

# Surface roughness of optical substrate finished by ion beam figuring

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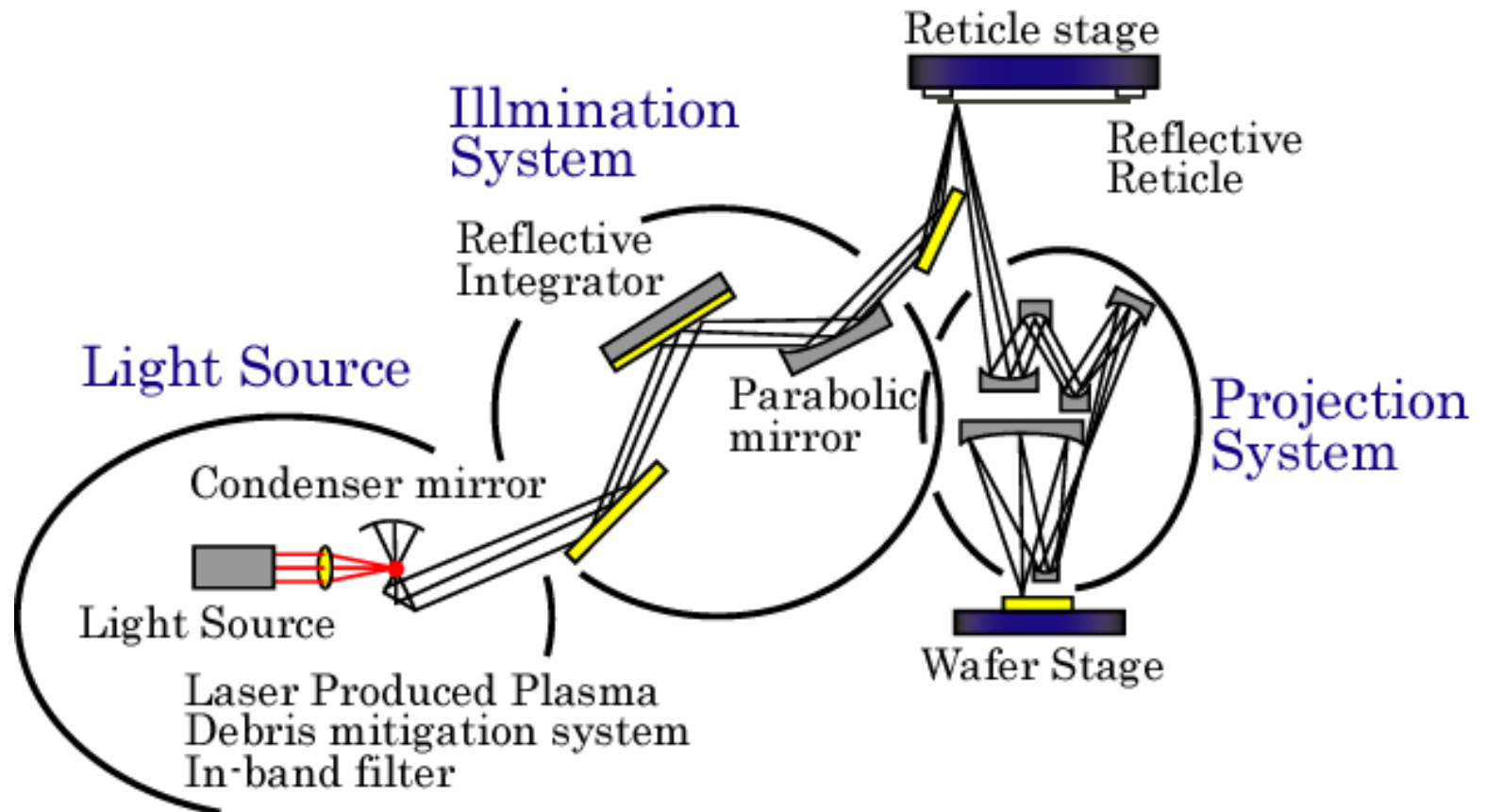
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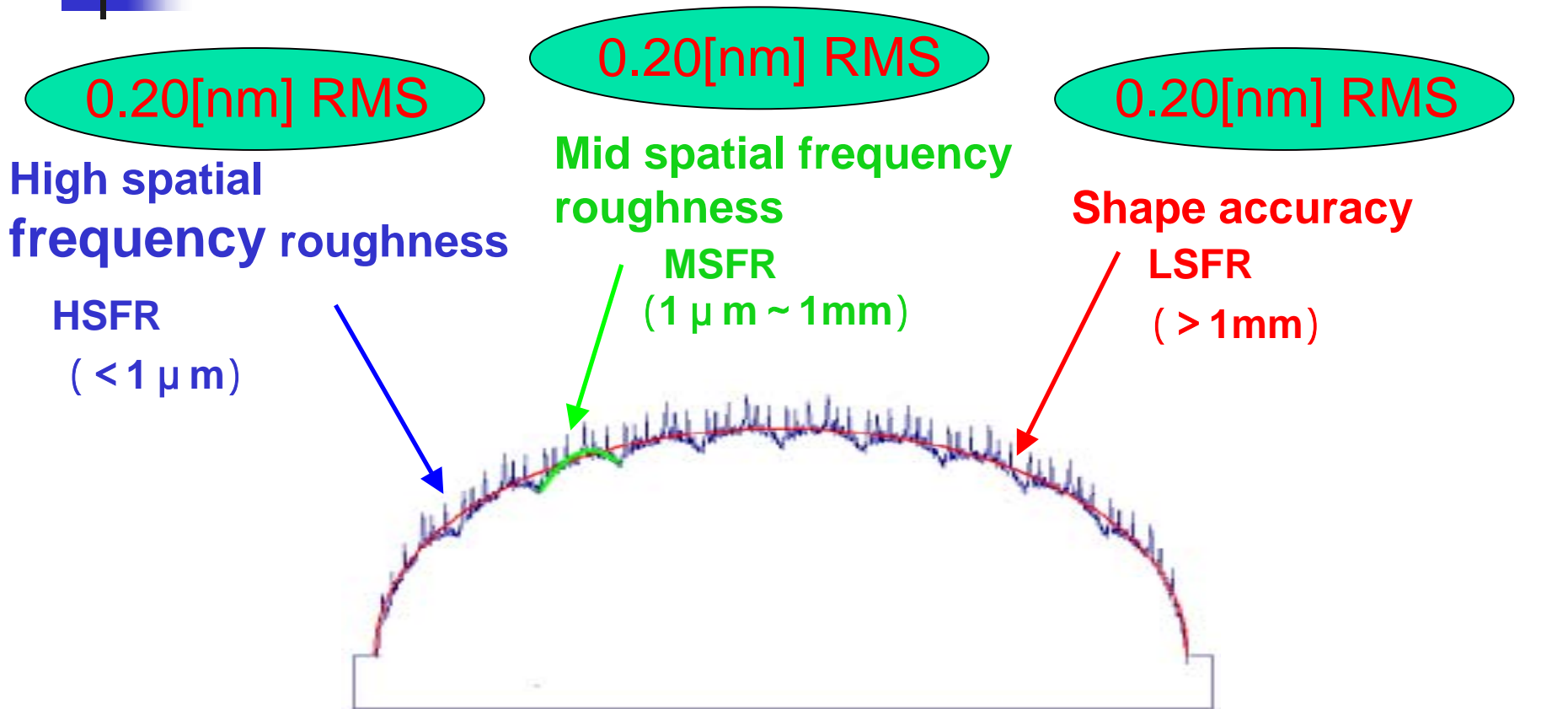
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# Optical system for EUV Lithography



# The Spatial frequency roughness requirement of EUV aspherical mirror



High and Mid Spatial Frequency Roughness, and Shape Accuracy



# Problems of mechanical polishing of aspherical mirror

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- At the edge of a work-piece, it is difficult to control the shape of the work-piece.
- The shape of polishing tool will be changed during polishing the mirror. So, more stability or long life time tool is required.
- The removal rate is not constant, when the compounding material or hard-brittle material is polished.

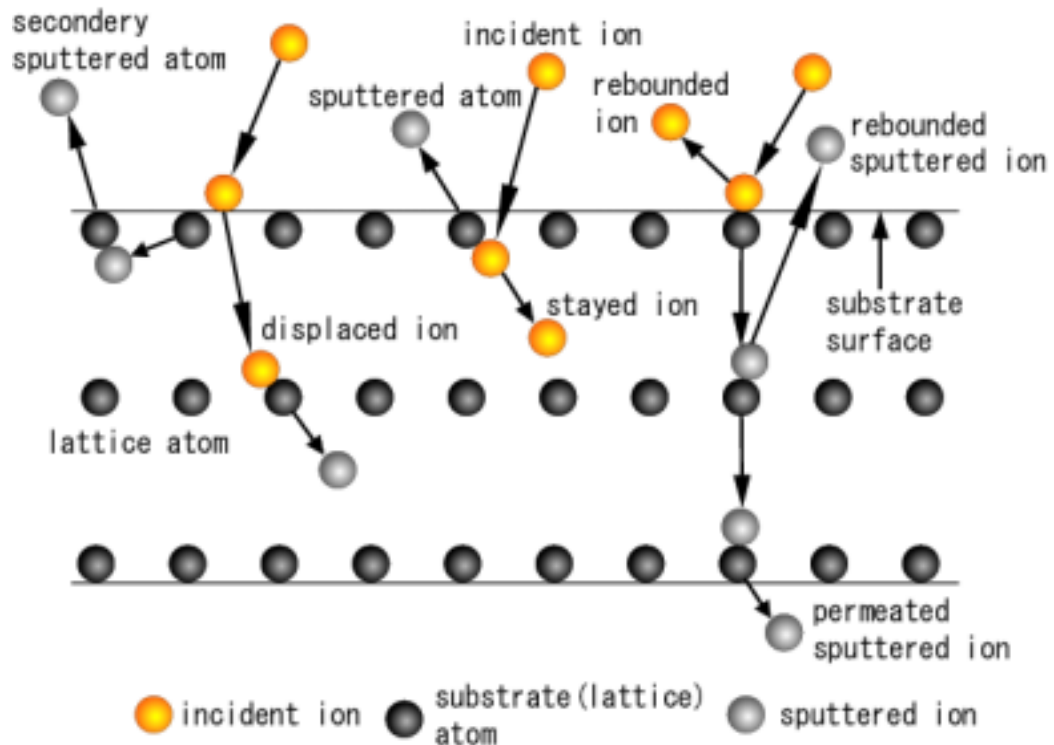


**Solve these problems**

**Ion beam figuring (IBF) is promising method for fine finishing of EUV mirror.**

# Advantages of IBF (1)

- Etching mechanism of IBF is based on physical sputtering. Therefore, atomic order machining of the work-piece is possible.
- 2) Ease of electrical control of ion beam is suitable for dwell time control of machining.

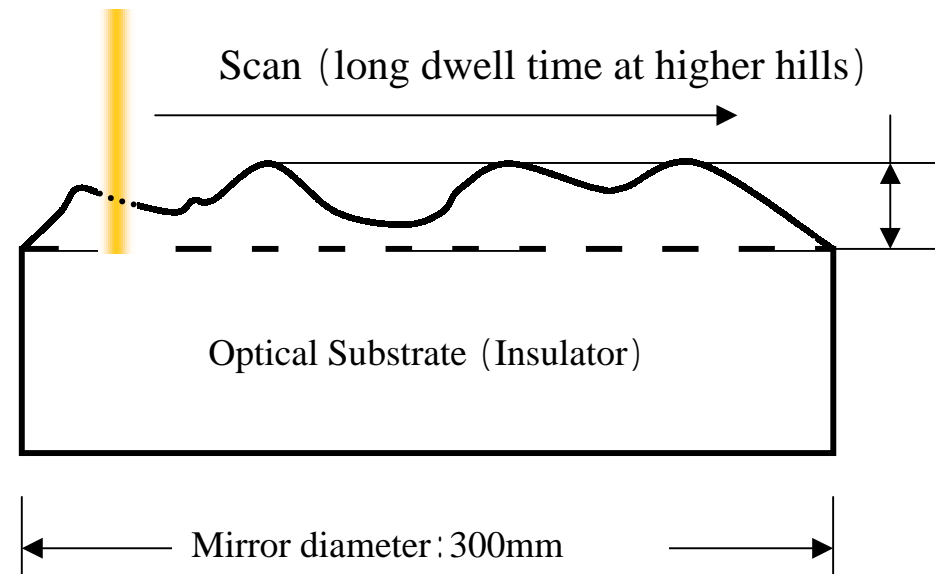


# Advantages of IBF (2)

3) The machining tool is ion beam, so wear of tool and changing the tool shape do not occur. But stability of ion beam current sometimes become problem.

4) IBF is performed in a vacuum chamber, so clean surface will be maintained.

Ion beam (diameter: 1mm ~ few mm)



Dwell time control using IBF



# Motivation

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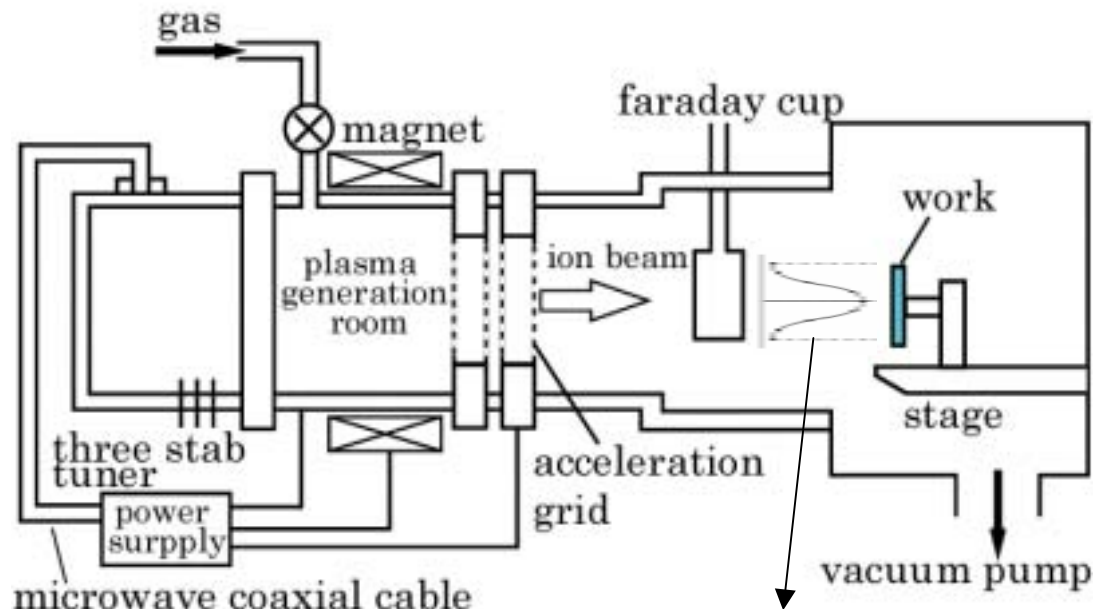
**IBF is expected to fabricate and correct of EUV mirror shape with middle spatial frequency roughness (MSFR).**

**Thus, to examine spatial frequency roughness after IBF is important.**



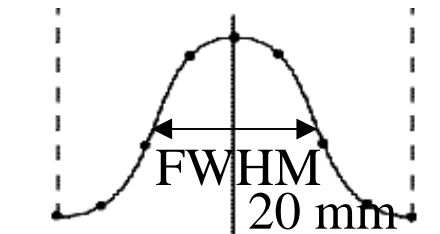
**The change of surface roughness and power spectrum density (PSD) of EUV mirror substrates before and after IBF were examined.**

# Ion beam Figuring (IBF) apparatus



Ion beam shape

Gaussian beam

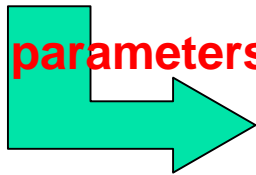


Electron cyclotron resonance  
(ECR) ion beam source

# Experimental procedure

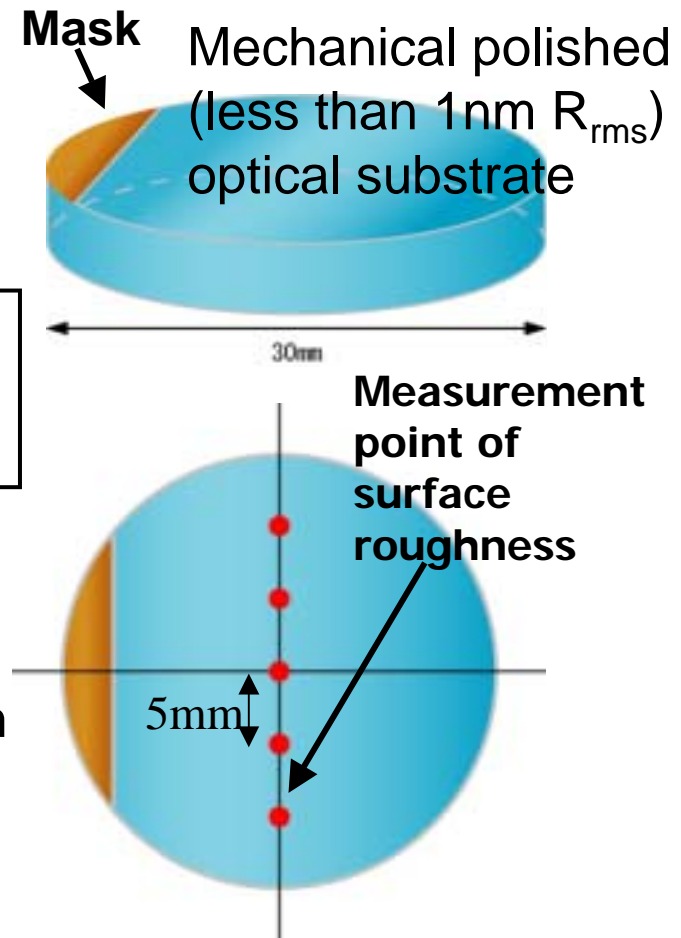
- Mask of substrate with copper tape to measure the etching depth.
- Ion beam etching for 3min.

**Change parameters**



**Ion species: Ne, Ar, Kr**  
**Ion beam energy: 500eV, 700eV, 1keV**

- Measurement apparatus
  - i) Laser interferometer (GPI)
    - Measurement of figure, etching depth
  - ii) 3-D Surface Profilers (New View)
    - Measurement of surface roughness



# Experimental results

## --- Results of etching depth ---

### Experimental Condition

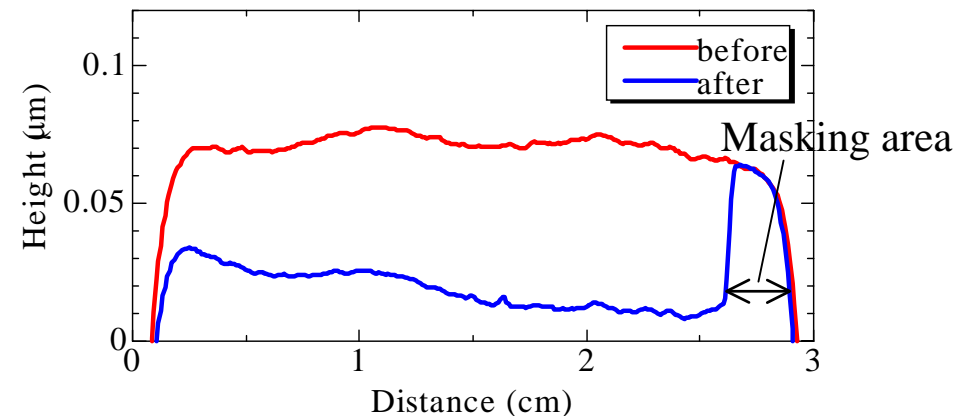
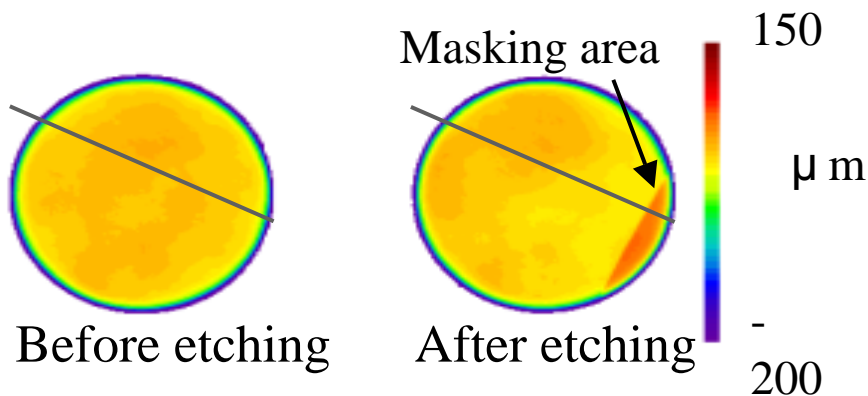
**Ar** gas flow rate 2.0 SCCM

Ion beam energy **500eV**

Microwave power 100W

Ion beam density 1.50mA/cm<sup>2</sup>

Etching depth (Max) 60.6nm

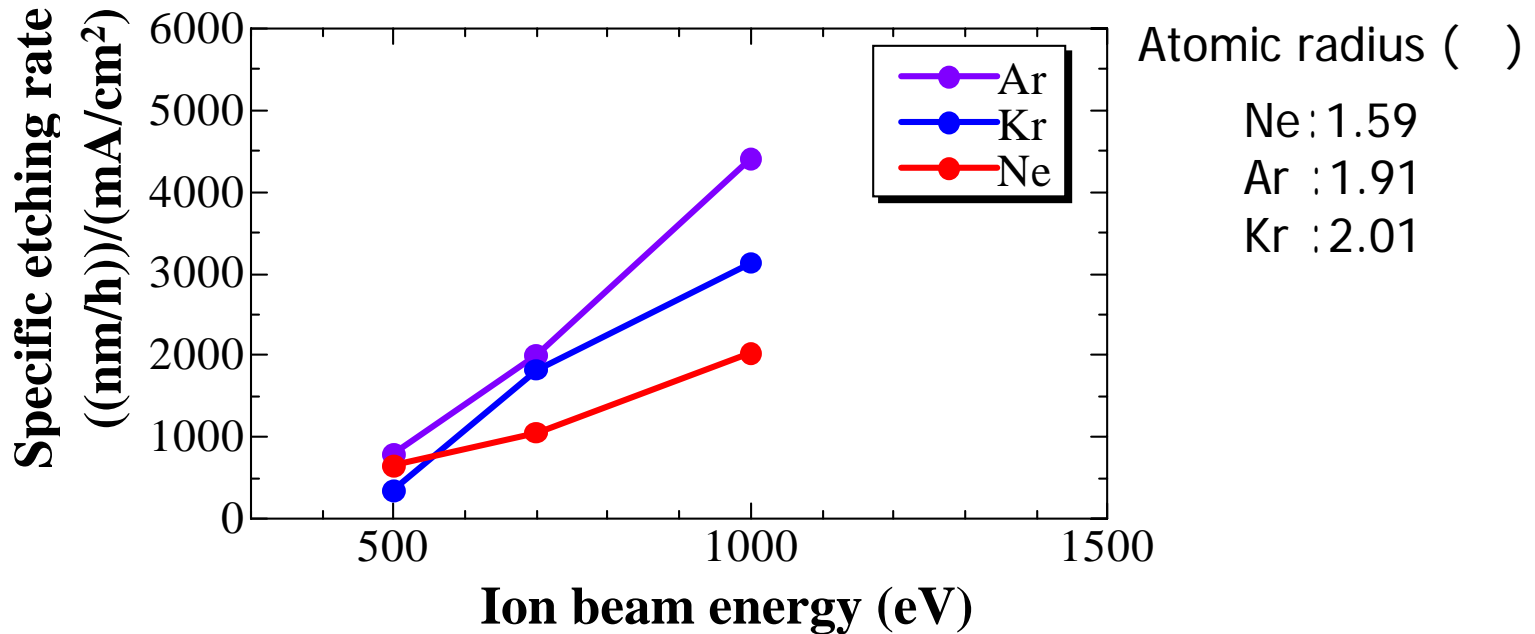


Top surface view with GPI

Cross-sectional profile

# Experimental results

## - Results of specific etching rate -

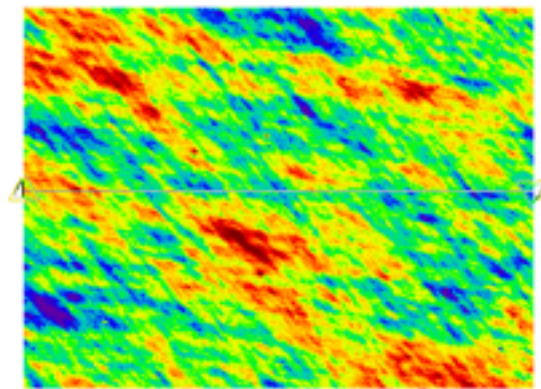


$$\text{specific etching rate} \left( \frac{\text{nm/h}}{\text{mA/cm}^2} \right) = \frac{\text{etching depth (nm)} \times 60 \text{ (min)}}{\text{etching time (min)} \times \text{ion beam density (mA/cm}^2)}$$

# Experimental results

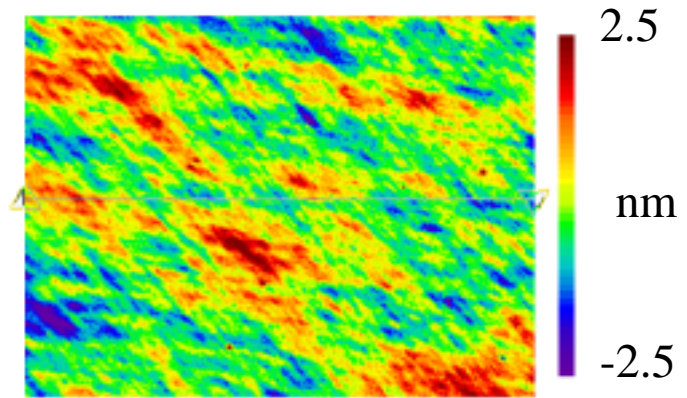
## - Results of surface roughness (MSFR) -

Ar ion beam with ion beam energy of 500eV



50 μ m      PV 10.51nm  
RMS 0.759nm

Before etching  
with New View



50 μ m      PV 12.76nm  
RMS 0.765nm

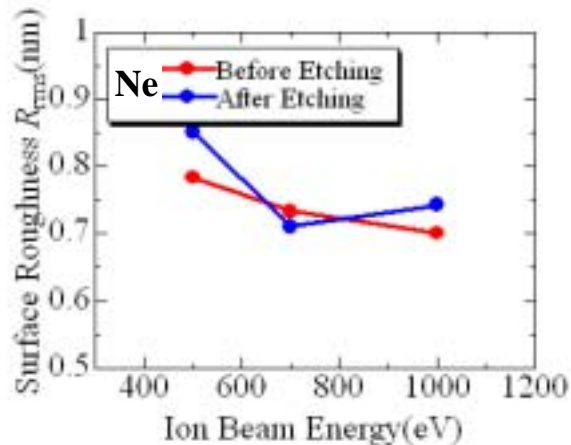
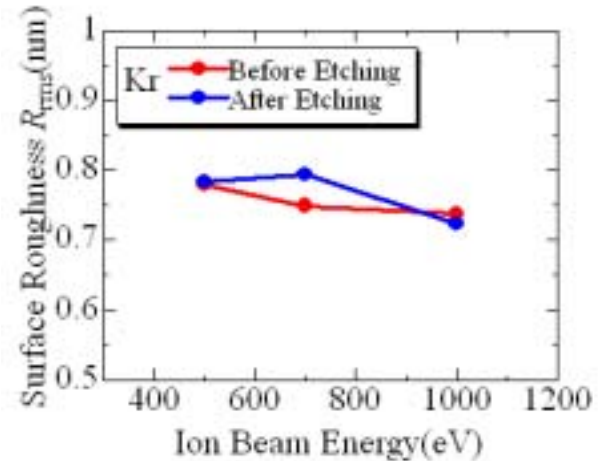
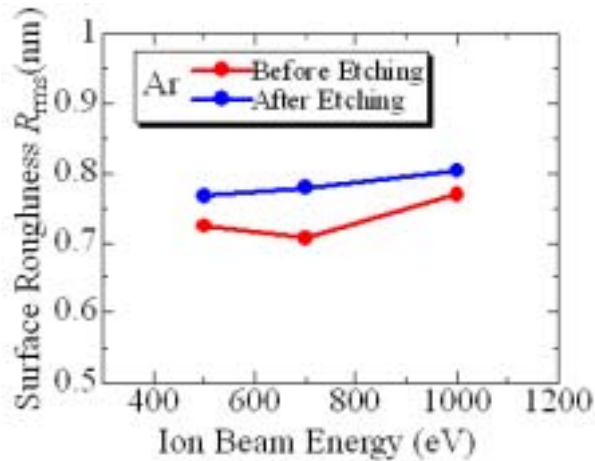
After etching @etched depth of  
55.8 nm

Measurement area 108×144μm ?Same place?

**MSFR did not change.**

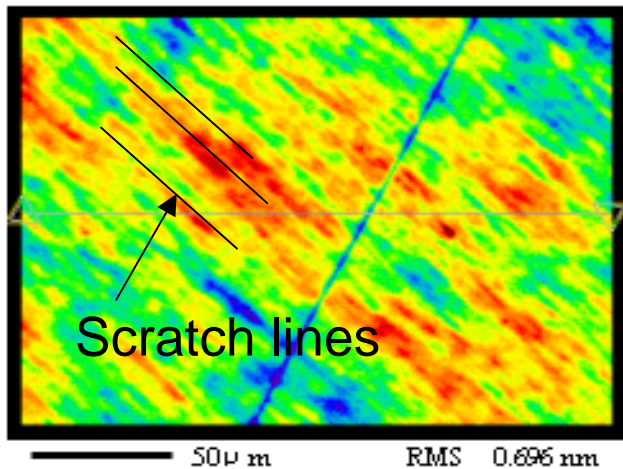
# Experimental results

## - Results of surface roughness (MSFR) -

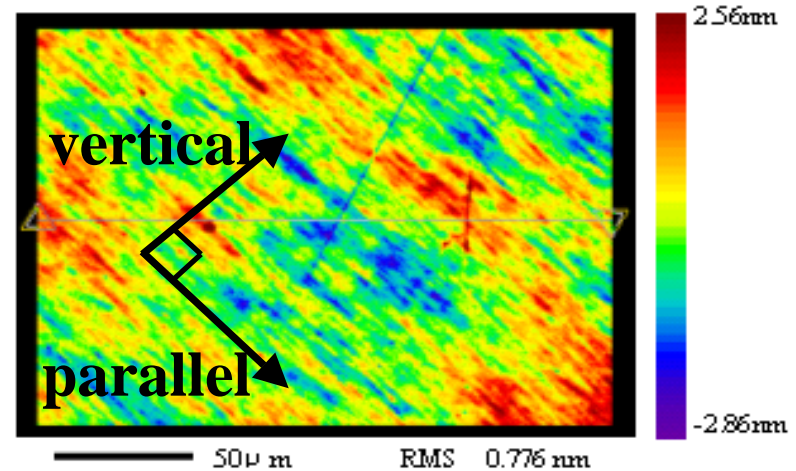


**The deterioration of MSFR is small !!**

# The relationship between surface roughness and scratch lines



Mechanical polished surface without IBF  
RMS 0.696 nm



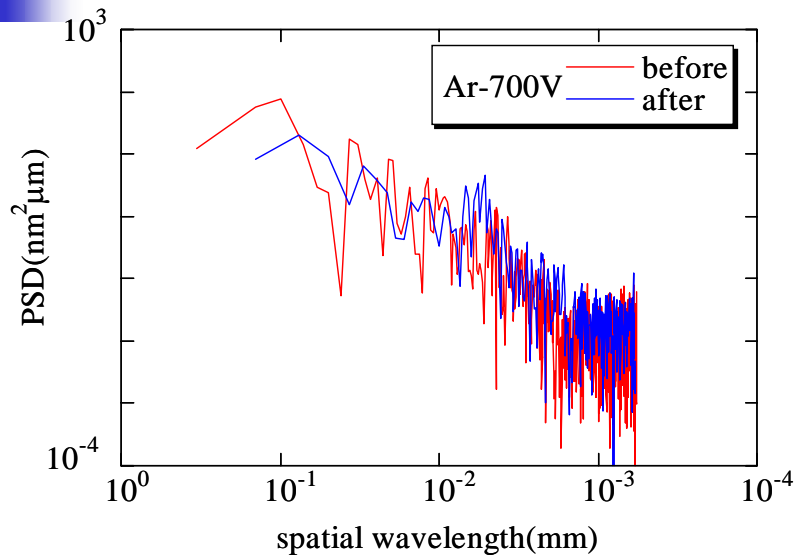
After Ar ion beam etching ( Ion beam energy: 700V) RMS 0.775 nm

MSFR in the vertical direction of the scratch line is differ from MSFR in the parallel direction of that.

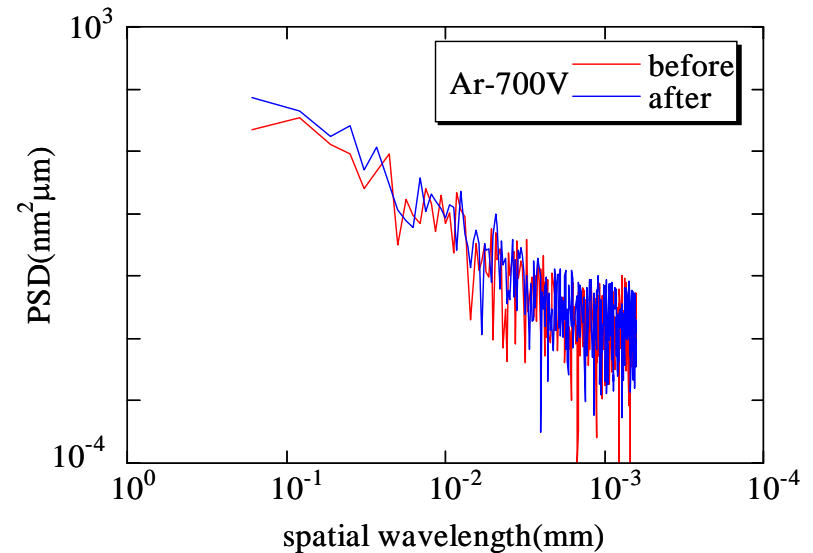
**Analysis of power spectrum density (PSD) for two directions were examined.**

# Results of PSD

## Ar ion beam, Ion beam energy at 700 eV



Vertical direction



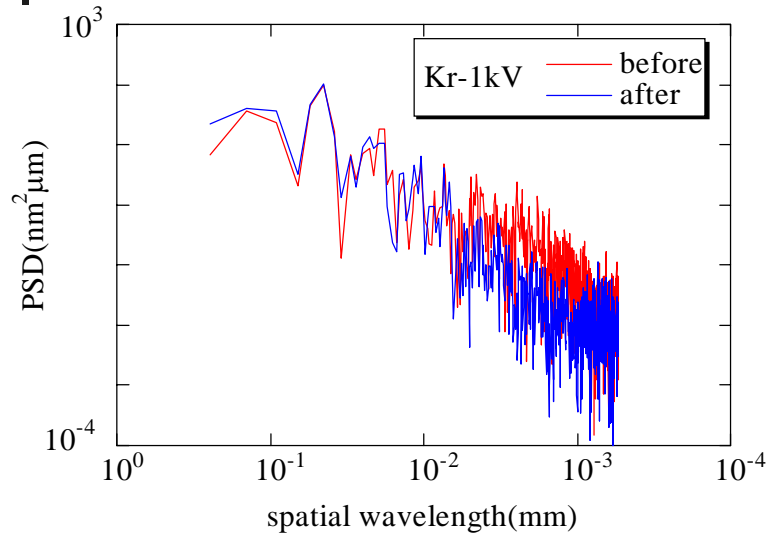
Parallel direction

Average of 5 lines

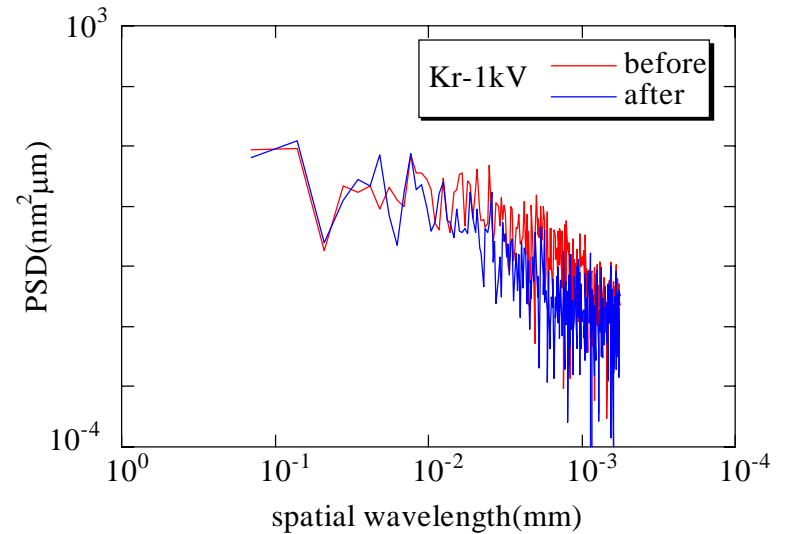
In this case, PSD of vertical direction gets worse.  
On the other hand, PSD of parallel direction keeps MSFR.

# Results of PSD

## Kr ion beam, Ion beam energy at 1000 eV



Vertical direction



Parallel direction

In this case, PSD of both directions get better !!



## Table of results of PSD at various etching conditions

Get worse on both directions	(Ne, 1000V)
Keep MSFR on parallel direction, but get worse on vertical direction	(Ar, 1000V), (Ar, 700V)
Keep MSFR on both directions	(Ar, 500V), (Kr, 500V), (Ne, 500V) (Kr, 700V), (Ne, 700V)
Get better on both directions	(Kr, 1000V)

**Almost conditions, deterioration of MSFR is small !!**



# Summery

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Ion beam figuring (IBF) of optical substrate was examined. The IBF apparatus was consisted of electron cyclotron resonance (ECR) ion source, vacuum chamber and sample stage. The IBF conditions were follows. Ion species were Ne, Ar and Kr, ion beam energies were 500, 700, 1000 eV. Mid spatial frequency roughness (MSFR) of substrate surface before and after IBF was examined with 3-D surface profilers. Analysis of power spectrum density (PSD) was applied to vertical and parallel directions of scratch lines which was caused at mechanical polishing. The results of PSD indicate that almost IBF etching conditions remain MSRF, therefore IBF is suitable for figuring and correction of aspehrical EUV mirror.



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