Performance of Laser Produced Xe Plasma Light Source for EUV Lithography

EUVA

(Extreme Ultraviolet Lithography System Development Association)

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Outline

- Roadmap
- Technologies for 10W @ IF
  - High Power Nd:YAG Laser
  - Xenon Jet
  - LPP Light Source Performance
- Technologies for 115W @ IF
  - Xe Droplet Target
  - Magnetic Field Mitigation
  - CO_2 Laser
- Summary

EUV LPP Source Roadmap

Fiscal Year	2003	2004	2005	~2008
EUV power @ intermediate focus	--	4W	10W	115W
Plasma target	Xe	Xe	Xe	Droplet
Conversion efficiency	0.6%	0.7%	0.8%	TBD
Laser power	1.5kW	2.5kW	5kW	TBD
EUV power in 2pisr 2%BW	4.0W	9.1W	40W	300W
Available collection solid angle	--	--	4sr	5sr
Repetition rate	10kHz	10kHz	10kHz	TBD
Technology for 10W **Nd:YAG Laser, Liquid Xe jet**				
Technology for 115W **CO_2 Laser, droplet target** **Magnetic field mitigation**				

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Technology for 10W @ IF

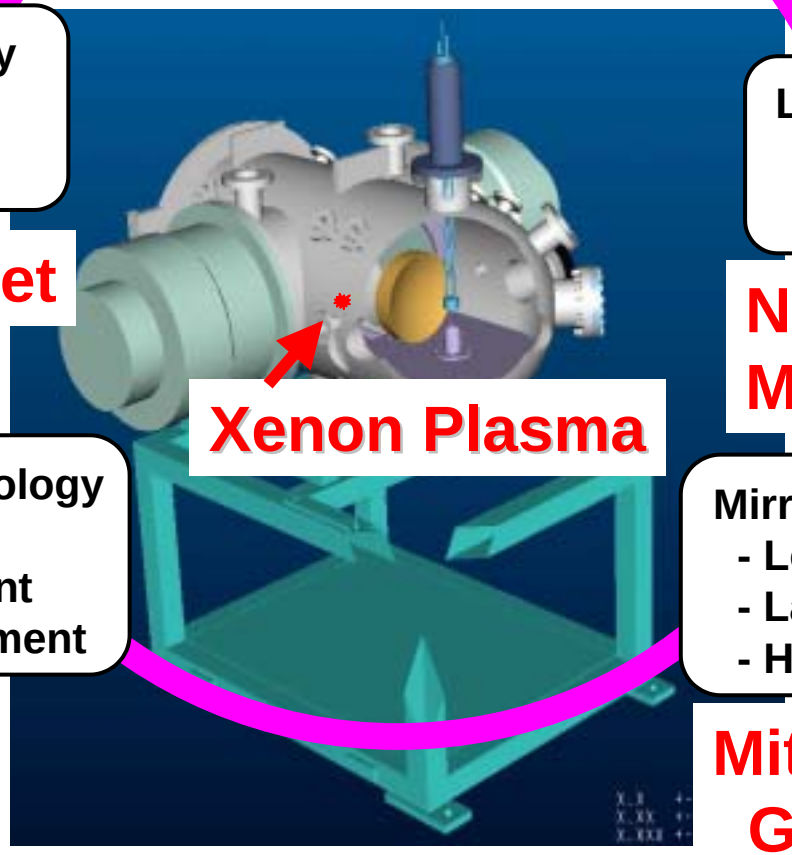
LPP-EUV light source
/High power/stability
/Long lifetime
/Low CoO

Target Technology
- High velocity
- High stability

Xenon Jet Target

Laser Technology
- High power
- Short Pulse duration

Nd:YAG MOPA Laser



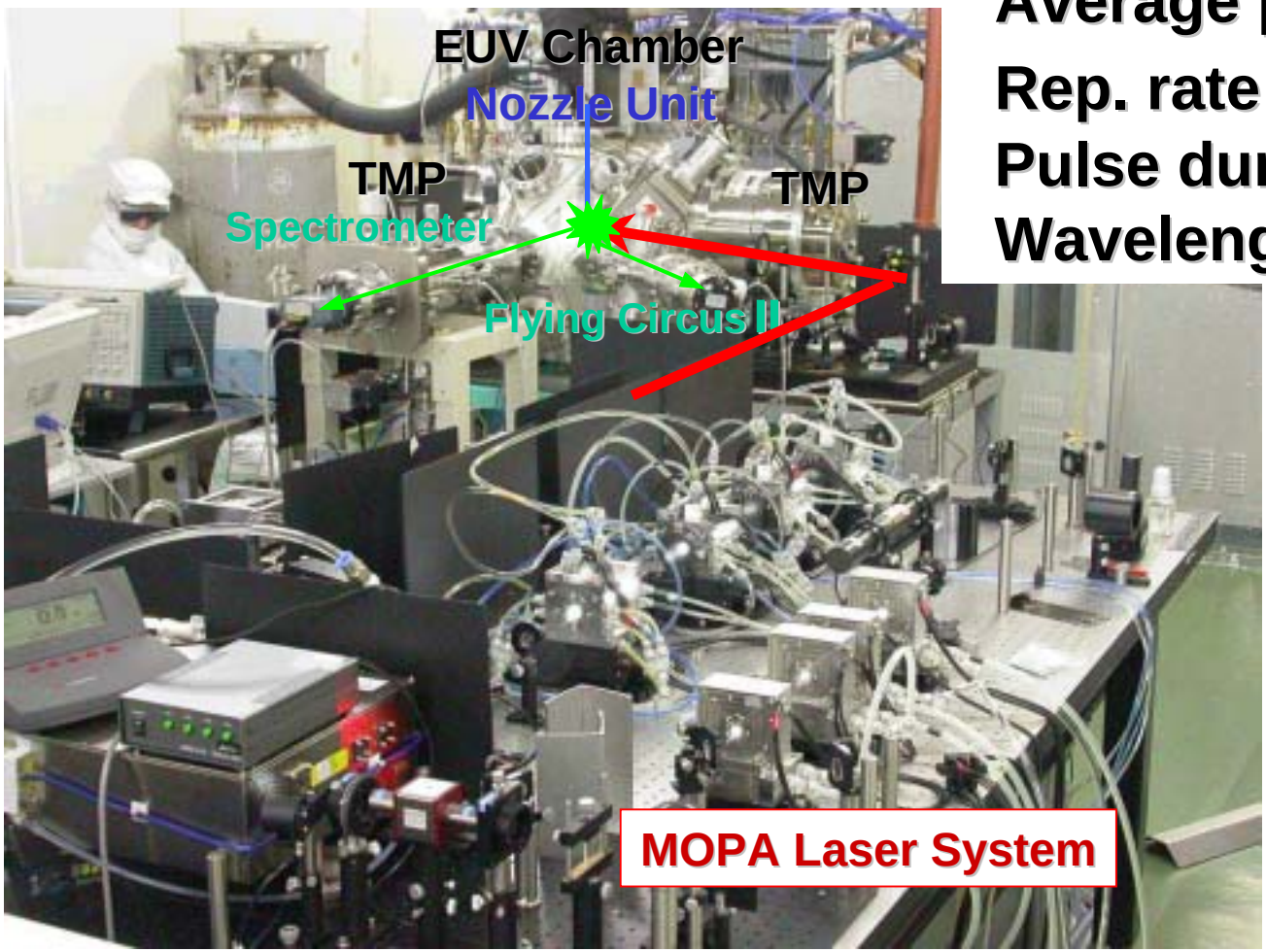
Xenon Plasma

Chamber Technology
- High vacuum
- Small foot print
- Heat management

Mirror technology
- Long lifetime
- Large solid angle
- High reflectivity

Mitigation: Gas Curtain

Nd:YAG Driver Laser System



MOPA system specification

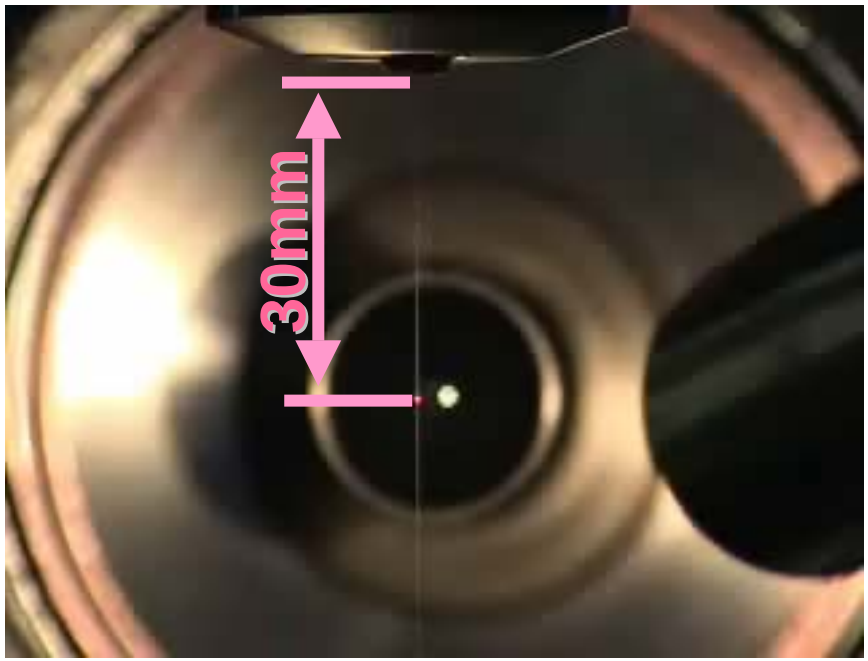
Average power : 1500 W

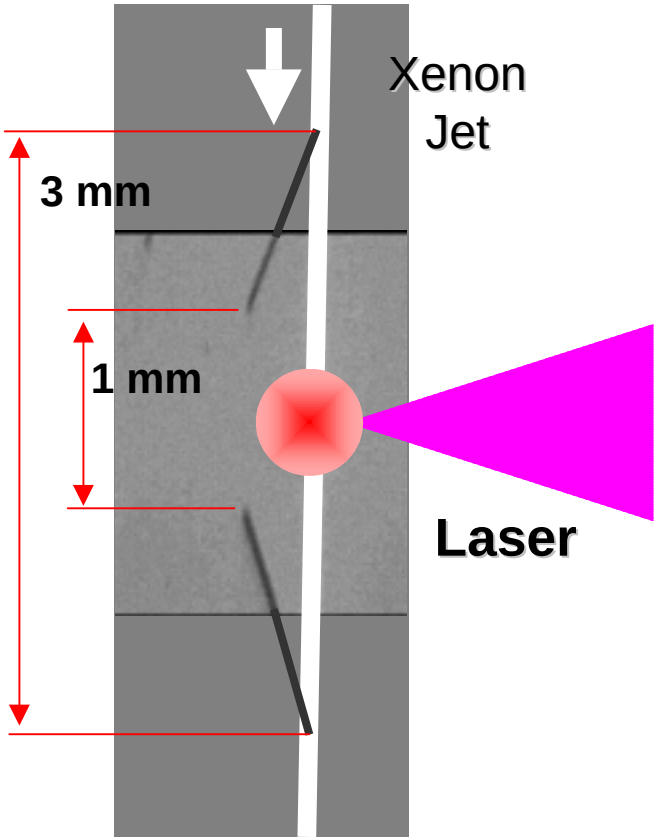
Rep. rate : 10 kHz

Pulse duration : 6ns (FWHM)

Wavelength : 1064nm

Xenon Jet Target





Xenon jet

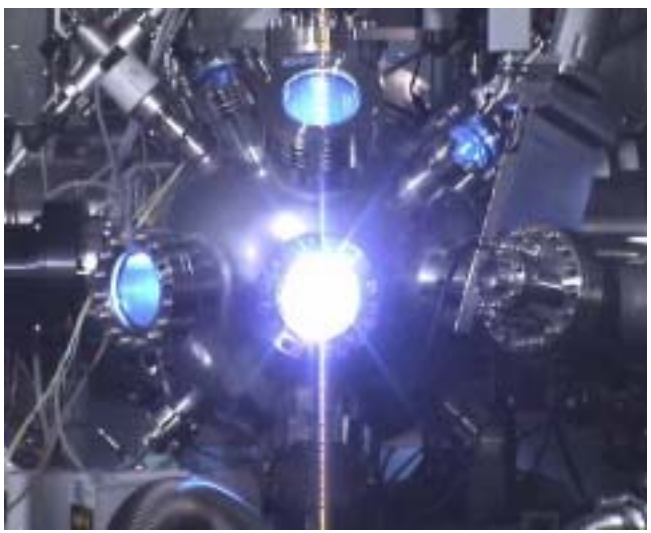
- Jet diameter: Approx. 50 μm
- Jet speed: >35m/s
- Jet stability: 9% (1σ)
  @ 30mm from nozzle

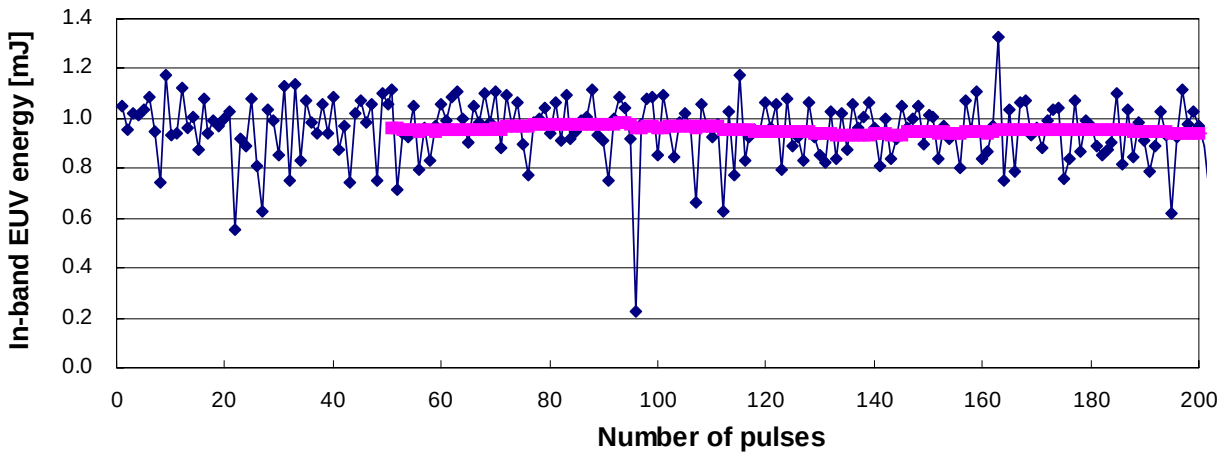
Behavior after laser irradiation (115mJ, 2Hz)

- Break up length 1mm/pulse
- Deformation length 3mm/pulse

EUV Power and Stability

- **EUV Power at Source: 9.1W (2%BW/2π sr)**
  at I.F.: 4W (Calculated)
- **Conversion Efficiency: 0.61%**
- **EUV Energy Stability: 1.3% (1σ, 50-pulse ave.)**
- **Laser Power: 1500W@10kHz, 6ns**
- **Target: Liquid Xenon jet**



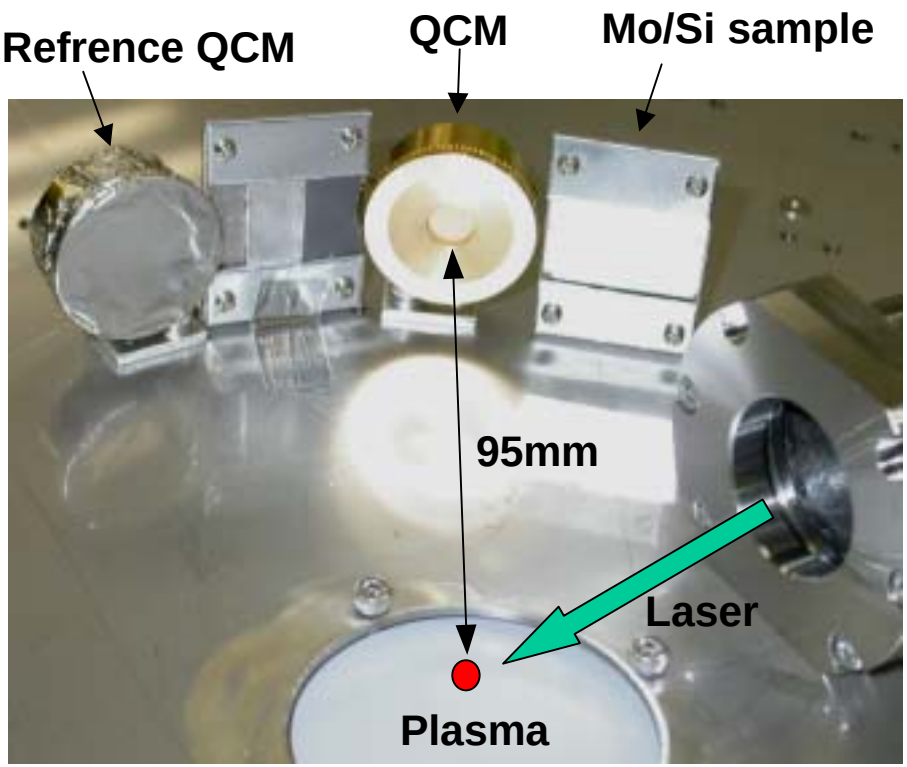


EUV Power Development

	Jun 2003	Aug 2003	Sep 2003	Nov 2003	Jun 2004	Today
In-band EUV power (2π sr)	0.6W	1.0W	2.2W	4.0W	7.2W	9.1W
EUV energy stability (1σ, 50-pulse ave.)	--	1.44%	0.72%	0.53%	1.2%	1.3%
Conversion efficiency	0.14%	0.33%	0.33%	0.44%	0.55%	0.61%
Average laser power	420W	300W	600W	900W	1300W	1500W
Repetition rate	10kHz	10kHz	10kHz	10kHz	10kHz	10kHz
Laser pulse duration	32ns	6ns	6ns	6ns	6ns	6ns

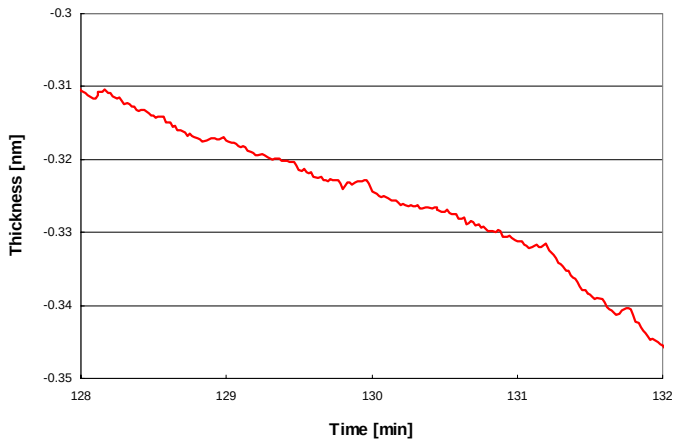
Mirror Lifetime

Experimental Setup



Exposure conditions

Sample : Au coated QCM
(QCM : Quartz crystal micro balance)
YAG laser : 100 mJ, 10 Hz
Plasma target : Xe liquid jet
Chamber pressure : < 0.1 Pa



Mirror lifetime (estimated) : 10x10^6 pulses w/o mitigation scheme

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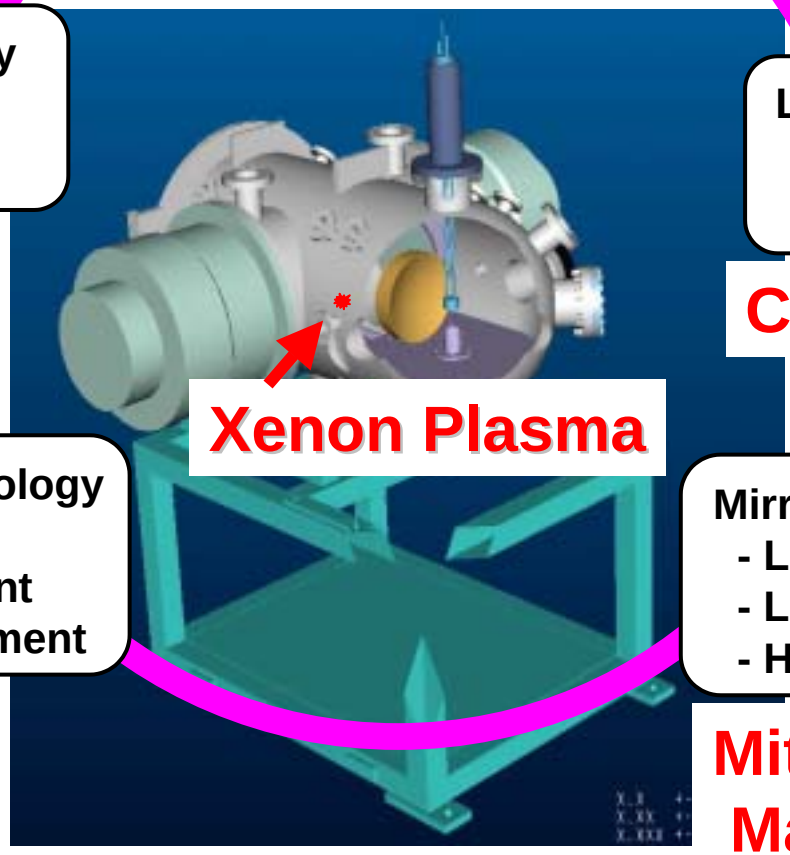
Technology for 115W @ IF

LPP-EUV light source
/High power/stability
/Long lifetime
/Low CoO

Target Technology
- **High velocity**
- **High stability**

Xenon Droplet



Laser Technology
- **High power**
- **Short Pulse duration**

CO2 Laser

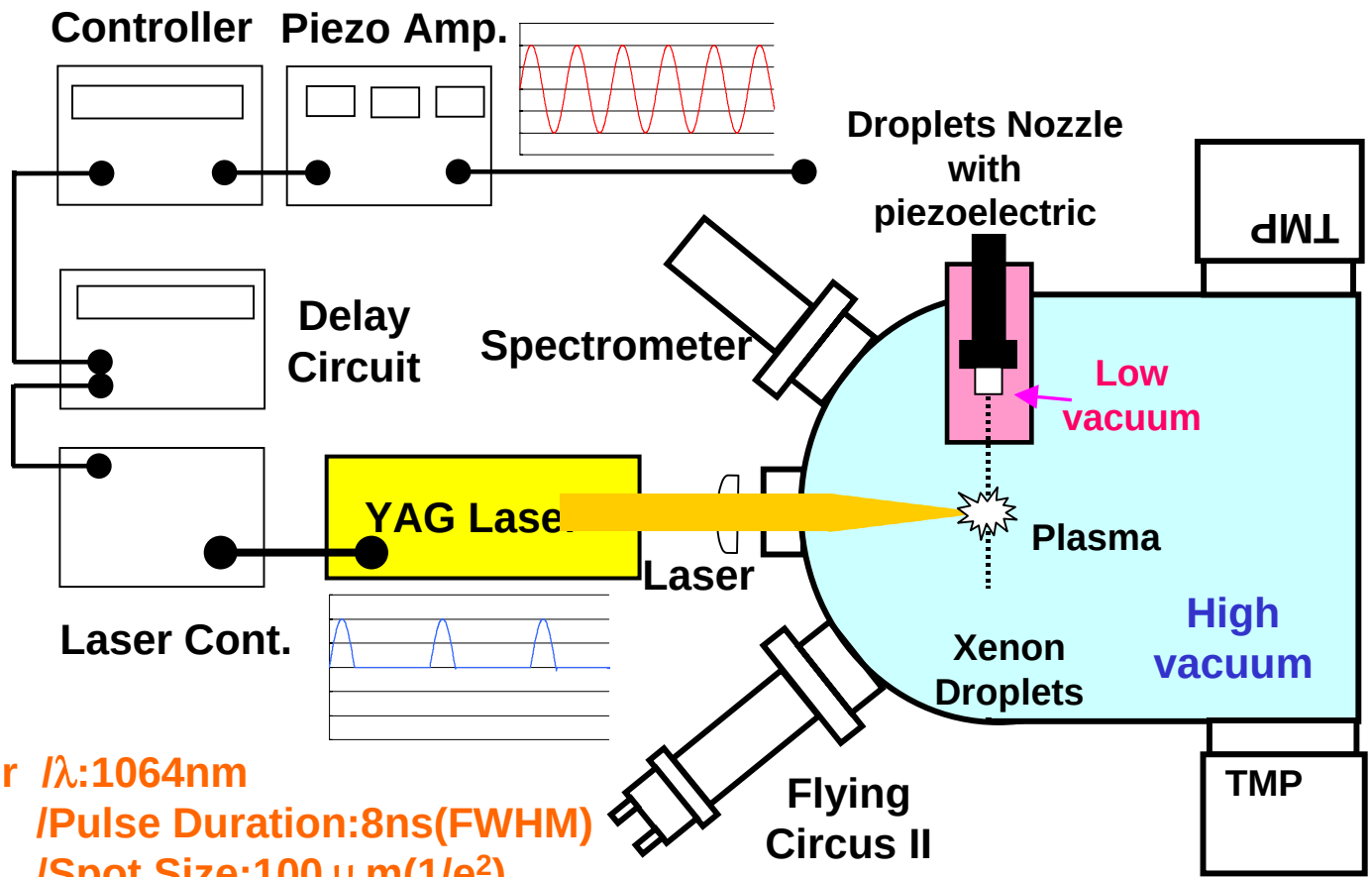
Chamber Technology
- **High vacuum**
- **Small foot print**
- **Heat management**

Mirror technology
- **Long lifetime**
- **Large solid angle**
- **High reflectivity**

Mitigation:
Magnetic Field

Xenon Targets Development

Schematic of Xenon droplet

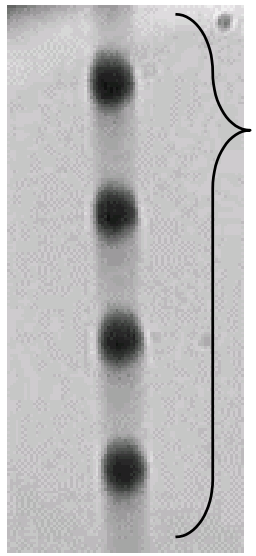


Laser /λ:1064nm
/Pulse Duration:8ns(FWHM)
/Spot Size:100 μm(1/e²)

Xenon Targets Development

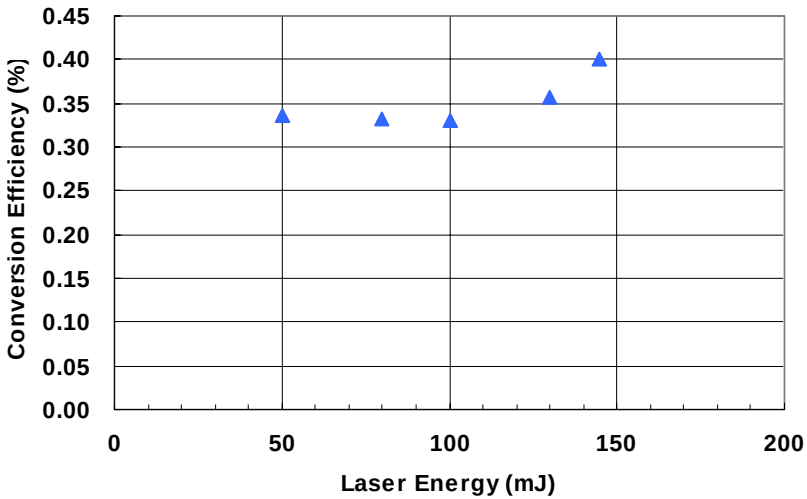
Xenon droplet

- Diameter : 90μm
- Droplet speed: 17 m/s
- Frequency: 90kHz
- In high vacuum

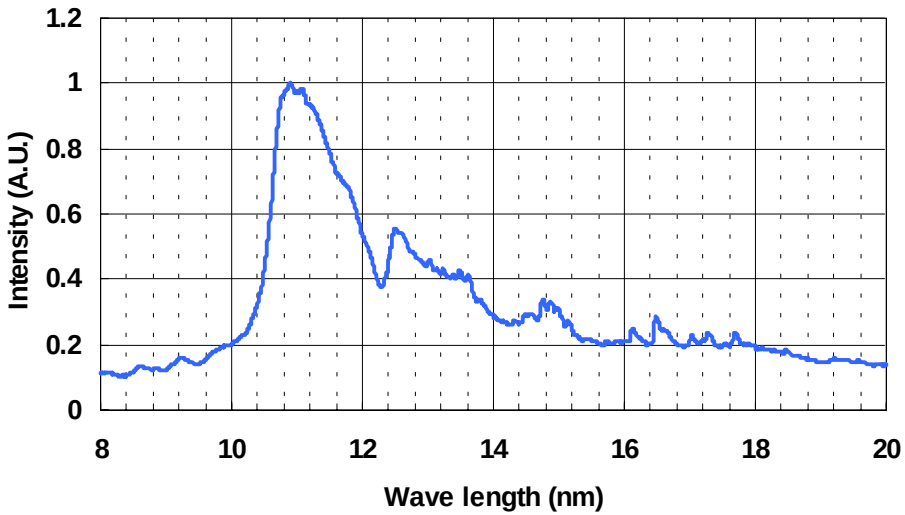


Xenon droplets train

Experimental results



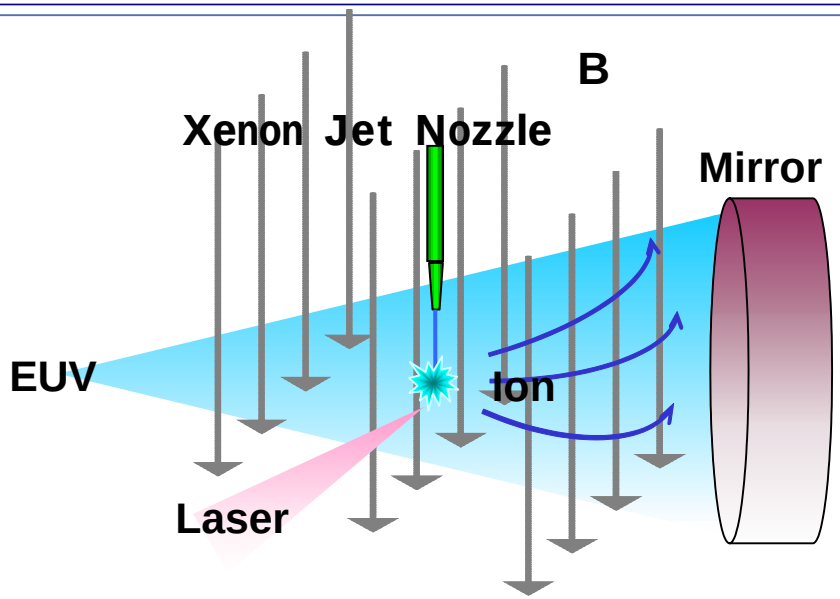
Conversion Efficiency : 0.4%
(Not optimized)

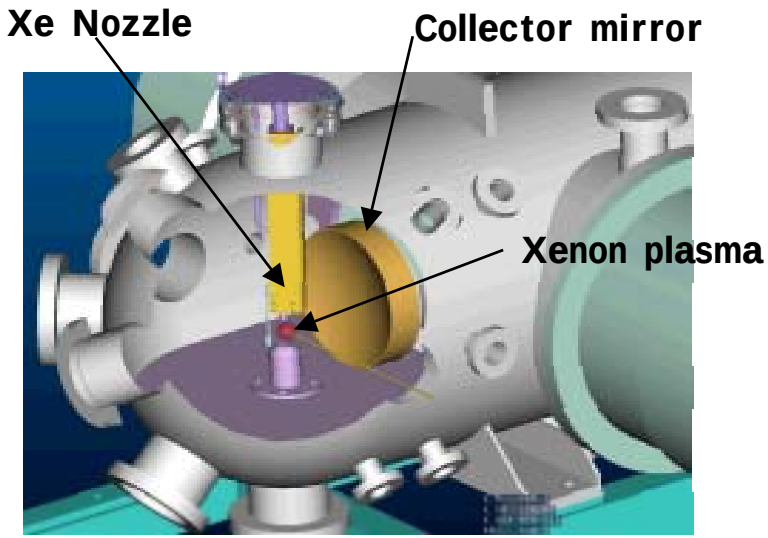


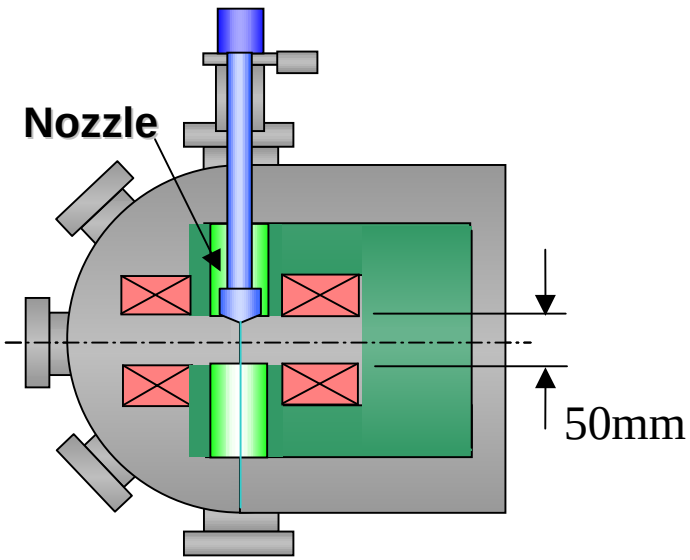
Spectrum

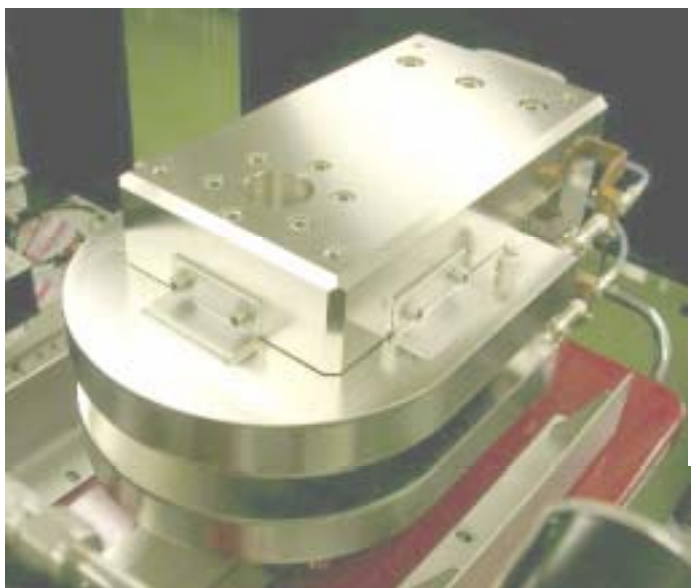
Related presentation: Nov. 2-3 by Mr. Nakano from EUVA

Fast Ion Mitigation for Xenon Plasma





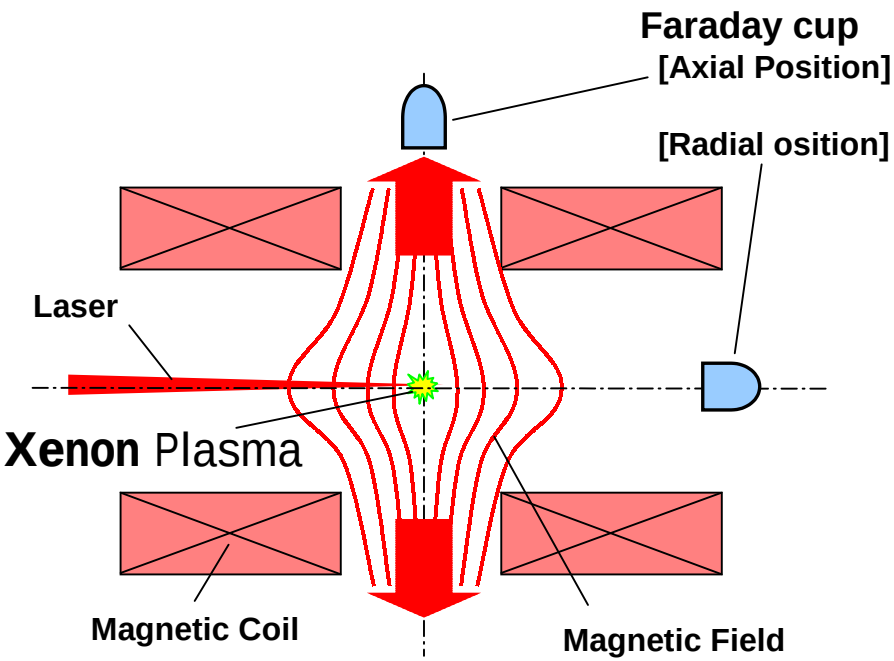


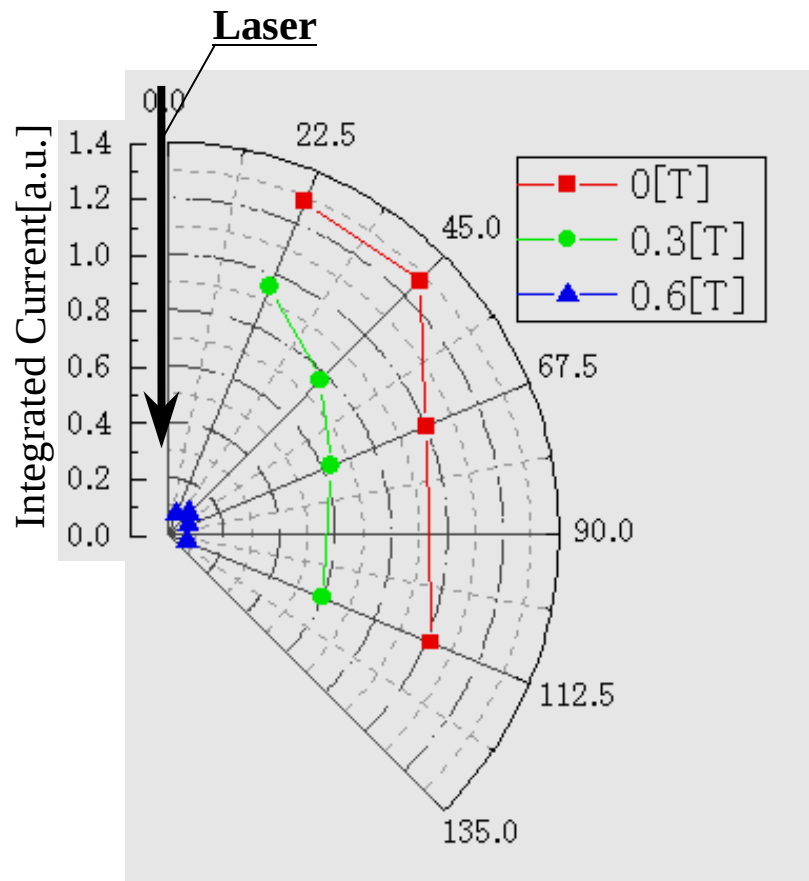


Electromagnet

Fast Ion Mitigation for Xenon Plasma

■Experimental results





Angular dependence of Total charge of Faraday cup (Radial Position)

Related presentation: Nov. 2 by Mr. Komori from EUVA

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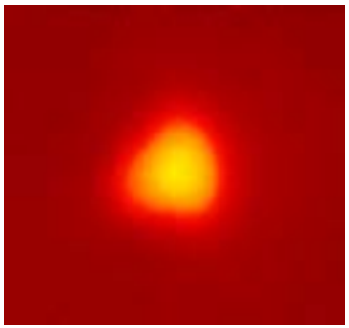
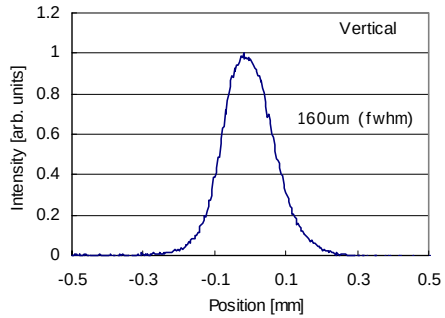
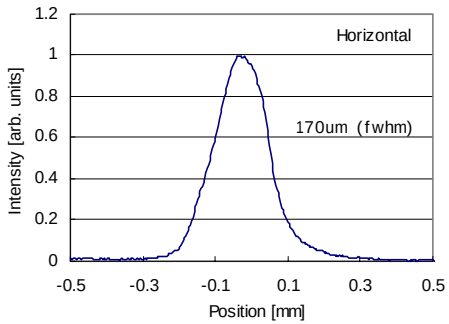
EUV Characteristics using CO_2 Laser

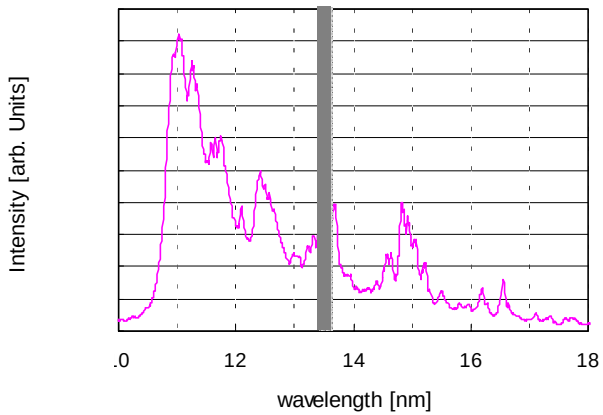


EUV Image

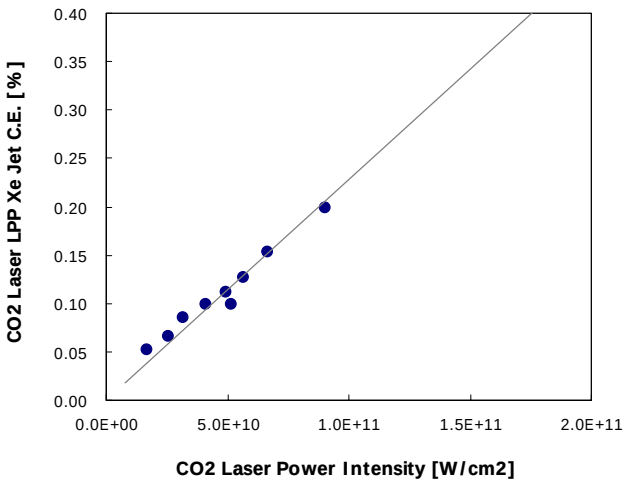




Etendue : <1mm^{2}sr



Xenon plasma spectrum



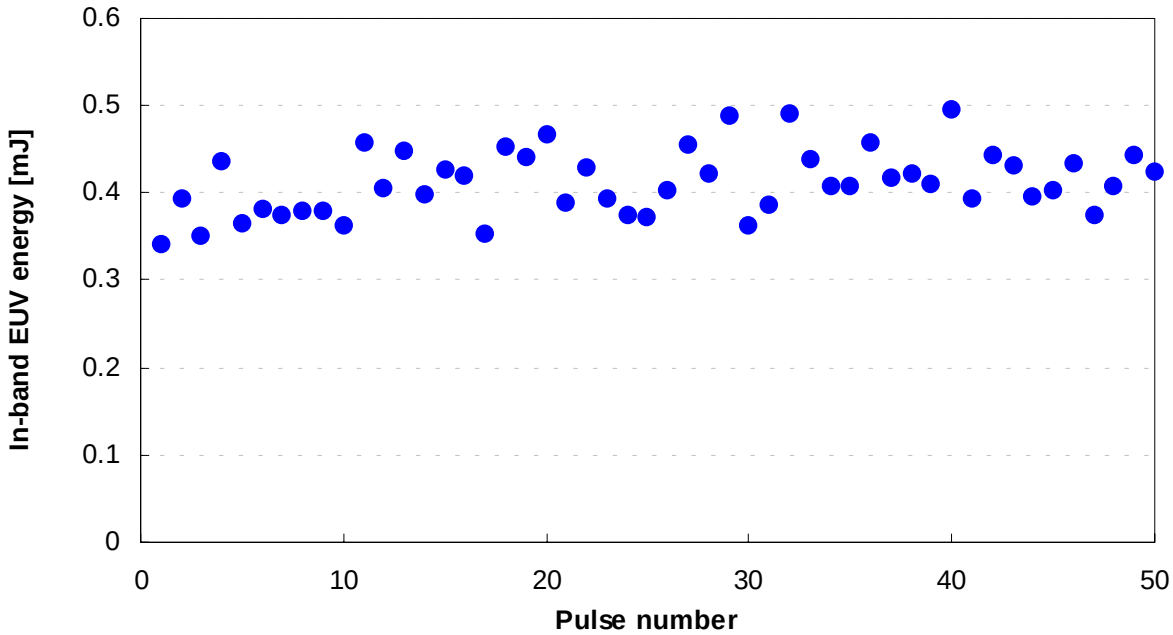
Conversion Efficiency

Average EUV In-band Power

EUV Power : 0.7W (2%BW, 2π sr)

CO_2 Laser : 360W @1.8 kHz

< Pulse duration : 100ns (fwhm)>



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Summary

10W Source

- 9.1 W in-band power has been generated with a 1.5kW Nd:YAG laser and a xenon jet target.
- Mirror lifetime is estimated 10×10^6 pulses using Au coated QCM without mitigation scheme.
- 10W light source will be based on Xenon jet and Nd:YAG MOPA laser technology.

115W Source

- For 115W light source alternative technologies (CO2, droplet, magnetic field mitigation) are considered.
- Xenon droplet target has been generated in high vacuum.
- Effectiveness of magnetic field ion mitigation has been experimentally confirmed.

The Present Performance in EUVA

■ LPP(YAG)

- In-band Power — **9.1 W** (2%BW, 2π sr) at Primary Source
  4 W (2%BW, 2π sr) at IF <Calculated>
- Conversion Efficiency — **0.61 % @10kHz** (2%BW, 2π sr)
  0.85 % @10Hz (2%BW, 2π sr)

■ LPP(CO_2)

- In-band Power — **0.7 W** (2%BW, 2π sr) at Primary Source
- Conversion Efficiency — **0.2 % @1.8kHz** (2%BW, 2π sr)

Main target for 1Q 2006 : 10 W (intermediate focus)

Acknowledgements

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