Research Institute for Science and Engineering
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Optimization of high average power FEL for EUV lithography application

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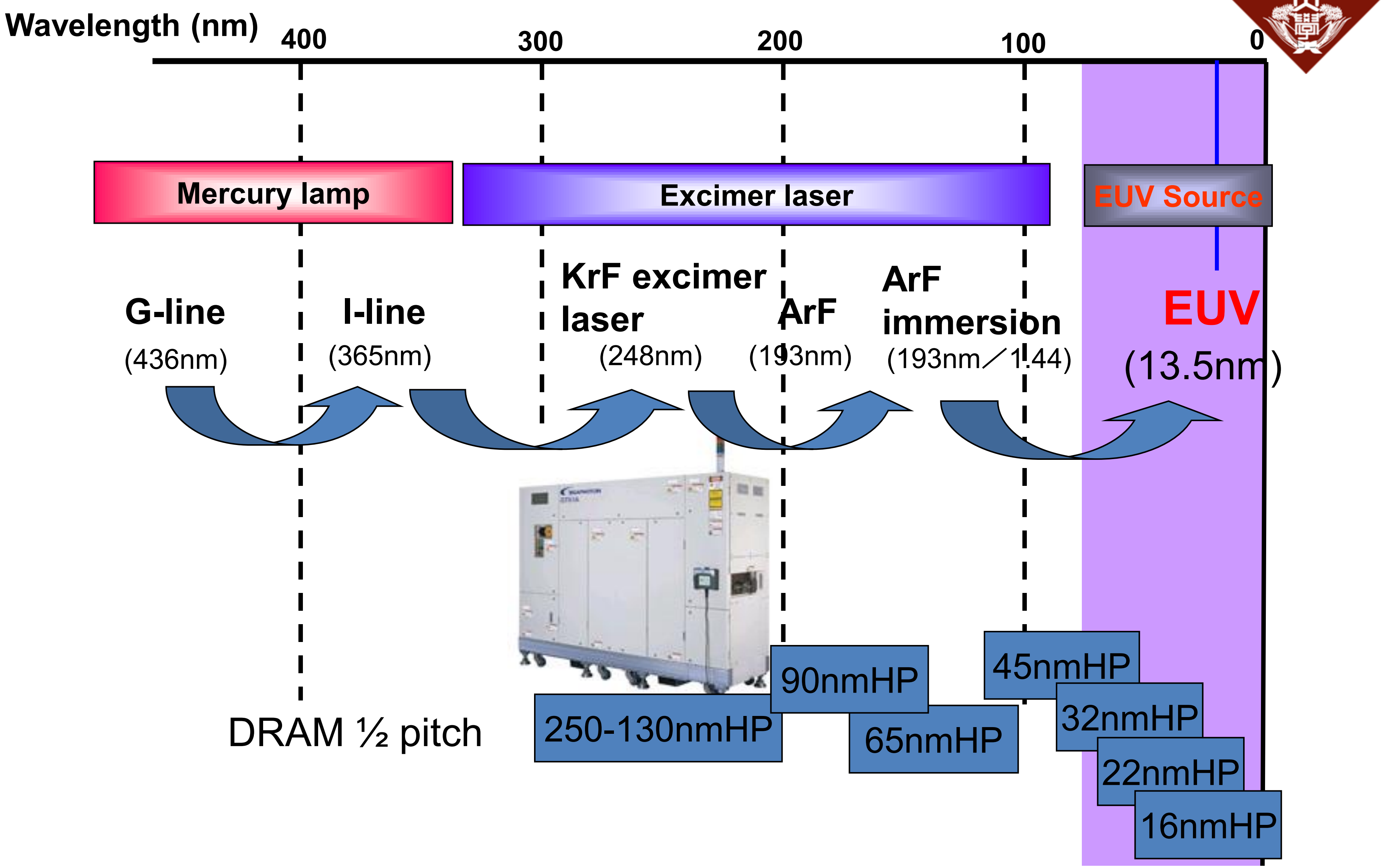
Outline

- EUV lithography source
- Power scaling of SASE FEL technology
- EUV resist under FEL pulses
- Spatial coherence and EUV homogenizer
- Temporal smoothing and HGHG
- Laser seeding technology at MHz
- Perspective

Trends of optical lithography

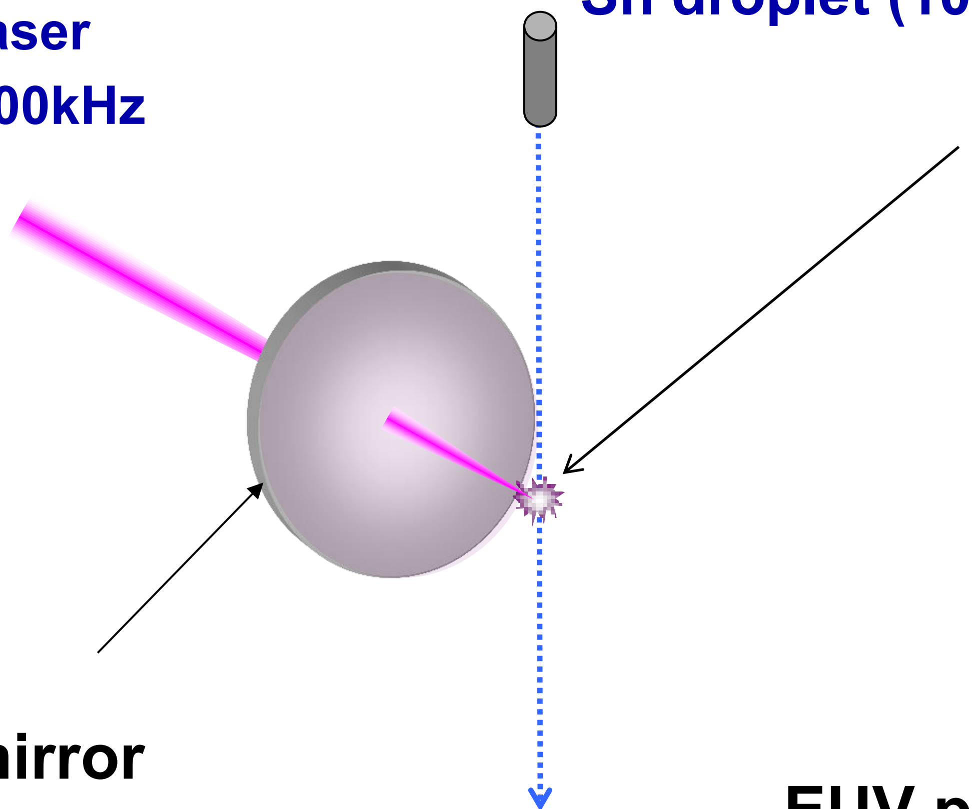


Typical configuration of EUV source

CO2 laser
>20kw 100kHz

Sn droplet (10μm, 100m/s)

EUV power at plasma
> 1kW



EUV C1 mirror
lifetime : > 12months (800Bpls)
（R10%loss＝Sn deposition ＜thickness 1nm ）

EUV power at IF
> 250W
13.5nm 2%BW
(fwhm:0.27nm)

FEL Conference 2014 Basel, Switzerland

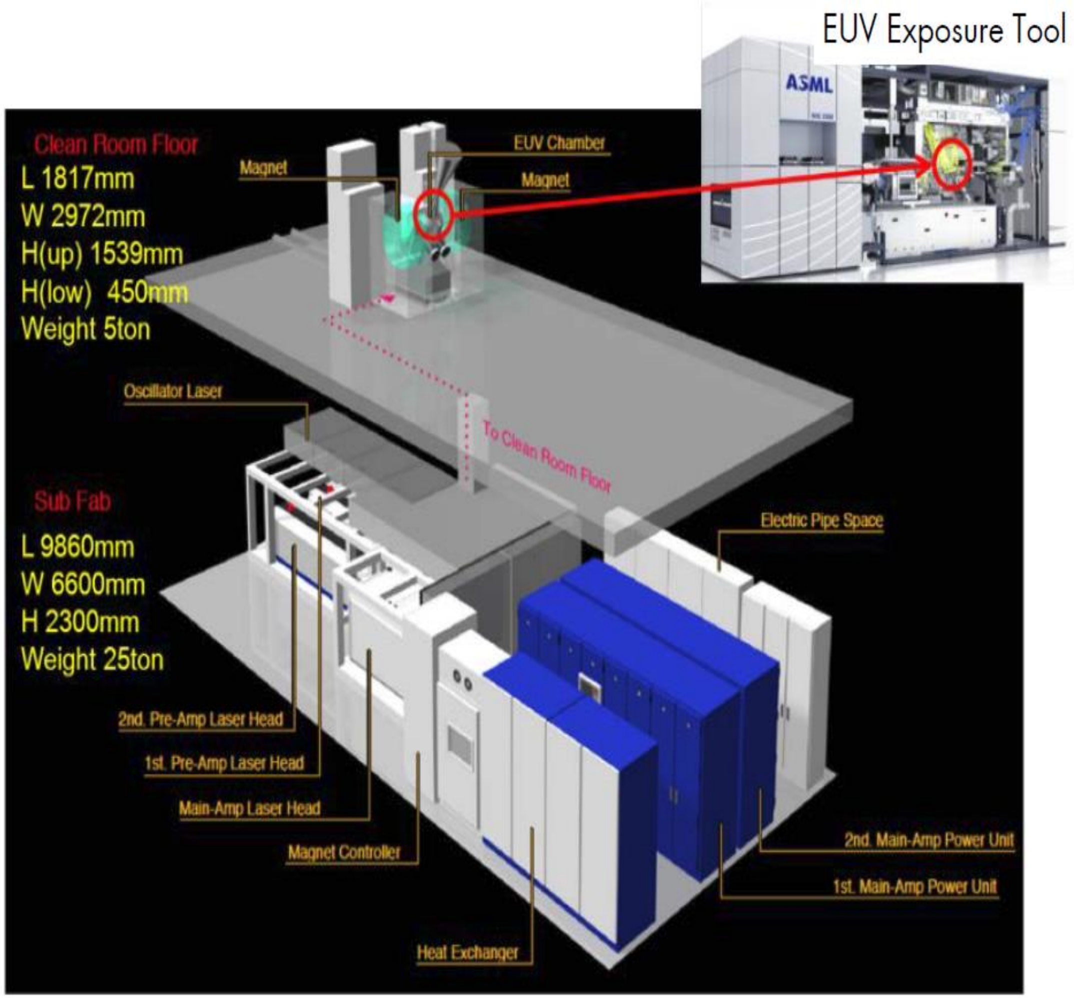
Power-up Scenario of HVM Sources

Layout of 250W EUV light source

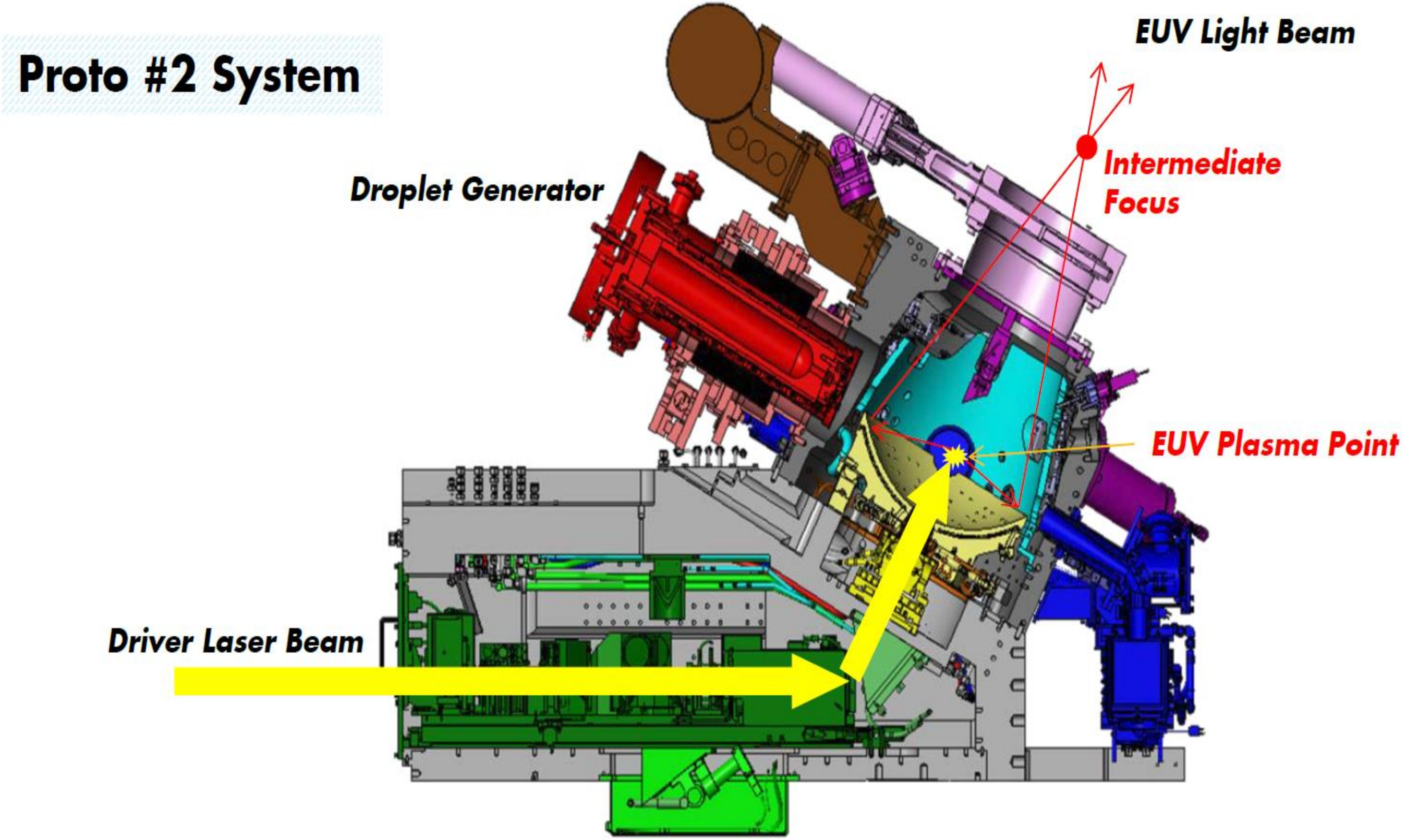
First HVM EUV Source

- Gigaphoton is developing 250W EUV source
- Target is 2015

Operational specification (Target)			HVM Source
Performance	EUV Power		> 250W
	CE		> 4.0 %
	Pulse rate		100kHz
	Availability		> 75%
Technology	Droplet generator	Droplet size	< 20mm
	CO2 laser	Power	> 20kW
	Pre-pulse laser	Pulse duration	psec
	Debris mitigation	Magnet, Etching	> 15 days (>1500Mpls)



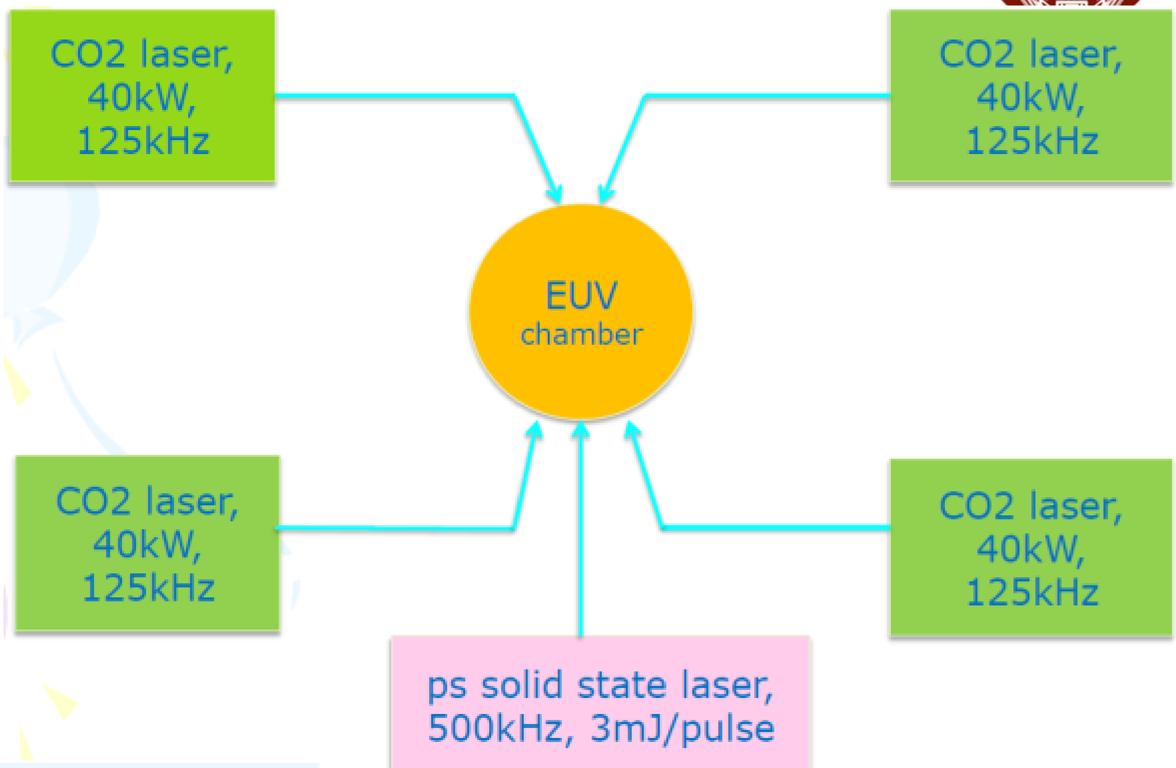
High Power EUV Light Source



Scaling to shorter wavelength, multi kW operation

Scaling to 6.xnm,

kW source

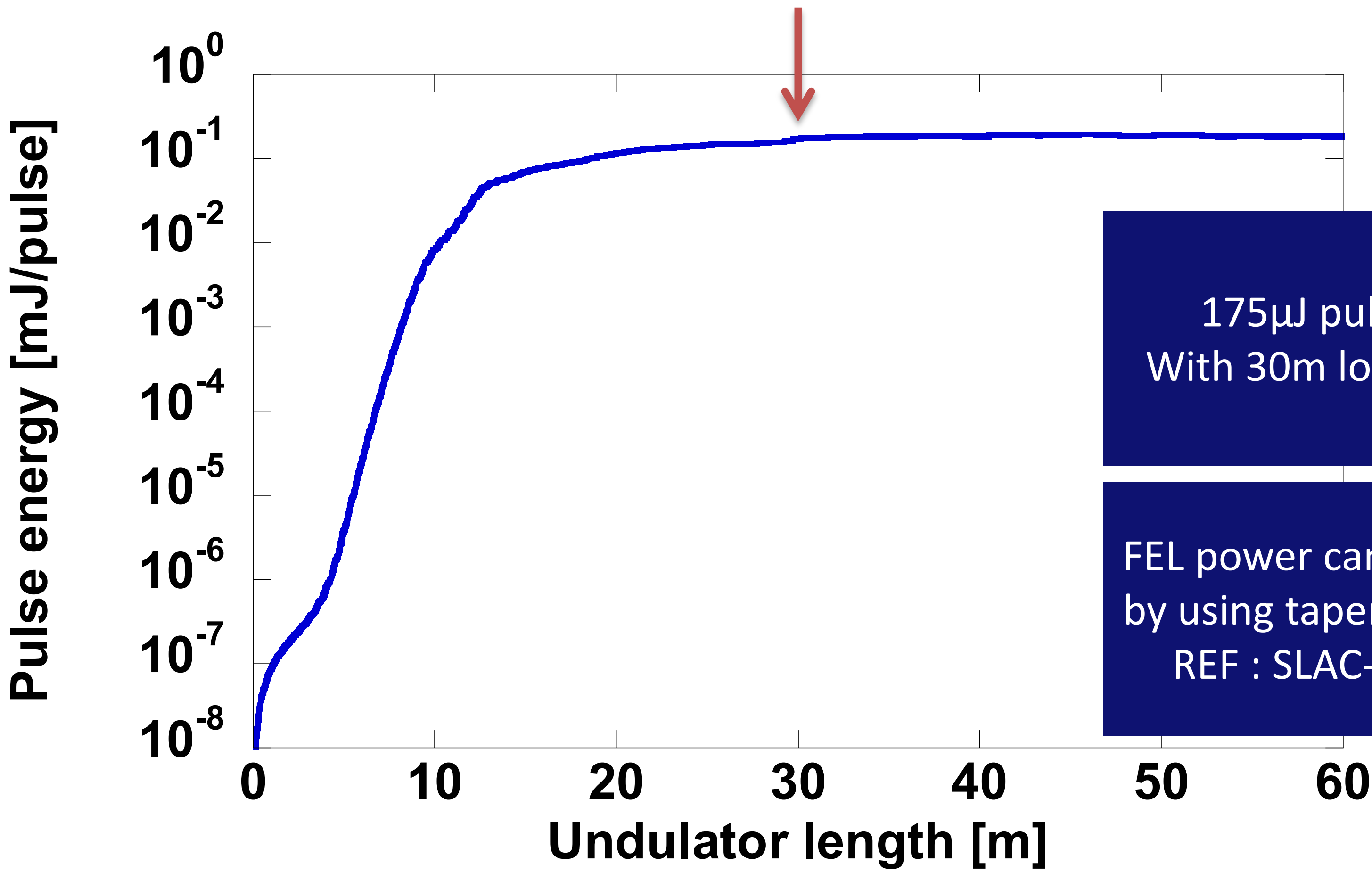


EUV IF power	1kW (6.xnm)
CO2 laser power	160kW
Conversion efficiency	1.5%/0/6%b.w. *
Collection efficiency	40%
Mirror reflectivity	70% **

GENESIS Calculation Parameters

Parameter	Value
Charge	300pC
Emittance	1 mmmrad
Energy Spread	1 E-4
Bunch length	200fs
Energy	331.13MeV
Undulation Period	9mm
K Value	1

GENESIS Calculation



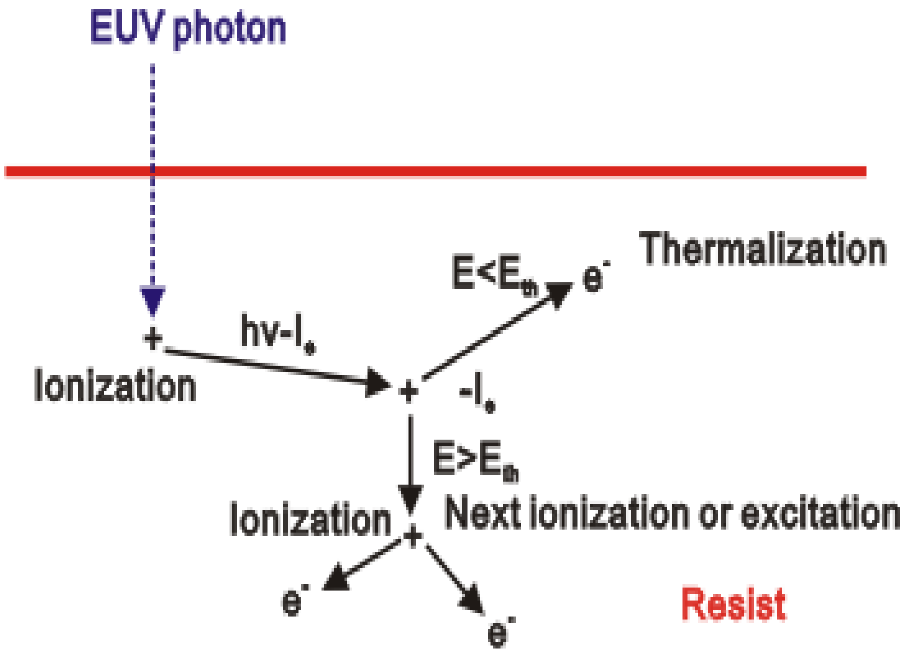
175µJ pulse energy
With 30m long undulator

FEL power can be increased by using tapering undulator
REF : SLAC-PUB-15900

Scaling of SASE-FEL power

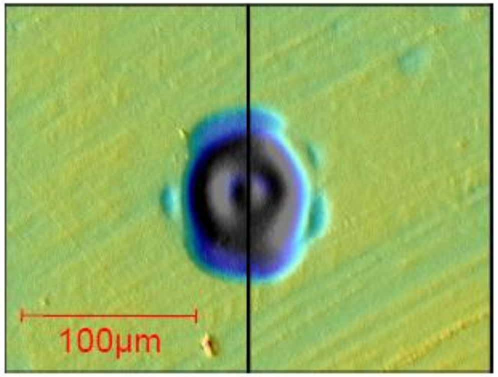
- MHz >100W
- 10MHz >1kW

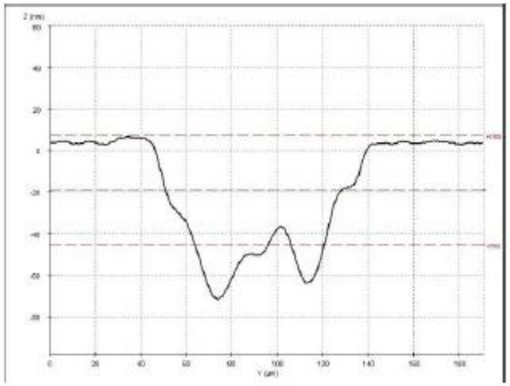
Chemically amplified resist



Resist sensitivity > 10mJ/cm^2 (10ns, 13.5nm)

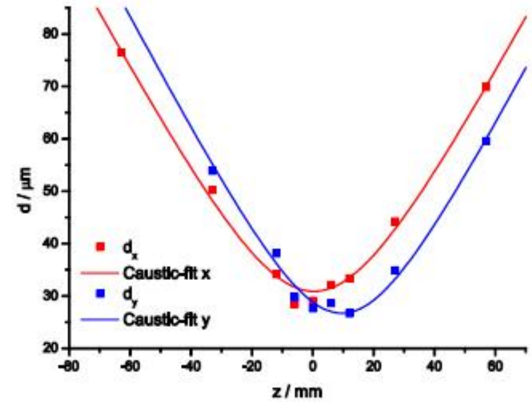
Second moment beam diameter from PMMA



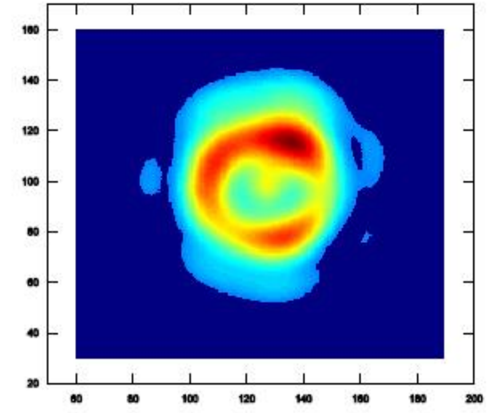


Ablative PMMA imprint, white-light interferometer

- Bulk PMMA sample at same position as phosphor
- Single pulses
- Assuming Lambert-Beer's law with
  - Ablation threshold 7.2mJ/cm2
  - Attenuation length 55.2nm
- Second moment beam diameter



PMMA caustic



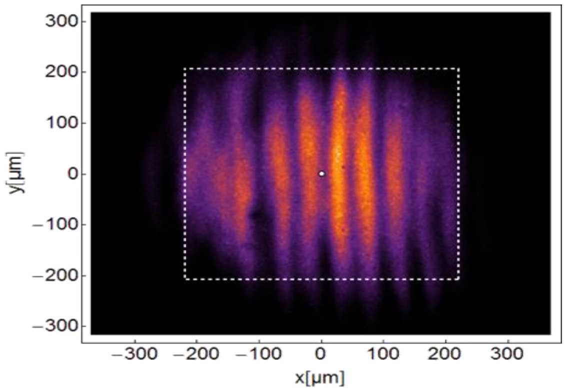
Beam profile

Issue 1 : ablation threshold < resist sensitivity

Spatial coherence

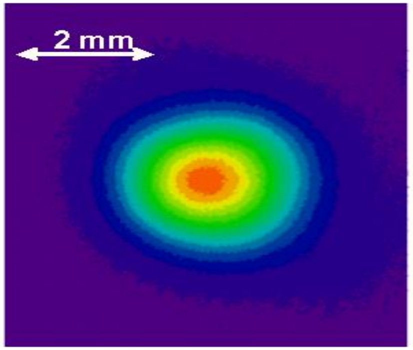
K of SASE FEL

~ 0.5



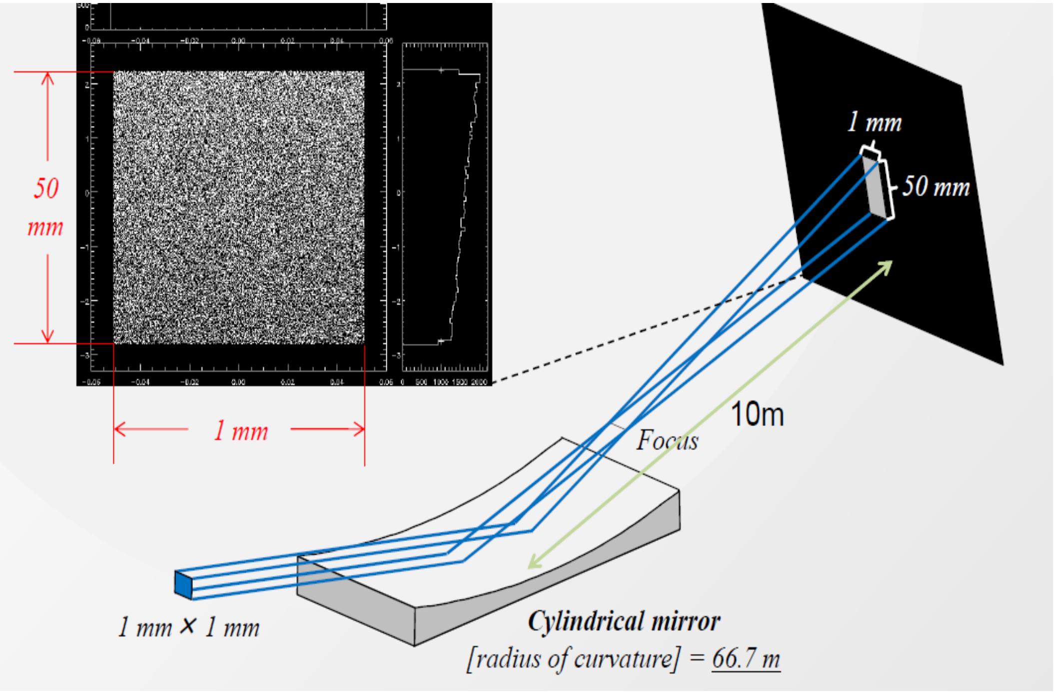
K of plasma source

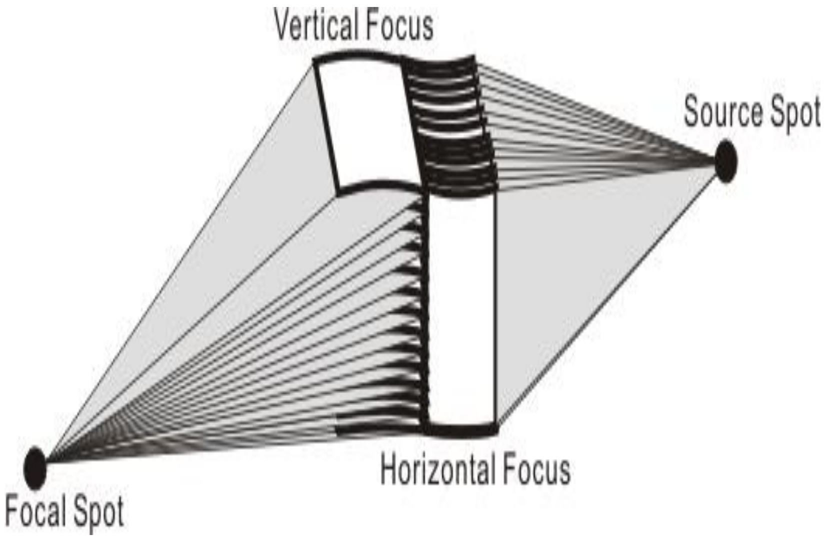
~ 3.2 x 10^{-9}



Issue 2 : interference pattern

Beam homogenizer by reflective optics

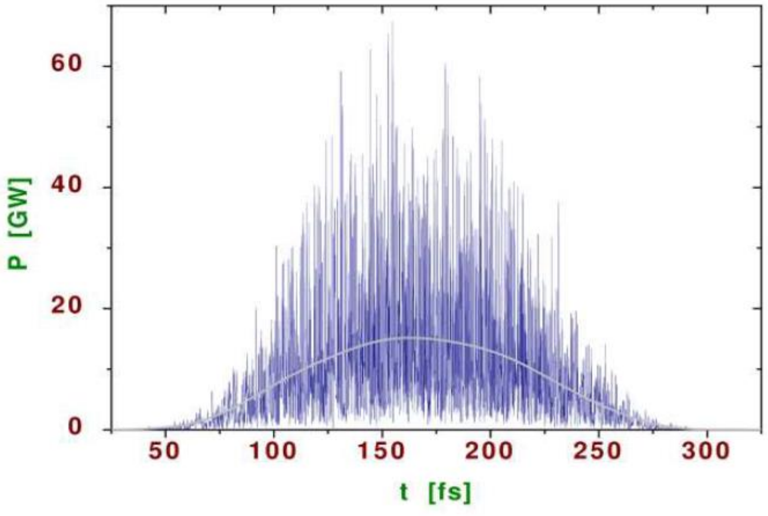




- Low roughness surface to avoid speckle pattern generation
- Higher transmission for low loss

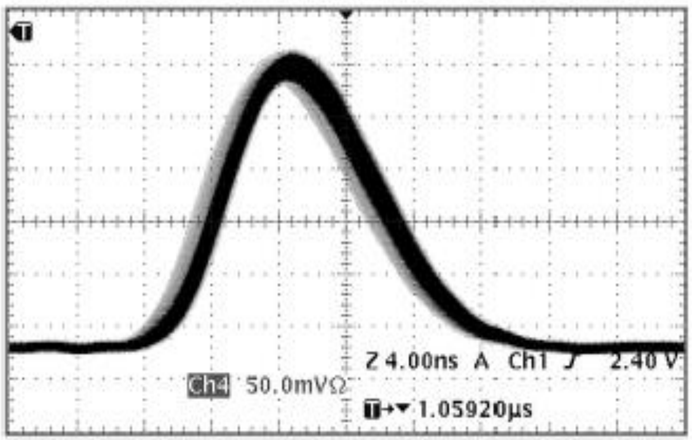
Temporal pulse structure

SASE FEL (FLASH)



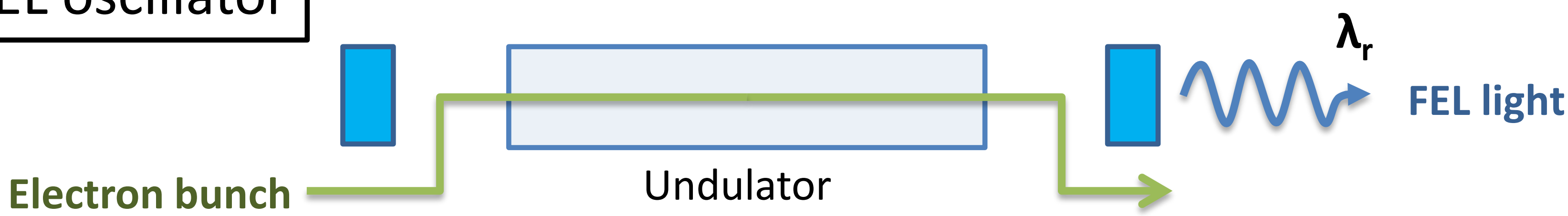
E.A. Schneidmiller and M.V. Yurkov, Coherence properties of the radiation FLASH, FLASH Seminar, September 17, 2013

Sn laser plasma

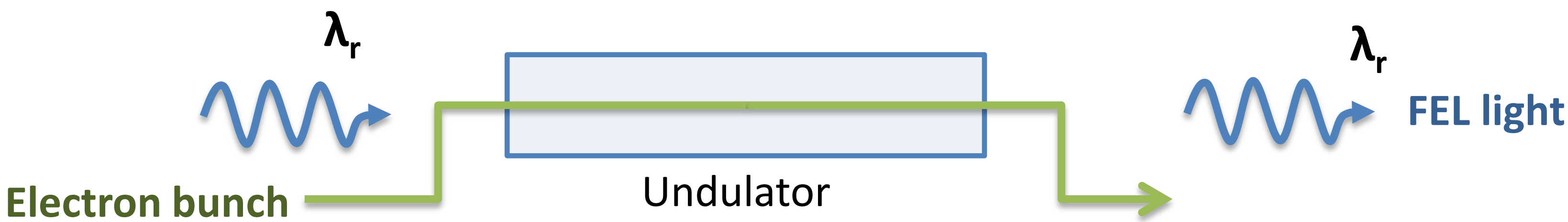


4ns/div

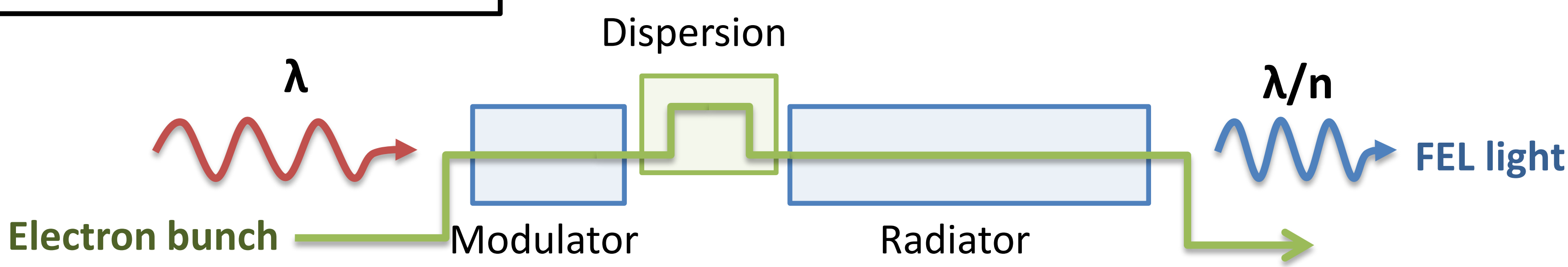
FEL oscillator

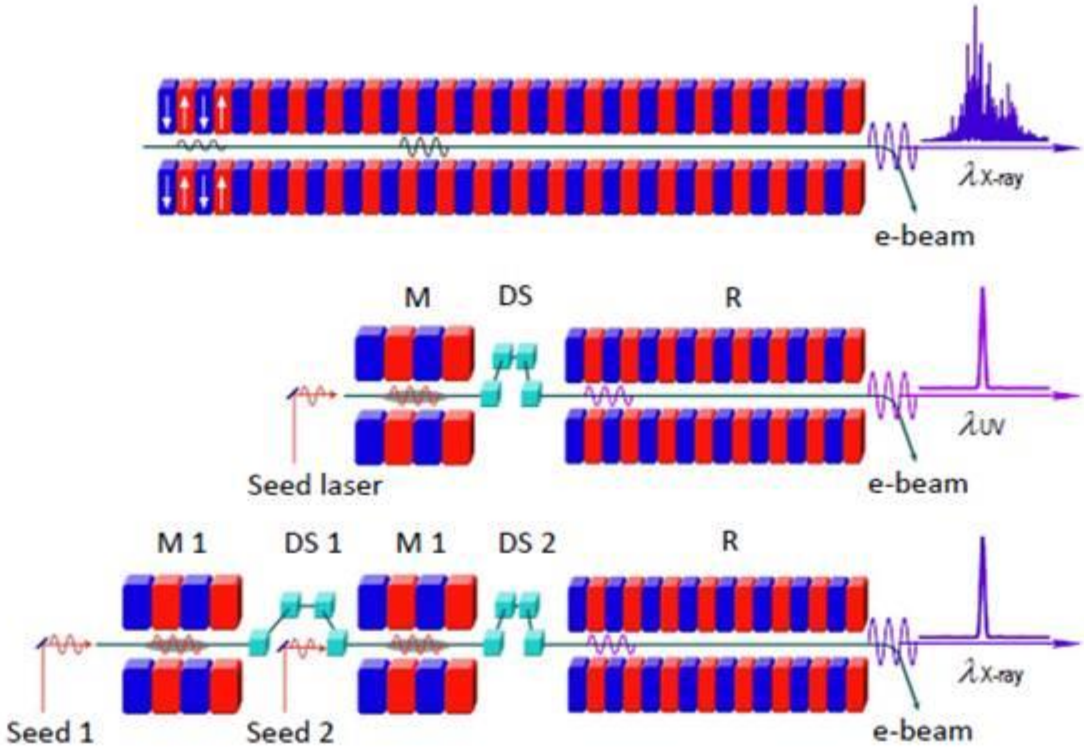


Single-pass FEL (Seeded)



Harmonic Generation





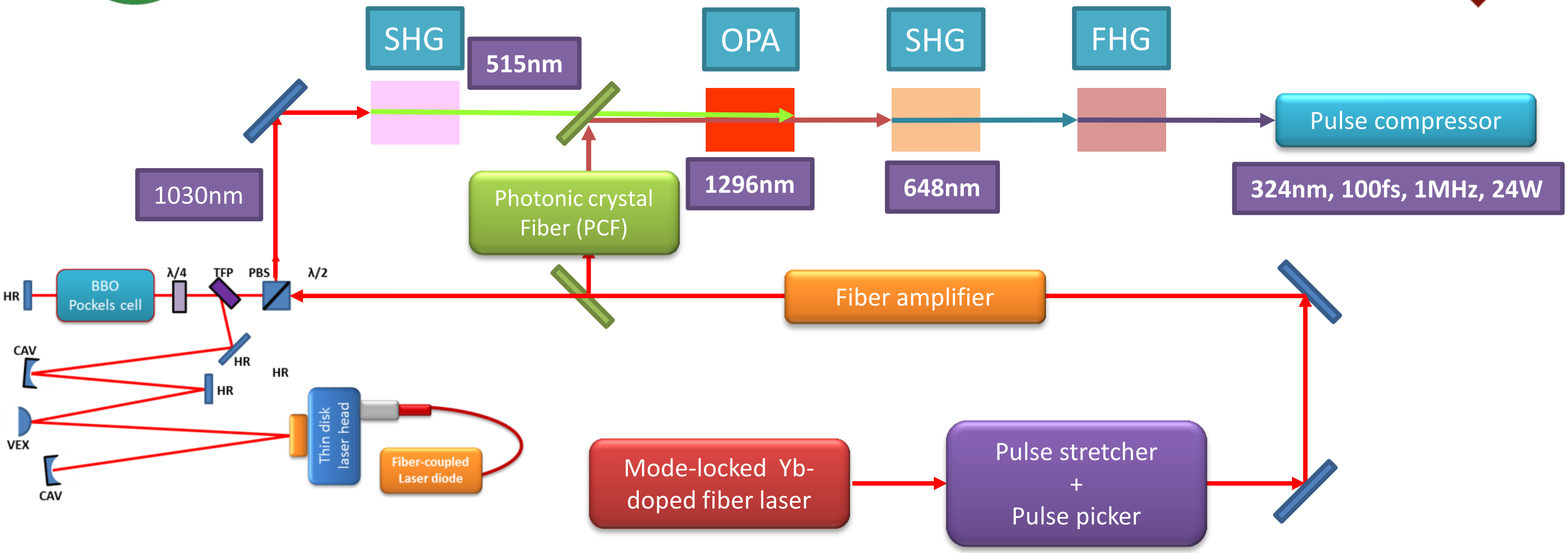
13.5nm

324nm, 100fs,
20μJ

40.5nm

Fresh bunch injection HGHG

EUV FEL Seed Source



Development of CW seeded picosecond mid-IR parametric light source pumped
By the high average power Yb:YAG thin disc laser, Ondreji Nowak

FEL Conference 2014 Basel, Switzerland

Conclusion

- Scaling of EUV source over kW
- SASE FEL can generate over kW power at 13.5nm
- Matching of FEL pulse for lithography
  1. Resist sensitivity & ablation
  2. Spatial coherence reduction
  3. Temporal smoothing