Xe droplet target development for a LPP EUV light source

EUVA
(**E**xtreme **U**ltra**v**iolet Lithography System Development **A**ssociation)
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Outline

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- Key technologies for droplet generation
- Experimental setup
- Experimental results
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  - Laser irradiation in “high vacuum”
    /EUV Energy & CE
    /Droplet behavior
    /EUV Spectrum
- Summary

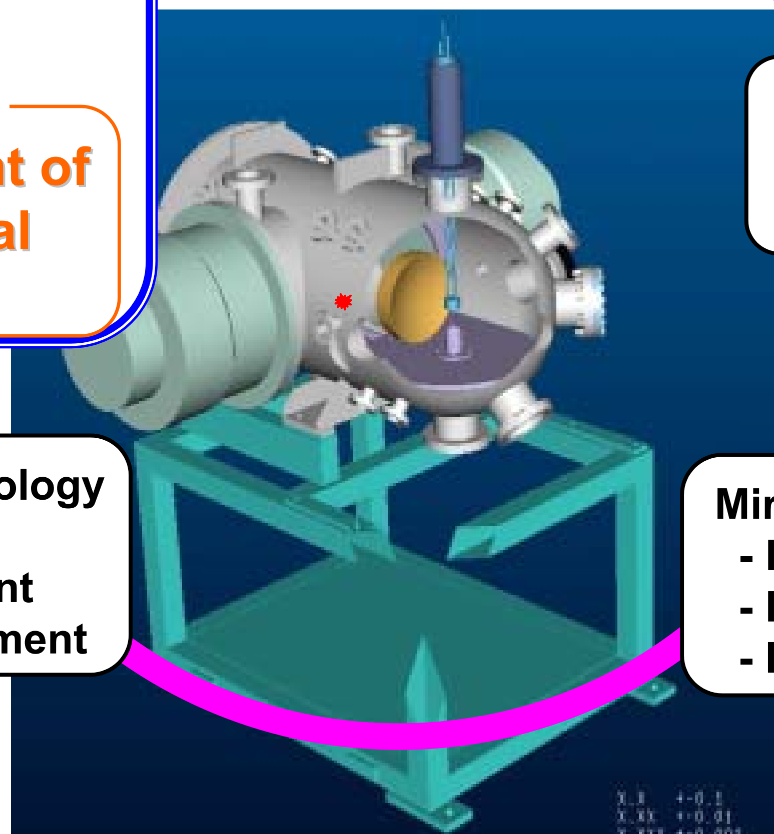
115W EUV Light Source

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

Target Technology
/High velocity
/High stability

Droplets
/Reduced amount of target material
/Debris free

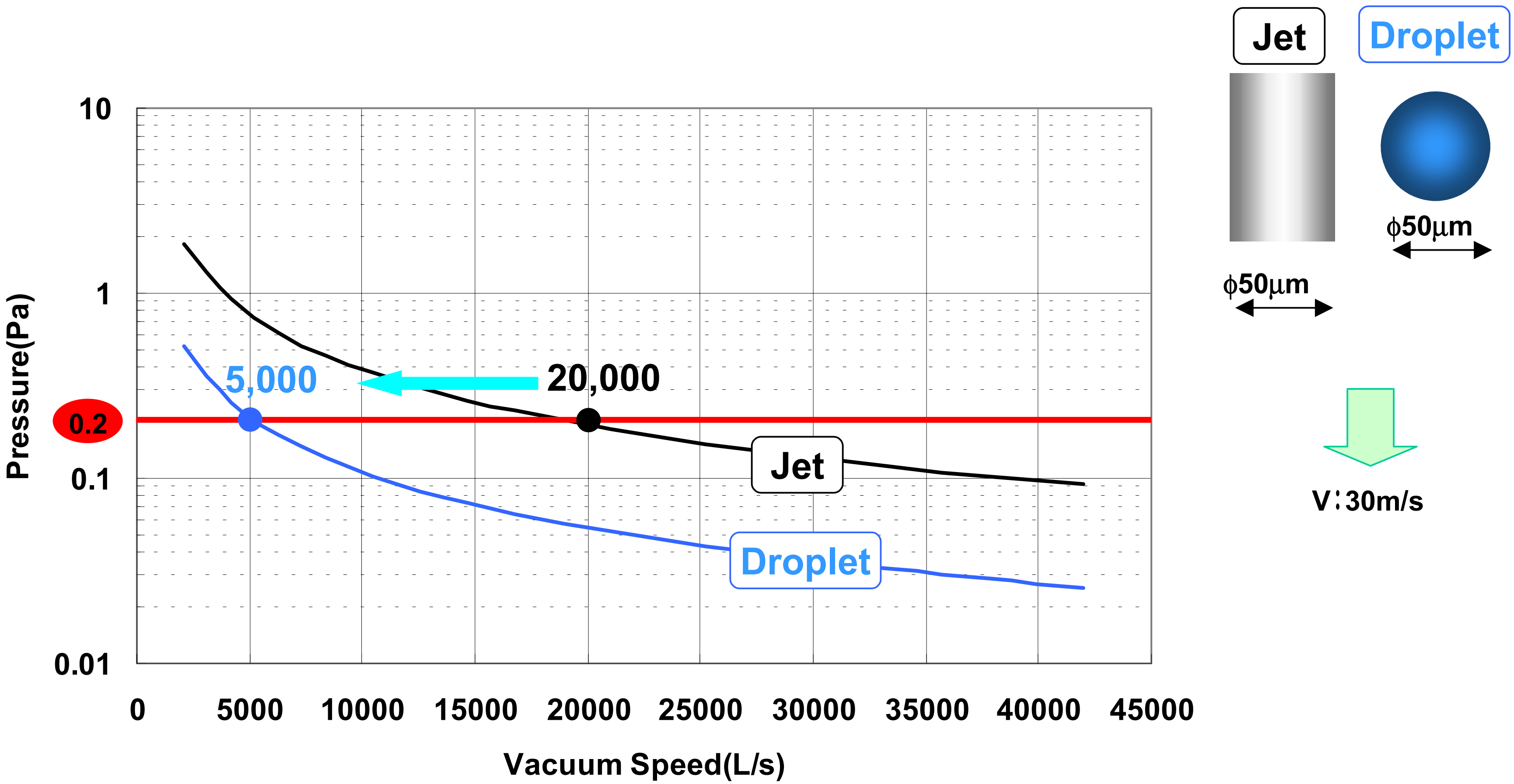
Laser Technology
- High power
- Short Pulse duration



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

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

Background - Required vacuum speed



Key Technologies for xenon droplet generation

➢Continuous Jet Method [Rayleigh's Theory]

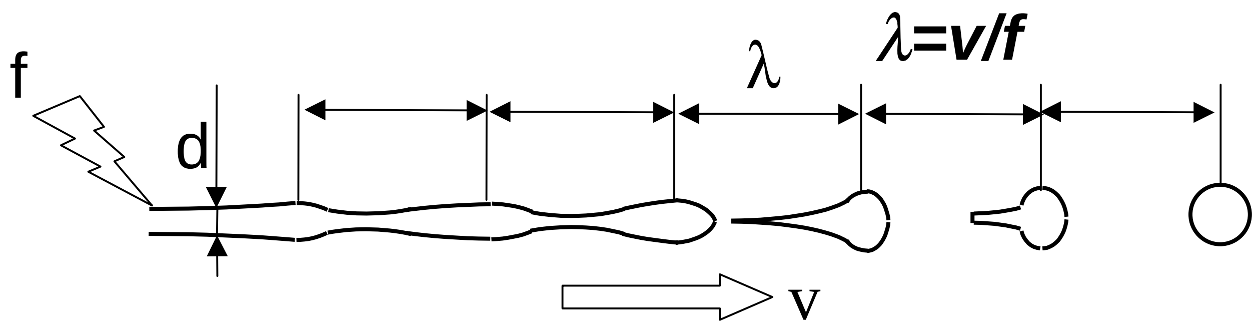
- Uniform droplet generation from continuous jet

$$r=(d/2)+\alpha e^{qt}\cos(2\pi x/\lambda)$$

$$q_{max}=0.97\sqrt{(\sigma/\rho d^3)}$$

$@\lambda/d:4.51$

r: Radius of the jet
d: Initial jet dia. α: Initial disturbance
q: Growth rate t: Time x: distance
σ: Surface Tension ρ: Density
λ: wavelength of disturbance
v: Velocity f: Frequency of disturbance

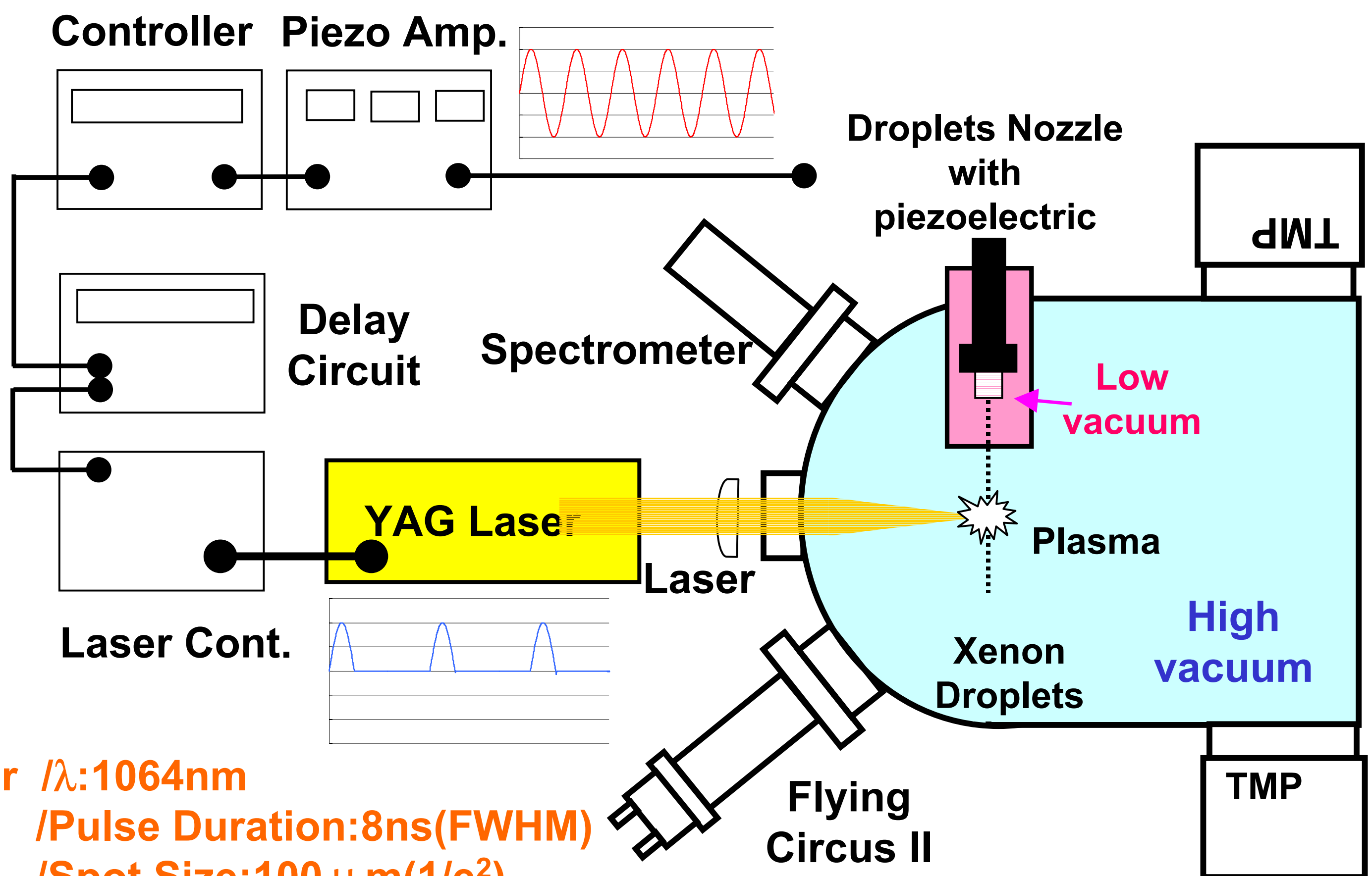


➢Differential Pumping System

-In order to avoid rapid boiling and freezing of the liquid xenon jet

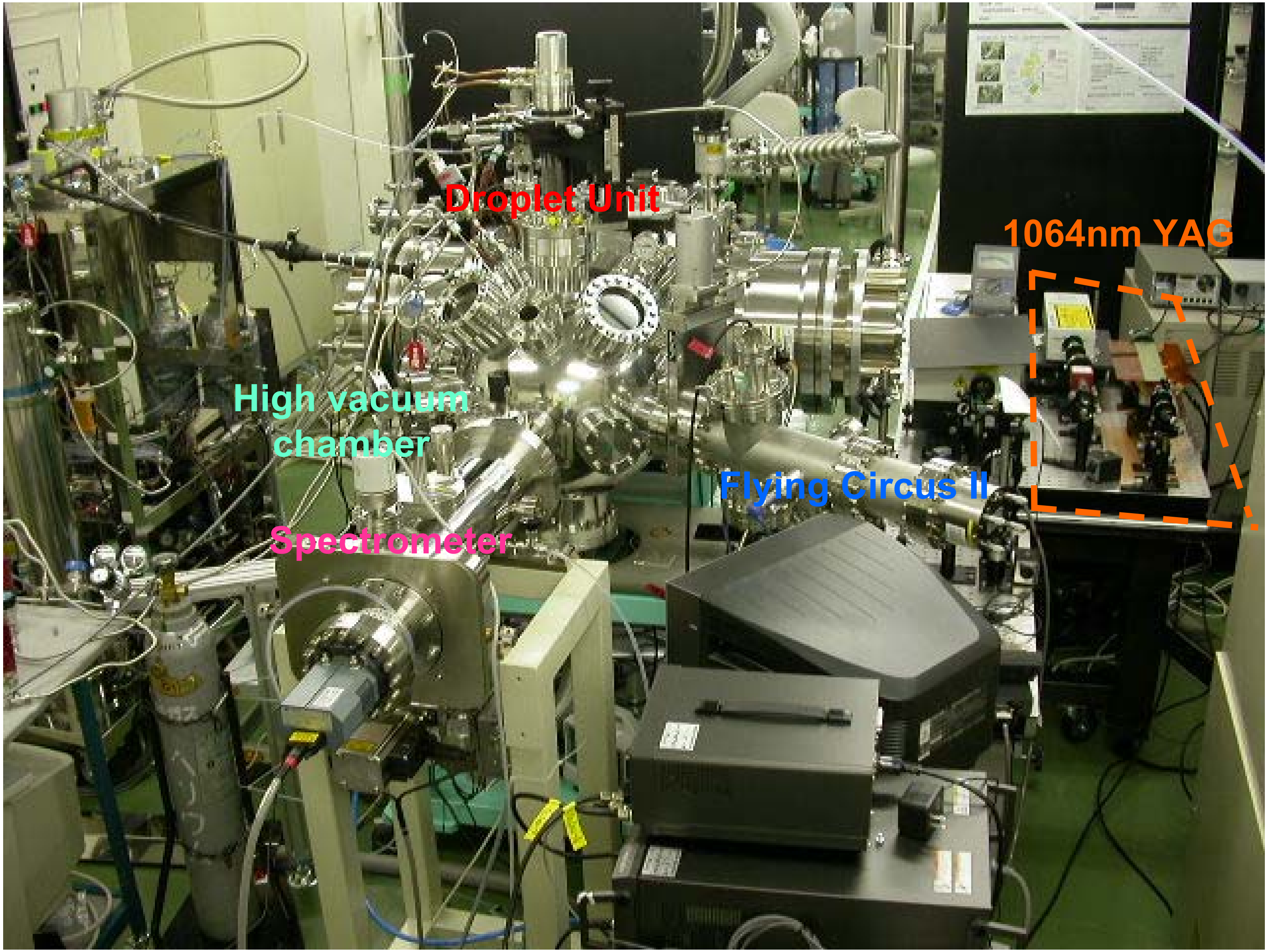
Experimental Set-Up - Schematic

Laser irradiation system for Xe droplets



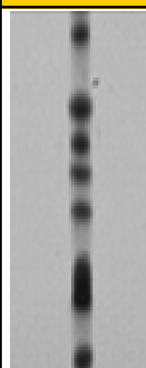
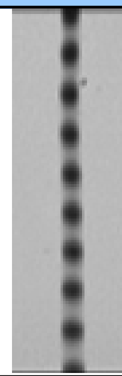
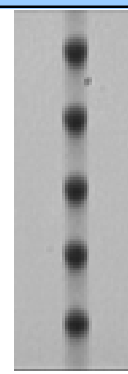
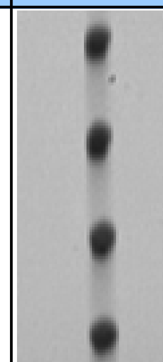
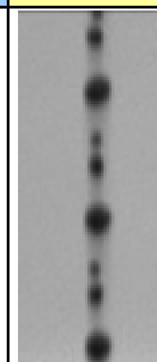
Laser /λ:1064nm
/Pulse Duration:8ns(FWHM)
/Spot Size:100 μ m(1/e²)

Experimental Set-Up - Photo

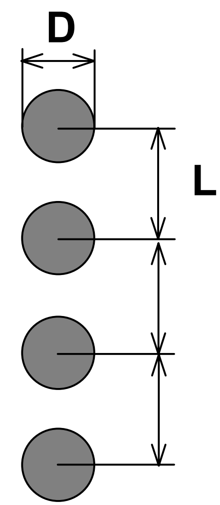


Experimental Results I – Droplet Formation

Observed Xenon droplets

Freq.(kHz)	230	200	117	82	61
λ/d	2.4	2.8	4.8	6.8	9.2
D(μm)	---	79	94	102	---
L(μm)	---	145	250	360	---
Droplets					

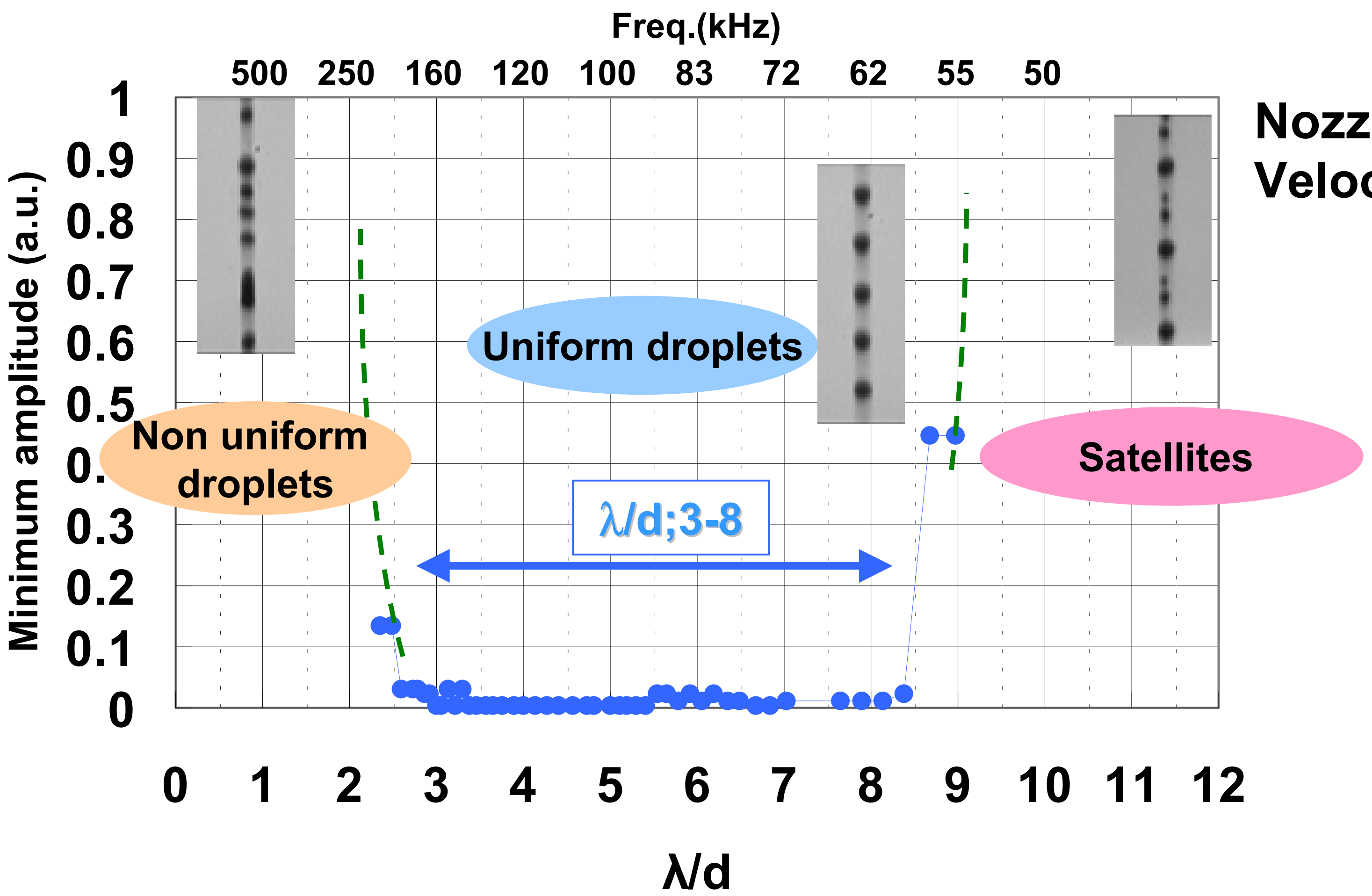
Nozzle Dia.:50μm
Velocity :28m/s



Under low vacuum condition

Experimental Results II – Uniform Droplets

Range of λ/d for uniform xenon droplet formation

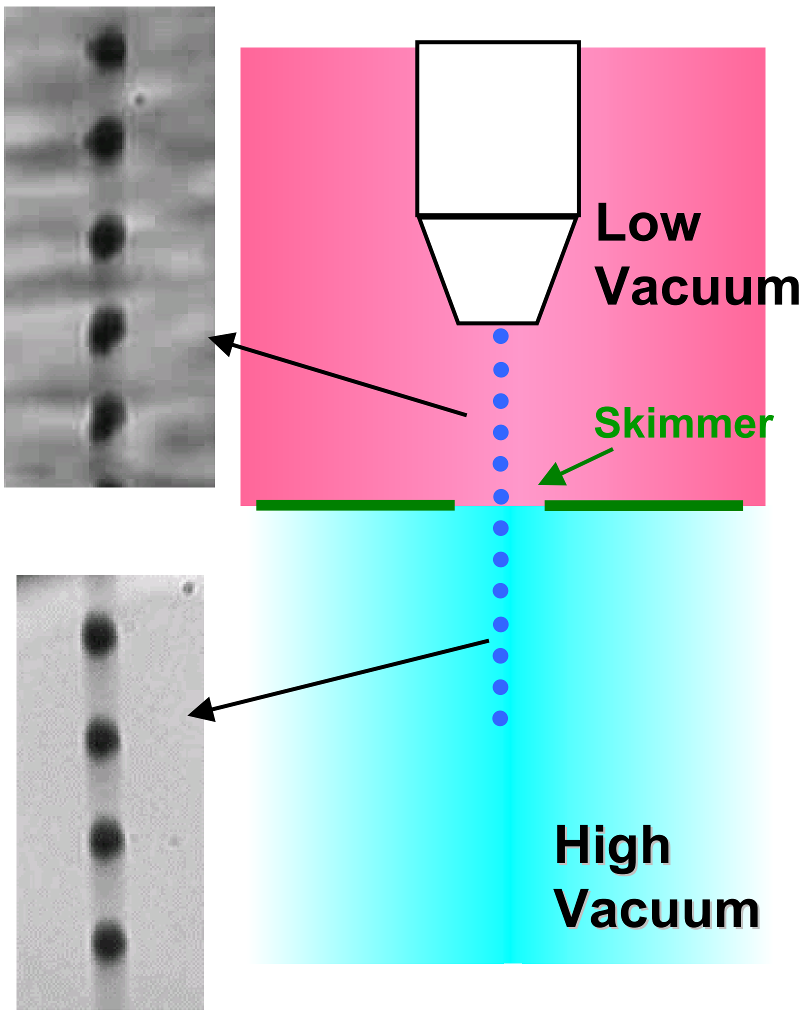


Nozzle Dia.:50μm
Velocity :24m/s

Under low vacuum condition

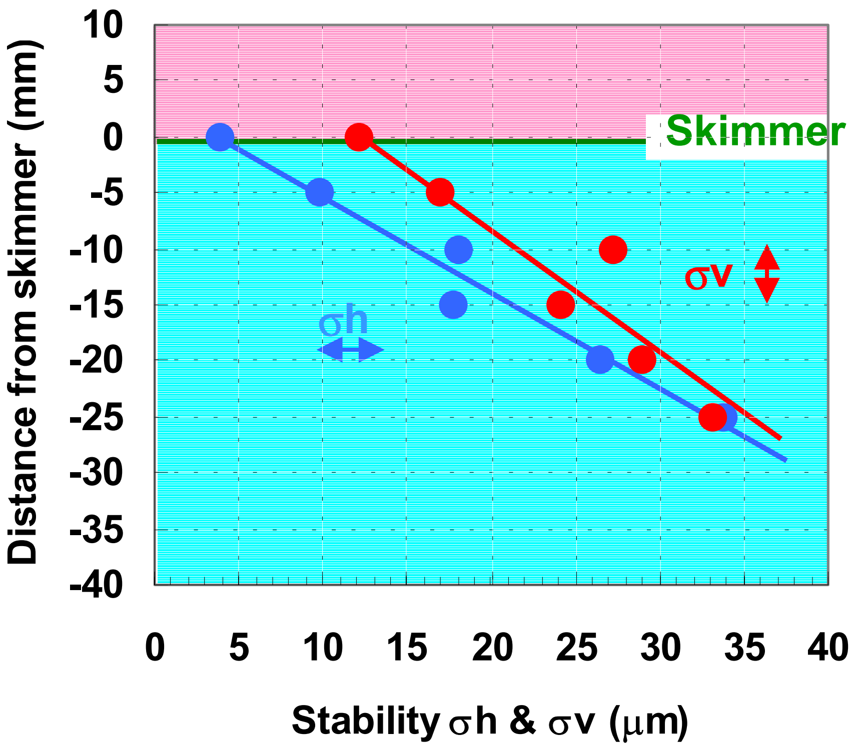
Experimental Results III – Droplet Stability

Droplet position stability in “high vacuum space”



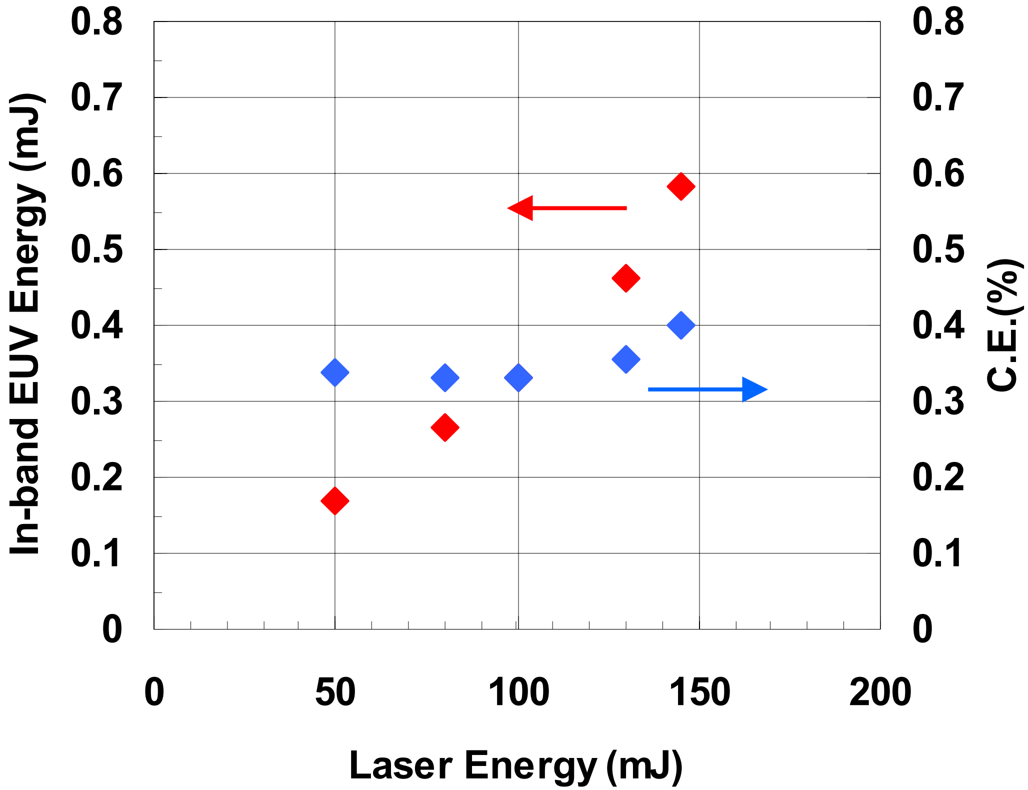
==Droplets==

Nozzle Dia. :50 µm
Velocity :17m/s
Drop. Dia. :90µm
Drop. Dist. :190µm
Frequency :90kHz



Experimental Results IV - Laser Irradiation

EUV Energy & CE vs Laser energy



==Droplets==

- Drop. Dia. :90μm
- Drop. Dist. :190μm
- Velocity :17m/s
- Frequency :90kHz

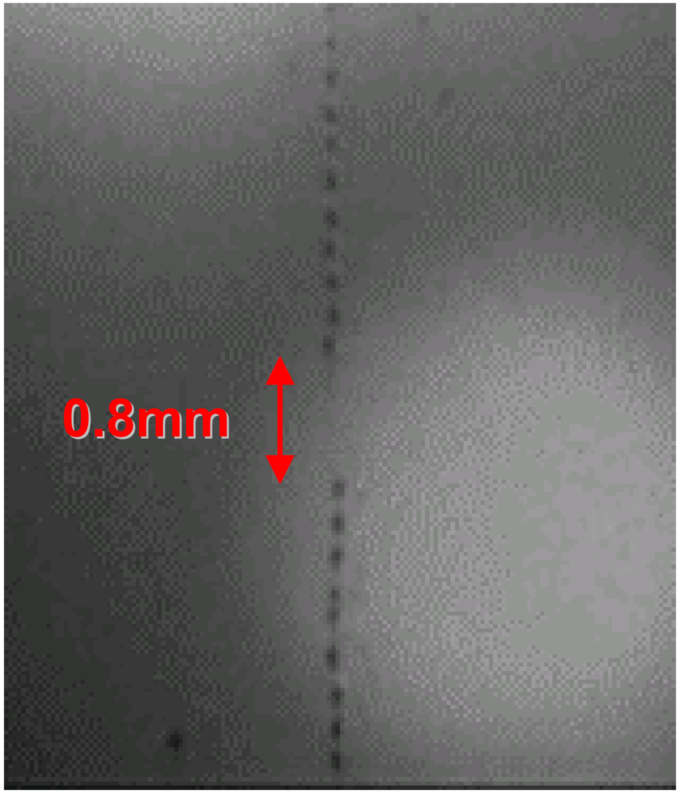
==Laser==

- Wave Length :1064nm
- Spot Size :100μm(1/e^2)
- Pulse Duration :8ns(FWHM)
- Rep.Rate :Single shot

In-Band EUV Energy(2%BW,2πsr):0.6mJ
Conversion Efficiency:0.4%

Experimental Results V - Laser Irradiation

Droplets behavior after laser irradiation



==Droplets==

Drop. Dia. :90μm
Drop. Dist. :190μm
Velocity :17m/s

==Laser==

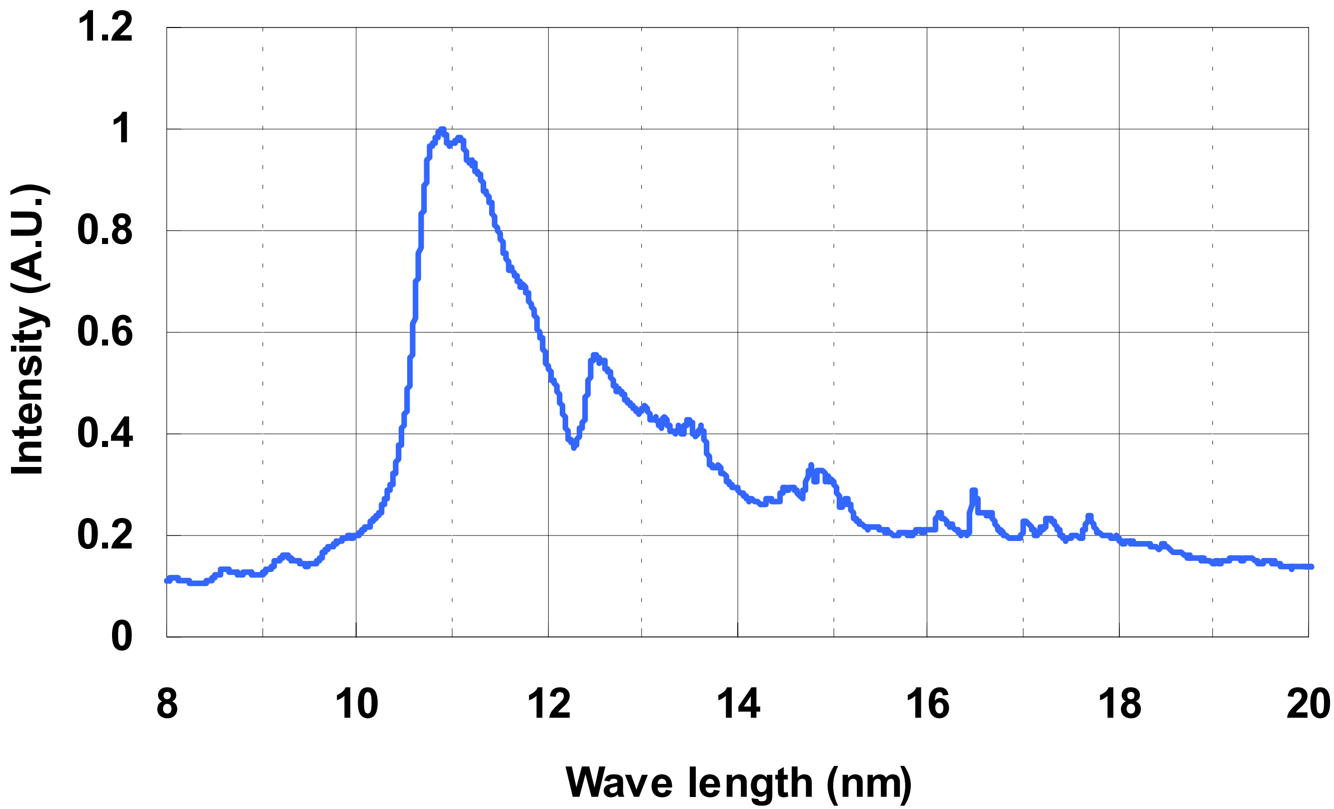
Wavelength :1064nm
Spot Size :100μm(1/e^2)
Energy :130mJ

10mm below the Plasma

- Droplet "consumption" after laser irradiation is approx. 1mm. (about 5 droplets)

Experimental Results VI - Laser Irradiation

EUV Spectrum



==Droplets ==

Drop. Dia. :90μm
Drop. Dist. :190μm
Velocity :17m/s

==Laser==

Wavelength :1064nm
Spot Size :100μm(1/e^2)
Energy :100mJ
Pulse Duration:8ns(FWHM)

Summary

- We have succeeded in the generation of uniform Xenon droplets under "**high vacuum condition**";
  - Continuous-Jet Method and Differential Pumping
  - Key parameter; λ/d 3 - 8 for uniform droplets
  - Stability $\sigma_{horiz.}$ is about 20μm at 15mm below the skimmer
- We evaluated the EUV characteristics under laser irradiation for the xenon droplet target
  - In-band EUV energy ; 0.6mJ(2%BW,2πsr) @Laser energy 150mJ
  - Conversion efficiency ; 0.4% @ single shot
  - Droplets "consumption" ; approx. 1mm (5 droplets/plasma)
- Next Step / High repetition rate laser irradiation for xenon droplets

Acknowledgements

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EUVA ,

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NEDO