



中国科学院 上海高等研究院  
SHANGHAI ADVANCED RESEARCH INSTITUTE, CHINESE ACADEMY OF SCIENCES

# EUV Interference lithography and application in SSRF

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Shanghai Advanced Research Institute, CAS

2023/10/25

<http://www.sari.cas.cn>

# Content

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1

**SSRF XIL/EUV-IL beamline**

.....●

2

**EUV-IL for EUV photoresist evaluation**

.....●

3

**XIL/EUV-IL for nano-manufacturing**

.....●

4

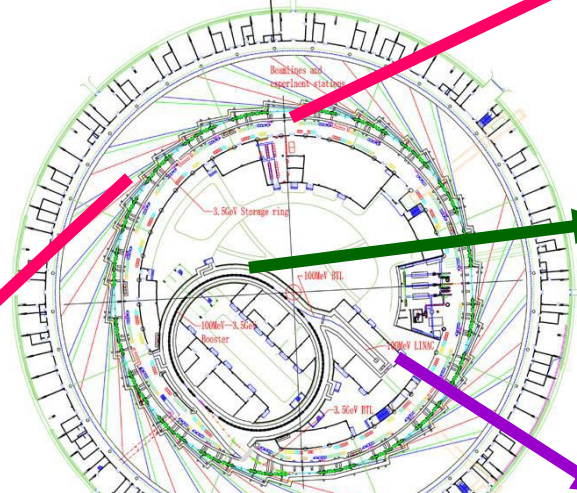
**Conclusion**

.....●

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The electrons are linearly accelerated to 150MeV and further enhanced to 3.5GeV, entering the storage ring to generate synchrotron radiation for about 30 beamline and experimental stations.

beamline&stations



3.5GeV storage ring, with length 432m

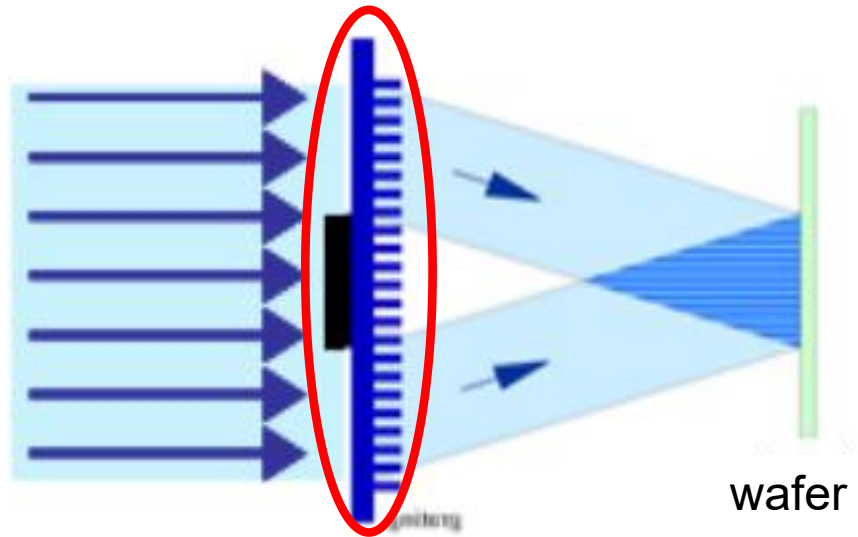


booster, C=180m



150MeV linear accelerator

# Soft X-ray/EUV interference Lithography (XIL/EUV-IL)



mask grating

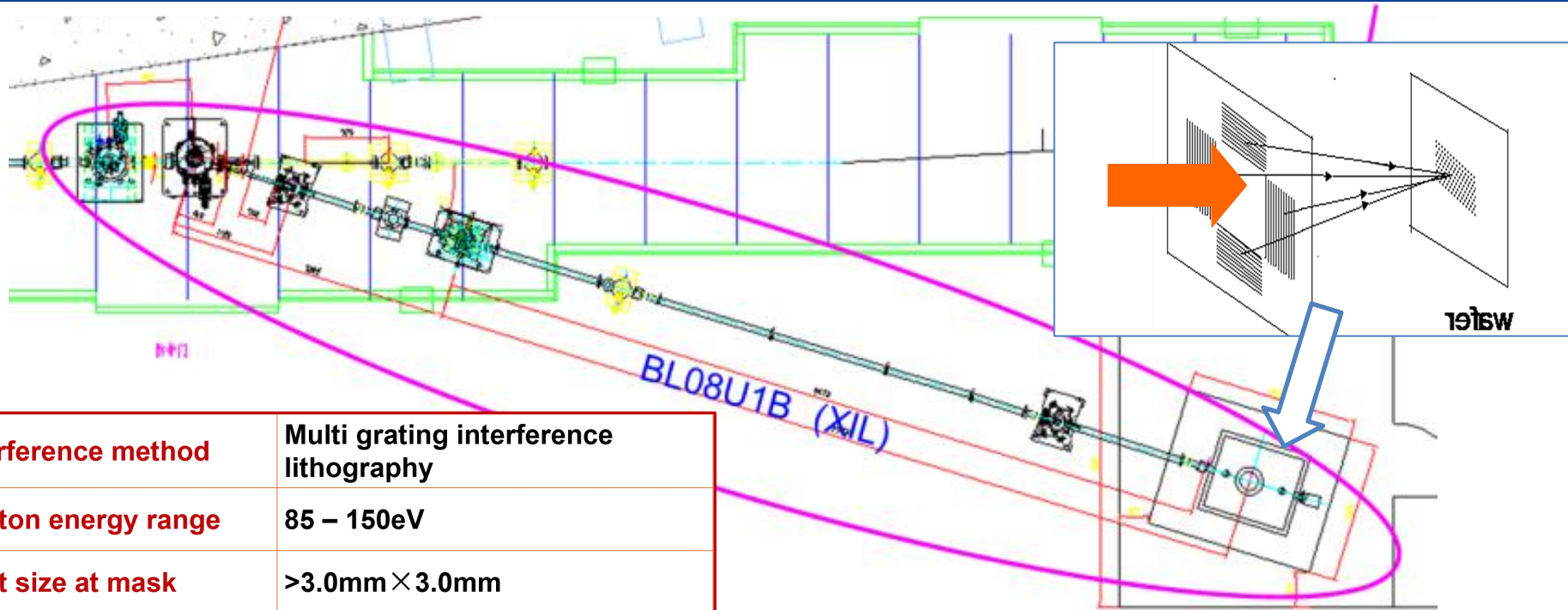
XIL/EUV/IL

**interference with multi-grating diffraction**  
**Achromatic, spatial coherent light required**



**EUV & Soft X-ray from Synchrotron radiation**  
**quasi-monochromatic, spatial coherent beam**

# Layout of SSRF-XIL beamline @station



<b>Interference method</b>	Multi grating interference lithography
<b>Photon energy range</b>	85 – 150eV
<b>Spot size at mask</b>	>3.0mm × 3.0mm
<b>Single exposure size</b>	0.4mm × 0.4mm
<b>Coherent photon flux</b>	>3.0 × 10 <sup>14</sup> phs/s/cm <sup>2</sup> /0.3A@92eV

$\lambda=13.5\text{nm}$



# Key Technologies

**Simulation of Partially Coherent Soft X-ray/EUV**

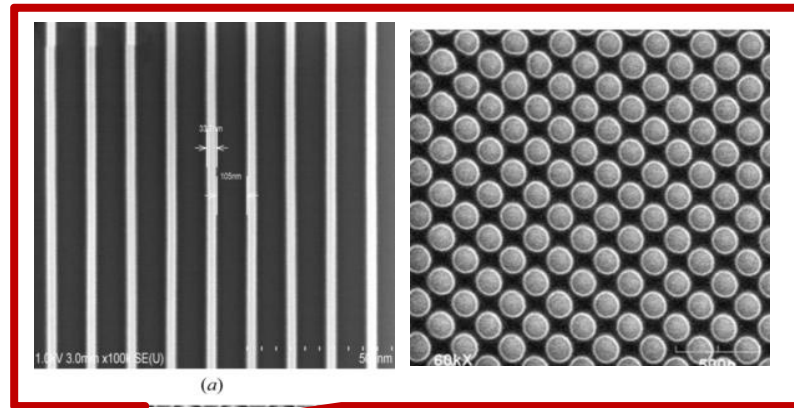
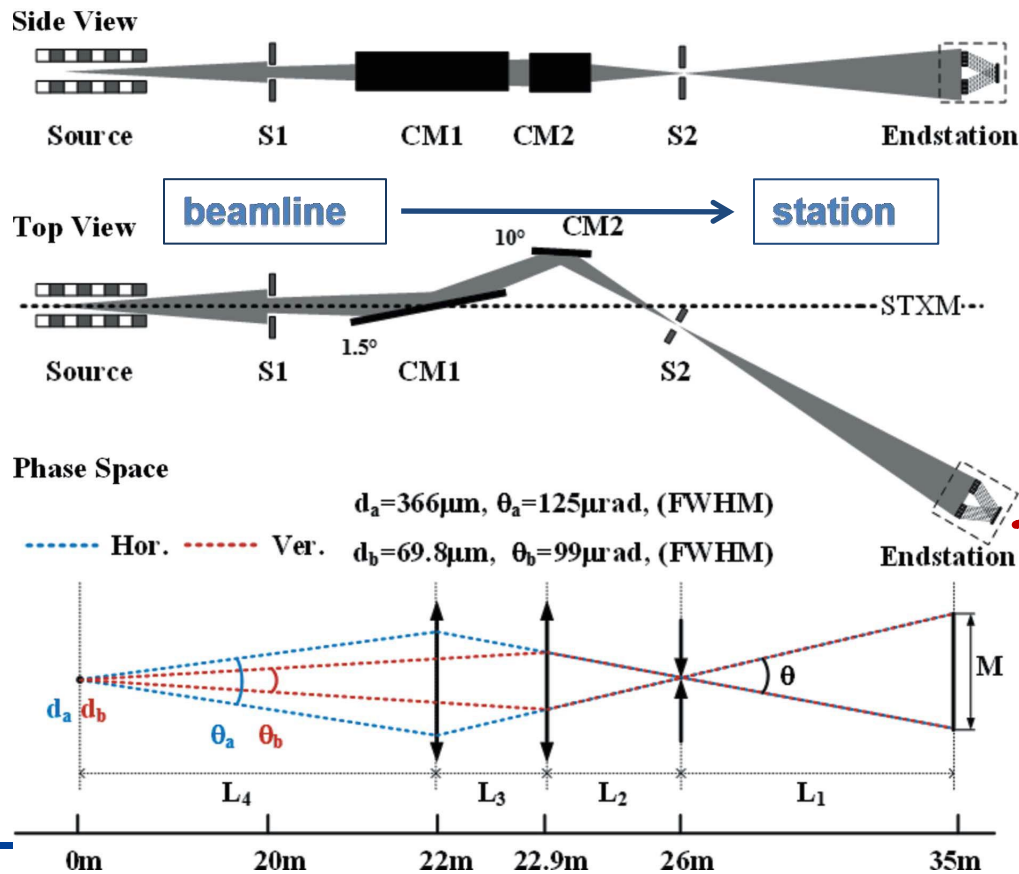
**Optics and Fine mechanics for X-ray beamline**

**High stability precision mask sample stage**

**High diffraction efficiency EUV/SX transmission grating  
with small pitch**



# Whole process simulation of XIL beamline & station



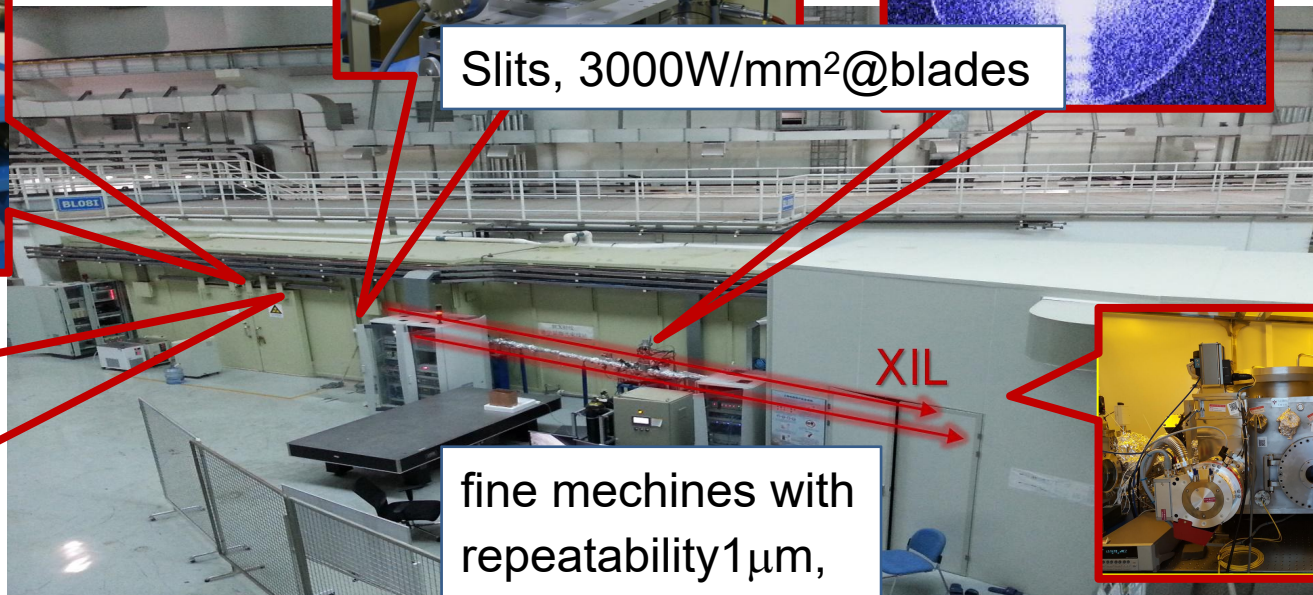
**Simulation of Partially Coherent Soft X-ray Based on Mutual Intensity Theory**

JSR, 25 (2018) 1869

# precision optics and fine mechanics@XIL beamline

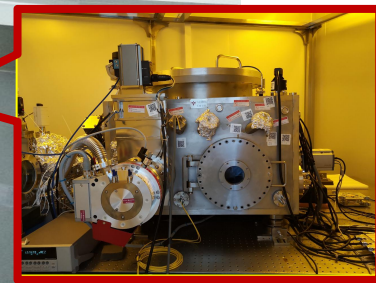


Slits,  $3000\text{W}/\text{mm}^2$ @blades



XIL

fine mechnes with  
repeatability  $1\mu\text{m}$ ,  
and  $10\text{nm}$



XIL exposure chamber

mirrors, with roughness  
 $0.3\text{nm}$ , slope error  $0.3\mu\text{rad}$ ;



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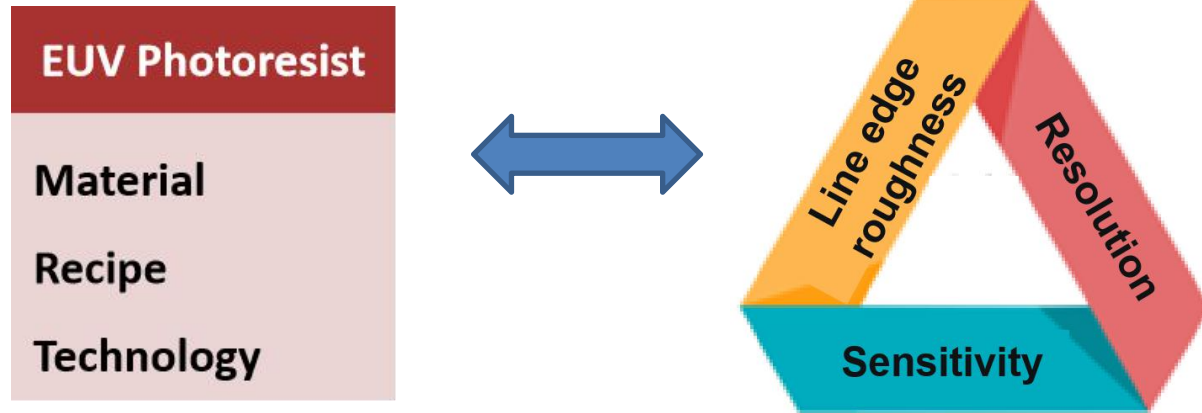
Conclusion

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# EUV photoresist evaluation

During the development process of photoresist, lots of iterations and tests are required to obtain the best exposure performance

## 13.5nm at wavelength test by EUV-IL



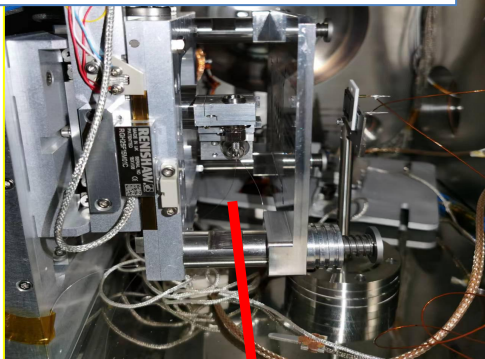
$\text{Resolution}^3 \times \text{Line Edge Roughness (LER)}^2 \times \text{Sensitivity} = \text{Z factor (mJ}\cdot\text{nm}^3)$

**vibration control + grating masks with small pitches**

# Control the vibration between mask and wafer

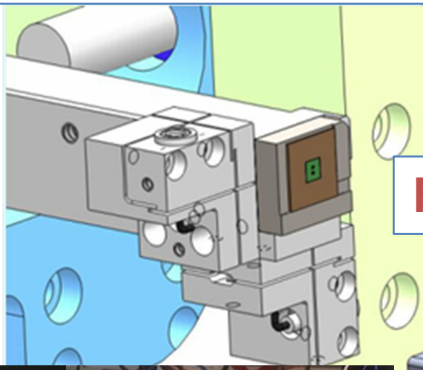


high stability  
mask-wafer stage

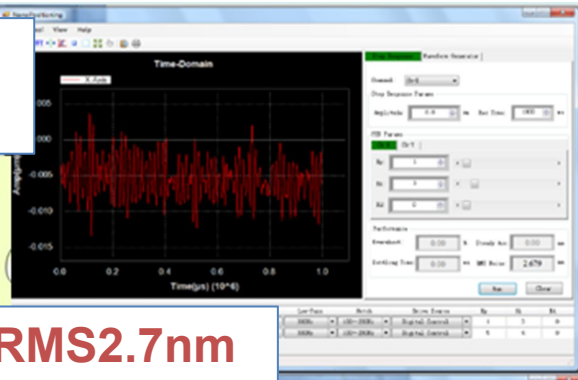


(a)

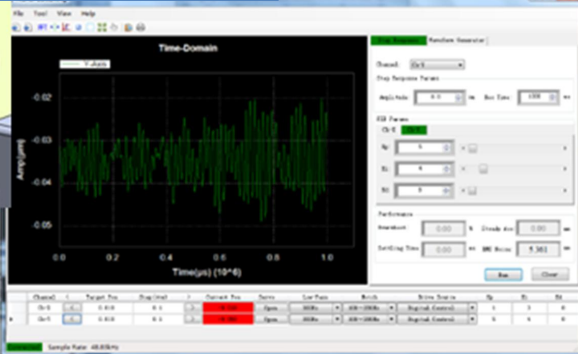
vibration measurement  
by laser interference



(b)

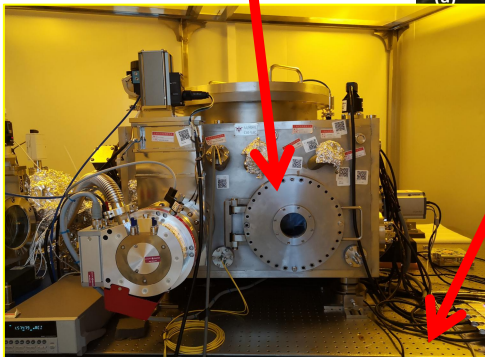


RMS2.7nm



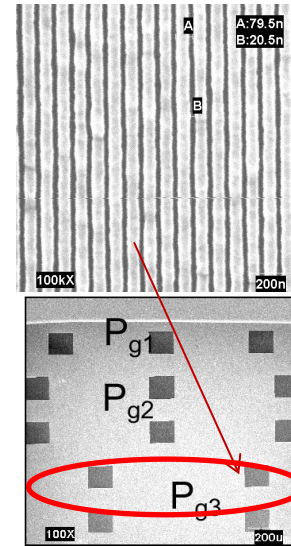
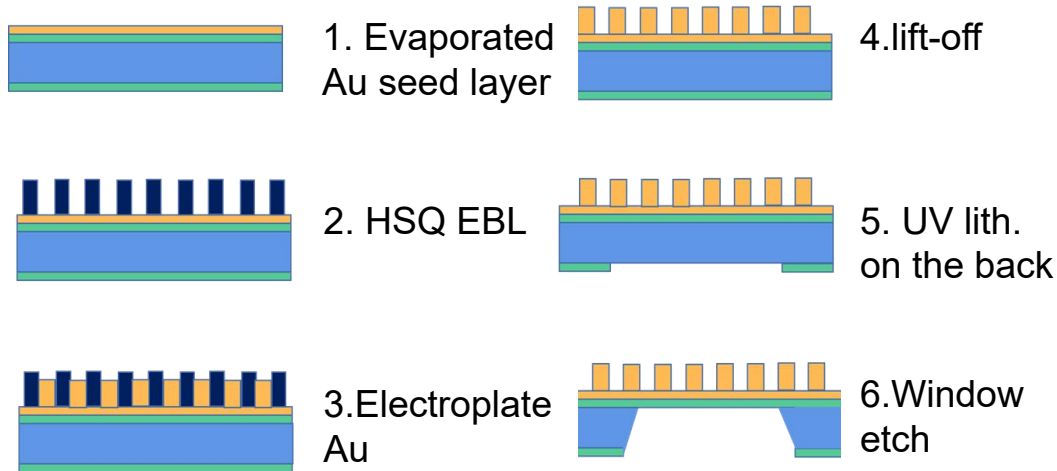
Active anti-vibration

By monitoring the vibration, eliminating various vibration sources and further strengthening the structure, high-resolution XIL exposure was achieved

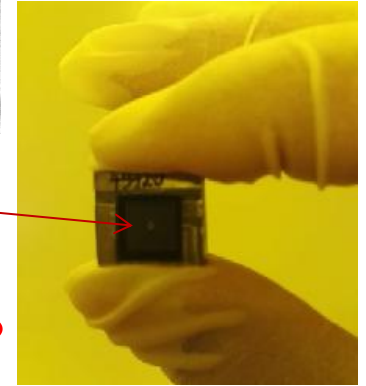


# Fabrication of XIL Grating mask with a small pitch (by Electroplating)

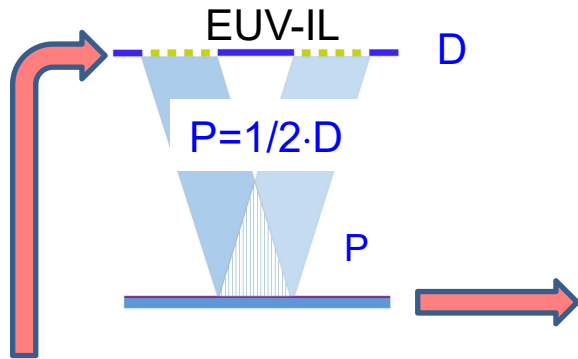
process of mask grating (**by Electroplating**)



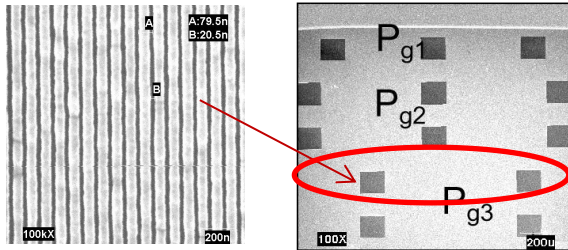
Pitch 78nm



# EUV photoresist test by the mask with pitch 78nm

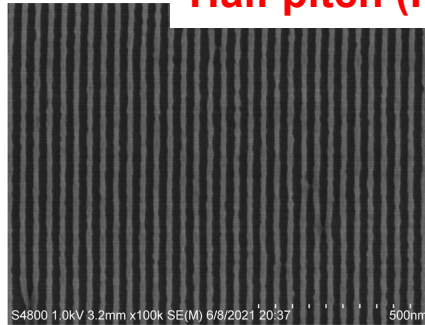


mask grating (by **Electroplating**)

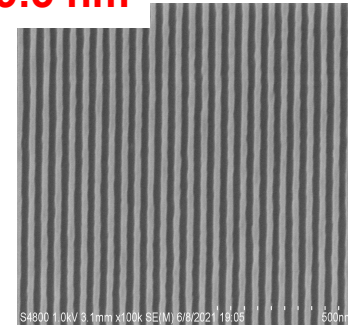


Pitch 78nm

**Half pitch (HP) 19.5 nm**



Dose= 光通量\*曝光时间      Dose= $3.31 \cdot 10^{14}$

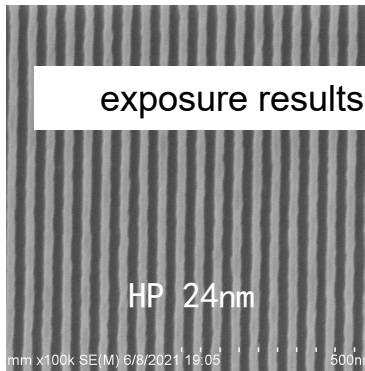
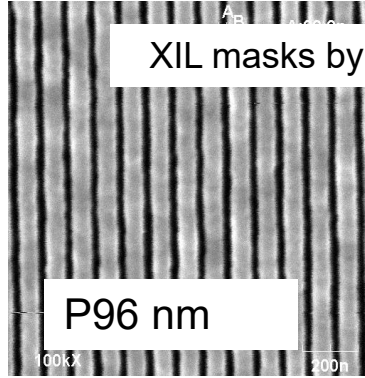
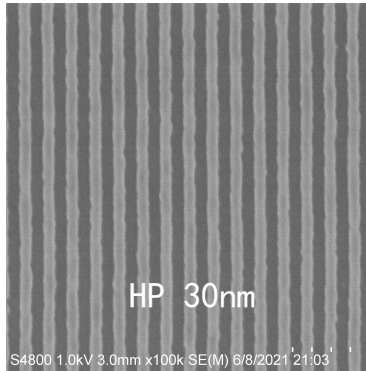
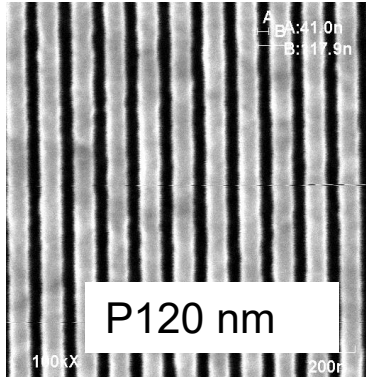


应用化学2021, V38 1168;  
Int. J. Extrem. Manuf. 2020,101

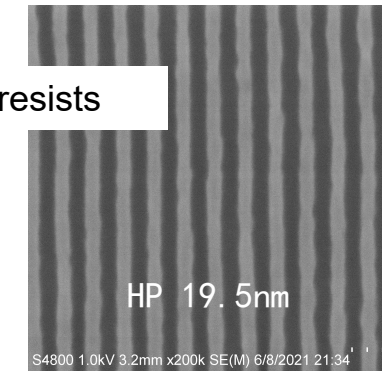
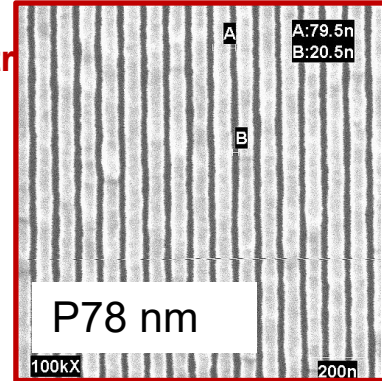
**for EUV photoresist evaluation (7nm EUV  
Litho.Tech.Note**

# EUV-IL Exposure results with XIL masks by Electroplating

exposure

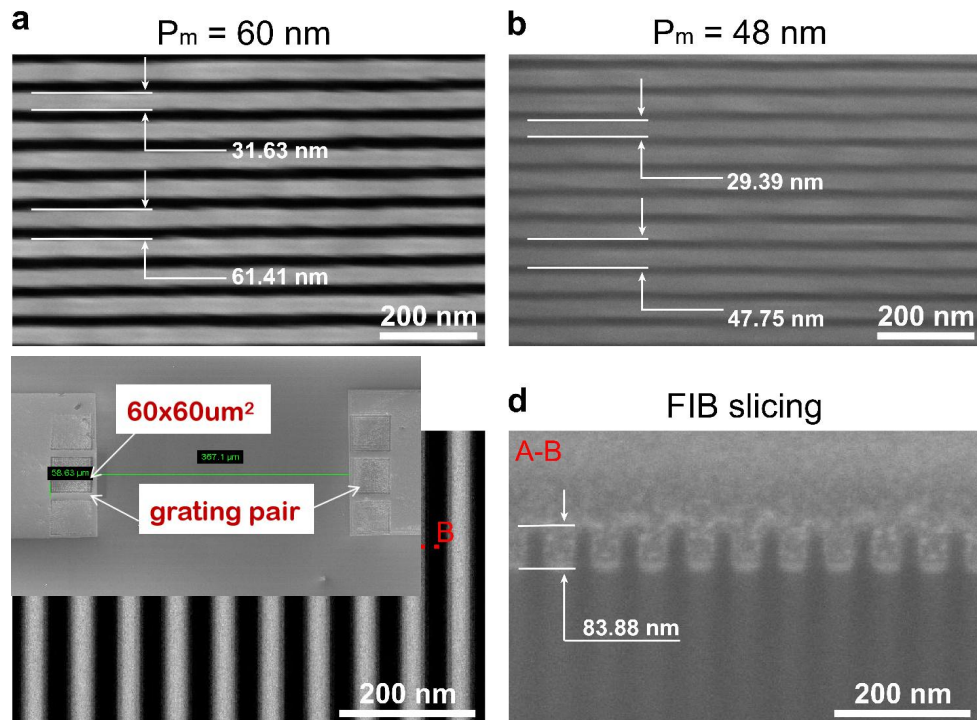
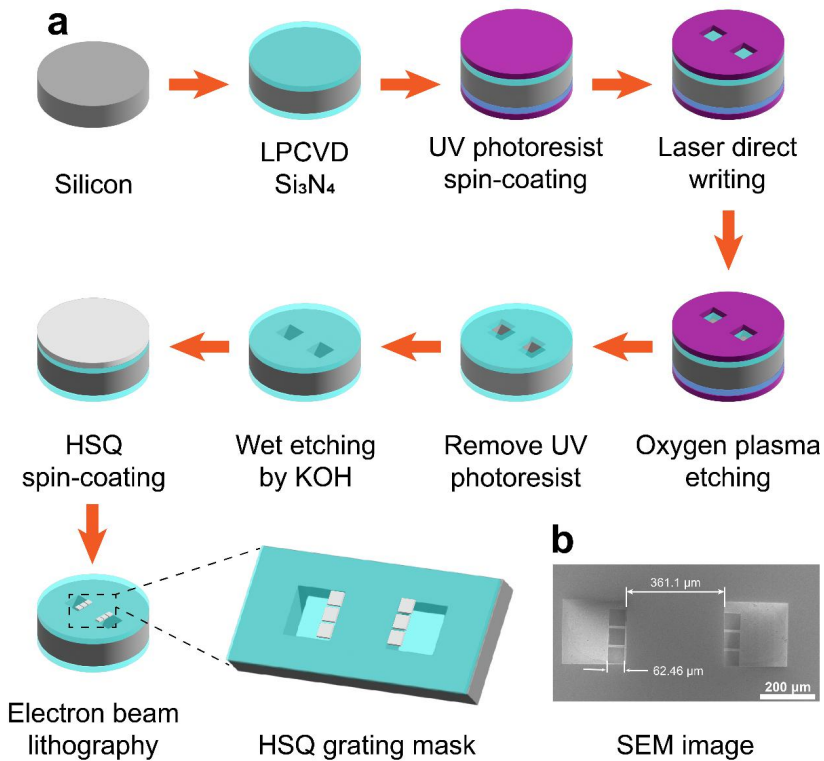


XIL masks by by Electroplating



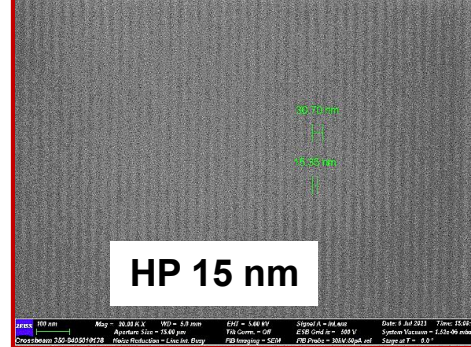
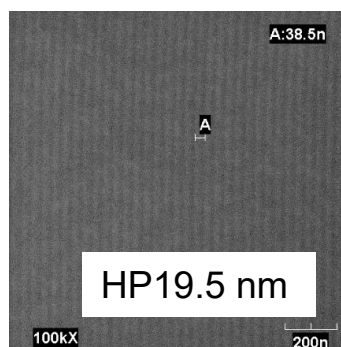
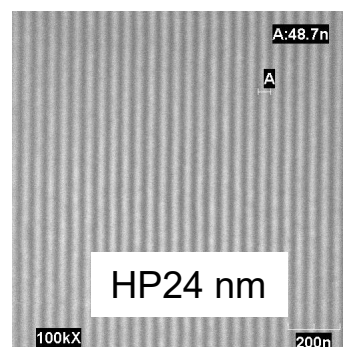
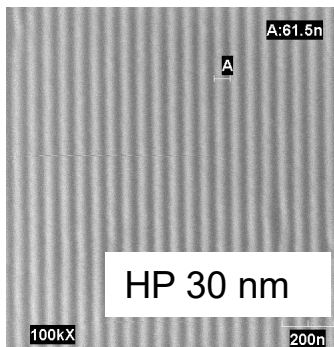
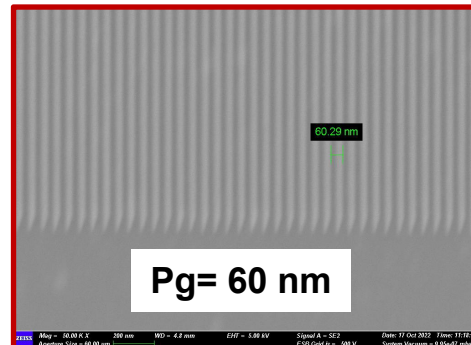
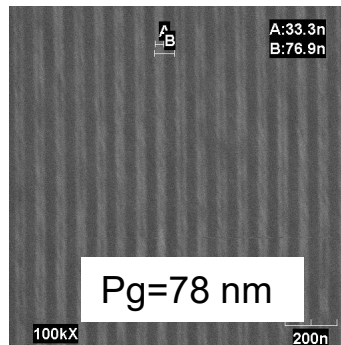
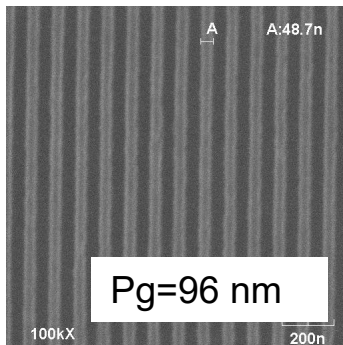
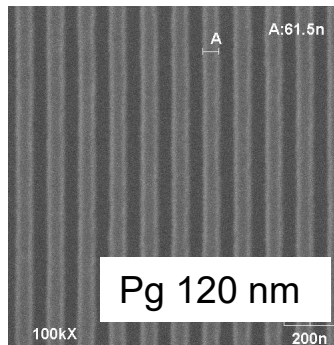
exposure results on EUV resists

# EUV-IL grating masks by HSQ photoresist



# EUV-IL Exposure results with HSQ XIL masks

XIL exposure



Info Map = 60.00 kV X 200 nm WD = 4.2 mm EHT = 5.00 kV Stage A - SE2 Date: 01 Oct 2012 Time: 17:42:31  
Aperture Size = 60.00 µm F50 Grid # = 008 V System Vacuum = 0.95e-6 mbar  
Crossbeam 350-S4550P178 Noise Reduction = Line for Clarity FEI Imaging - SEM FEI Probe = XILV-00A.v1

Info Map = 60.00 kV X 200 nm WD = 6.3 mm EHT = 5.00 kV Stage A = H4 000 Date: 1 Jul 2013 Time: 15:02:39  
Aperture Size = 51.00 µm F50 Grid # = 008 V System Vacuum = 1.42e-6 mbar  
Crossbeam 350-S4550P178 Noise Reduction = Line for Clarity FEI Imaging - SEM FEI Probe = XILV-00A.v1 Scope at F = 0.0



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Conclusion

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# Mask by Atom lithography

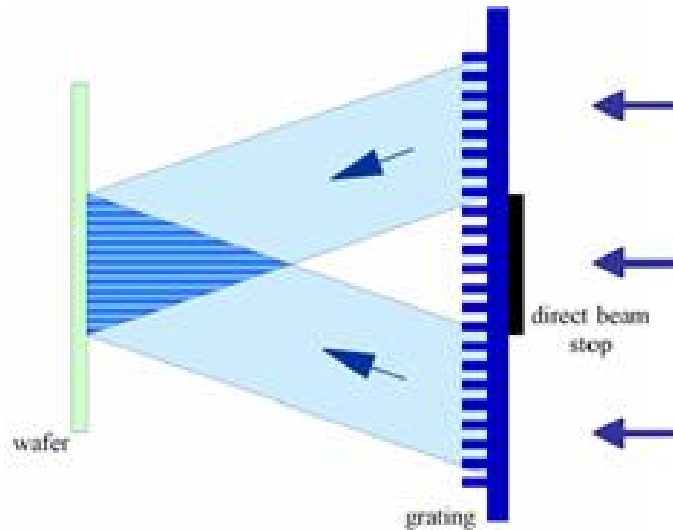
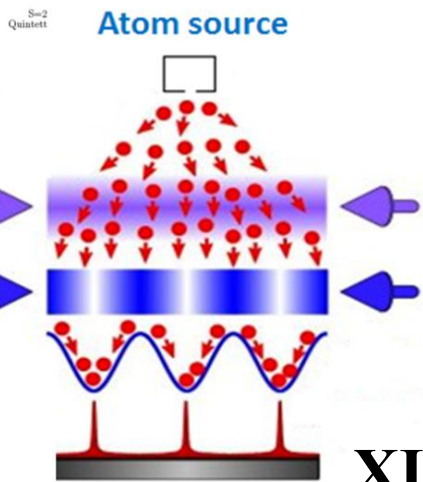
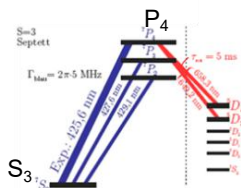
Cr atom  $S_3 \rightarrow P_4$  transition

by 1<sup>st</sup> & 2<sup>nd</sup> order diffraction

period: 425.6nm  $\rightarrow$  212.8nm



period: 106.4nm & 53.2nm



Atom Lithography

XIL mask

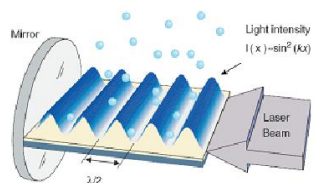
EUV-IL

mask with a pitch from Atom eng.level (Natural standard)  
+ spatial frequency multiplied by XIL

# Fabrication of nano-pitch standard (GBW13983)

for high precision measurement and calibration of SEM, AFM and other instruments.

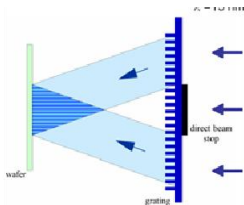
## Atom Lithography



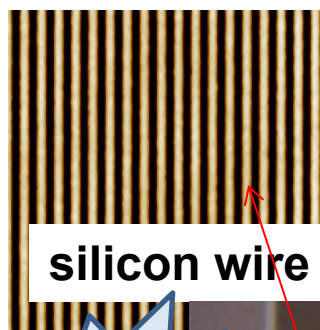
212.8nm 自溯源光栅



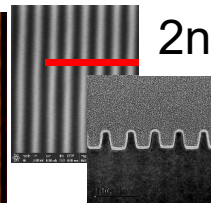
## XIL



106.4nm 自溯源光栅



silicon wire with pitch 106.4nm



2nd diffraction

pitch  
53.2nm

product

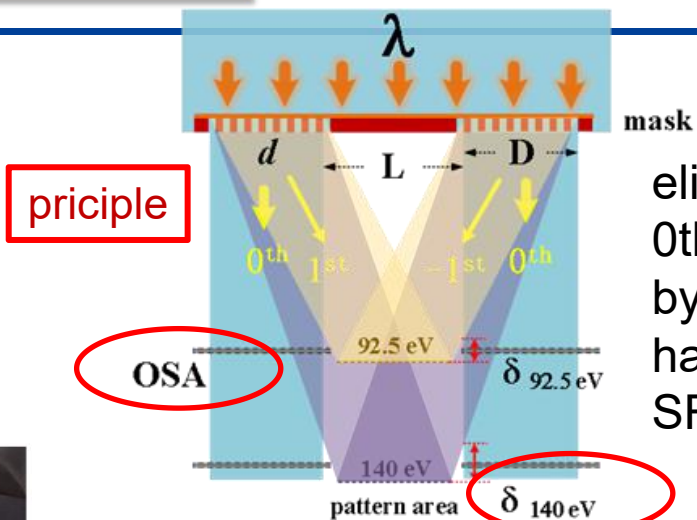
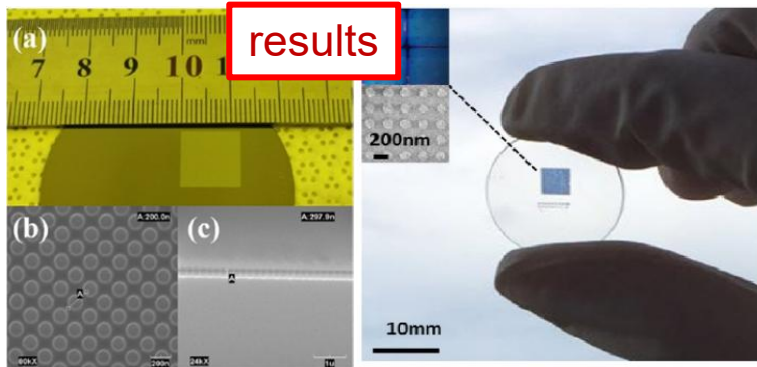
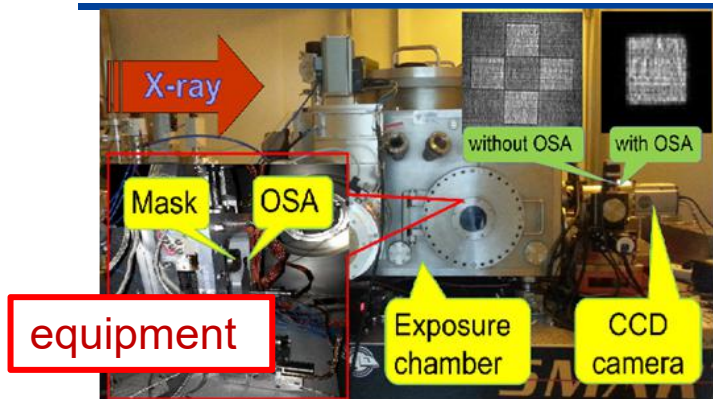
tongji univ. &SSRF

pitch error <1nm,  
LER<3nm,  
the grooves :the  
same height



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# deep-XIL & stitching (up to 4cm<sup>2</sup>)



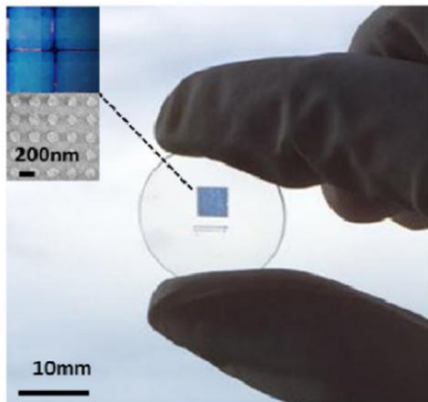
eliminate the 0th order block by high order harmonics from SR Undulator

发明专利201510666500.3;  
实用新型ZL201520095051.7

Rev. Sci. Instrum. 87, 043303 (2016);  
Applied Surface Science 425 (2017) 553–557  
Int. J. Extrem. Manuf. 2 (2020) 012005

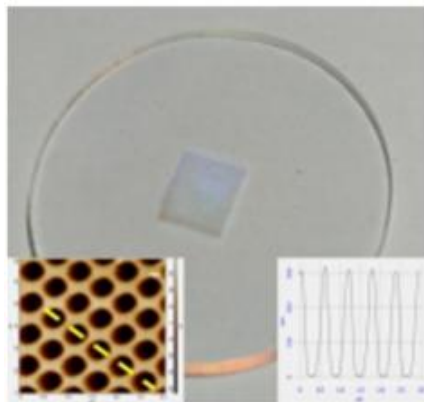
# Application of XIL stitching

The large-area nanoscale patterns can be produced and transferred, with strictly consistent lattice orientation



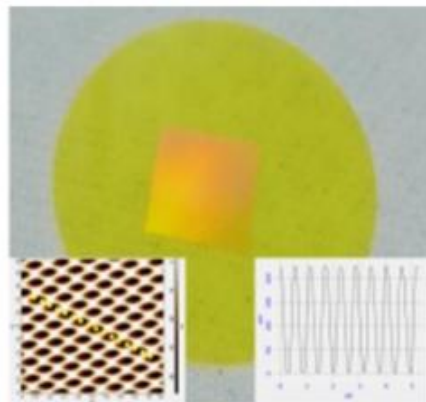
optical filter  
(zhejiang Univ.)

Optics Letters, 2019



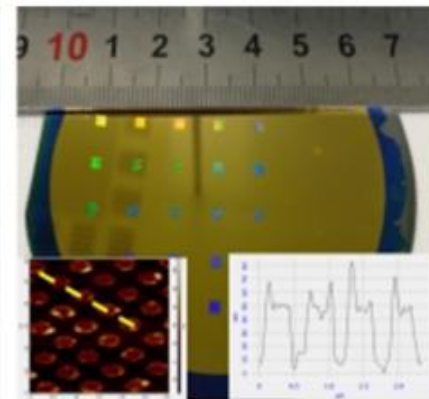
Efficient  
scintillator  
(tongji Univ.)

Scientific Reports



coded X-ray  
indirect imaging  
(SSRF, in-house)

Photonic research 2020  
Nanophotonics, 2023

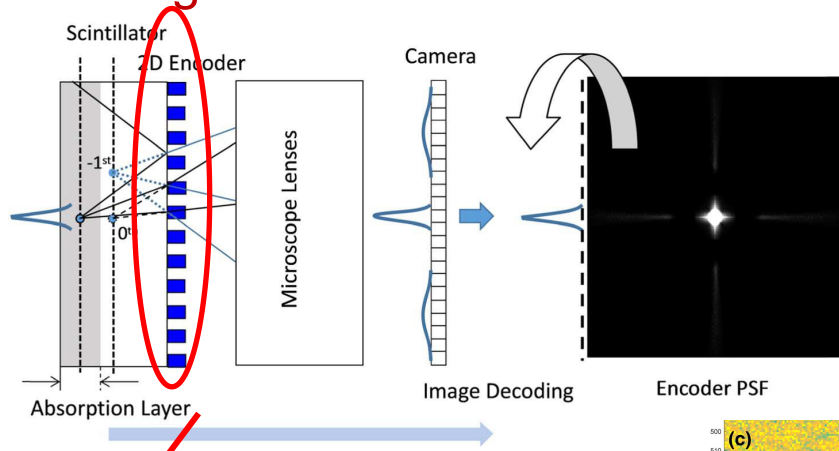


surface plasmon  
(Nanjing Univ.)

Photonics Journal IEEE

# coded X-ray indirect imaging

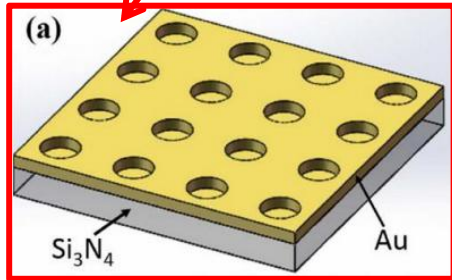
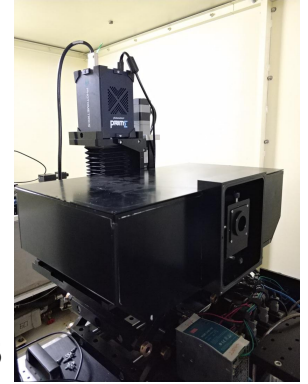
high frequency information to go through the scintillator-air interface



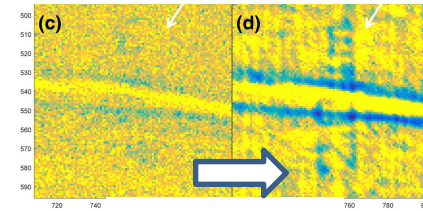
High frequency SNR increase 6-50times

Photonics Research  
2020,1079

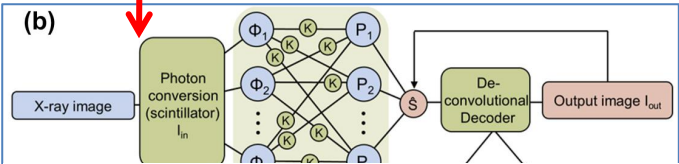
Nanophotonics, 2023,3793



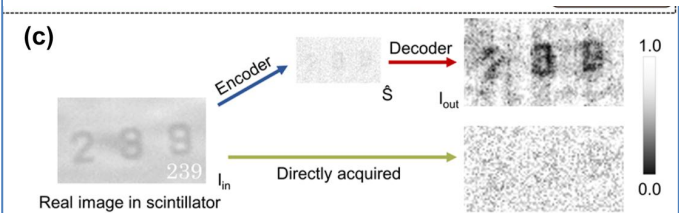
the encoder by EBL



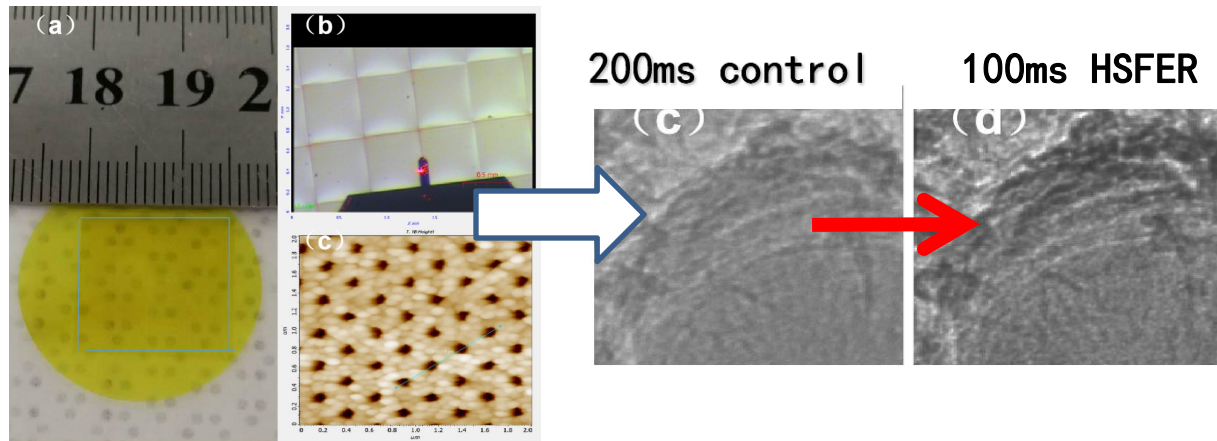
imaging results



decoding by deep learning

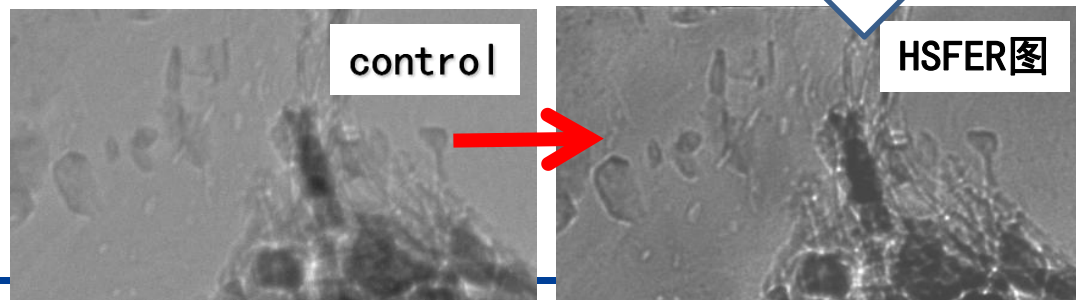
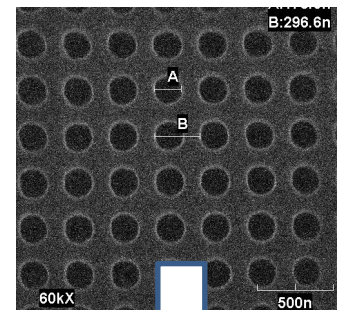


# the encoder by stitching XIL

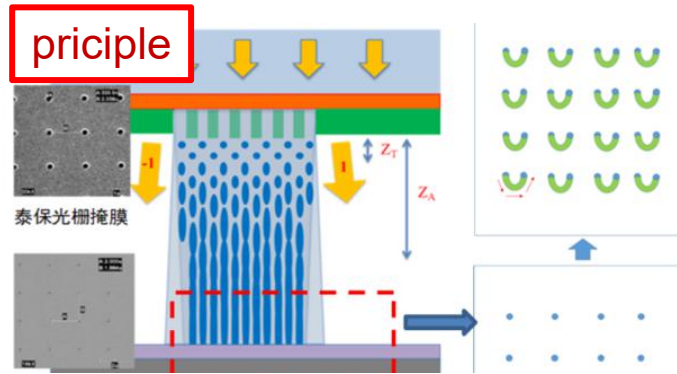


$1.5 \times 1.5 \text{cm}^2$   
by XIL stitching,  
for large field of view

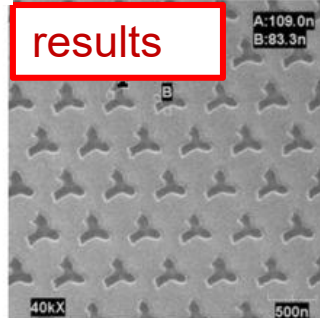
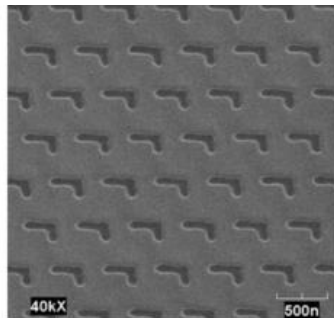
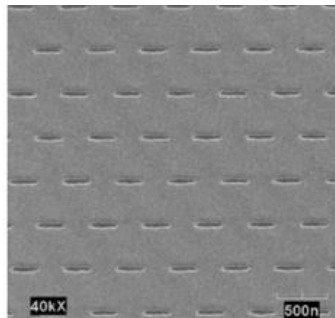
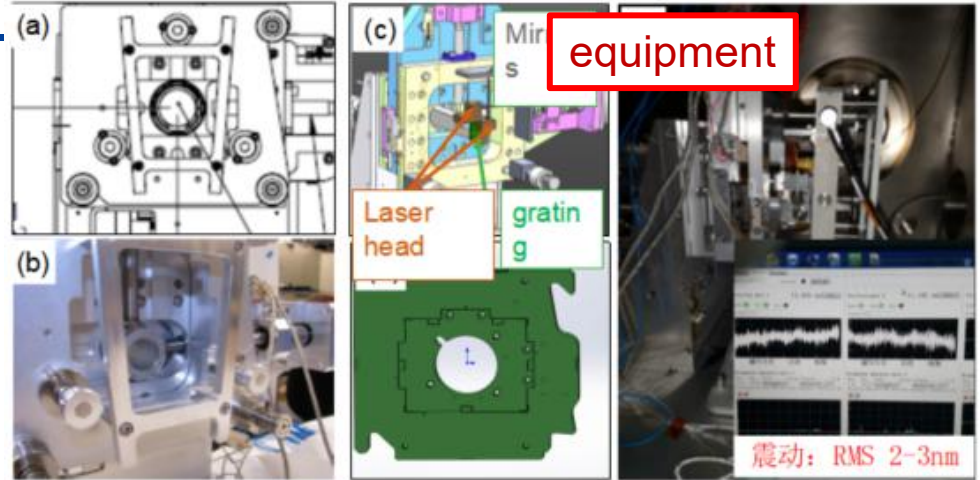
high precision HSB  
encoder by direct EBL



# Direct writing achromatic Talbot Lithography (DW-ATL)



Small duty cycle dot array by ATL



**nanostructures with complex cell and 500nm pitch**

J. Vac. Sci. Technol B, 35 (2017) 021601

Nanotechnology 30 (2019), 315301

can be applied to metasurface



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SSRF XIL/EUV-IL beamline

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EUV-IL for EUV photoresist evaluation

.....●

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XIL/EUV-IL for nano-manufacturing

.....●

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**Conclusion**

.....●



- **As an EUV photoresist detection platform, the SSRF-XIL station has met the requirements of the 7nm technical node and is moving towards 5nm.**
- **As a unique processing tool for nano periodic structure , SSRF-XIL station has developed new interference lithography methods according to the needs, for the research in various fields and the Synchrotron radiation experimental methods and equipment development**