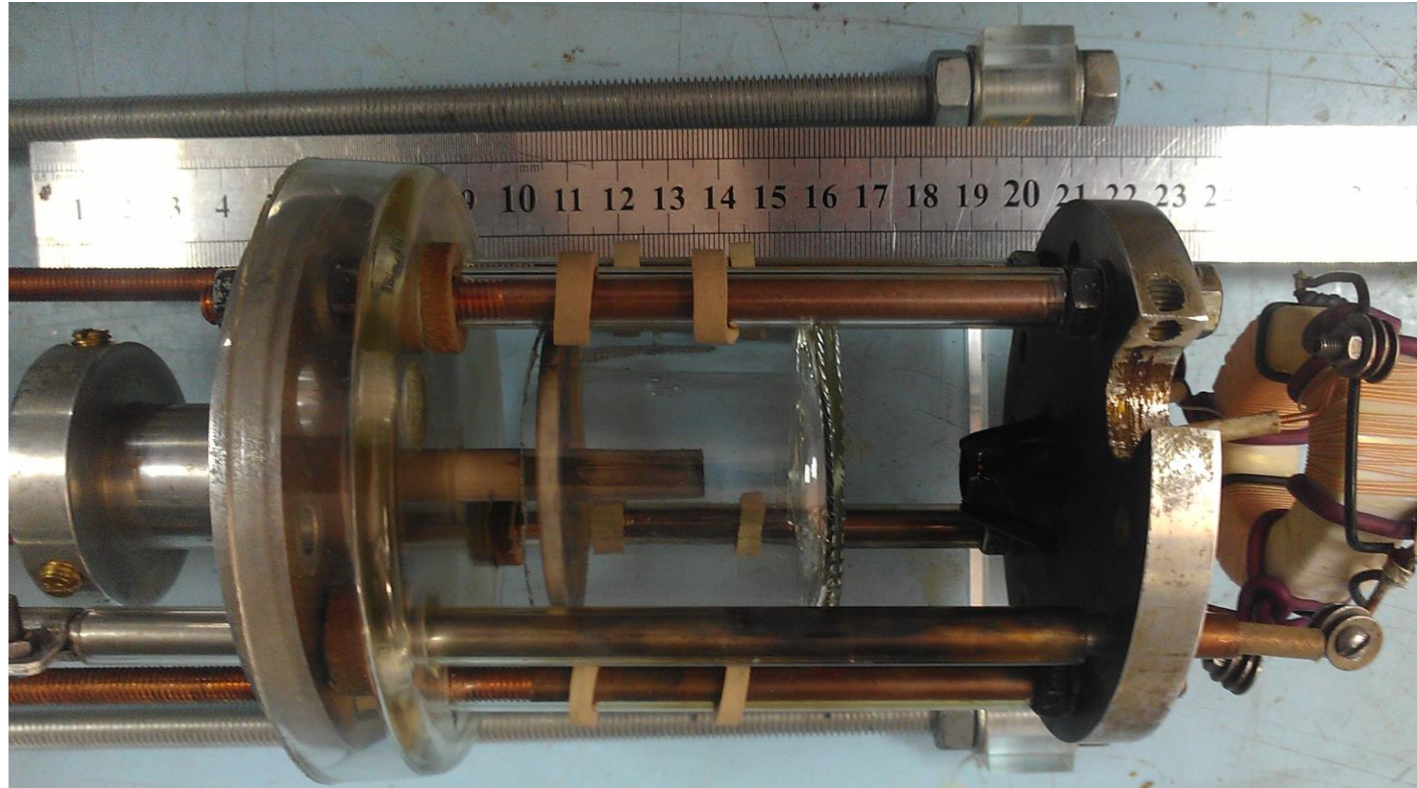
2nd and 4th half-periods of the discharge current oscillation







Розрядна комірка



$CE_{peak}^{2h.p.} = 1.36$ %

Перше українське настільне ЕУФ джерело?

Дякую за увагу!!!