

Next Generation Lithography Light Sources

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NANO-UV sas



PROLOG

- a long story

- would not be possible to tell the full story in 15 minutes
- short synopsis
 - Why, How, What for, What now
- formula for success



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EUVL

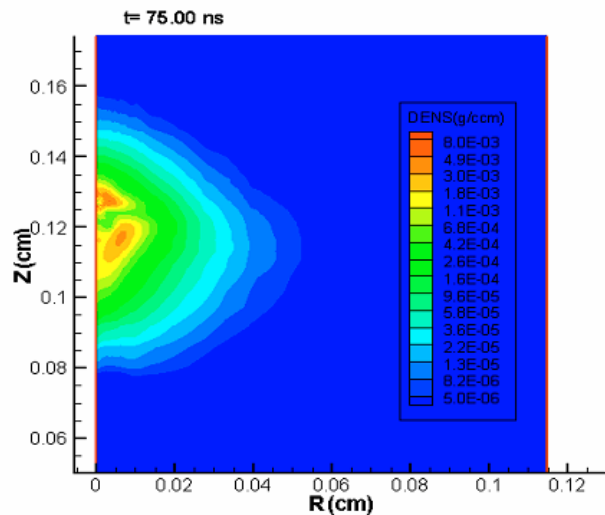
[the “WHY”]

- Photolithography today is at a cross road
- Optical projection lithography has served the industry since the beginning of integrated circuits
- EUVL lithography was considered as the NGL tool holding the most promise for industrial application at the 32 nm node, due to begin in 2009/2010
- This ambitious roadmap is facing some technical challenges
- The top most challenge to EUVL deployment is the availability of a powerful and reliable light source and the associated optics to collect the EUV photons, the so called SoCoMo (source collector module)

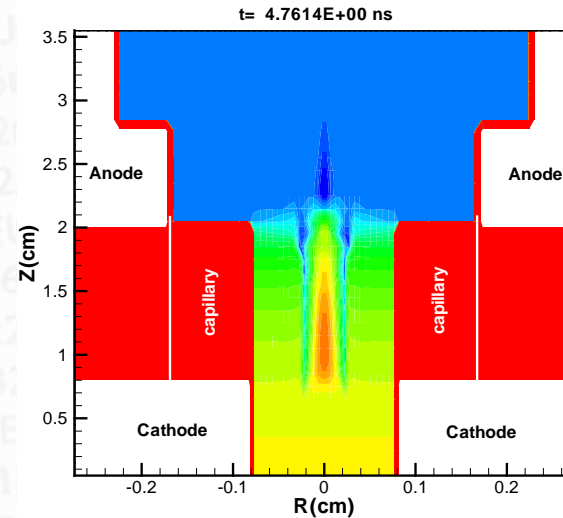


The EUV Light Source

- high energy density plasma - source of EUV light
- LPP & DPP - methods to produce the HED plasma



LPP
(laser produced plasma)



DPP
(discharge produced plasma)

Z* simulation

- the source of the problem -

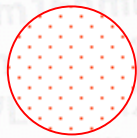
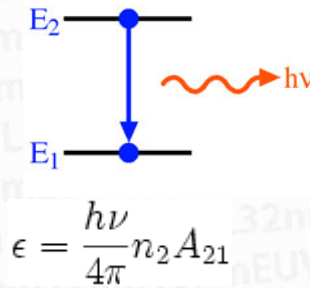


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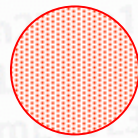


Plasma Radiation Source - I

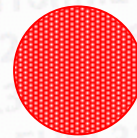
- basic radiator - $n'A$,
 n' - excited state ion density, A - Einstein coefficient
- packing radiators - $n' \propto n_i n_e$



low density

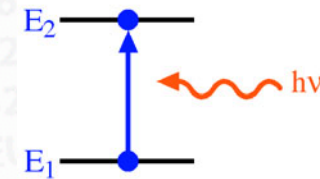


high density



maximum density

- optical thickness - self absorption
- black body radiator
 - redistribution of spectral energy
 - surface vs volume radiation source



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Plasma Radiation Source - II

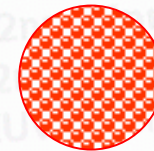
- Heuristic argument:
 - optimal narrow band radiation \Rightarrow maximum mass density for given volume, V_s
 - only possible to increase EUV radiation power efficiently by increasing source size, A_s
 - etendue : constraint of optical system \Rightarrow set source size limit
 - not possible to increase usable power beyond optimal limit without losing efficiency

- Solution - Multiplexing

- re-packing radiators from 1 into N separate smaller volumes
- $V_s \propto R^3, A_s \propto R^2 \Rightarrow R_n \propto (V_s/N)^{1/3}$

$$\Rightarrow N * A_n = A_s * N^{1/3}$$

- **etendue of a multiplexed source increases slowly with N in optically thin limit** -



Multiplexing - real world conditions

EUV POWER of a single source operating with a frequency f

$$P_{EUV} = \int_t \int_{\vec{\Omega}} \int_{R^3} \int_0^s \frac{(\hbar\omega \cdot n_i' A)_{EUV}}{K_{EUV}} e^{s'-s} ds' r dr dz d\vec{\Omega} dt \times f$$

n_i' is the density of excited ions; A is the Einstein coefficient;

$$x = \sqrt{R^2 - r^2 \sin^2 \varphi} + r \cos \varphi; \quad s = \int_0^x \frac{K_\omega}{\sin \theta} dx \sim \kappa_\omega R \propto n_i R$$

the
plasma
optical
thickness

The (plasma density $\times R$) is limited due to radiation self-absorption and broadening of the emission spectrum as a result. (black-body has a very low efficiency in 2% EUV band).

To increase the power significantly we have to increase the plasma dimension R or operation frequency f , or number of sources N .



Multiplexing - the solution [the “HOW”]

But etendue is limited as required:

$$E \sim \pi R^2 N \Omega < 3 \text{ mm}^2 \text{ sr}$$

The in-band part of energy of the emission spectrum (radiation conversion efficiency C_{Er}) is maximal in almost transparent plasma at

$$n_i R = (n_i R)^{\wedge}, \text{ near } \kappa_{\omega} R \sim 1$$

The resulting EUV power of multiplexed N sources is

$$P_{EUV} = N p_{EUV} \propto \frac{4}{3} \pi R \cdot N \cdot (n_i n_e R^2)^{\wedge} \cdot C_{Er} \cdot \Omega \cdot t \cdot f;$$

$$\text{as } n_i' \propto n_i n_e$$

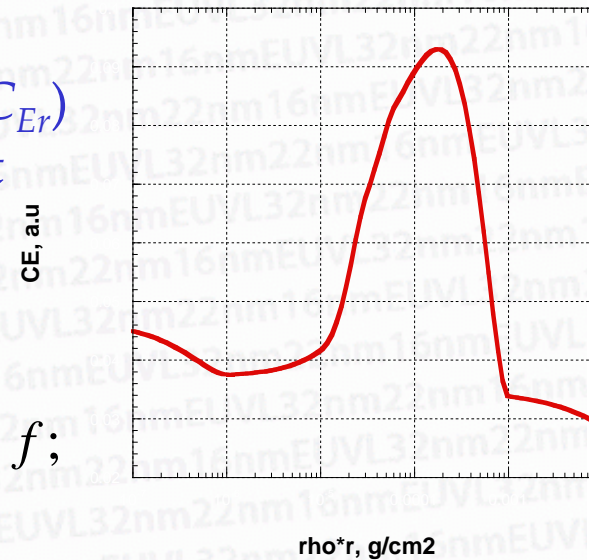
Finally:

$$P_{EUV} \propto \sqrt{E \cdot N \cdot \Omega \cdot t \cdot f}, \text{ as } R \sim \sqrt{E / (N \cdot \Omega)}$$

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

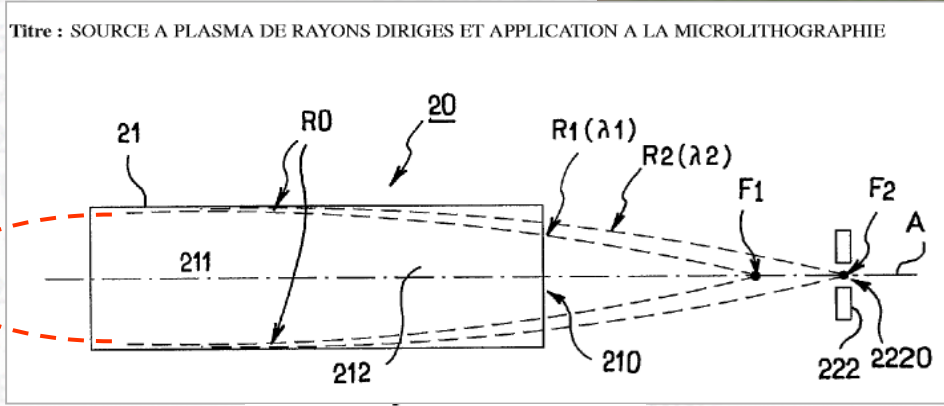
- **problem is physical size of SoCoMo** -

Z* calculations



Next Generation Lithography Light Source

- i-SoCoMo™
 - compact form factor
 - high peak power plasma discharge
 - 1 kW/kHz average power consumption
 - in-build photon collection & projection plasma structure - PlasmaLens™
 - in-build debris mitigation
- Intrinsic Source Collector Module

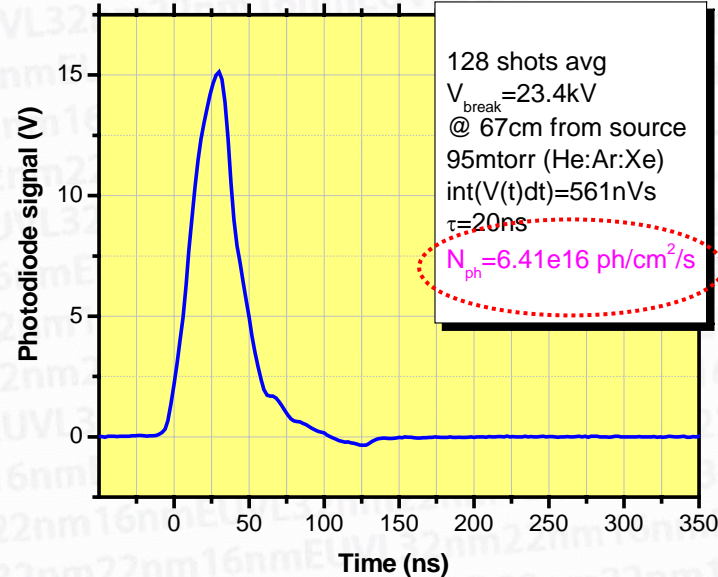
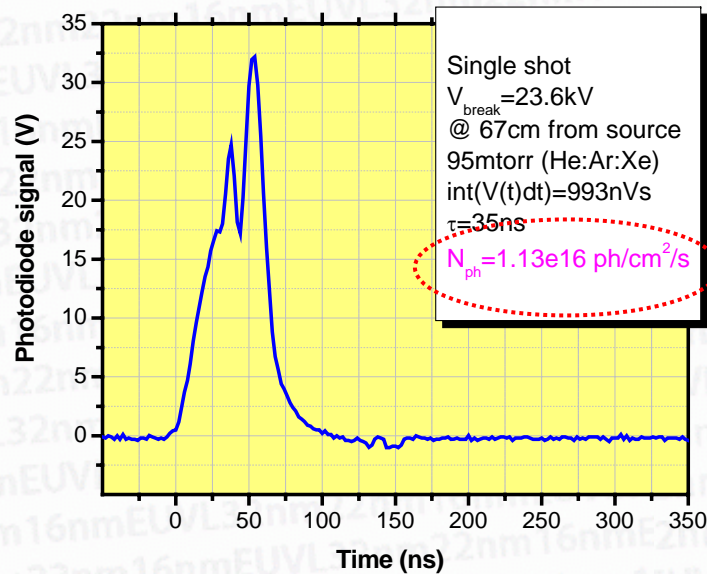


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i-SoCoMo™

- Exceptional source brightness* and power** at 1 kHz



* irradiance - greater than 10^{16} EUV photons/cm²/s measured at 67 cm from the source over a 5 mm² area, 13.5nm, 4% BW

XIL beamline at the Swiss Light Source

Energy range:	10 - 135 eV
Flux (91 eV):	2.4×10^{15} ph / s / cm ² / 2.8%BW / 0.3A
Spot size:	4 mm x 4 mm

** equivalent source power - more than 7.5 kW (2π .sr, 13.5 nm, 4% BW)

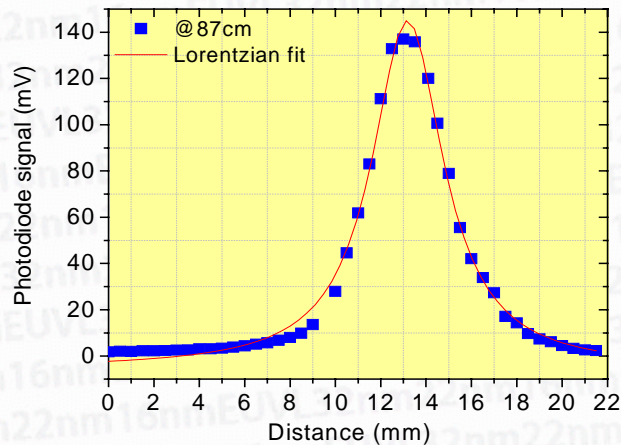
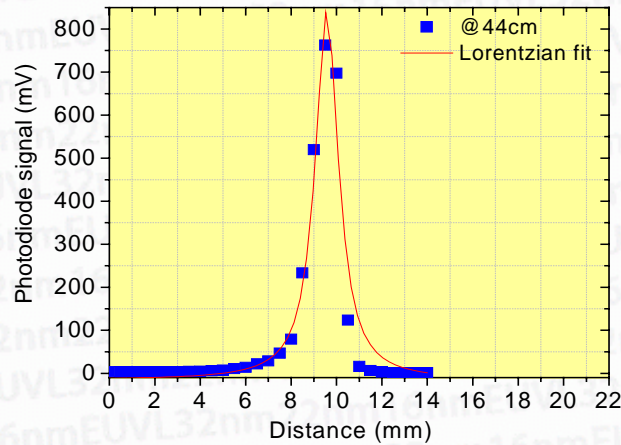


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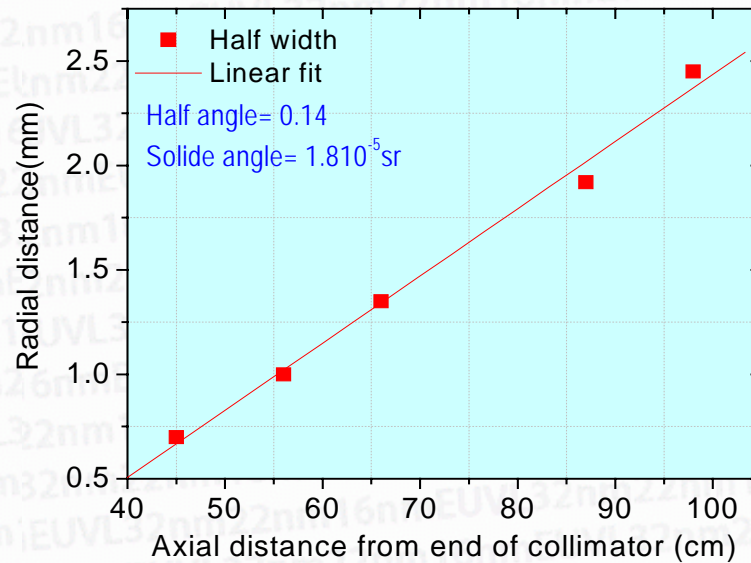
PlasmaLens™

- Optical properties



Slit-scan spatial profile

- single Gaussian profile fitting to obtain radiation half width
- source diameter ($1/e^2$ spot size) 2.5 mm at 44 cm from exit of PCS; 69 cm from plasma source



– **very small etendue: $8.6 \text{ e-}5 \text{ mm}^2 \cdot \text{sr}$** –



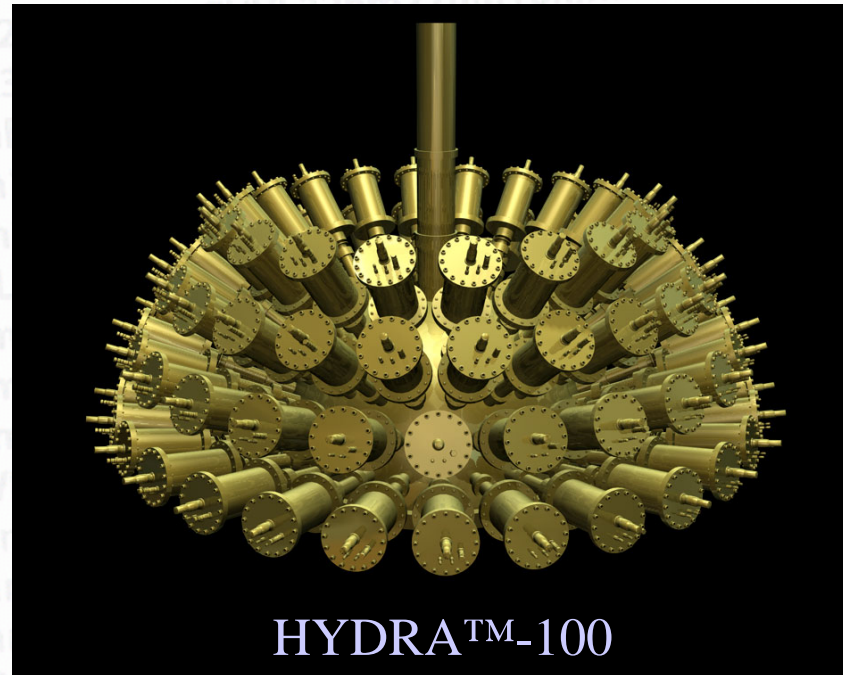
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HYDRA™ - an EUV Source for HVM

[the “WHAT FOR”]

- HYDRA™ -100
 - 100 W @IF, 25 kHz source
 - 100 i-SoCoMo™ units
 - each working at 5 kHz to deliver 1.0 W to IF
 - arranged as 5 groups of 20 units for 25 kHz multiplexed
 - total etendue < 1 mm².sr



- modular construction
- fault tolerant
- economy of scale
- low cost of ownership
- scalable to higher power



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HYDRA™ - Competitive Advantages

HVM SOURCE	HYDRA™	DPP	LPP	LA/DPP
etendue	small	high	small	medium
IF power	high	low	high	high
frequency	high	low	high	high
pupil uniformity	good	moderate	good	moderate
thermal management	easy	difficult	moderate	difficult
debris	low	high	high	high
collector	none	yes	yes	yes
complexity	moderate /modular	low	moderate	high
reliability	excellent	poor	good	moderate
cost of ownership	low	low	high	moderate
scalability	excellent	poor	moderate	poor

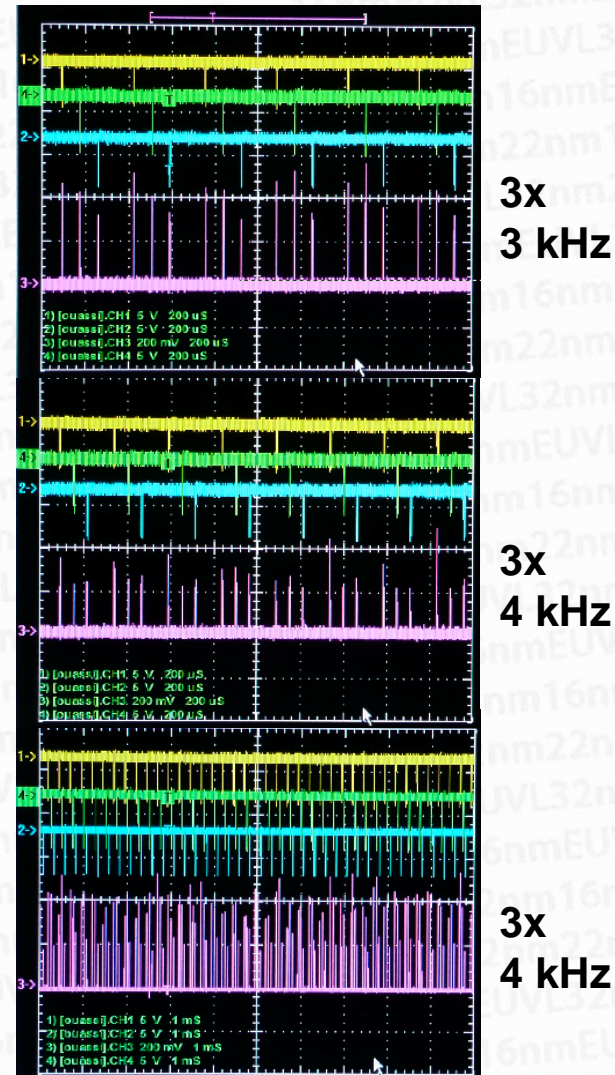


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4 units Multiplexer - 12 kHz source [the “WHAT NOW”]

- a little step forward
 - 4 cells multiplexer operational to evaluate design, engineering and physics issues
 - proof of principle demonstrator to potential end users
- road map
 - establish platform for open dialogue on applications
 - 24 cells beta multiplexer to be ready 1Q 09
 - 100 cells HVM multiplexer to be ready 4Q 09



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EPILOG - acknowledgements

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- RAKIA & NANO-UV team



Government of Ras Al Khaimah
RAK Investment Authority



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Market Forces

- Scanner Manufacturers - ASML, Canon, Nikon
 - **demand driven products and product cycle, but innovation driven time scale** -
- Shozo Saito san - Key Note Speech
 - 2007 EUVL International Symposium, Sapporo

Conclusion

■ **Toshiba has led world in device pattern shrink.**

- ✓ EUVL will not support hp 3Xnm NAND mass production, therefore Toshiba will start by using Toshiba's DPT in 1Q/2009.
- ✓ Need to prepare mass production EUVL technology. For 2Xnm HP and beyond.
- ✓ Hp 3Xnm-2Xnm node SoC also needs EUVL technology for process migration to reduce cost and power consumption.

“Future success in the EUVL marketplace will be achieved through innovative partnering and dynamic strategic alliance of specialist key players.”