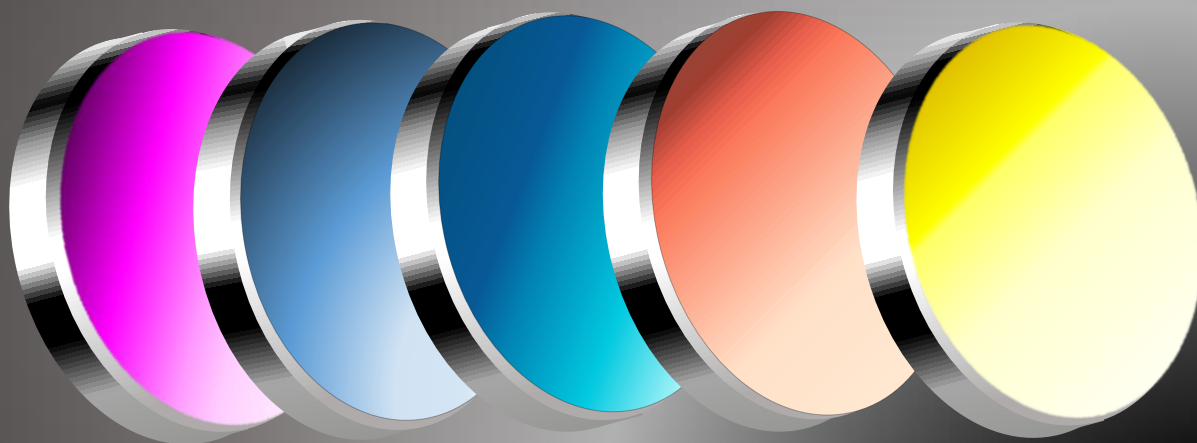


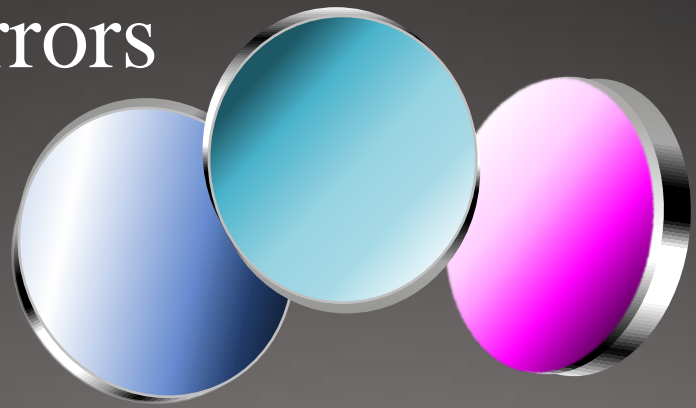
# NTT-AT's Optics and Materials



# Contents

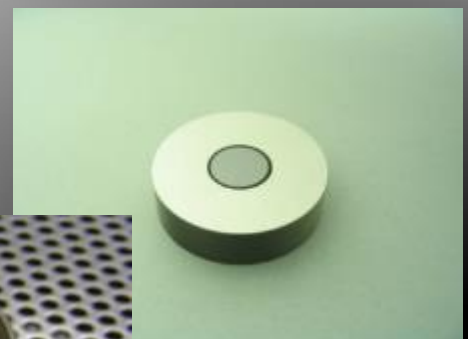
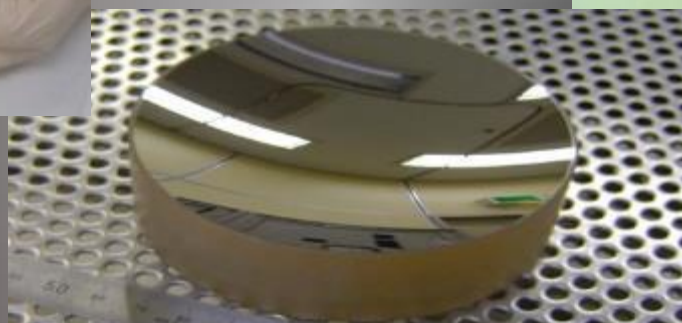
1	EUV optics	
	Overview	2
1.1	EUV Multilayer Mirrors	3
1.2	Toroidal Mirrors	7
1.3	Multilayer Polarizer	9
1.4	EUV Transmission Gratings	11
1.5	Multilayer Type Half Mirrors	12
1.6	EUV Dichroic Mirrors	13
2	Lenses	
2.1	UV Focusing Lenses	15
3	X-ray optics and samples	
3.1	X-ray Gratings	16
3.2	X-ray Fresnel Zone Plate	17
3.4	X-ray Filter	18
3.5	SiN membrane, SiC membrane	19
3.6	Test Pattern for EUV Diffraction Imaging	20
3.7	X-ray Resolution Test Chart	21
4	Analysis	
	Overview	22
4.1	TEM Analysis	23
4.2	FIB-SEM 3D Imaging	24
4.3	ICP Mass Spectroscopy	25
4.4	Total Reflection X-ray Fluorescence Spectroscopy	26
5	Materials	
5.1	GaN Epitaxial Wafers	27
6	Fabrication and Evaluation Tools	29
7	Contact	30

# Multilayer Mirrors

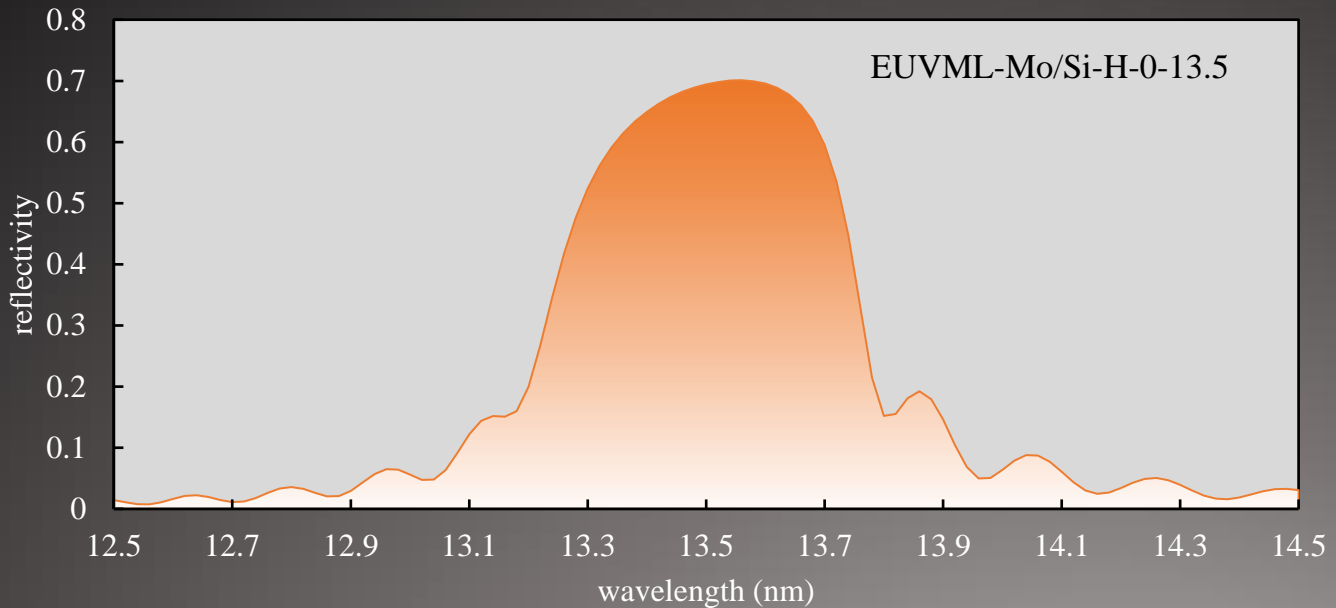


NTT-AT provides custom-made EUV multilayer mirrors for both academic fields and industrial fields. For high-quality mirrors developments, not only fabrication techniques but also optical design know-how is necessary. We have been supplying kinds of mirrors corresponding to the customers' requirements, such as high reflectivity, broad-bandwidth, narrow-bandwidth, and high contrast.

Our technologies will support your research and developments.



# EUV Multilayer Mirrors



P/N: EUVMML-(a)-(b)-(c)-(d)-(e)(f)



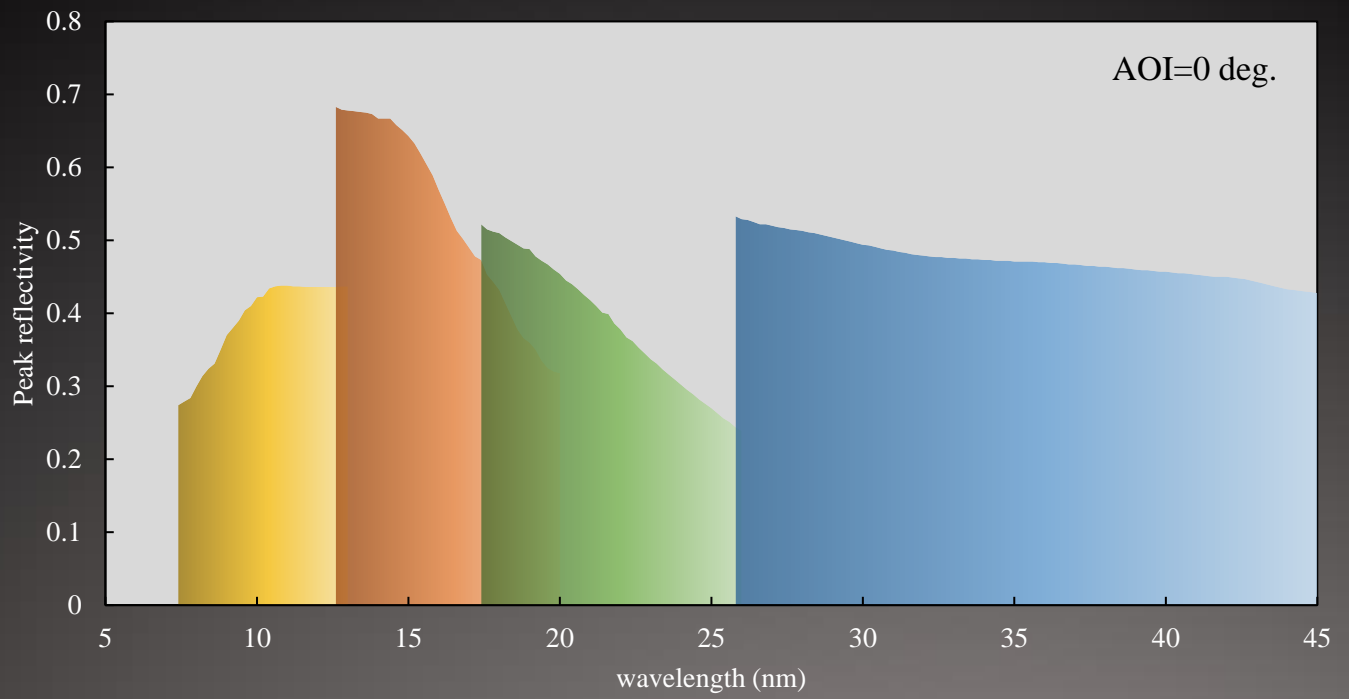
## Coating Specifications

- a) Multilayer material
  - Ru/B<sub>4</sub>C (7 nm – 13 nm)
  - Mo/Si (13 nm – 18 nm)
  - Zr/AlSi (17.5 nm – 26 nm)
  - SiC/Mg (26 nm – 50 nm)
- b) Reflection type
  - H: High reflection
  - N: Narrowband reflection
  - B: Broadband reflection
- c) AOI : 0 deg. – 60 deg.
- d) Peak wavelength (nm)

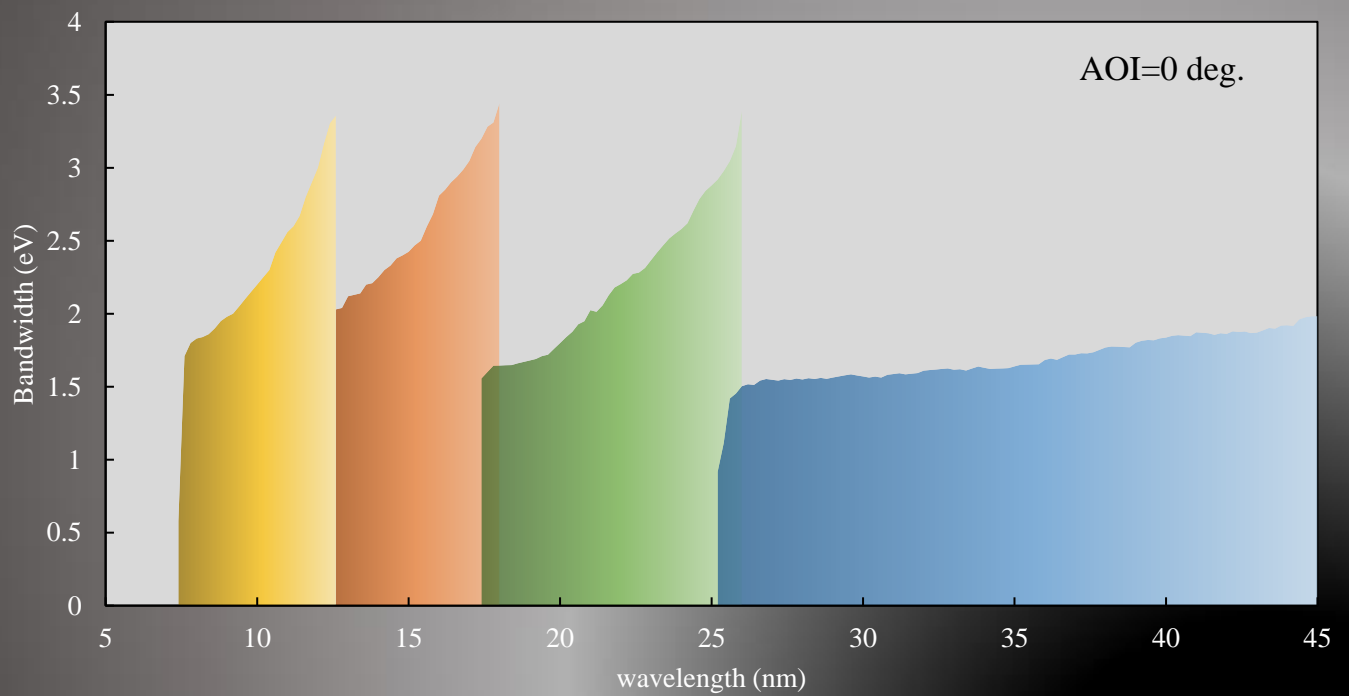
## Substrate Specifications

- e) Dimensions
  - 1025: 1" dia., 0.25" thick
  - 0525: 0.5" dia., 0.25" thick
- f) Figure and radius of curvature
  - F: Flat
  - C: Concave

# High reflection mirrors

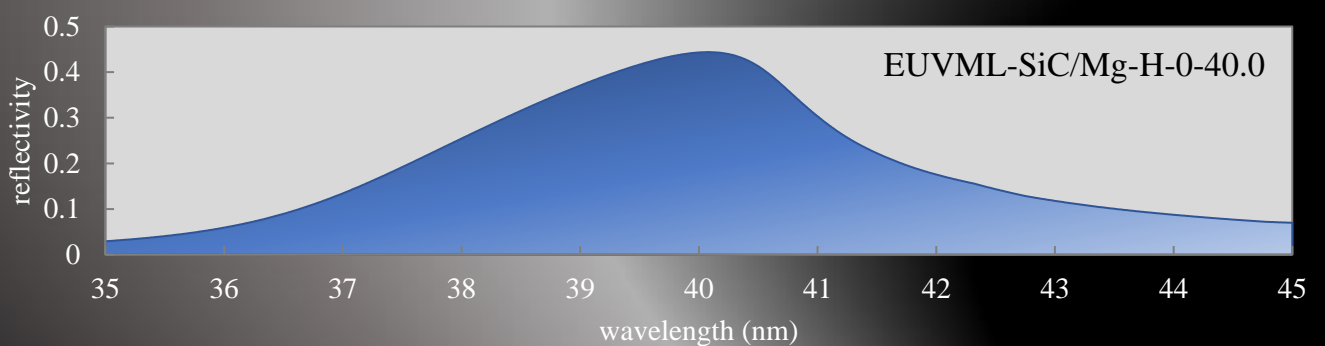
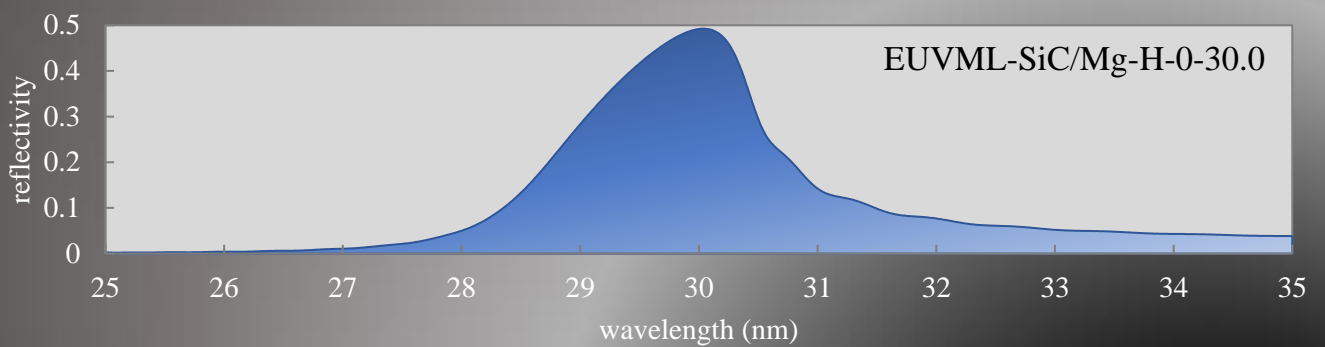
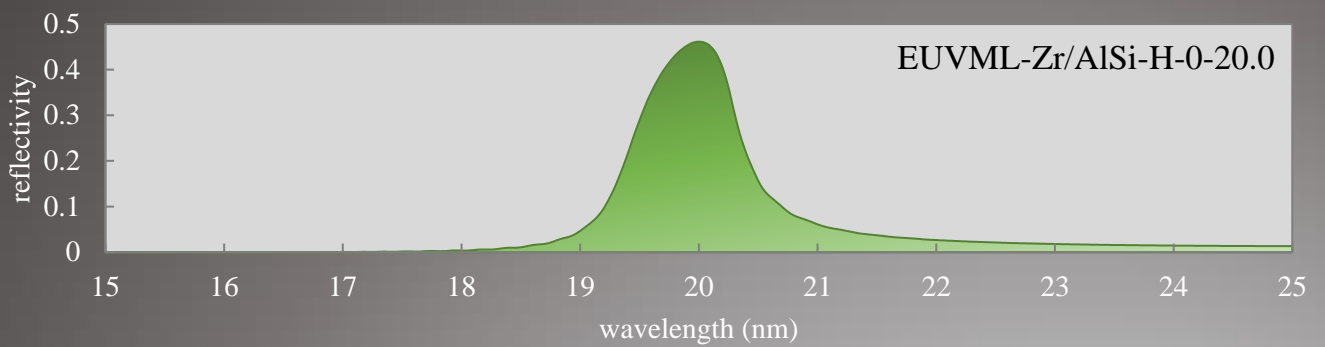
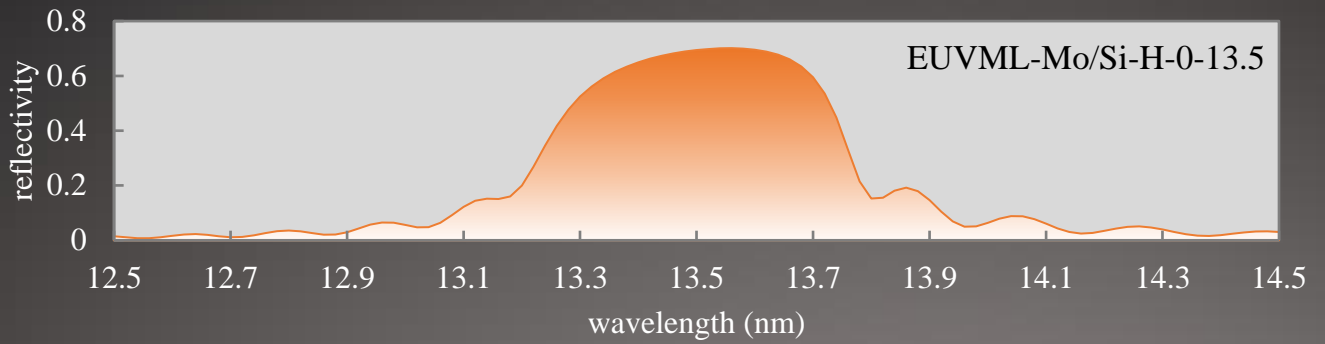
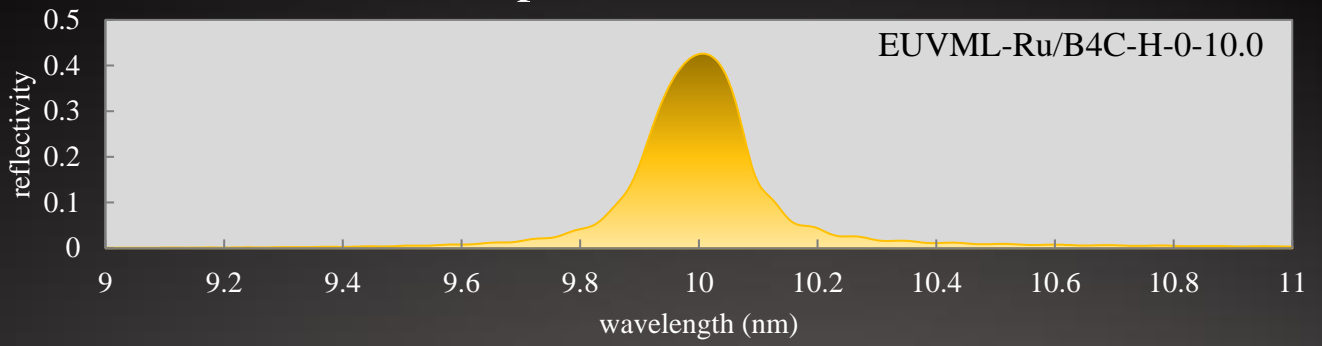


# Narrowband reflection mirrors

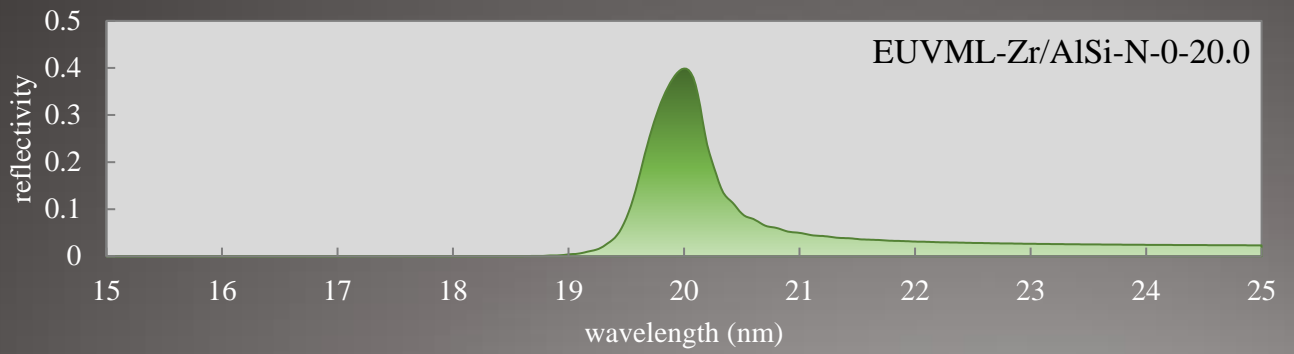
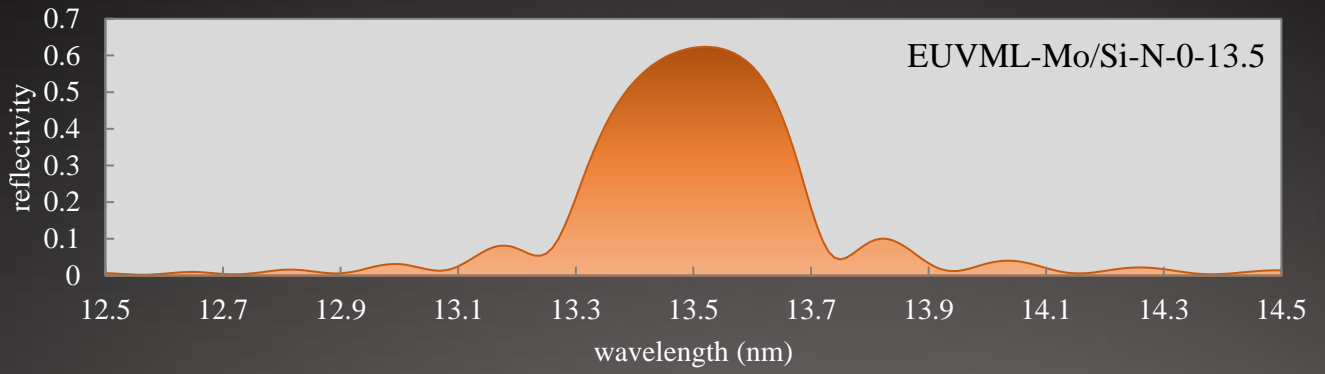


- Ru/B<sub>4</sub>C (7 nm – 13 nm)
- Mo/Si (13 nm – 18 nm)
- Zr/AlSi (18 nm – 26 nm)
- SiC/Mg (26 nm – 50 nm)

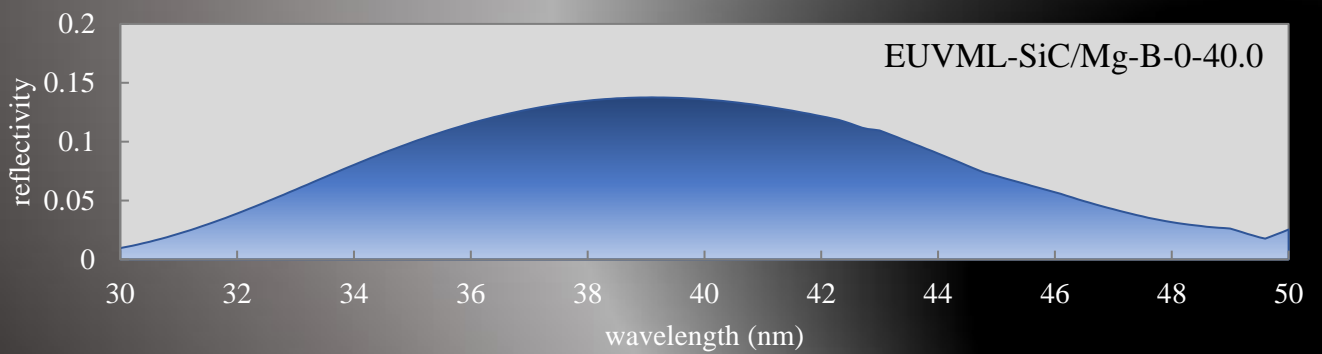
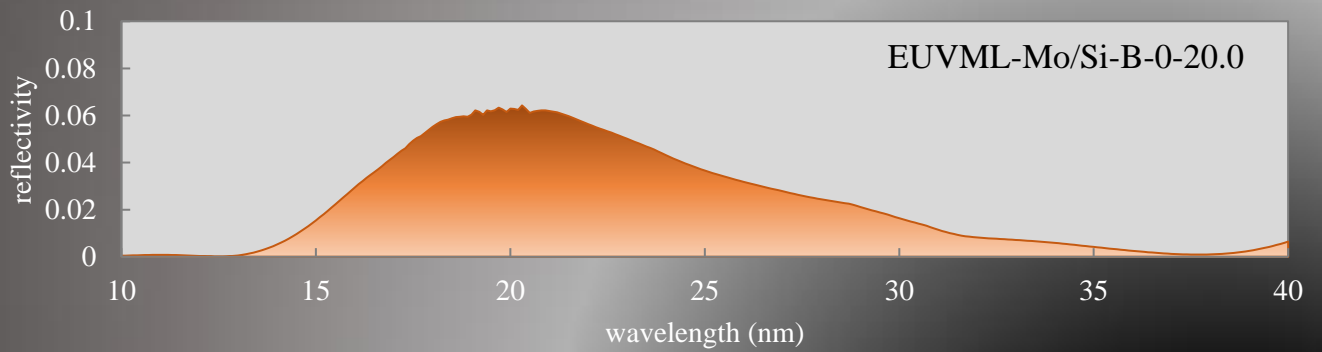
# High reflection mirrors example



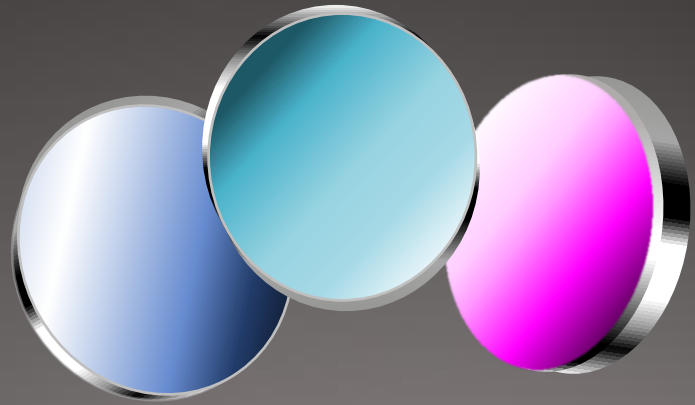
# Narrowband reflection mirrors example



# Broadband reflection mirrors example



# Toroidal Mirrors



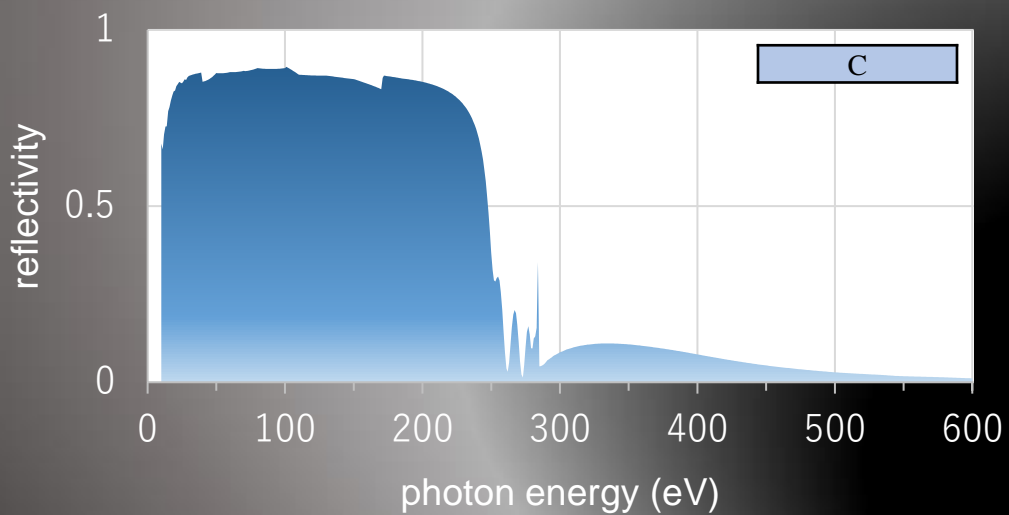
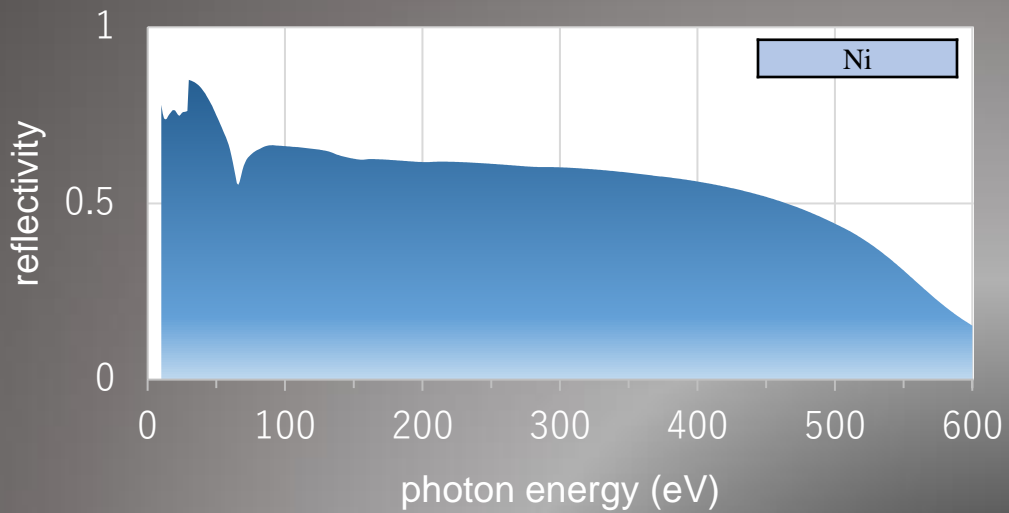
NTT-AT has been supplying high-quality custom toroidal mirrors for all UV-EUV applications. In particular, backed by its extensive experience and outstanding skills, it provides custom-designable toroidal mirrors adapted to meet individual customer requirements.





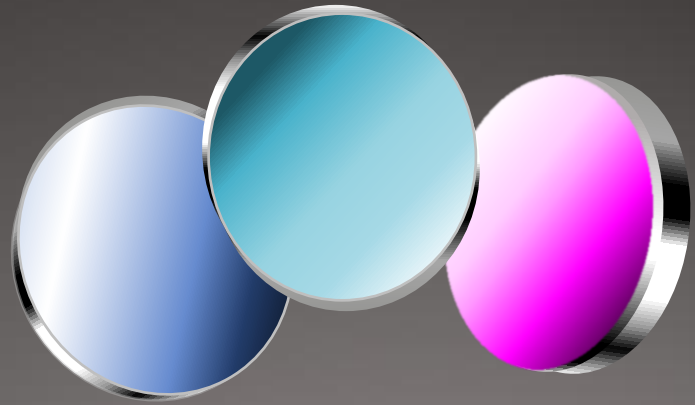
Parameters for custom specifications	
Max Length	150 mm
Radius	> 10 mm
Surface Accuracy	< $\lambda / 4$ @ 633 nm
Surface roughness	< 0.5 nm rms
Surface Quality	20-10
Material	Fused Silica
Coating	Au, Ni, Ru, SiC, B <sub>4</sub> C, C

## Coating examples



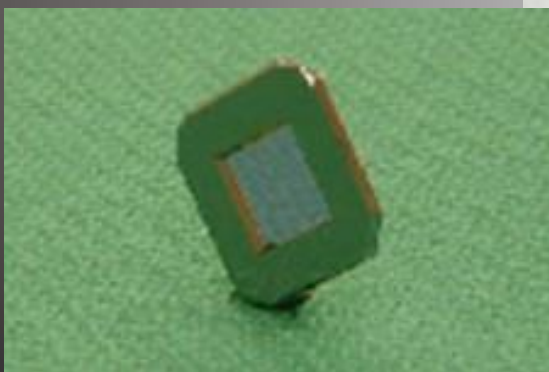
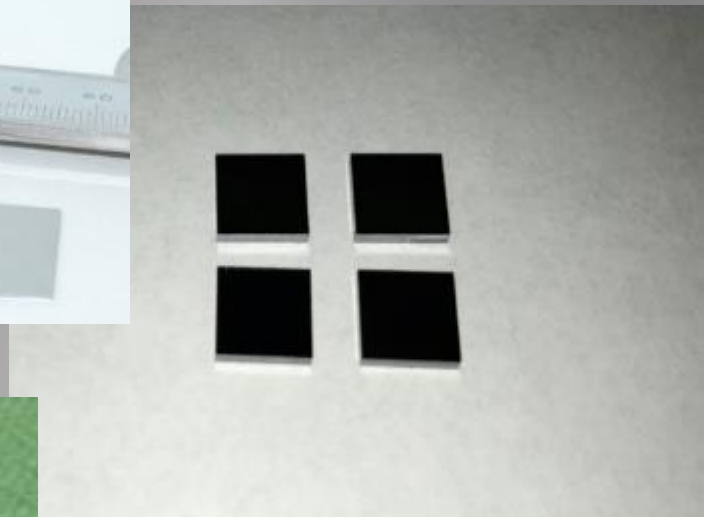
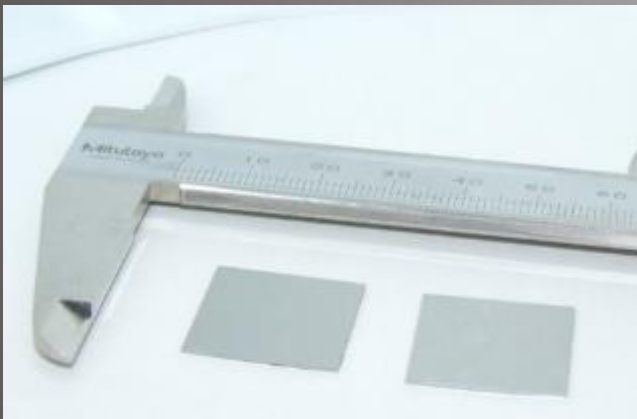
Grazing incident angle: 5 deg.

# Multilayer Polarizer

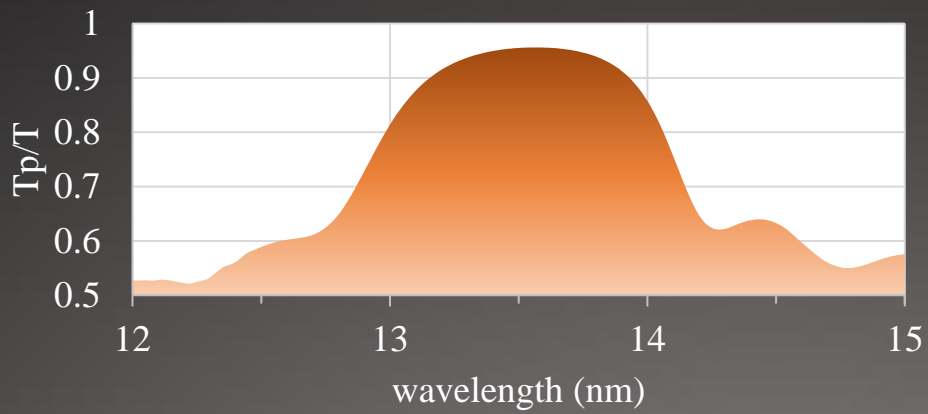


In EUV and soft x-ray region, Brewster angle of multilayer materials are around 45 deg., thus, in synchrotron science and ultrafast EUV science fields, 45-deg. multilayer are used as polarizers.

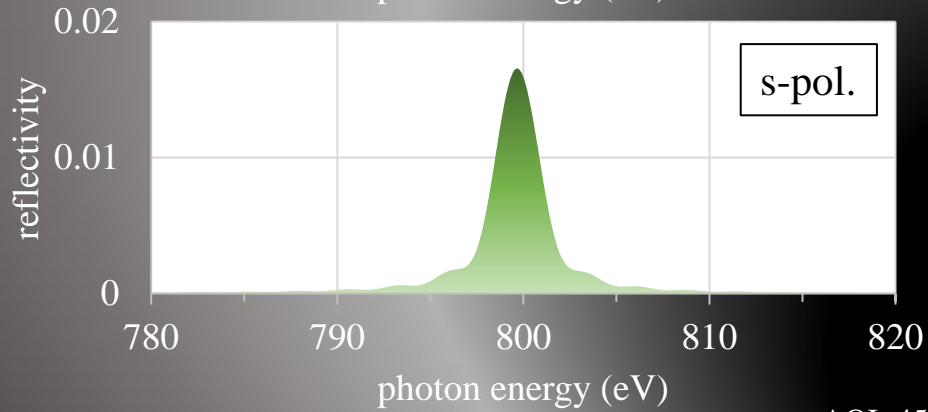
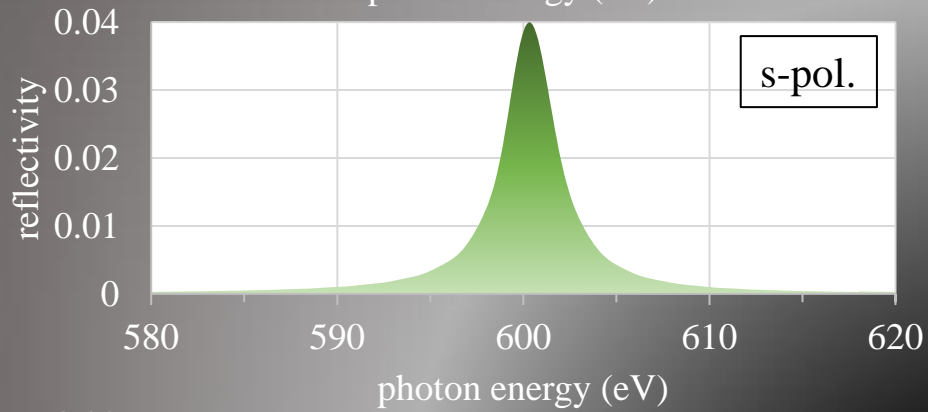
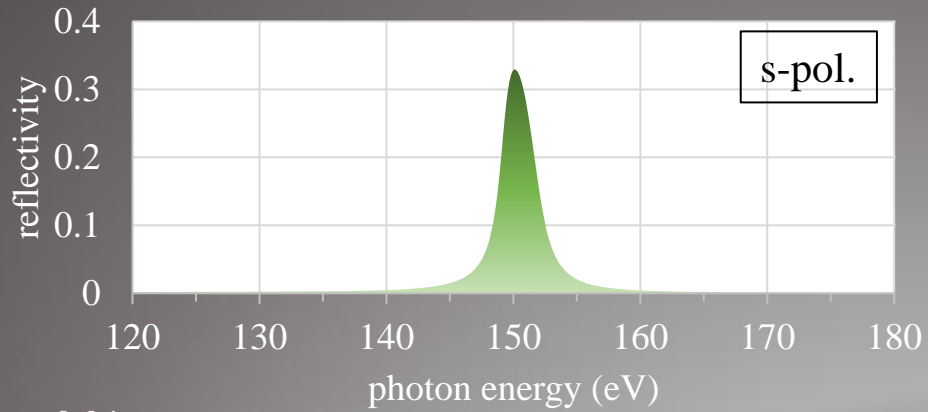
NTT-AT provides both reflective type and transmission type multilayer polarizers corresponding to your required material bandgap.



## Transmission type examples



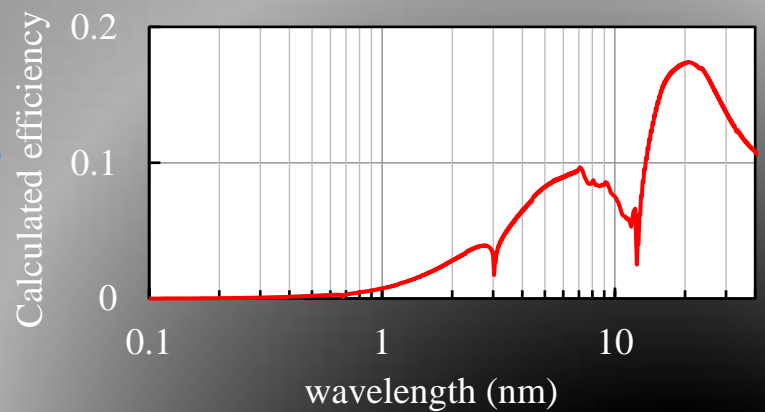
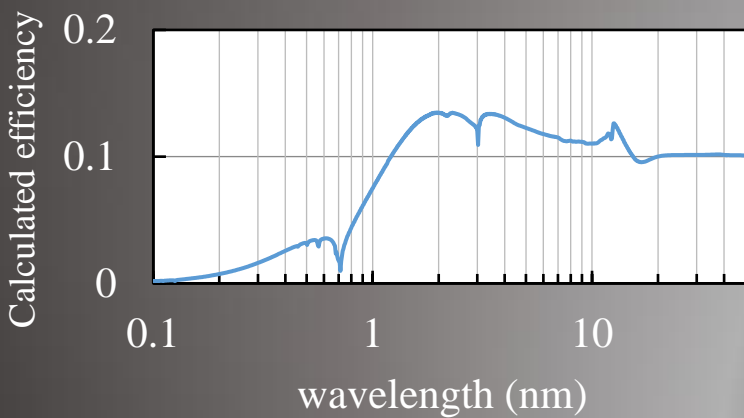
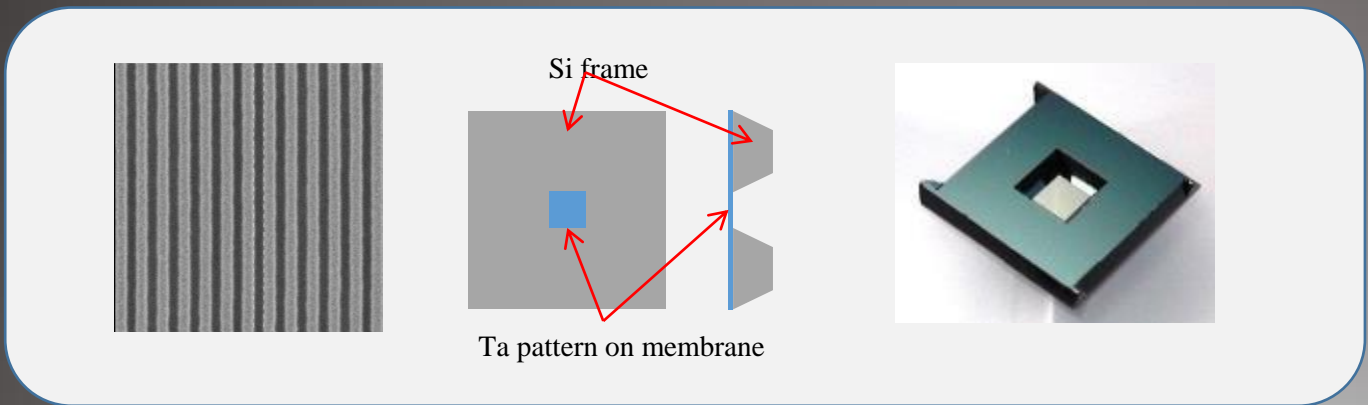
## Reflective type examples



AOI=45 deg.

# EUV Transmission Grating

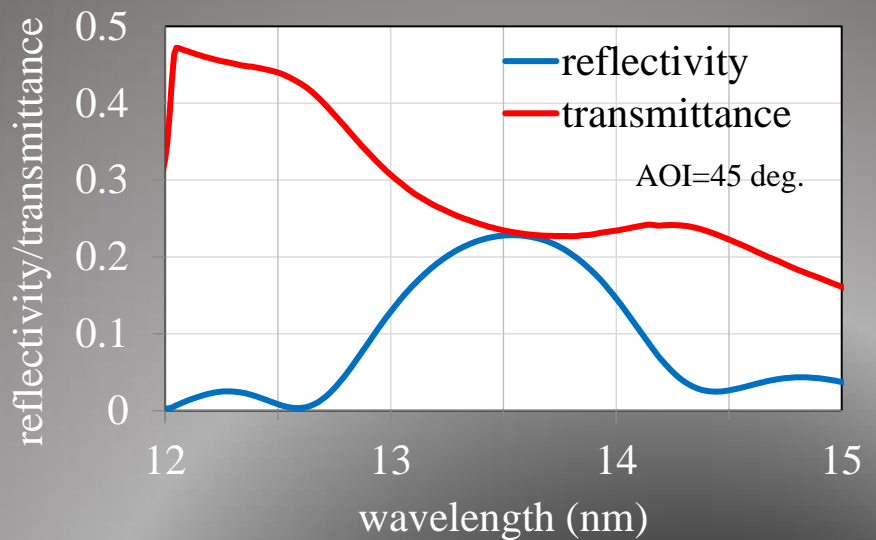
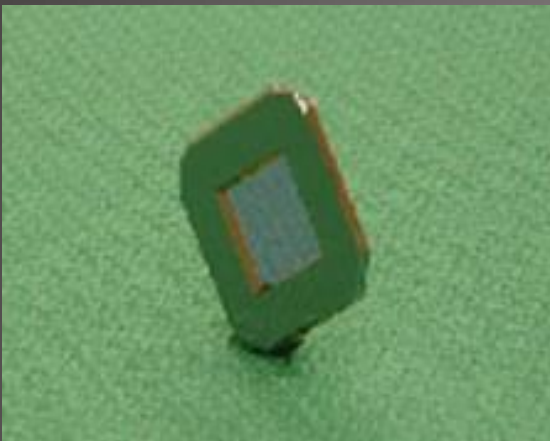
NTT-AT provides custom-made EUV transmission grating (TG) for spectroscopy, beam monitor, and beam separator. This free-standing Ta/SiN bilayer or SiN single-layer grating with low side-wall roughness and high-sharpness realizes ideal EUV diffraction



	Ta/SiN type	SiN type
Grating area	2 × 2 mm	
Grooves	100 – 1200 lines/mm	
Support bar	500 nm width, 50 μm pitch	
Material	Ta (100 nm) and SiN (100 nm)	SiN (100 nm)
Flame	10 × 10 × 0.625 mm Si	

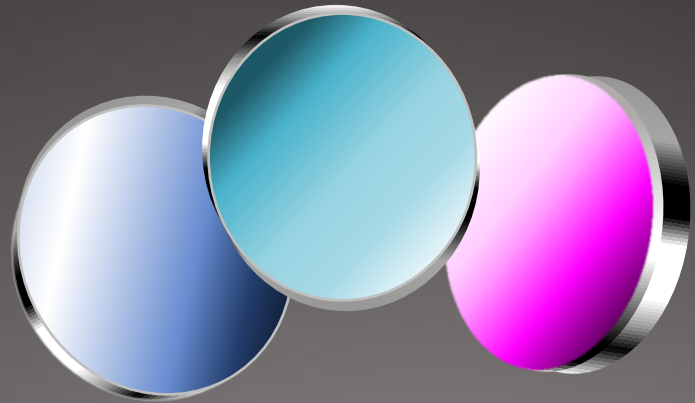
# Multilayer type Half Mirrors

NTT-AT's multilayer type half mirrors, also known as a EUV beam splitter, realizes interferometric experiments operating in a similar way to those for the visible region. This free-standing Mo/Si multilayer is applied to various applications in the EUV field such as microscopes, astronomical telescopes, pump-probe experiments and beam monitor systems.



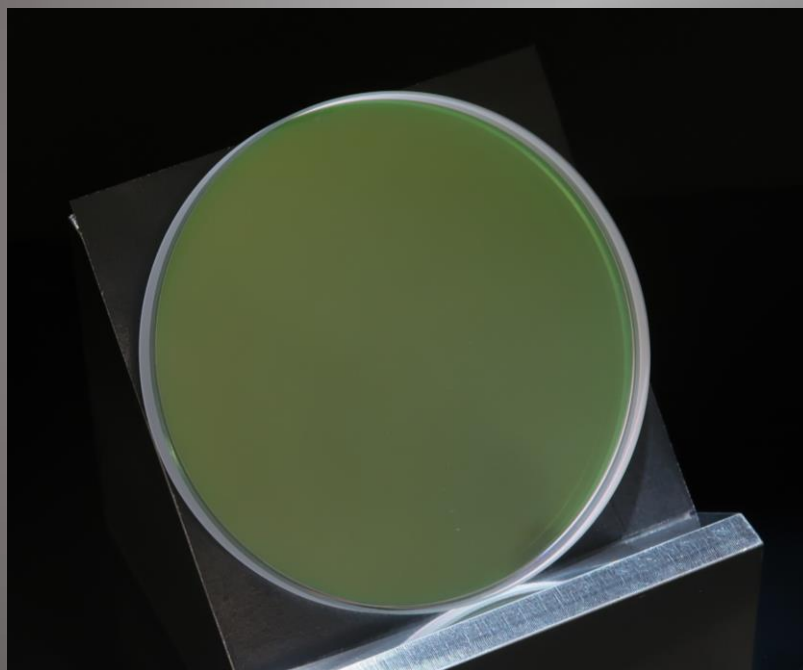
Typical specifications	
Holder diameter	25.4 mm
Half mirror area	10 mm × 10 mm
Incident angle:	0 deg. – 45 deg.
Center wavelength:	13 nm – 15 nm
Customization is available upon request.	

## EUV Dichroic Mirrors



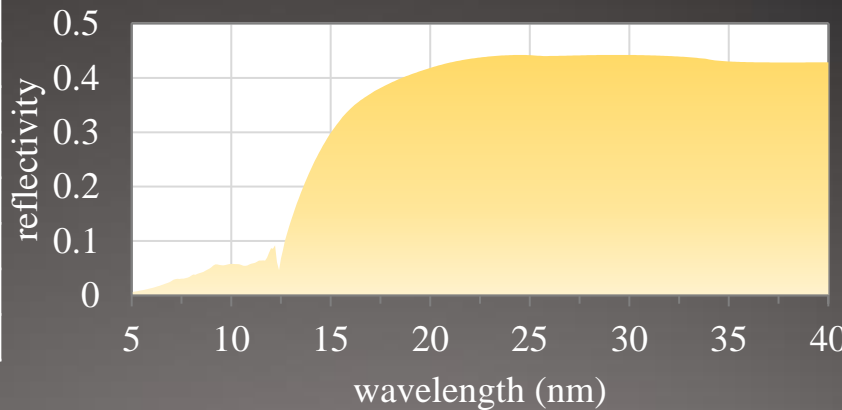
For high-order harmonics experiments, beam separation technology between EUV and NIR with high-efficiency, high-damage threshold, and broad bandwidth is required. NTT-AT provides standard and custom-made EUV dichroic mirrors (DM) corresponding to your target energies.

The dielectric multilayer AR coating based DM has higher damage threshold than that of Brewster angle type beam separator and thin film EUV filter. In addition, this mirrors can be used for beam combiner between EUV and NIR.

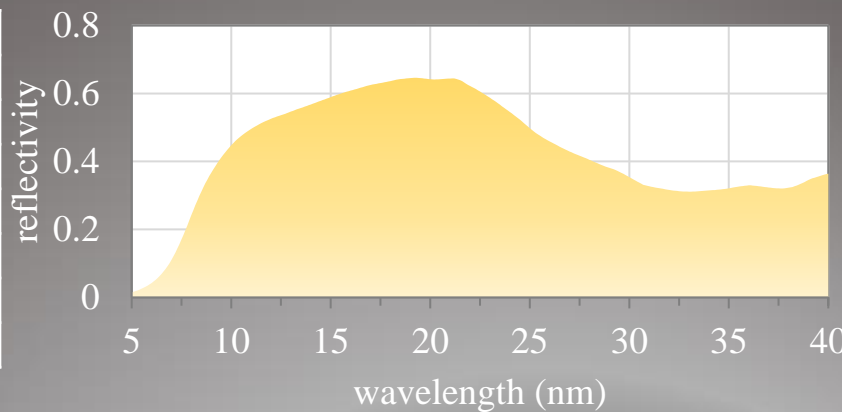


## Standard Dichroic Mirrors

Design Name	DM-30/800-2010
AOI	78 deg
polarization	p
NIR reflectivity	~2% @800 nm+/- 50 nm
EUV reflectivity	~45% @30 nm
Coating	Dielectric AR
Substrate material	Fused silica
Size	2" dia., 0.2" thick



Design Name	DM-20/800-2010
AOI	78 deg
polarization	p
NIR reflectivity	~2% @800 nm+/- 50 nm
EUV reflectivity	~60% @20 nm
Coating	Dielectric AR
Substrate material	Fused silica
Size	2" dia., 0.2" thick



## Custom made Dichroic Mirrors

AOI	70 deg. – 87 deg.
Polarization	s, p
AR wavelength	Visible, NIR, MIR
HR wavelength	Soft x-ray, EUV, VUV
Substrate material	Fused silica
Substrate size	1" dia. – 4" dia.

Reflectivities are depended on incident angle, target wavelength and polarization.



# UV Focusing Lenses

NTT-AT provides focusing relay lenses for UV and VUV photoelectron spectroscopy application. Both standard models and custom-made model will help your sub-5  $\mu\text{m}$  ARPES experiments.



## Standard lenses

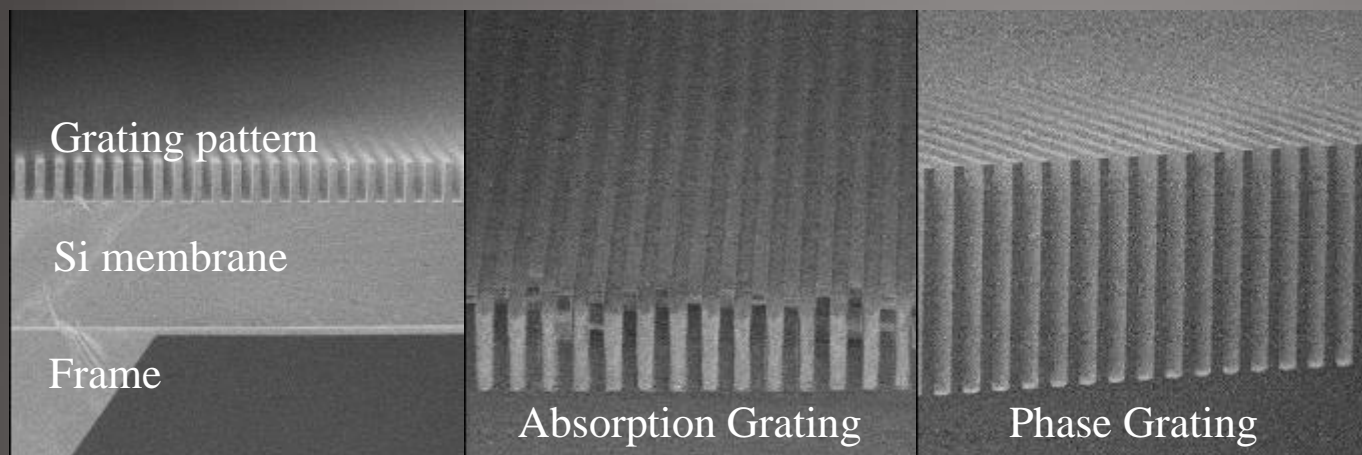
	AUL-250-190	AUL-320-177
Lens Material	Fused Silica	CaF <sub>2</sub>
Lens Coating	AR	AR
Wavelength	190 – 210 nm	177 nm
Incident beam dia.	1.7 mm	1.7 mm
Working Distance	250 mm @ 190 nm 310 mm @ 210 nm	320 mm @ 177 nm
Length	~145 mm	~250 mm
Throughput	91% @ 190 nm	75% @ 177 nm
Focusability	< 5 $\mu\text{m}$	~5 $\mu\text{m}$



# X-ray Gratings

NTT-AT's high-contrast and high-sharpness X-ray gratings are optimized for x-ray Talbot imaging.

- Low side-wall roughness
- High edge sharpness
- High contrast X-ray imaging



Specification	Absorption Grating	Phase Grating
Material	Au	Si
Membrane	Si, 50 $\mu\text{m}$ thick	Si, 50 $\mu\text{m}$ thick
Pitch/height	3 $\mu\text{m}$ / 10 $\mu\text{m}$	2 $\mu\text{m}$ / 20 $\mu\text{m}$
Max. area	10 mm sq.	40 mm sq.
Customized are available		

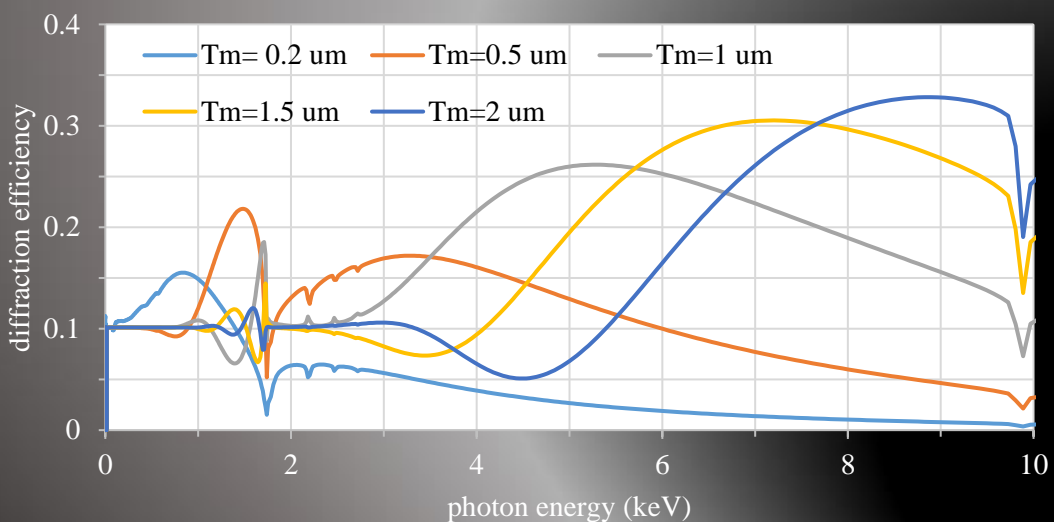
# X-ray Fresnel Zone Plate

NTT-AT provides custom-made Fresnel zone plate (FZP) for soft x-ray as well as EUV region. Only NTT-AT provide the SiC membrane based FZPs, which has high x-ray irradiation durability. And our Ta absorber FZPs have high pattern sharpness, low side-wall roughness, and high spatial uniformity.

## Proposal Specification FZPs



Minimum zone width (outer most zone)	25 nm
Maximum diameter	5 mm
Membrane material	SiN, SiC
Membrane thickness	0.2 – 2 $\mu\text{m}$
Absorber material	Ta
Absorber thickness ( $T_m$ )	0.1 – 2 $\mu\text{m}$
Si substrate shape	10 mm square
Si substrate thickness	0.625 mm

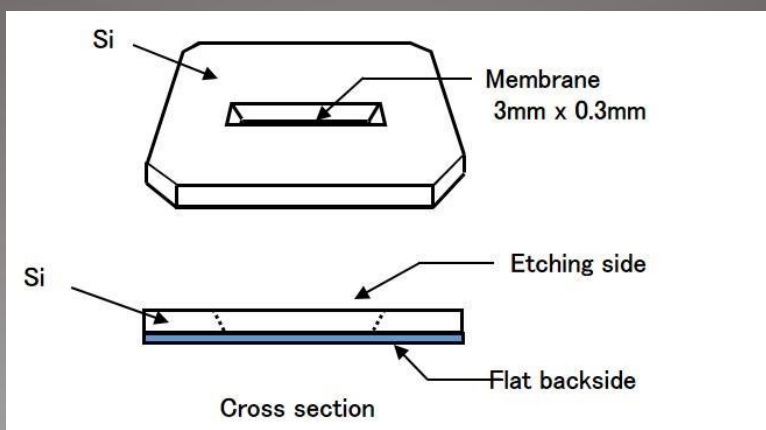


# X-ray filter

Suitable for sample analysis at soft x-ray application

Both SiN and SiC membranes available

Very thin metal layer coated on the flat backside as well as the etching side (optional)



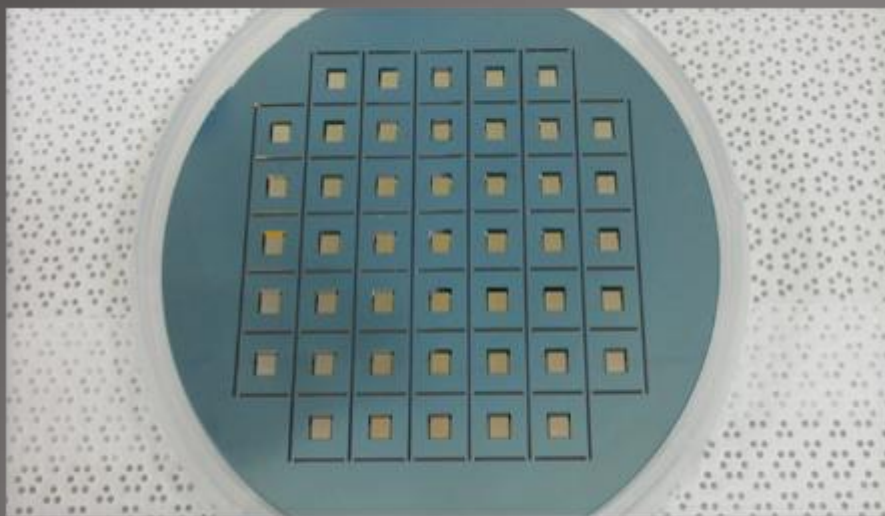
Model	Membrane material and thickness	Metal layer on the Flat backside
FIL-AUTI-SIC-20-303	SiC, 150 nm	Au (11 nm)/Ti (3 nm)
FIL-AUCR-SIC-20-303	SiC, 150 nm	Au (11 nm)/Cr (3 nm)
FIL-SIC-20-303	SiC, 150 nm	non-coating
FIL-AUTI-SIN-10-303	SiN, 150 nm	Au (11 nm)/Ti (3 nm)
FIL-PTTI-SIN-10-303	SiN, 150 nm	Pt (11 nm)/Ti (3 nm)
FIL-SIN-10-303	SiN, 150 nm	non-coating

Optin: rTI: Ti (3 nm) coating on the etching side

# SiN membrane, SiC membrane

Only NTT-AT provides SiC membranes. This SiC poly-crystalline thin film has a higher durability for x-ray irradiation and e-beam irradiation comparing that of SiN membrane.

Our SiN membranes and SiC membranes are used as sample holders, liquid cells and vacuum window in both basic research fields and industrial fields.

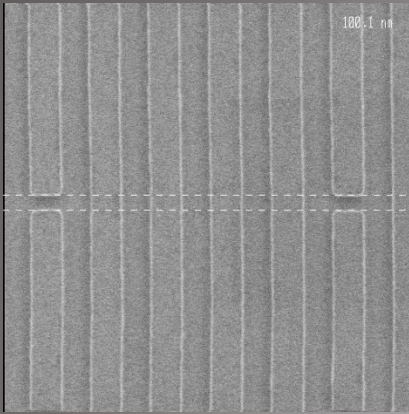


Specifications	SiN membrane	SiC membrane
Thickness	50 nm – 6 μm	100 nm – 2 μm
Window size	0.5 mm × 0.5 mm to 10 mm × 10 mm	
Flame material	Si	
Flame thickness	0.625 mm ( or thinner)	
Options	Metal coating Slit / Pinhole formation Multi-window on chip	

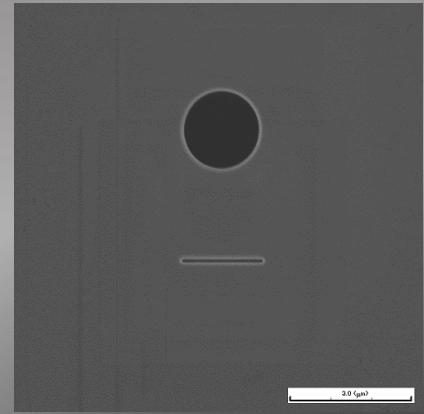
# Test Pattern for EUV Diffraction Imaging

NTT-AT's reflection type test patterns are used for high-order harmonics based diffraction imaging at EUV wavelength region, especially 13.5 nm. The Ta absorber pattern design on Mo/Si multilayer is customized for depending on your experimental set up.

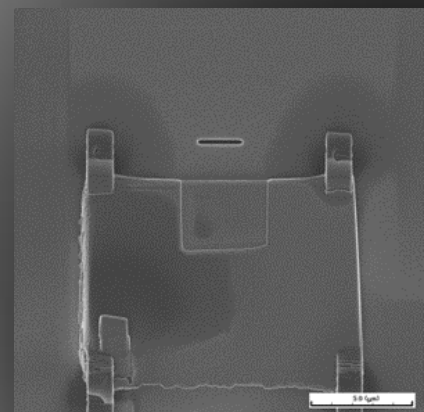
The transmission type test patterns are applied for broadband source at EUV region. Slits, pinholes, and other patterns are fabricated by using FIB on metal coated SiN membrane. The micro-sampling also offered.



Ta absorber on Mo/Si multilayer  
LS pattern with 100 nm bridge



100 nm width slit and pinhole

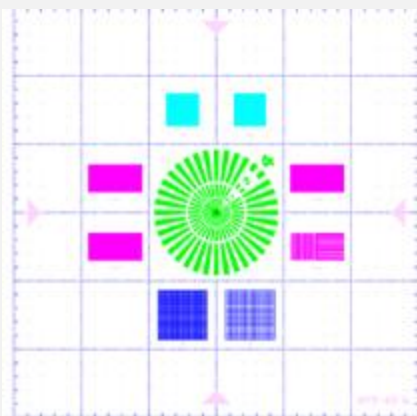


Micro sampling chip on pinhole



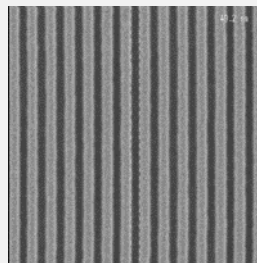
# X-ray Resolution Test Chart

NTT-AT's x-ray resolution test charts are applied to several x-ray analysis required ultra-fine resolution, such as x-ray microscopy and x-ray inspection. Our Ta absorber resolution test charts are used as de facto standards in world wide customers.

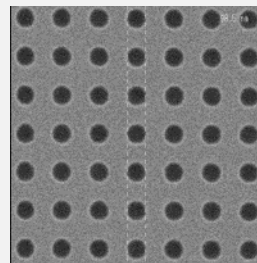


Pattern layout overview

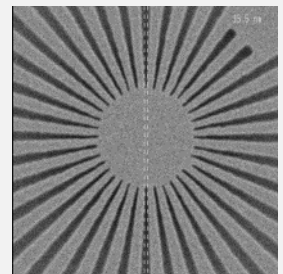
50 nm L&S



100 nm hole



20 nm radial pattern



XRESO Series Specifications		XRESO-100	XRESO-50HC	XRESO-20
Substrate	Material / Size	Si 10mm square		
	Thickness	1 mm	1 mm	0.625 mm
Membrane	Material /Thickness	Ru 20 nm SiN 2 μm	Ru 20 nm SiN 50 nm SiC 200 nm	Ru 20 nm SiN 50 nm SiC 200 nm
	Size	1 mm square	1 mm square	1 mm square
Pattern	Absorber	Ta 1μm	Ta 500 nm	Ta 100 nm
	Minimum pattern size	100 nm	50 nm	20 nm at Radial Pattern
	Patterned area	250 μm × 350 μm	300 μm square	300 μm square

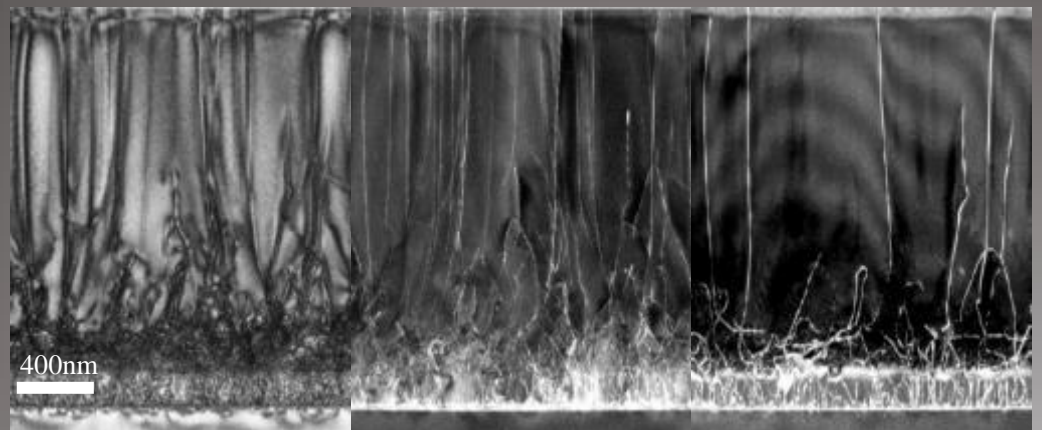
# Analysis

NTT-AT provide most advanced material analysis services. Even atomic level observations are available. We have supported NTT's leading telecom services directly or indirectly through NTT Laboratories' R&D. Our technologies come from reputed NTT Laboratories, which have been publishing outstanding analytical data and images on top academic and technical journals. We can cater to corporate R&D, quality assessments and trouble shooting as well as academic research with track records over 30 years. Technical areas extend across semiconductor, nano-technologies, material science, optics, electronics, and others. Combined with those analytical services, we can offer micro-fabrication services to meet your various demands and requests.

# TEM analysis

NTT-AT provides TEM solutions for material science, opto-electro science, and the other wide fields. We also support TEM related simulations for better understanding of microscopic material properties.

## Dislocations

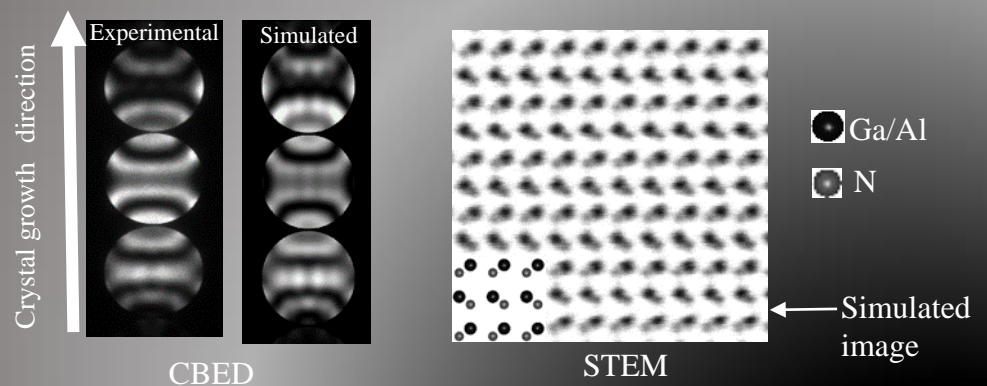


Bright field

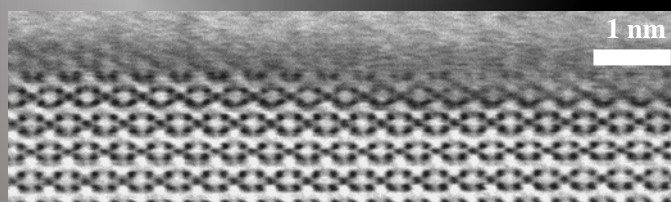
Dark field ( $g=1120$ )

Dark field ( $g=0002$ )

## Polarity



## Substrate



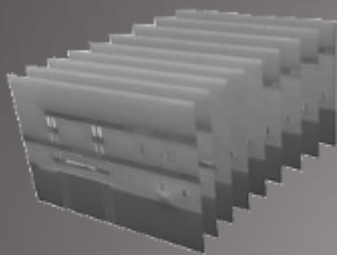
STEM image of sapphire substrate surface (R-plane)



# FIB-SEM 3D Imaging

NTT-AT provides 3D reconstructed SEM images to observe various materials from a three-dimensional viewpoint, and analyzes their structures, defects, and vacancies. 3D FIB-SEM can analyze the structure in three dimensions by repeatedly processing and observing the sample. 3D FIB-SEM can grasp the structure from various directions by extracting and visualizing arbitrary cross sections.

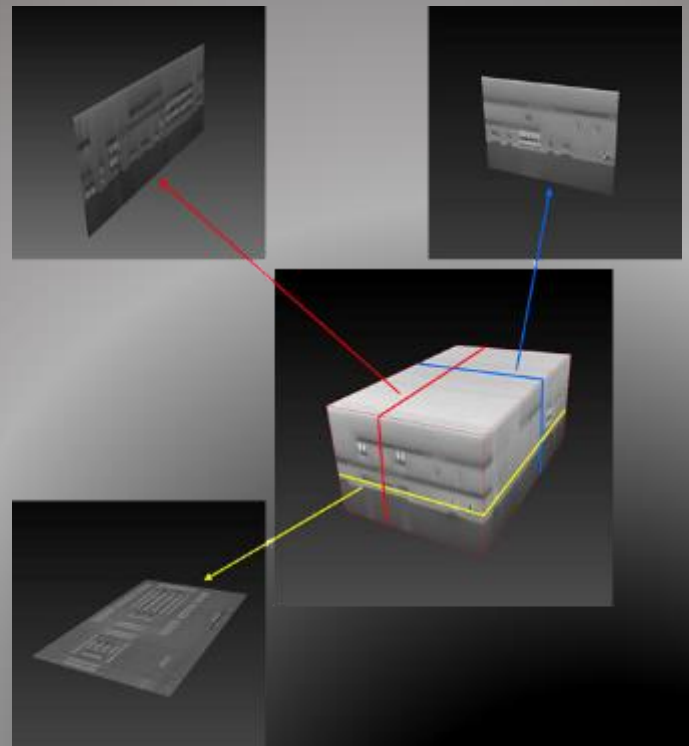
## Example of FIB-SEM 3D Imaging



Step1 FIB slightly process and observe the exposed cross section with SEM



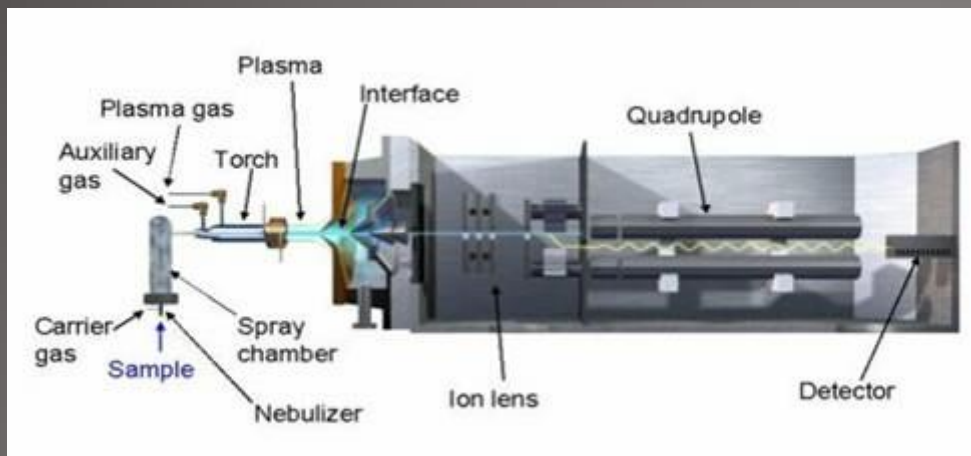
Step2 The acquired SEM images are reconstructed into 3D software



Step3 Extract and visualize any cross section

# ICP Mass Spectroscopy

NTT-AT provides high-sensitivity and high-precision ICP mass spectroscopy (ICP MS) solutions for both basic research fields and industrial fields. Our ICP MS sensitivity reach to sub parts per trillion level.

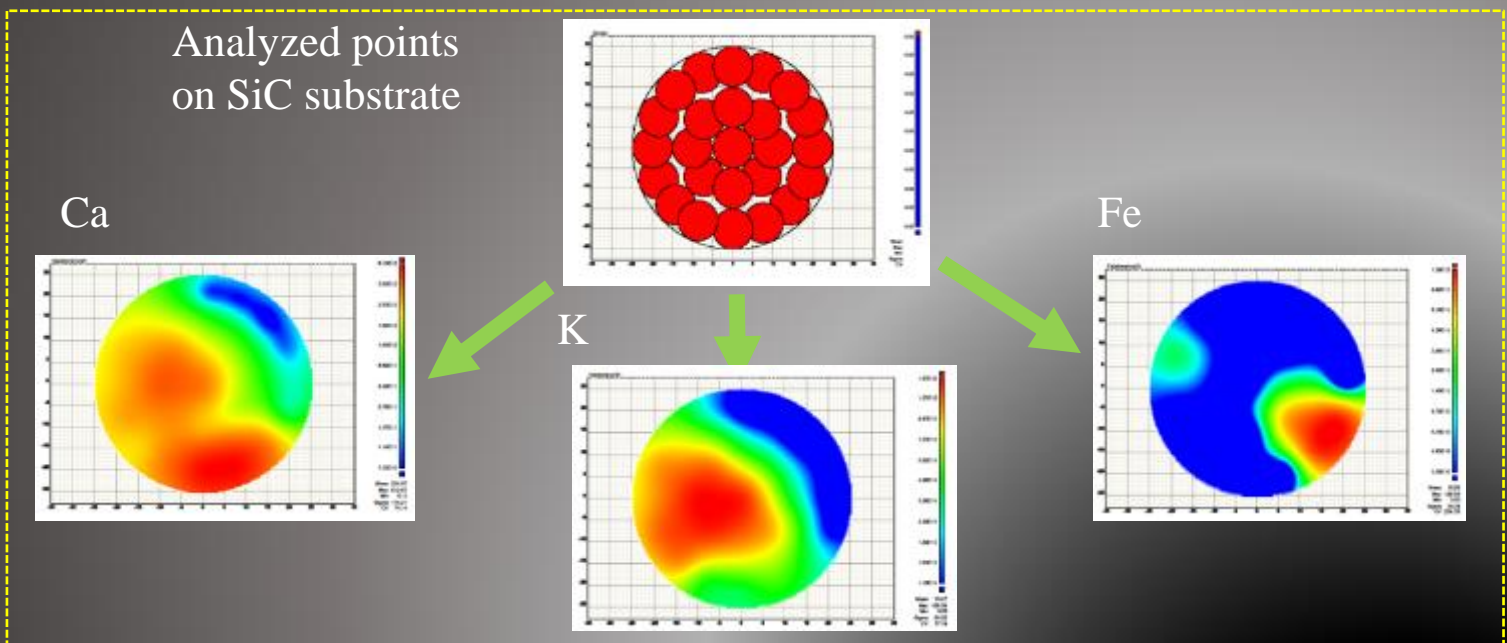
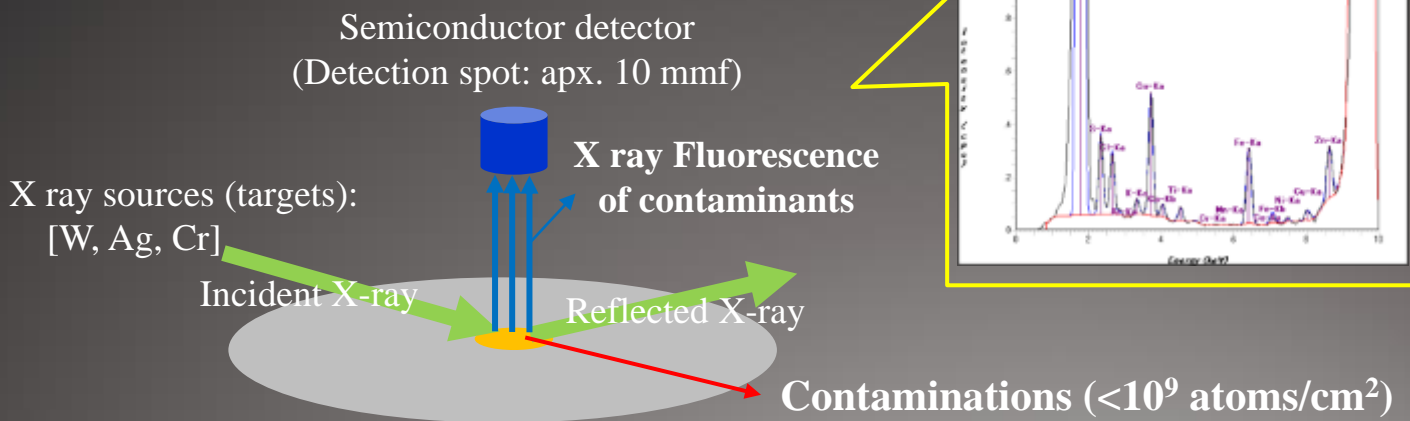


Provided by Agilent Technologies

## Example

- Wafer surface metal contamination  
Applicable size 4 inches to 12 inches
- Impurity in bulk
- Pure water, impurities in reagents
- Dissolution amount of metal component from parts
- Thin film composition and impurity analysis
- Environmental analysis of river water

# Total Reflection X-ray Fluorescence Spectroscopy



- Various substrates: Si, sapphire, GaAs, Glass, thin films (metal, organic inorganic), others which wet analyses can not handle.
- High sensitivity:  $<10^9$  atoms/cm<sup>2</sup>
- Simultaneous multiple elements analyses (Na - U)
- Quick, non-destructive, non-contact (without pretreatment), highly-reproducible

# GaN Epitaxial Wafers






NTT-AT provides excellent GaN HEMT epitaxial wafers for device manufacturers, with high uniformity and high breakdown voltage which are achieved by controlling the growth conditions precisely and by using a unique buffer layer.

## GaN Epi Product Lineup

Epi-products	Substrate	Wafer size
AlGaIn/GaN HEMT InAlN/GaN HEMT (also other structures available, like SBD, single layers, sensor)	Si	3 - 8 inches
	SiC	2 - 4 (6) inches
	Sapphire	2 - 3 inches
	GaN	2 - 4 inches

## Layer Structure and Typical Features (AlGaIn/GaN HEMT)

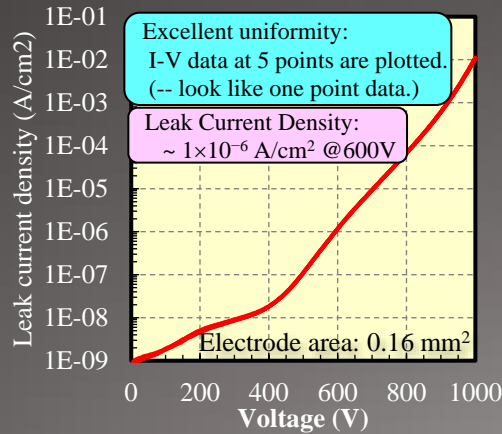
<b>Barrier Layer</b>	AlGaIn/GaN Surface	 on Sapphire	Sheet resistance	~300 ohm/sq. <sup>1)</sup> , ~400 ohm/sq. <sup>2)</sup>
<i>2DEG</i>			Sheet carrier density	~10 <sup>13</sup> cm <sup>-2</sup>
GaN Layer			Electron mobility	~2,000 cm <sup>2</sup> /Vs
Buffer Layer			 on Si	
Sub.	 on SiC			

1) with AlN spacer  
2) without AlN spacer

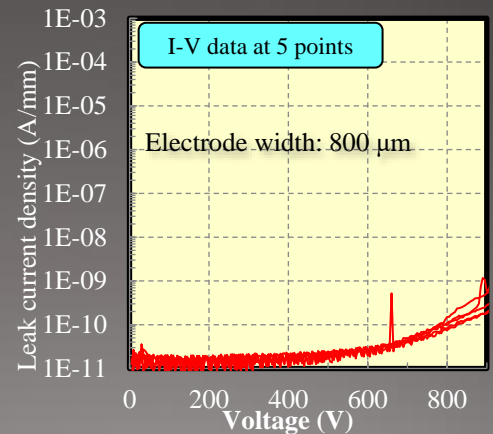
# AlGaN/GaN HEMT on Si for Power Device



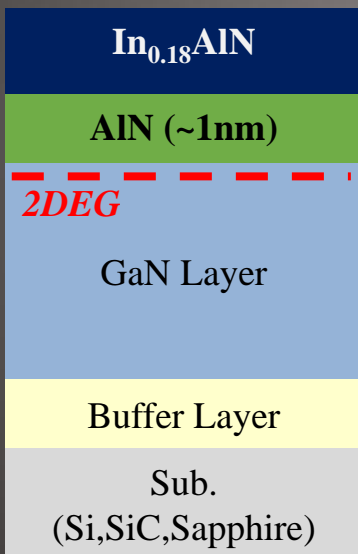
Leak Current Density  
- vertical direction -



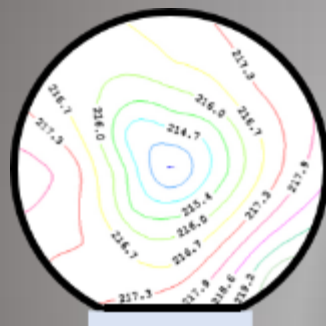
Leak Current Density  
- lateral direction -



# Layer Structure and Typical Features ( InAlN / GaN HEMT )



on 6 inch Si



Sheet resistance  
Average : 216 ohm/sq.  
Variation : 3.6%

Sheet resistance	220 ohm/sq.
Sheet carrier density	$2.2 \times 10^{13} \text{ cm}^{-2}$
Electron mobility	1,300 $\text{cm}^2/\text{Vs}$

# Fabrication and Evaluation Tools

## Multilayer deposition

- Magnetron-sputtering multilayer deposition

## Thin film deposition

- LP-CVD, ECR-CVD, Plasma-CVD, E-beam evaporation

## Lithography

- E-beam lithography system, i-line stepper, Mask aligner

## Dry etching

- ECR etching, RIE, deep-RIE

## Evaluation

- TEM, SEM, AFM, Optical microscope
- XRD
- ICP-mass, TXRF



Multilayer deposition system



XRD



# Contact

## NTT Advanced Technology Corporation

Web: <http://www.ntt-at.com>

### Japan

3-9-11, Midori-cho, Musashino-shi, Tokyo, 180-0012, Japan

Tel: : +81-422-39-8954

E-mail : [nano-sales@ml.ntt-at.co.jp](mailto:nano-sales@ml.ntt-at.co.jp)

### US

940 Stewart Drive, Sunnyvale, CA 94085, USA.

Tel : +1-408-392-4280

E-mail : [bizdevelop@ntt-at.com](mailto:bizdevelop@ntt-at.com)

### China

上海市黄浦区黄河路21号鸿祥大厦8楼 803室

Tel : +86-21-6236-8015/8016

E-mail : [service@ntt-at.com.cn](mailto:service@ntt-at.com.cn)

### Singapore

8 Kallang Avenue, #15-01 to 09, Aperia Tower 1, Singapore 339509

Tel : +65 6429 3151

E-mail : [nano-sales@ml.ntt-at.co.jp](mailto:nano-sales@ml.ntt-at.co.jp)

### Taiwan

Singo Lin

Tel : +886-0906746050

E-mail : [lsc8288@ms18.hinet.net](mailto:lsc8288@ms18.hinet.net)



# Contact

## Distributor

### China

Top Unistar Science & Technology Co., LTD.

Tel : +86-010-86467571

E-mail : [cavan.huang@top-unistar.com](mailto:cavan.huang@top-unistar.com)

### Korea

NCORE

Tel : +82 2-2245-1027

E-mail : [sales@ncores.co.kr](mailto:sales@ncores.co.kr)

### Europe

FAST Laser GROUP Ltd. (Israel)

Tel : +972-(0)9-7444-112

E-mail : [info@fastlaser.co.il](mailto:info@fastlaser.co.il)

### ATL Zrt.(Hungary)

Tel : +36 26 540 261

E-mail : [info.hu@atl-fo.eu](mailto:info.hu@atl-fo.eu)

### HP Spectroscopy GmbH (Germany)

Tel : +49 176 20949282

E-mail : [info@hp-spectroscopy.com](mailto:info@hp-spectroscopy.com)