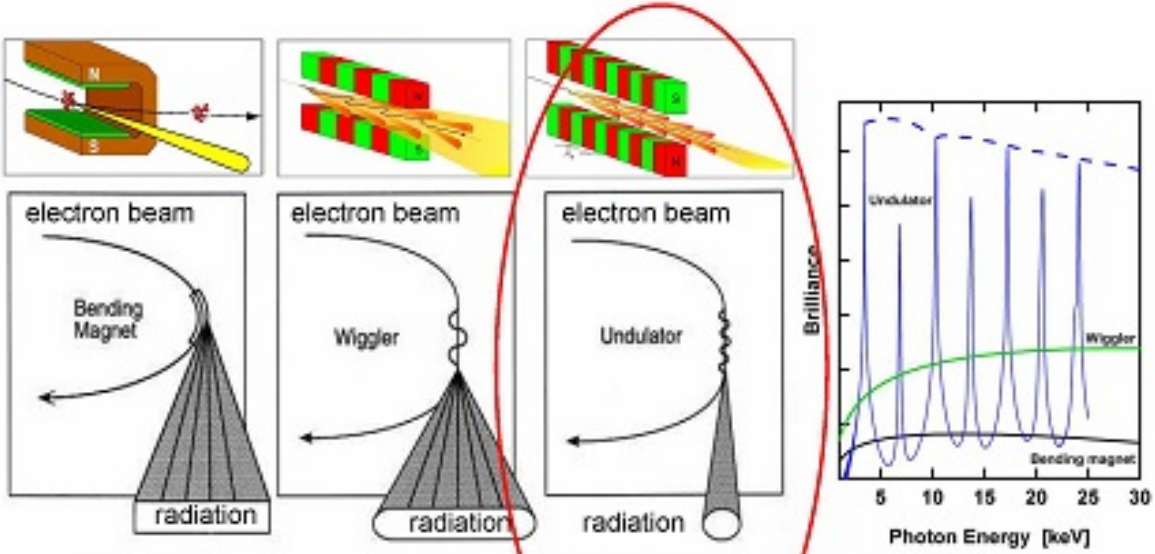
EUV resist testing and nano-periodic structure fabrication based on SSRF-XIL station: application and prospects

Yanqing Wu Jun Zhao Chaofan Xue Shumin Yang Liansheng Wang Renzhong Tai

Shanghai Synchrotron Radiation facility（SSRF）

Contents

Synchrotron radiation source



1 period

N periods, incoherent

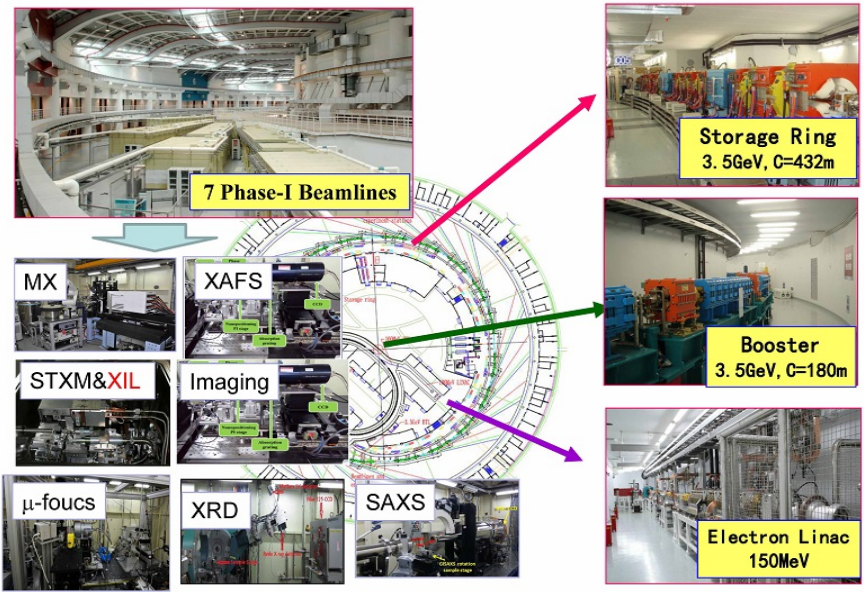
Brightness∝N

N periods, coherent

Brightness∝N^2

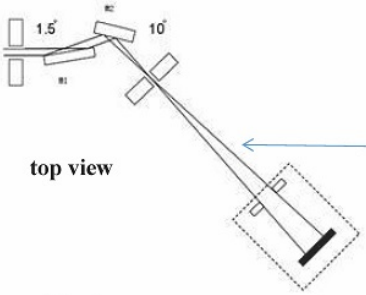
spectrum of the synchrotron radiation source

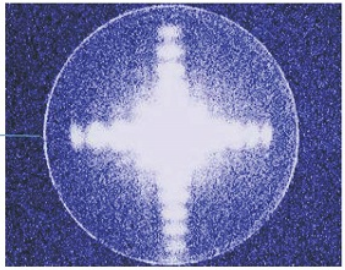
SSRF Complex and Phase-I Beamlines



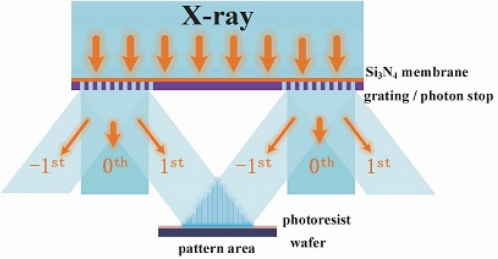
EUV/Soft X-ray inteference Lithography (EUV-IL&XIL) beamline & station

- ✓ stable and fully spatial coherent beam
- ✓ photon energy(wavelength)：92.5-150eV (13.5nm-8.1nm)
- ✓ coherent photon flux density@92.5eV(13.5nm)：
  $>1\times10^{15}$ph/s/cm^2/2.4%BW/0.3A)

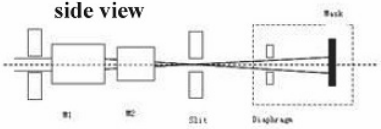




diffraction field



Achromatic diffraction system for the limit-bandwidth spatially coherent beam



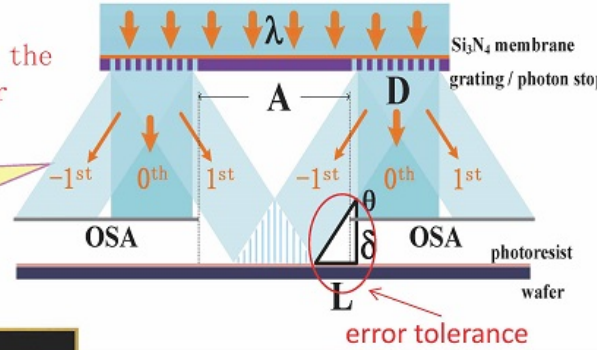
XIL beamline&station

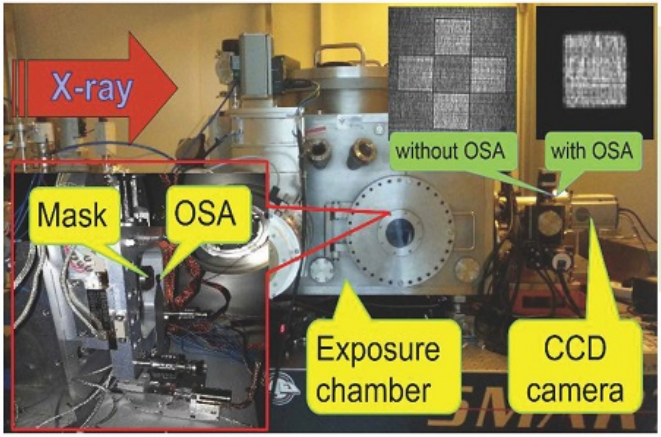
Contents

Large-area stitching with micron precision

- large sample
- towards devices
- grating efficiency、dose control in resist test

blocking the 0th order beam



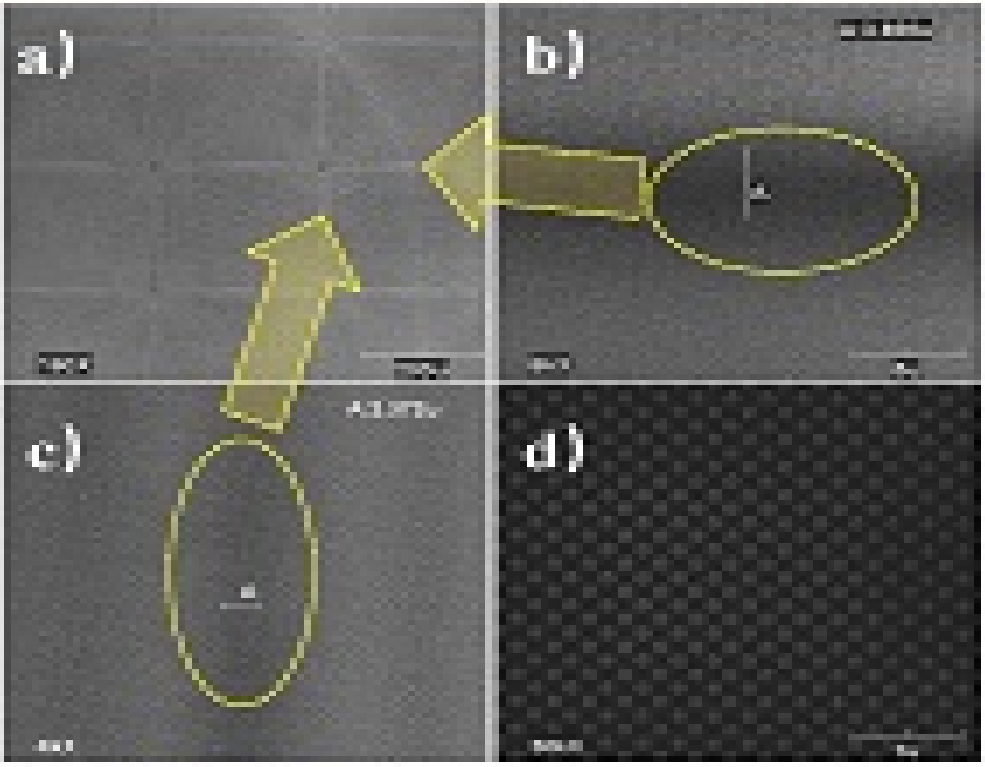


normal mask + order selecting apture (OSA) + online collimation by High-order harmonic impurities

Advantages: stitching withoput defeats; easy fabrication of masks

Chaofan Xue, Yanqing Wu*, et.al.
Rev. Sci. Instrum. 87, 043303 (2016)
Chinese patent: **201510666500.3**

Large-area stitching with micron precision



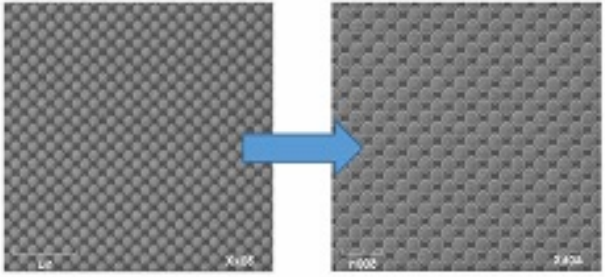
Soft X-ray Interference Lithography

Soft X-ray has been employed to improve the Aspect Ratio:

(1) photon energy 140eV selected , on the requirement and the beamline status;

(2) blocking material of grating : 10nm Cr/150nm perm alloy/10nm Au

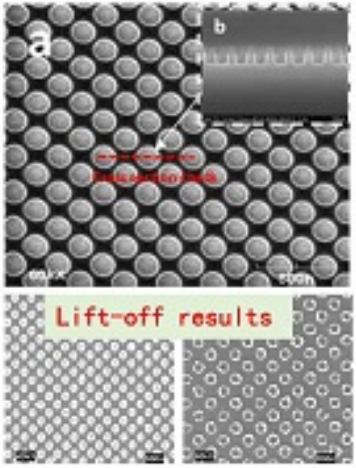
the mask is stable and its lift-time is long



92.5eV 140eV

photon energy

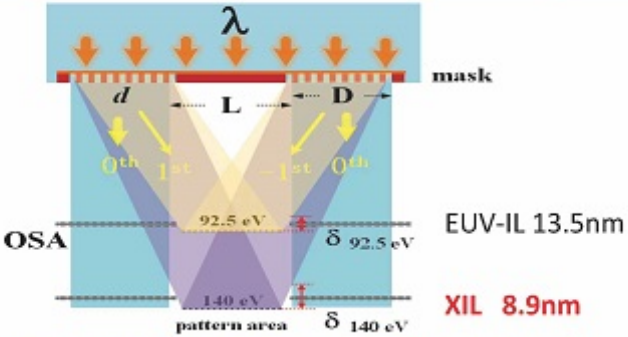
Jun Zhao, Yanqing Wu*,et al, MEE 170 (2017), p49

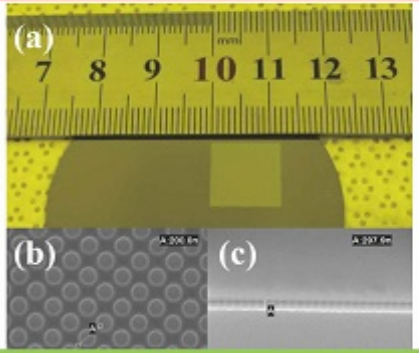


Au structure depth >70nm

Ag structure depth >20nm

Large-area stitching XIL and application

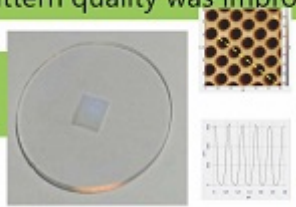


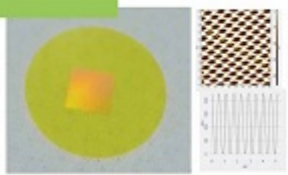


tolerance to OSA position error was increased by 50%, and then experimental difficulty is reduced; pattern quality was improved

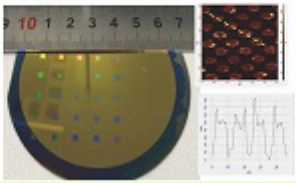
expoture area1.2×1.2cm², period 200nm, Depth300nm, **aspect ratio: 3**

resist pattern on SiO2, depth 300nm





SiNx pattern on YAG by etching, depth 220nm



Au pattern on Si/Au/SiO2, by lift-off, depth 50nm

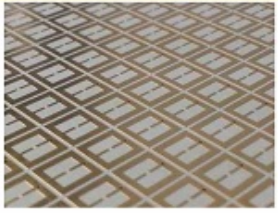
- different substract & transfer. tech.
- large area
- good aspect ratio

Chaofan Xue，Jun Zhao , Yanqing Wu* *et.al*，Applied Surface Science 425 (2017) 553–557

Direct writing Achromatic Talbot Lithography (DW-ATL) based on Synchrotron Radiation

Efficient fabrication of meta-surface consisting of periodic structures with complex units

Artificial meta materials have novel physical properties that are determined by the geometric properties of the material, and has a large number of applications in the fields of electromagnetism and optics.



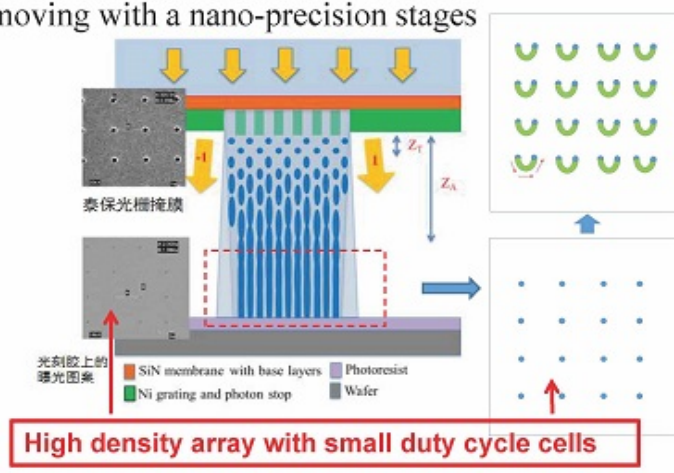
metasurface to collecting electromagnetic energy

method:

(1) A High-density "light needle" array produced with ATL；

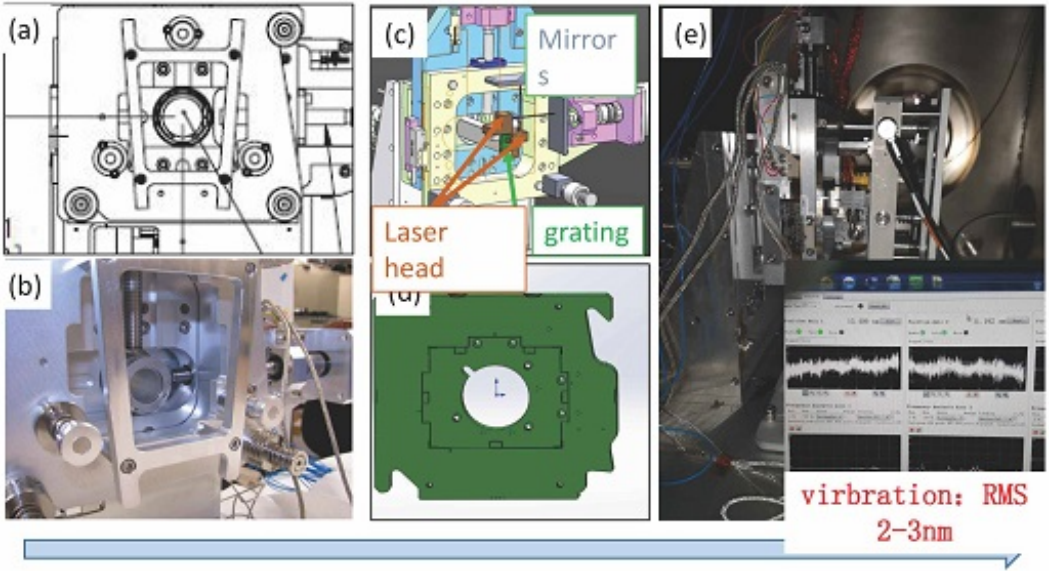
(2) Multiple exposures with under-critical dose

(3) moving with a nano-precision stages



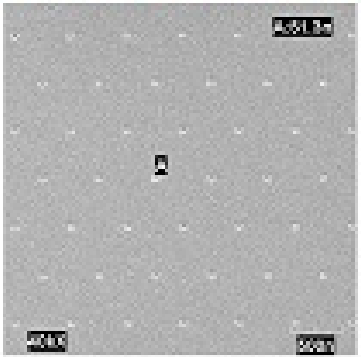
DW-ATL has the high efficiency of a parallel method and the flexibility of a direct write method.

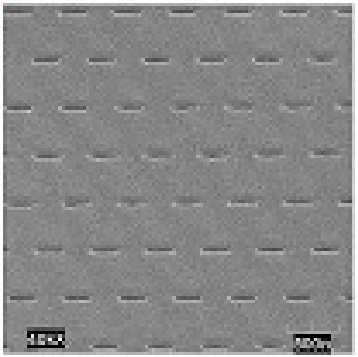
wafer stage upgrating - install nano-precision stages with interferometer feedback

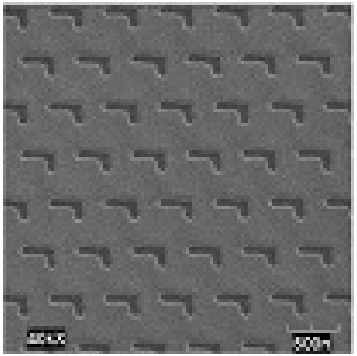


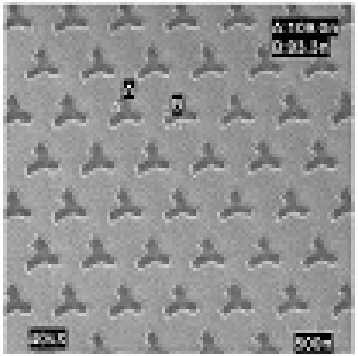
DW-ATL results, sub-100nm periodic pattern with complex cells

period 500nm,
Hole radius 56nm







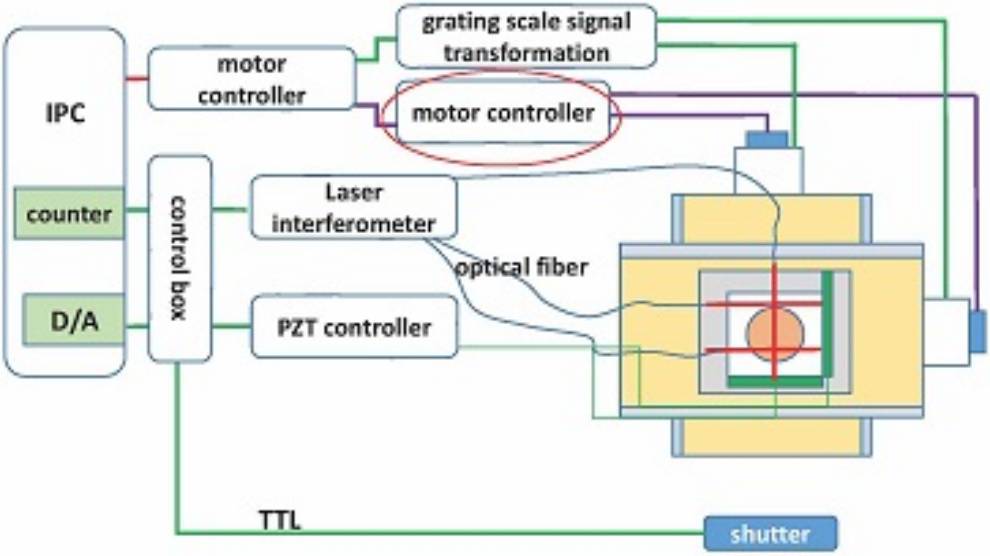


Shumin Yang，Yanqing Wu* et al., Nanotechnology 30 (2019) 315301

control system for DW-ATL

The software linkage between the sample stage and the laser interferometer is realized. The laser direct writing control system is being used to further realize the continuous direct writing, to overcome long step time delay and other weakness.

Control system topology



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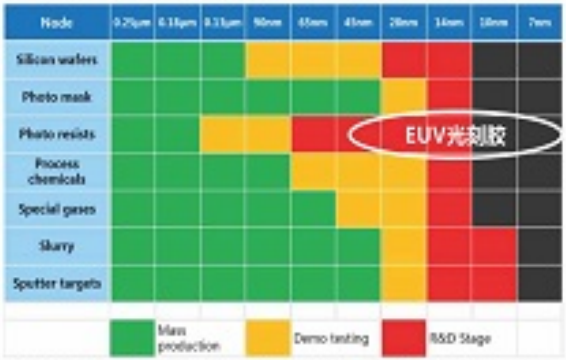
EUV photoresist -
One of the key technoledge in EUV lithography

SAMSUNG tsmc intel SMIC

中国晶圆制造材料技术进展



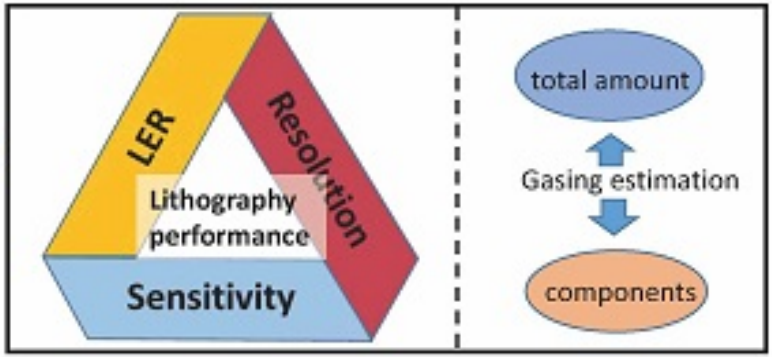
集成电路材料和零件产业技术创新战略联盟《快速成长的中国半导体制造材料产业》2017.10.23

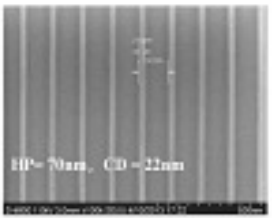
some important international semiconductor companies have announced their 7nm (or below) EUV lithography plan, of which EUV photoresist is an important part.

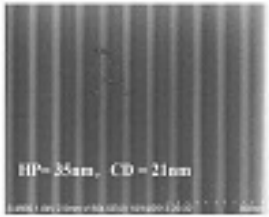
EUV photoresist testing

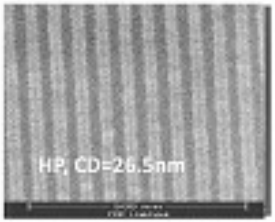
EUV photoresist

- materials
- formula
- processing









testing results by EUV-IL @SSRF-XIL station

A typical result of users on EUV photoresist testing

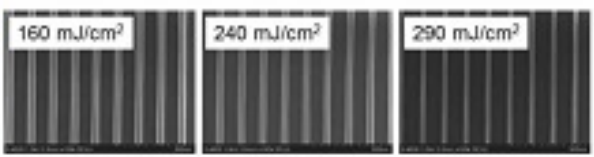
structures & performance on EUV photoresist

BPA-10 FPT-8 SP-2OH

LW : 68 nm
LER : 2.4 nm

LW : 53 nm
LER : 2.4 nm

LW : 46 nm
LER : 2.3 nm



LW : 40 nm
LER : 2.6 nm

LW : 32 nm
LER : 2.8 nm

LW : 22 nm
LER : 3.3 nm

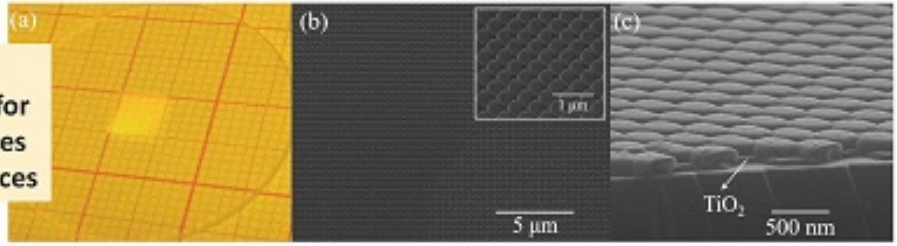
EUV-IL/XIL exposure chamber

gasing estimation chamber

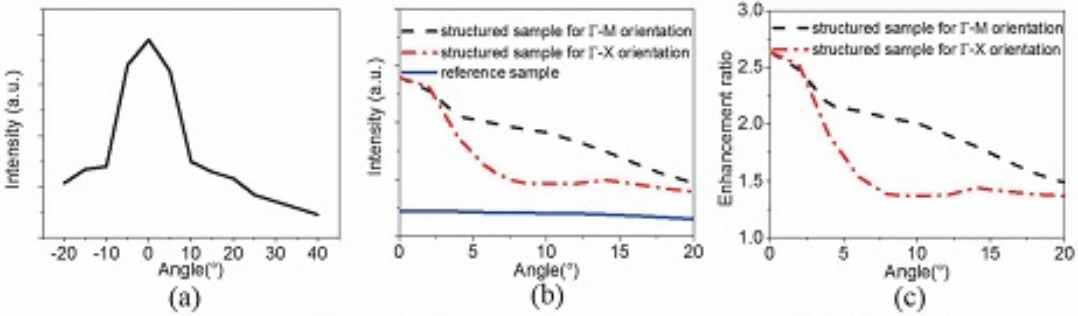
Science China-Chemistry, 2014 , 57(12): 1746–1750
ACS Applied Polymer Materials , 2019, 1, 526–534

Directional emission plastic scintillators by large-area stitching XIL (LAS-XIL)

Plastic light-emitting films have been widely studied for organic light-emitting diodes in electroluminescent devices

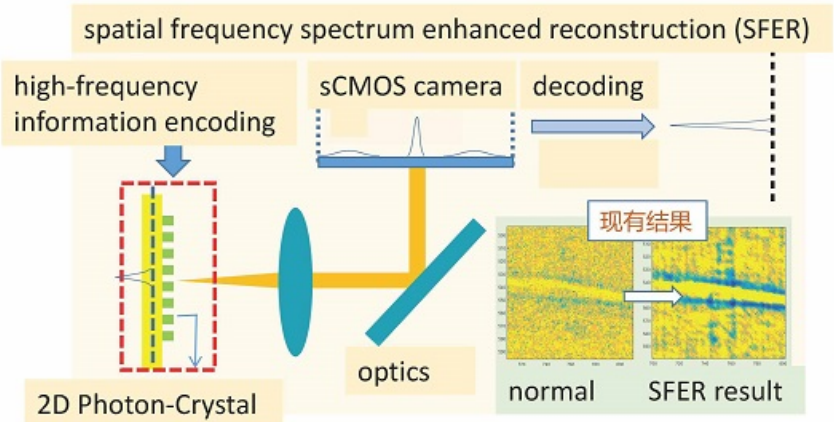


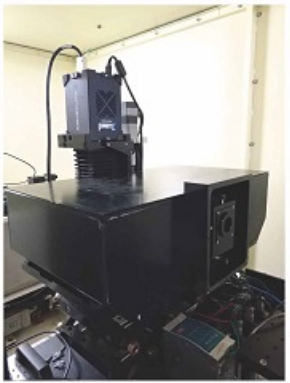
Lattice structures of sufficient depth have been fabricated by Large-area stitch XIL + double layer resist process; a layer of plastic luminescent film was coated on the photonic crystal layer to form a directional controllable emission luminescent layer.



Qiang Wu, Bo liu, Yanqing Wu et.al. Science Report (2018) 8:9254

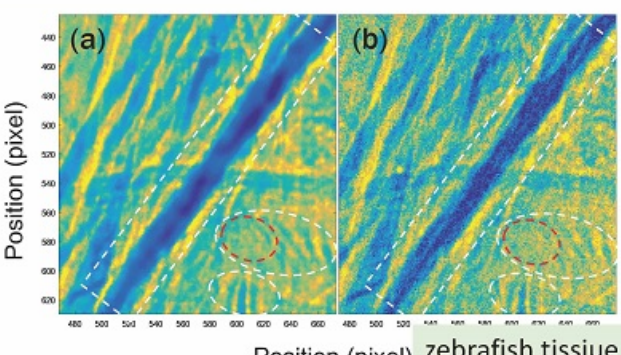
SFER indirect X-ray imager





High frequency signal to noise ratio increased by 6-50 times

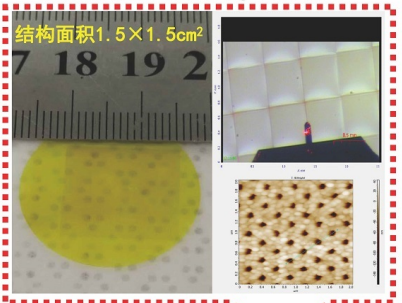
Chinese patent：201610118507.6
Paper submitted

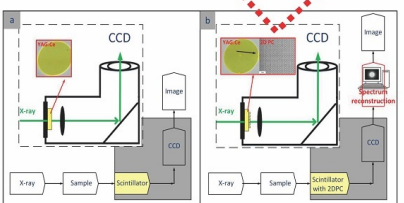


zebrafish tissiue

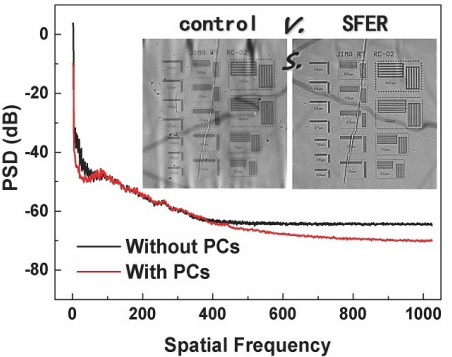
SFER imager fabricated by LAS-XIL

☐ large-area 2D photon crystal on YAG:Ce substract by LAS-XIL





☐ imaging results



Achieve selective high-frequency optical information extraction, image high-frequency signal-to-noise ratio increased by 5dB.

It is expected that the dose required for CT imaging will be greatly reduced under the same imaging condition.

Contents

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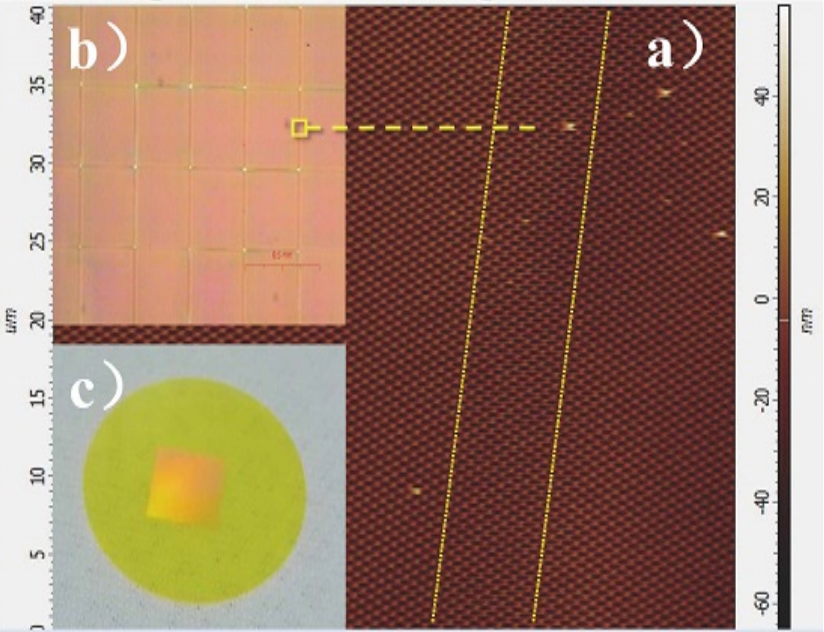
Nano-precision large-area stitching XIL

1. There are continuous structures on the edge region;
2. The light intensity of the edge region is decreased;
3. There are dislocations on the edge area

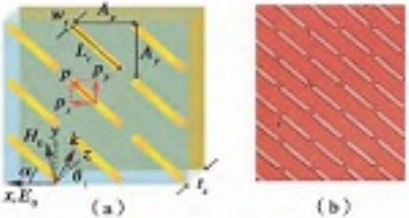


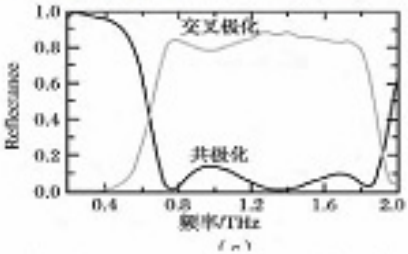
state of art
(AFM image)

Solution：Combine long-range motion with precise nano-displacement, which is achieved with holder moving stages with micron-level accuracy and a wafer stage with nanometer precision, along with feedback according interferemeter.

DW-ATL towards practical use

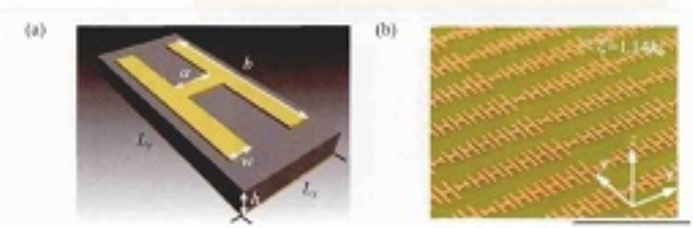
Physics of many metasurface is clear, However, the sample area is very small and far from practical use; DW-ATL can promote the practical and deviceized research on them.





sandwich structure meta-surface formed by periodic line segments

Efficient surface wave coupling with gradient-structure metasurface

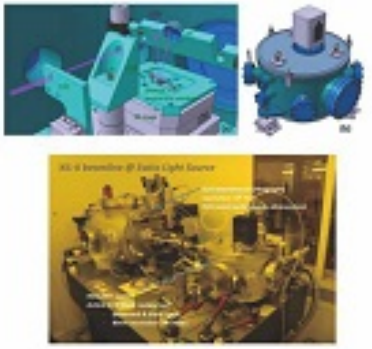


Change the arm length of the metal cell to control the reflection phase response of the meta-surface to electromagnetic waves.

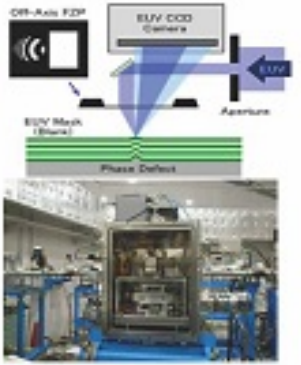
Synchrotron radiation application on EUV mask defect detection

Based on the synchrotron radiation source, the amplitude and phase imaging of the EUV mask can be performed by non-destructive using the reflective Ptychography method with nanometer resolution, especially the phase defects.

ALS SHARP Beamline

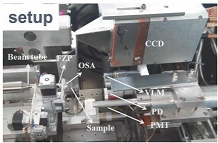


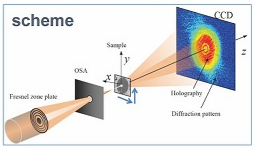
SLS XIL-II Beamline

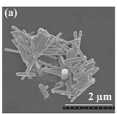


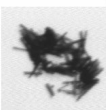
New Subaru BL03B

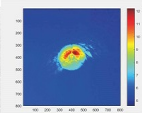
Ptychography Research at SSRF

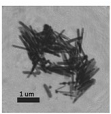


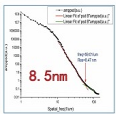












SEM image **20nm step STXM image** **diffraction image** **reconstruction** **PSD, resolution**

the spatial resolution is **better than 10nm** in our gruup

Welcome to cooperation to develop the method!

Summary

1. Some new interference Lithography methods have been developed in SSRF-XILbeamline， to meet users' needs:

1) Soft X-ray IL, Large-area stitching XIL for practical nanostructure fabrication;

2) Direct writing Achromatic Talbot lithography for meta-surface towards practice use in near future.

2. Some new plans are in progress, such as Nano-precision large-area stitching XIL and EUV mask testing based on synchrotron radiation.

Welcome all cooperations!

Thanks for your attention