High Efficiency EUV Source from Laser-Produced-Plasma of Tin-targets

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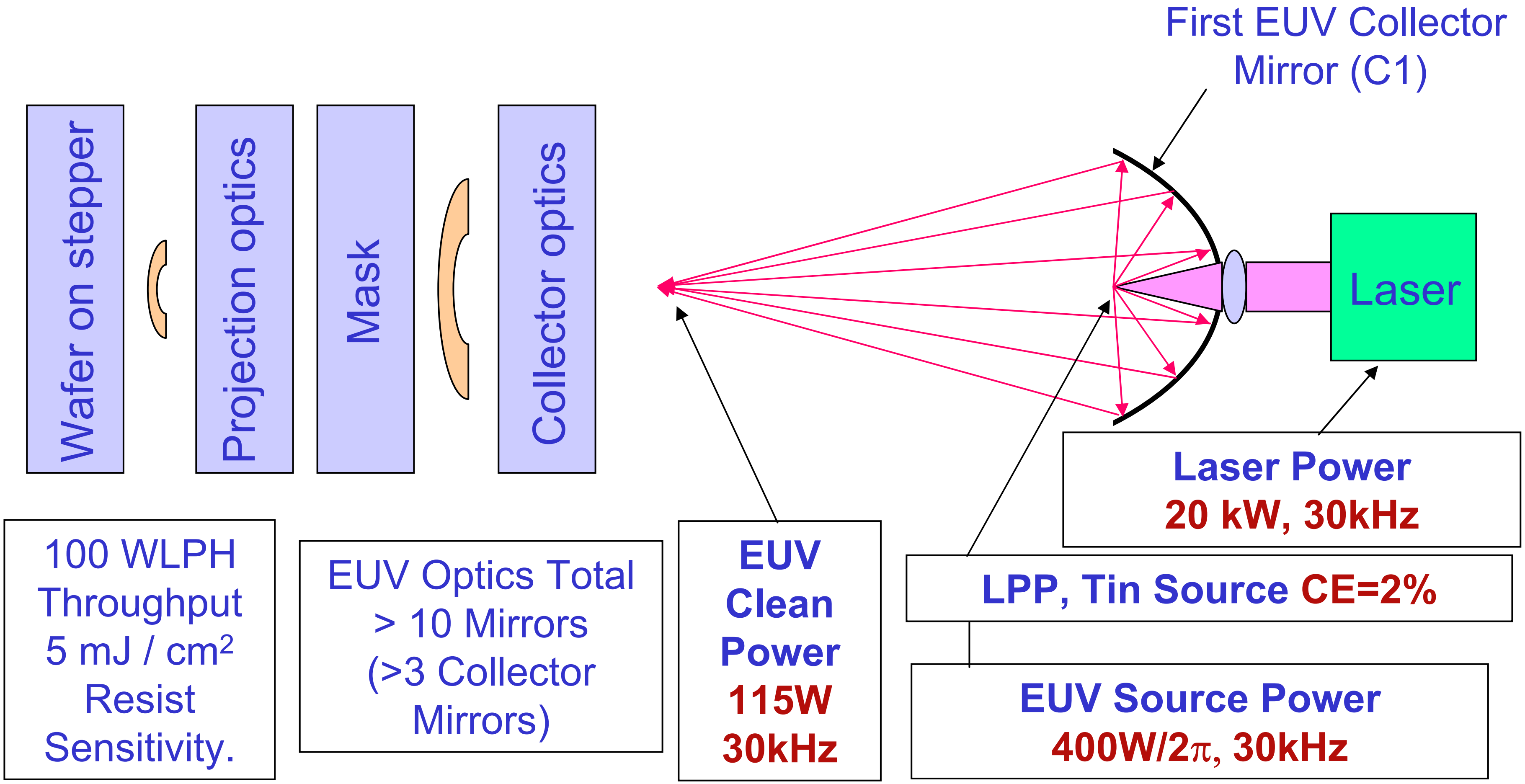
LPP EUV Source Concept



First EUV Collector Mirror (C1)

Wafer on stepper

Projection optics

Mask

Collector optics

Laser

Laser Power
20 kW, 30kHz

LPP, Tin Source CE=2%

EUV Source Power
400W/2π, 30kHz

100 WLPH Throughput
5 mJ / cm^2
Resist Sensitivity.

EUV Optics Total
> 10 Mirrors
(>3 Collector Mirrors)

EUV Clean Power
115W
30kHz

JMAR EUV strategy

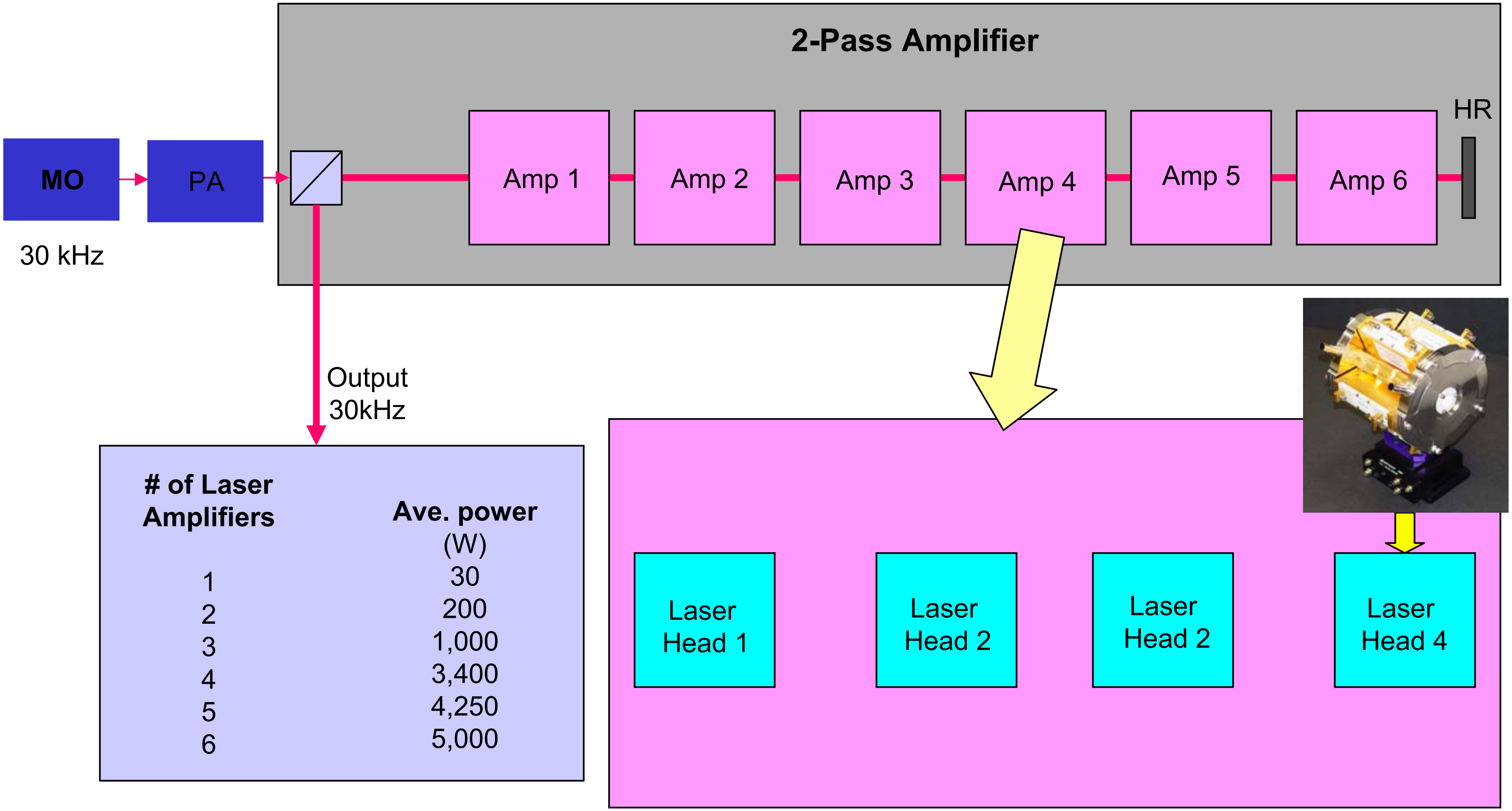
JMAR is developing both laser driver and EUV generator:

- High power CW diode pumped laser, at its Research Division in SD, CA
- High efficiency EUV generator based on two types of tin targets at:
  - Research Division in SD, CA,
  - University of Central Florida, Orlando, Fl

Motivation for CW Pumped Laser Development

- High average power needed for high throughput LPP lithography source
- Significantly lower cost in comparison to QCW pumped and other available lasers
- 30kHz repetition rate for scanning and precise dose control (EUVL requirement >10kHz)
- Strong synergy with existing JMAR's QCW laser technology
- High reliability (>20,000 hrs.)
- High thermal loading and beam power requires development
- Same development is applicable for high repetition rate QCW laser

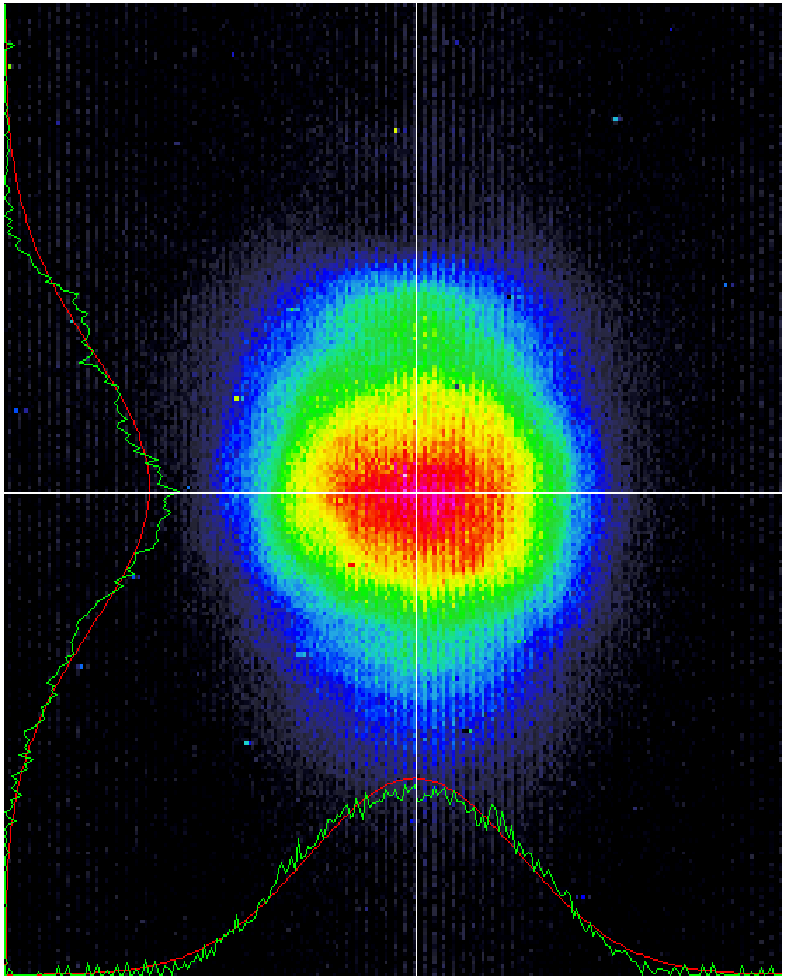
Nd:YAG Laser System Architecture (sample)



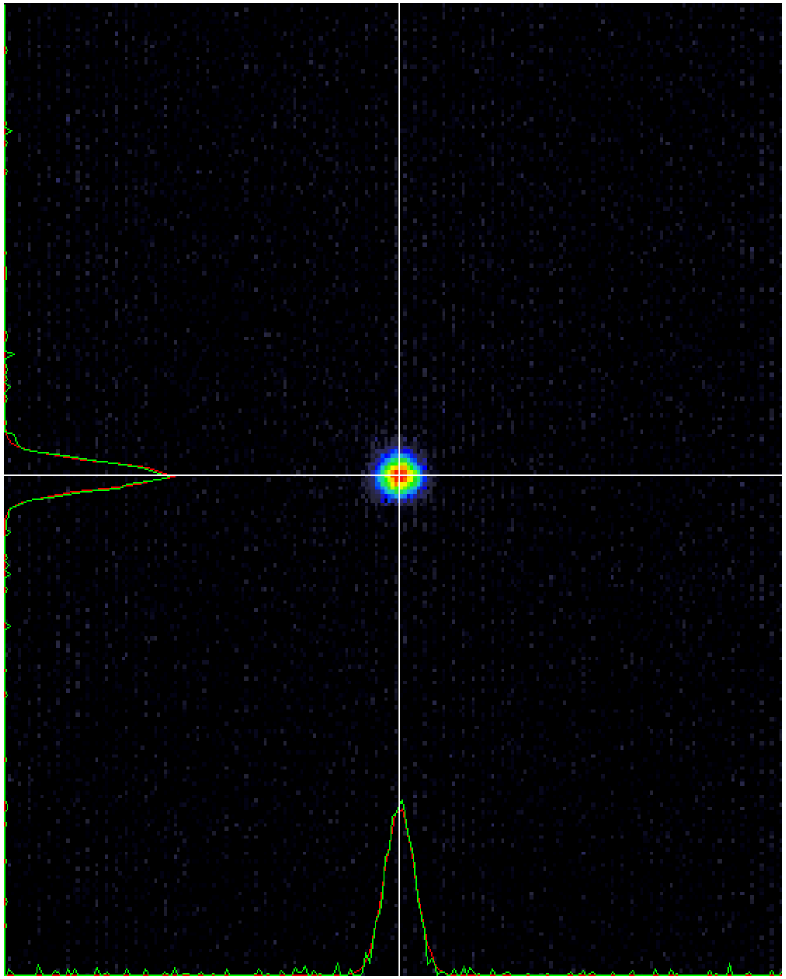
# of Laser Amplifiers	**Ave. power (W)**
1	30
2	200
3	1,000
4	3,400
5	4,250
6	5,000

Proof Of Concept CW Pumped Laser System (MO, PA, & 1 Amp.)

MO Laser Beam Profiles



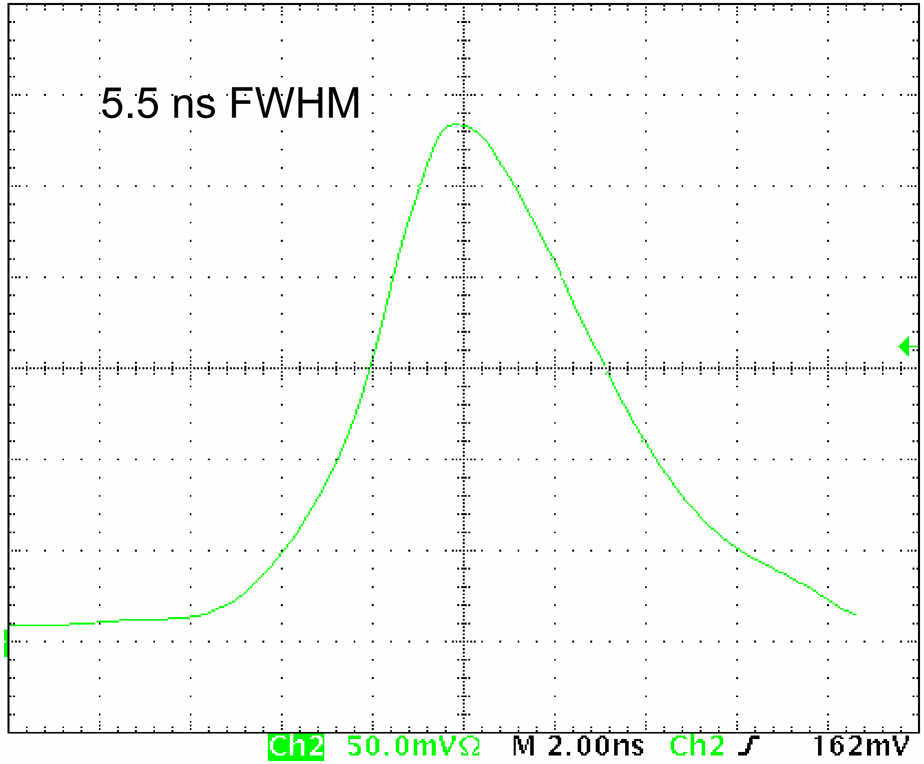
Near Field



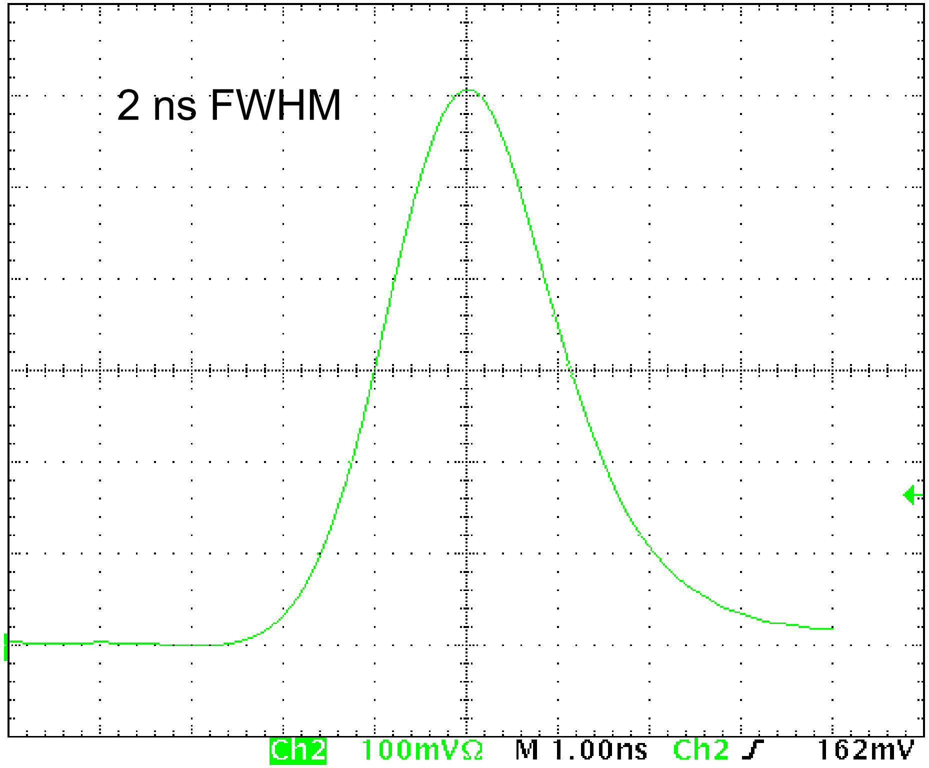
Far Field 1xDL

CW Pumped Laser MO Pulse Duration

Modelocker off



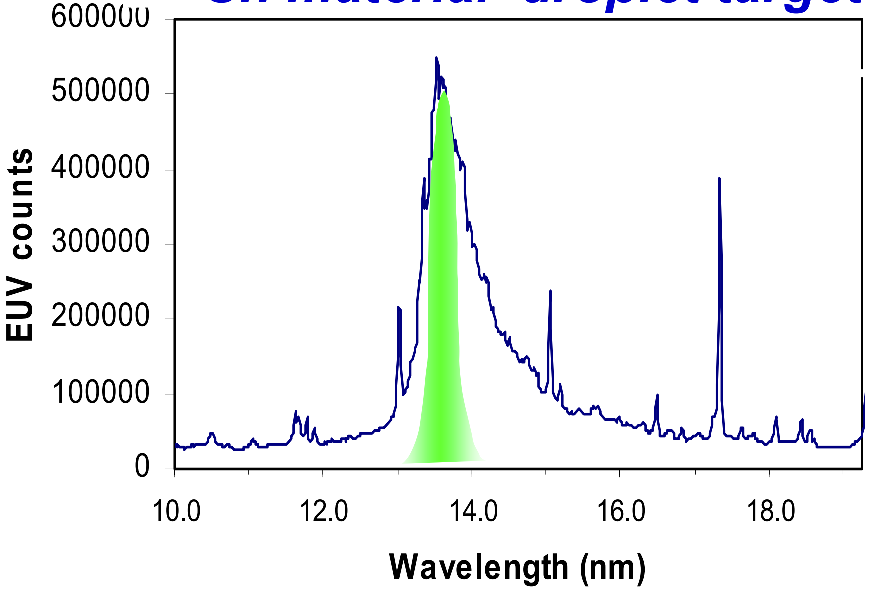
Modelocker on

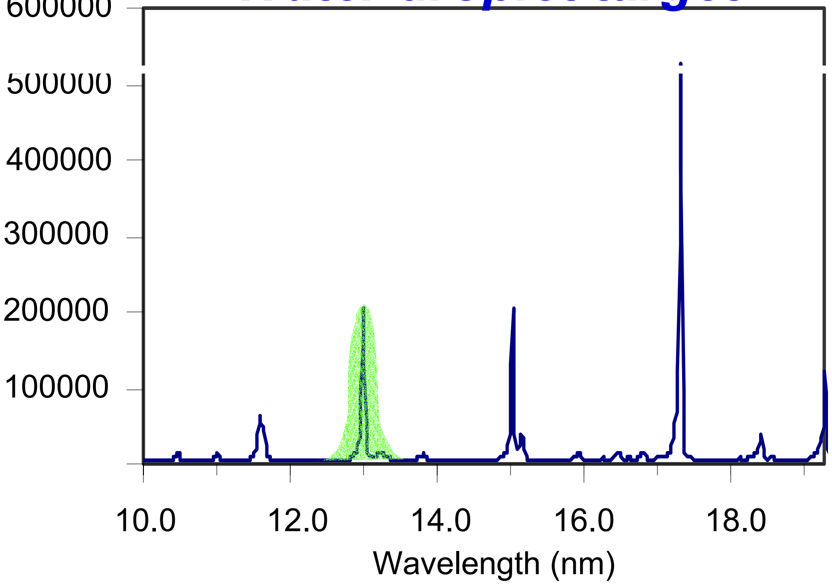


UCF development of high conversion efficiency sources - JMAR Contract

UCF has developed (proprietary) Tin containing sources possessing high conversion efficiency (See Poster session)

(patents pending)


Sn material droplet target

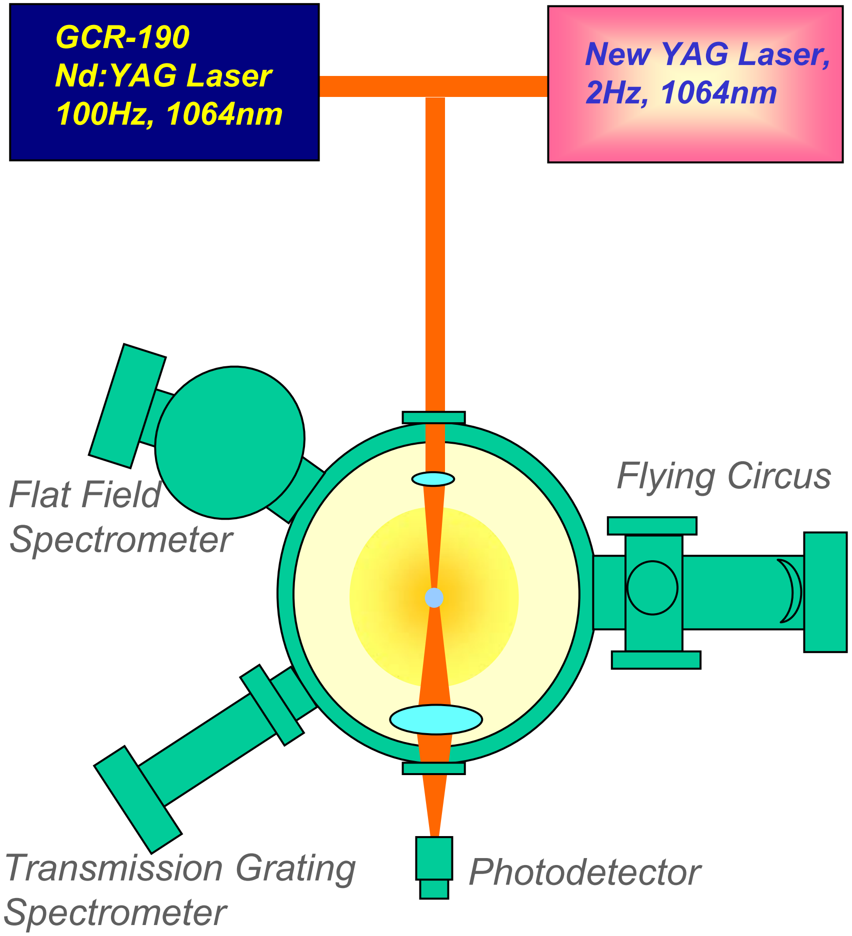

Water droplet target

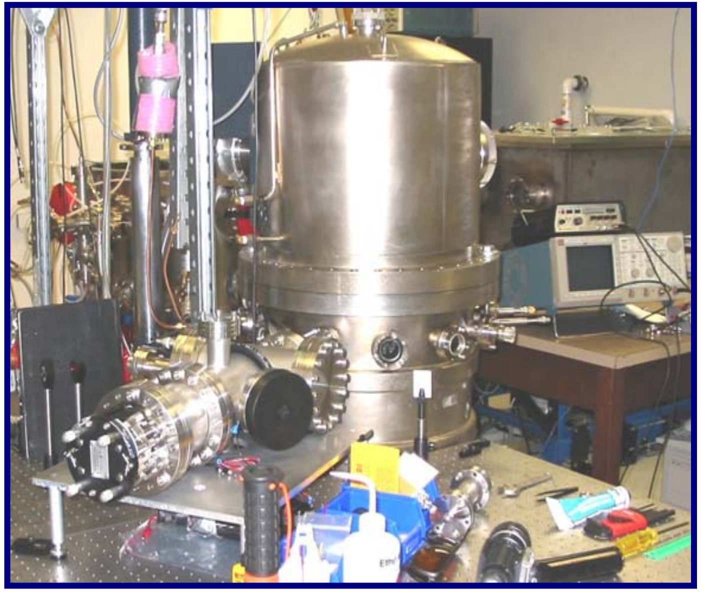
Conversion efficiency ~ 2% at 13.6 nm into 2% BW and 2π - based on measured CE for water of 0.315% in 2% BW and 2π

250 mJ, 10 ns, 1064 nm, 100 Hz laser. Spectra recorded for 150 shots

Initial Flying Circus measurements on conversion efficiency at CREOL

(See C. Koay 5037-151)





Laser: energy 0.67J/pulse, pulse width 10ns

Lens: focal length 50mm, minimum spot size 20μm

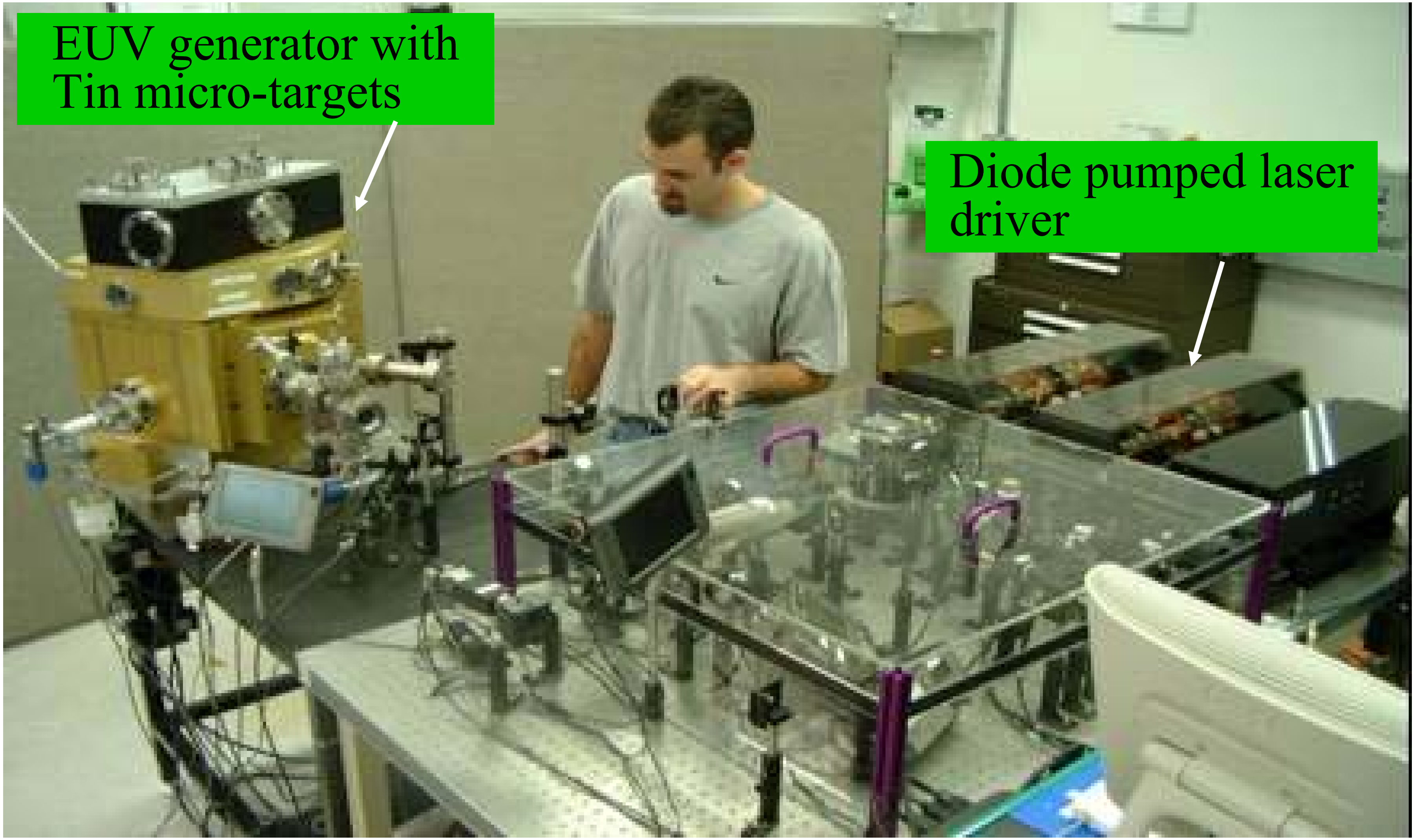
Target: Droplet of Tin mixture (<10% Sn by mass), diameter 35 μm

Conversion Efficiency > 1% (from Flying Circus)

Irradiance and target conditions not optimized

EUV Generator Development Facility in San Diego

J·MAR



EUV generator with Tin micro-targets

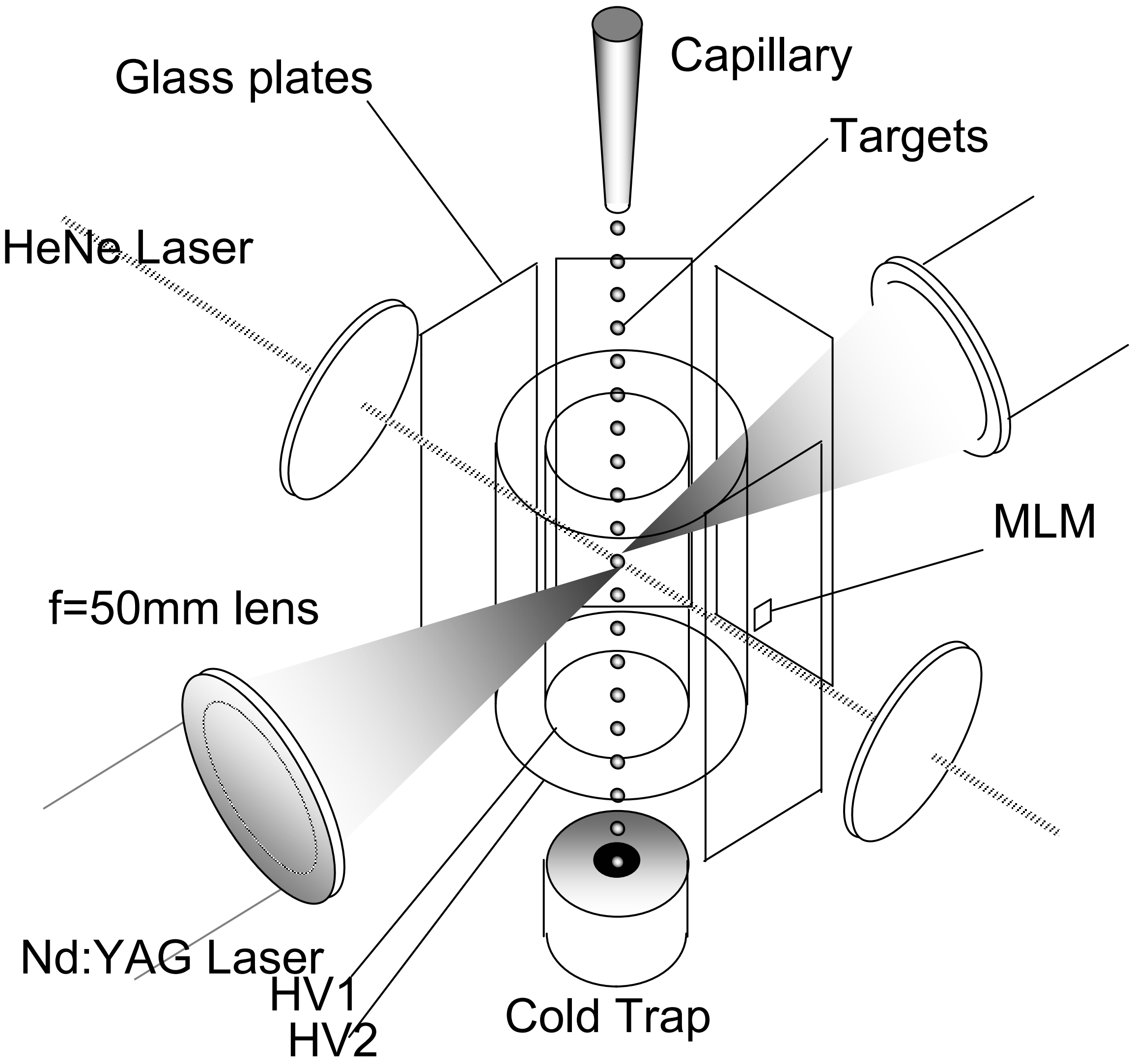
Diode pumped laser driver

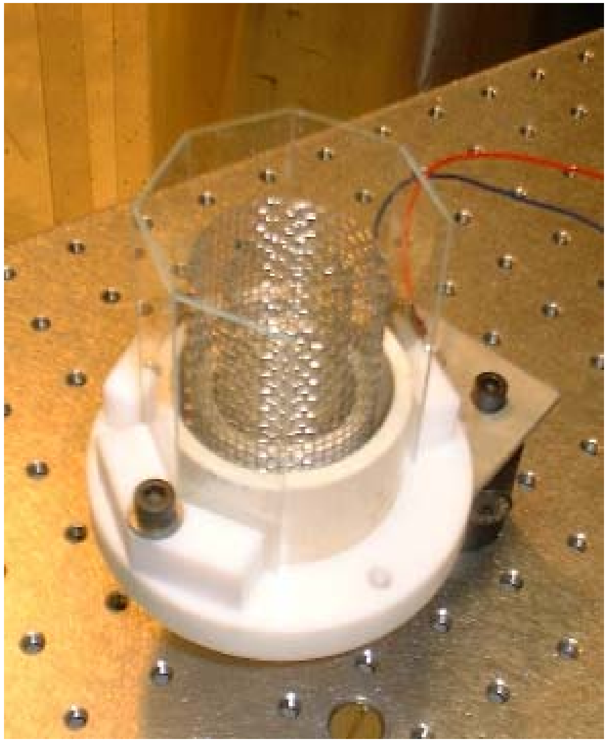
EUVL Source: Generator Concept

- **High CE target material containing Tin**
  - CE $\geq$ 2% / 2%BW / 2π @ λ = 13.5nm.
- **High repetition rate: 30 kHz**
- **Debris mitigation:**
  - minimum mass targets (micro-targets)
  - buffer gas
  - gas curtain
  - E&B fields
  - differential pumping at intermediate focus.
- **Large collection angle C1 mirror:**
  - small source etendu ~ 0.06mm^{2}sr
  - large accessible solid angle
  - stable source position

A new repeller field configuration at CREOL

(See K. Takenoshita 5037-150)



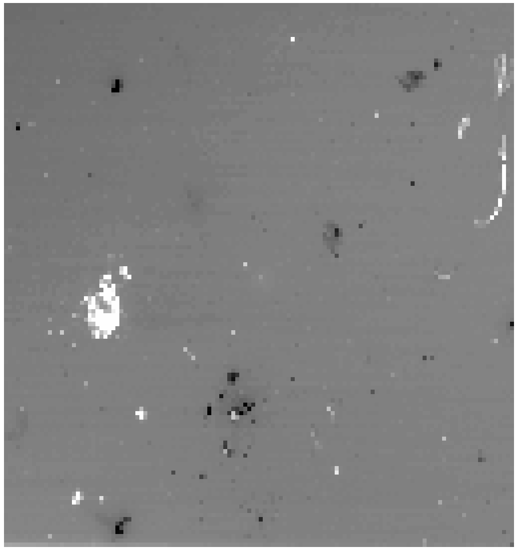


AEM measurements with and without Repeller Field at CREOL

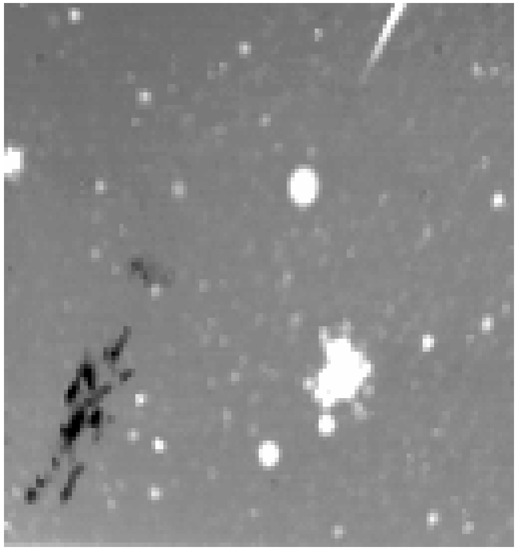
Auger Electron Microscopy Back-scattering

Image size 500 μm x 500 μm
30000 shots.
Witness plates 30 mm from target

Frequency ~102 kHz



With repeller field



Without repeller field

Less Sn deposition on MLM surface with repeller field than without the field

Development Path: Laser and Generator (*If External Funding Source Procured)*

	Conservative	***Aggressive***
Phase I		
– 200 W laser	Q4 ’03	Q3 ‘03
– 4 W EUV Prototype	Q4 ’04	Q3 ‘04
Phase II		
– 5 kW laser	Q4 ’04	Q2 ‘04
– 25 W clean EUV Prototype	Q4 ’05	Q2 ‘05
Phase III		
– 20kW laser	Q2 ’06	Q1 ‘05
– 115 W clean EUV Prototype	Q2 ’07	Q1 ‘06
Commercial EUV Source		
– 25 W	Q4 ‘06	Q1 ‘06
– 115 W	Q2 ’08	Q1 ‘07

Supplier Report

EUV Source Performance Roadmap				**External Funding Dependent**				
	Mar-01	Mar-02	Sep-02	Sep-03	Mar-04	Mar-05	Mar-06	Mar-07
Central Wavelength (nm)	13.5nm	13.5nm	13.5nm	13.5nm	13.5nm	13.5nm	13.5nm	13.5nm
Demonstrated collectable EUV power in a 2% spectral bandwidth in the region between13-14nm (W) *	0.5W/2π	0.5W/2π	1.6W/2π with TRW laser(+)	1W/2π	4W/2π	25W/Inter. Focus POC	115W/Int. Focus POC	115W/Int. Focus Commercia
Available collection solid angle (sr)	>2π	>2π	>2π	>2π	>2π	>2π	>2π	>2π
Source emission area (mm^2)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Etendue (mm2str)	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Demonstrated maximum repetition rate (kHz)	0.3	0.3	0.5-2.5+	0.3	30	30	30	30
Demonstrated steady state repetition rate (kHz)	0.3	0.3	0.5-2.5+	0.3	30	30	30	30
Dissipated total power in source region (at steady state) (kW)	0.03	0.03	0.3-0.6+	0.05	0.2	5	20	20
Source-facing condenser lifetime (# of pulses to 10% reflectance loss)	2E8**	2E8**	>E6 estimate	2.00E+08	2.00E+09	2.00E+10	2.00E+11	2.00E+11
Pulse to pulse spatial stability (μm 3s)	~20μm	~20μm	~20μm	~20μm	~20μm	~20μm	~20μm	~20μm
Pulse to pulse intensity stability (3s)	~50%	~50%	~50%	10%	5%	2%	<2%	<2%
Pulse to pulse angular stability (3s)	uniform	uniform	uniform	uniform	uniform	uniform	uniform	uniform
Pulse to pulse pointing stability (3s)	uniform	uniform	uniform	uniform	uniform	uniform	uniform	uniform
Key risk areas	Debris	Debris	Debris	Debris	Debris	Debris	Debris	Debris
Critial component lifetime	C1mirror	C1mirror	C1mirror	C1mirror	C1mirror	C1mirror	C1mirror	C1mirror

* No filters, ** Similar target, (+) Joint TRW/CEO and JMAR experiment

Activities for Development

- Top 3 issues for LPP technology development
  - Issue 1: Debris mitigation for 2year life of C1
  - Issue 2: Conversion efficiency of ≥ 2% 2p/ 2%BW@13.5nm from low debris targets
  - Issue 3: ≥ 5 kW CW DPSS laser development

- Topics for Pre-competitive research/development
  - Topic 1: Debris/heat mitigation
  - Topic 2: C1 mirror (geometry/collection angle).
  - Topic 3: Metrology standard.