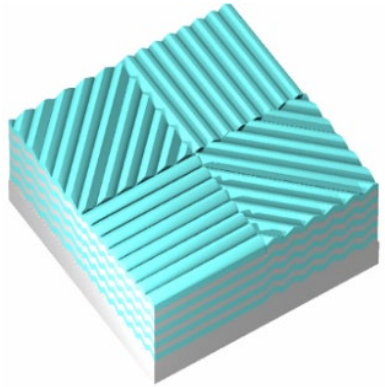
Multilayered photonic crystals and their applications

1. Basic principle and fabrication method
2. Applications



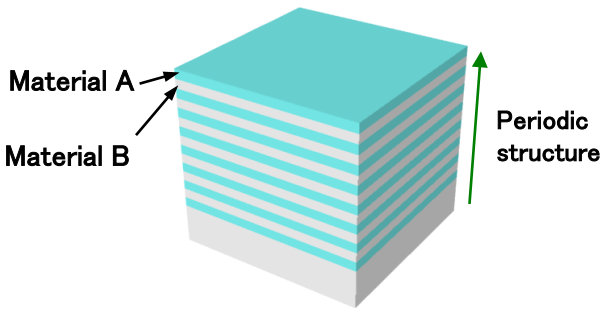
1. About multilayered photonic crystals

1_1. Different types of photonic crystals (basic principles)

"**Photonic crystal**" refers to a "Periodic structure of materials with differing refractive indices"

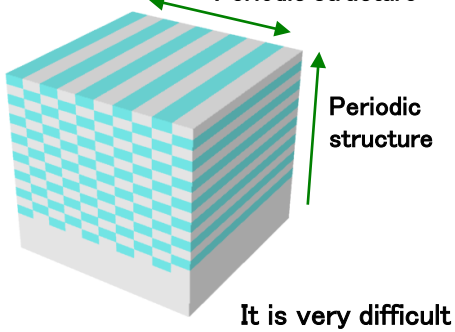
● Dimensions of the periodic structure

One dimensional structure

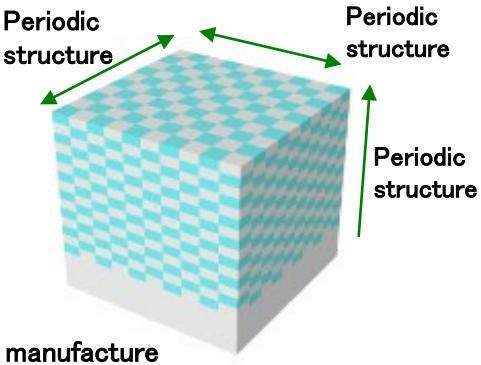


Flat multilayer film
→ widely used technique (AR coat, etc.)

Two-dimensional structure



Three-dimensional structure

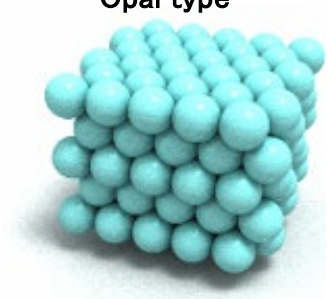


It is very difficult to manufacture

Those are what is usually called "photonic crystals".

● Various types of the photonic crystal

Opal type

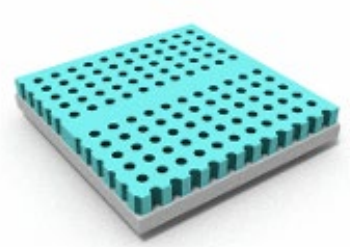


Typical method: sink beads in water
→ The process can takes several weeks…

Wood pile type

→ Huge amount of labor required for each individual layer

Slab structure



→ Hard to control finely hole size, whose influence is critical

Neither photonic crystal of this kind is mass-produced for now.

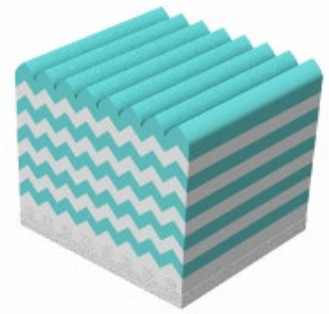
1_2. Autocloned photonic crystal

◆ Structure outline

Our method, called "auto-cloning", is suitable for mass production.
→ Starting from an engraved substrate, triangular cross-section is maintained throughout the whole multilayer structure.

Substrate
Material: Fused Silica, Si, etc.
pattern formation: EB- lithography,
Nano-inprint, etc.

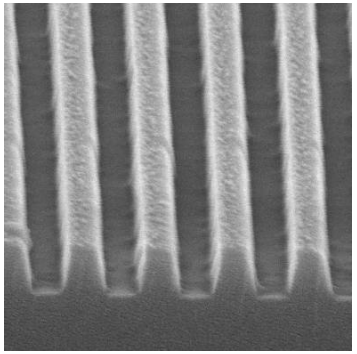
Auto-cloning method



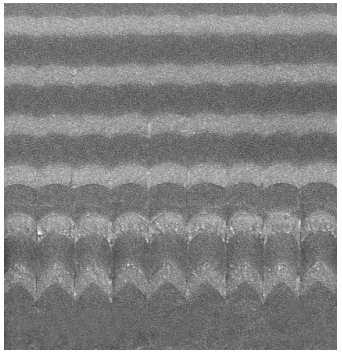
Films material examples: SiO_2, Si, Nb_2O_5, Ta_2O_5, Al_2O_5, etc.
= any materials which is available for sputtering deposition process.

◆ Image of electron microscopy

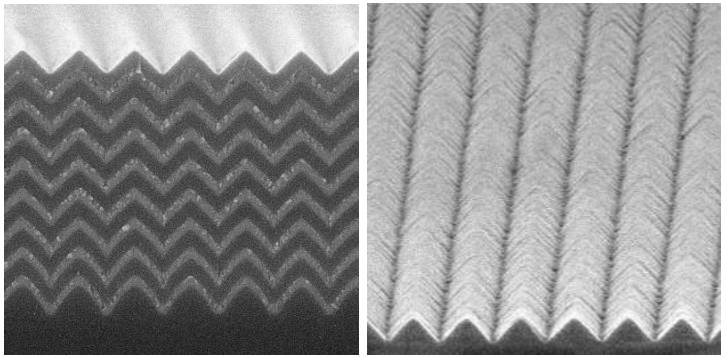
As a result of original process development, auto-cloning allows preserving stable triangular cross-section during the deposition process, which tends to destroy sharp details when standard deposition technique is used.



Corrugated substrate



Structure when normal deposition process is used: **FAIL**



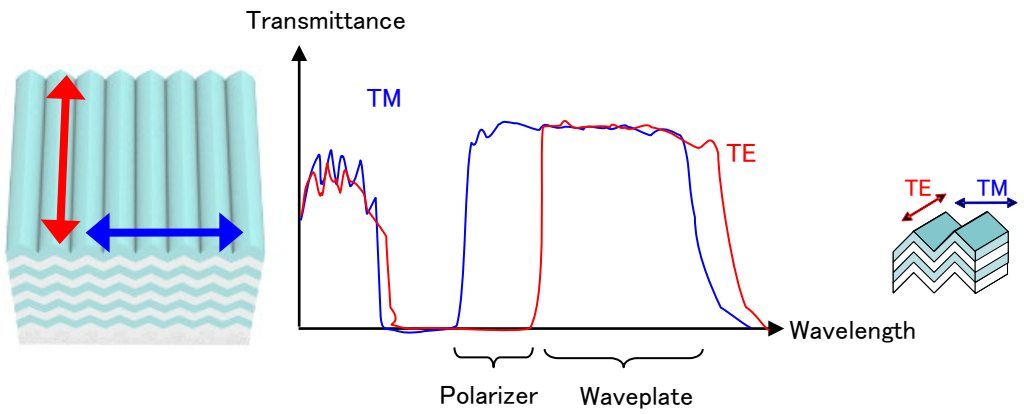
Photonic crystal manufactured with our original auto-cloning technique

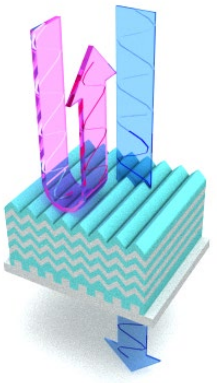
The corrugated nature of the structure results in optical **anisotropy**.

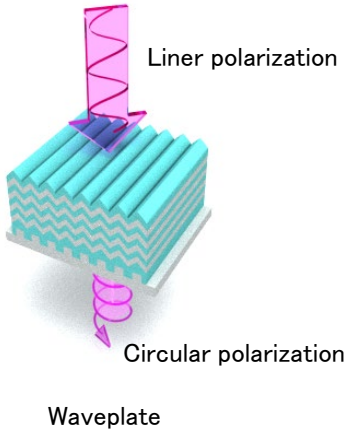
This anisotropy causes **polarization dependence** of the optical properties.

Depending on the design, the structure can operate as a **polarizer** or a **waveplate**, in a certain range of wavelengths.

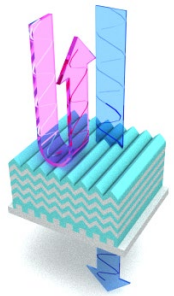
Operation wavelength is tuned by the choice of the optical materials, the pitch of the substrate and films thickness.

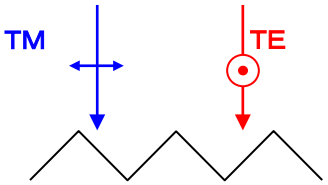






1_4. Large range of operating wavelengths, from deep ultraviolet to near infrared

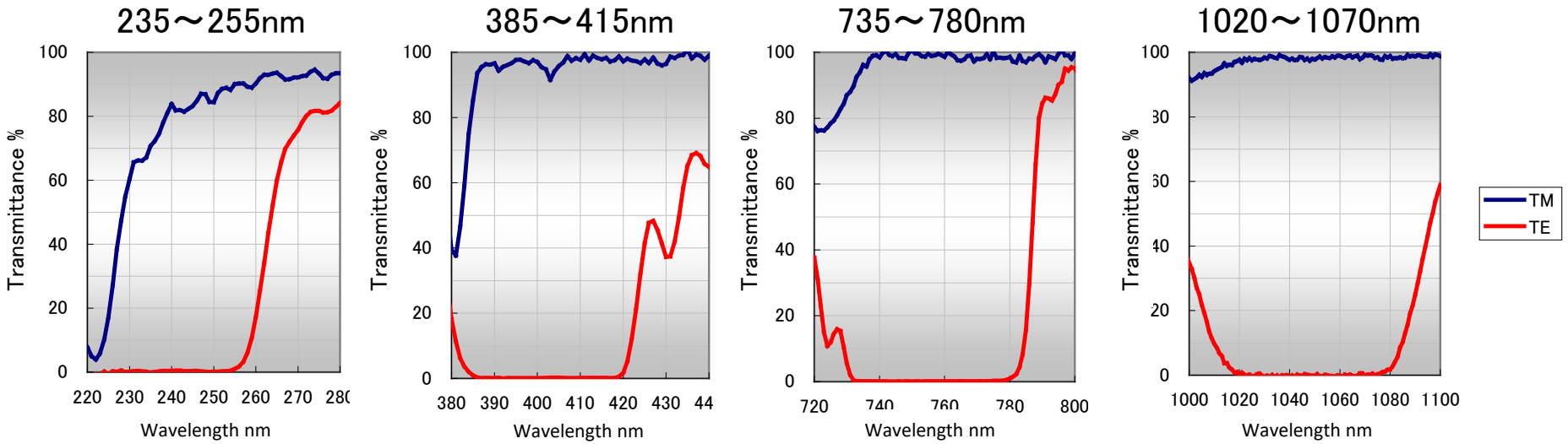




Polarizers and waveplates for
A WIDE RANGE OF OPERATING WAVELENGTHS

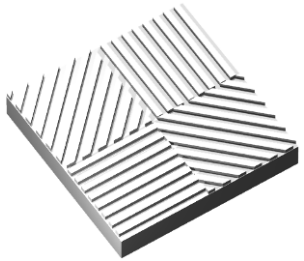
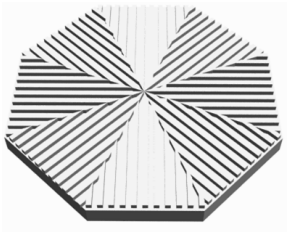
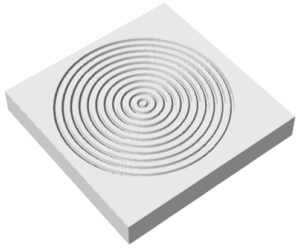
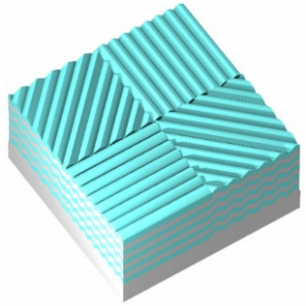
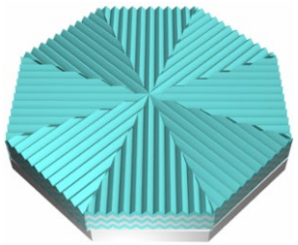
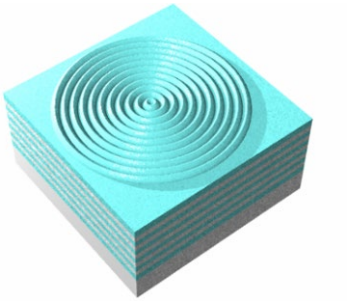
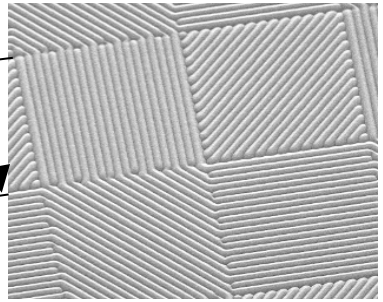
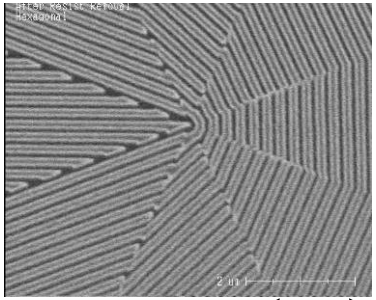
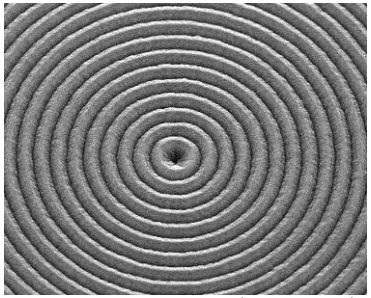
As an example, **DUV polarizers** (ex: 3rd and 4th harmonics of YAG laser (355nm and 266nm) are available.

Operation wavelength band:



We can produce elements for any wavelength band, from ultraviolet to infrared.
The **extinction ratio** of the polarizers is controlled by the number of layers. It can thus be improved as needed.

Any “exotic” pattern for axis orientation can be obtained by changing the substrate.

	Segmented	Radial	Concentric
Substrate: before deposition			
Photonic crystal : after deposition			
SEM images			

"Auto-cloned" photonic crystal are obtained using our original manufacturing process,
for which we own basic patents.

This technique allows manufacturing **polarizers** and **waveplates**.

Because of its inorganic nature, an element fabricated using this technique is **inherently heat resistant** and exhibits very **few temperature dependence**.

The optical elements are available in a **wide range of operating wavelengths**,
from **ultraviolet**, starting at around 250nm, to near **infrared**.

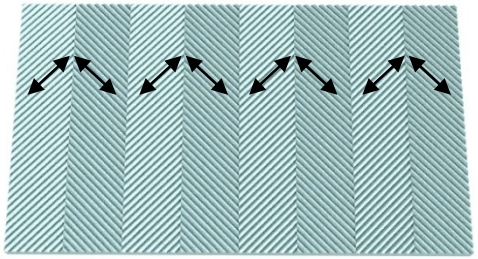
Polarizers are **reflective**, which means no **absorption**. As a result no significant loss in quality is observed after a long period of use, even at high power.

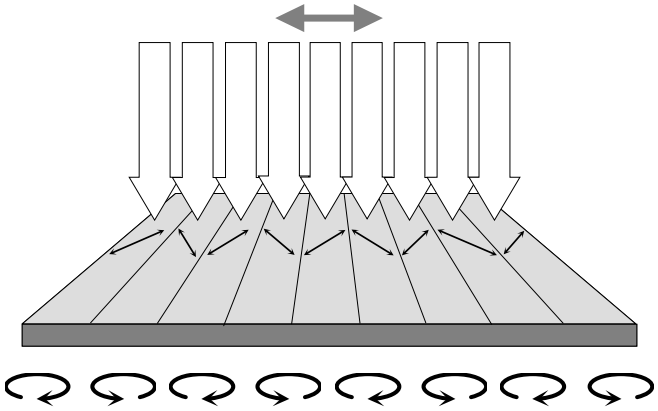
Elements are shipped as normal glass plates. Handling is the same as any coated optical element,
so the surface can be wiped normally.

We can provide customized elements based on specialized customer needs, like segmented or curved axis elements.
→ Please let us know your requests.

2. Application of multilayered photonic crystals

Quarter-wave plates arranged in parallel, with axis direction at right angles.

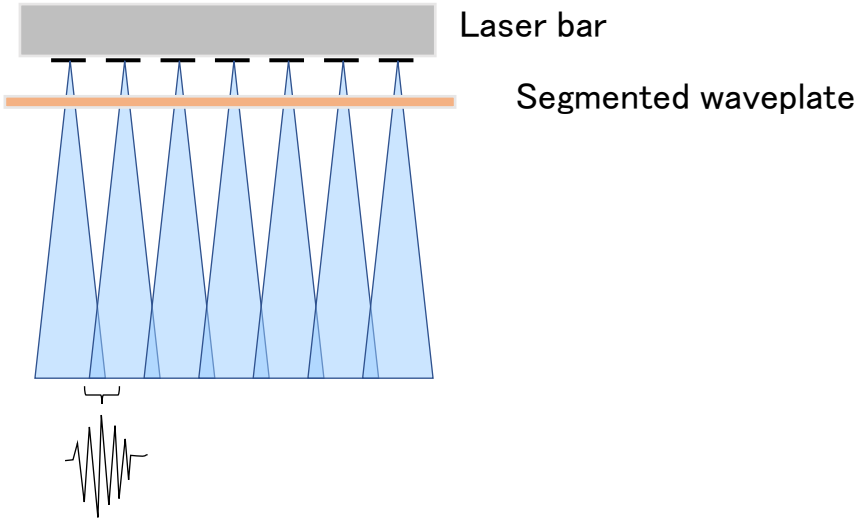


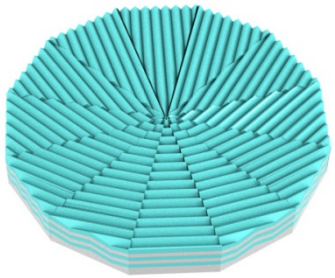


Even illumination using a laser bar

Interference occurs between light from adjacent lasers.

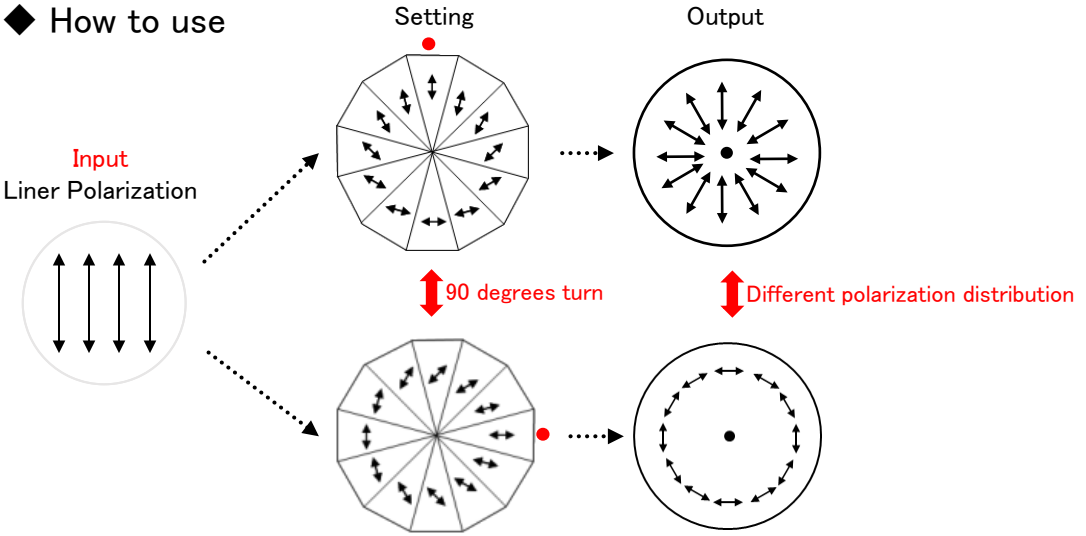
By inserting the segmented waveplate, one can prevent this interference from occurring.





Schematic view of SWP

◆ How to use



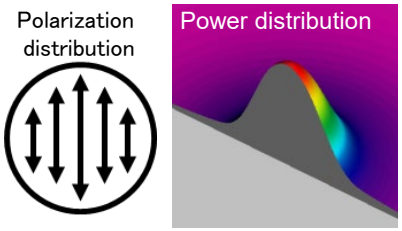
Axis symmetry polarization beam

A laser beam is usually uniform linear polarized light, like in the left drawing below. The power distribution is usually Gaussian.

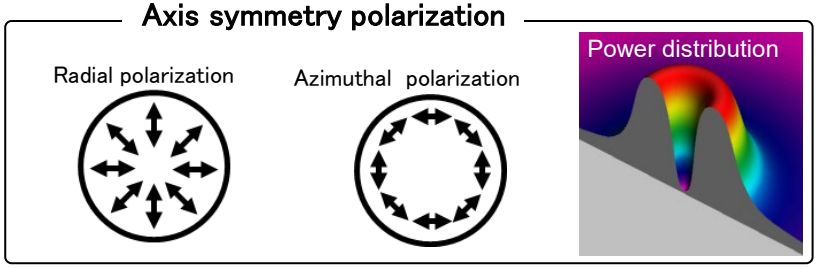
Axisymmetric polarization is the generic name for a beam with radial or concentric polarization distribution like in the drawing on the right.

Those axisymmetric beams exhibit doughnut-shaped power distribution, making them especially suitable for light tweezers or in laser machining applications.

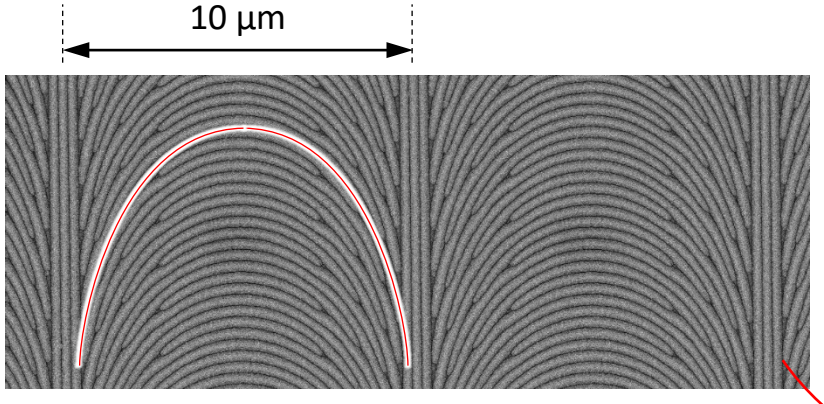
Uniform Linear Polarization



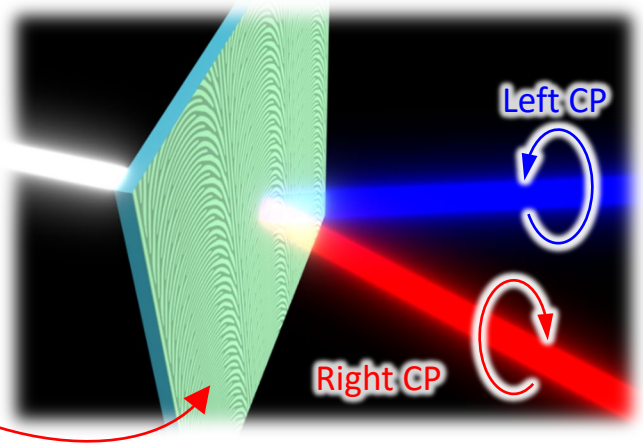
Axis symmetry polarization



Polarization grating can separate
linearly polarized input light into **two circularly polarized output** beams,
one clockwise, the other counterclockwise.

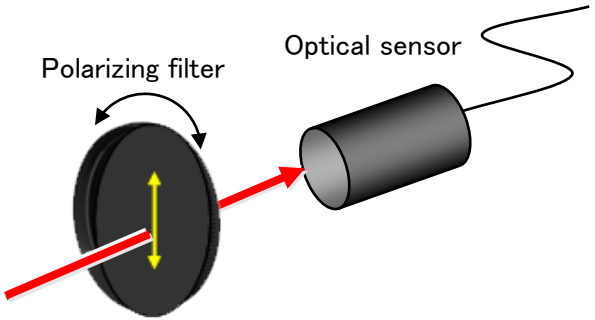


SEM image of the polarization grating surface



Combined with image sensors, patterned photonic crystal allows building polarization sensitive image sensors (a.k.a. **polarization imaging sensor**).

Conventional polarization measurement technique



Measure of polarization is made by measuring a change of brightness]when rotating a polarizing filter.

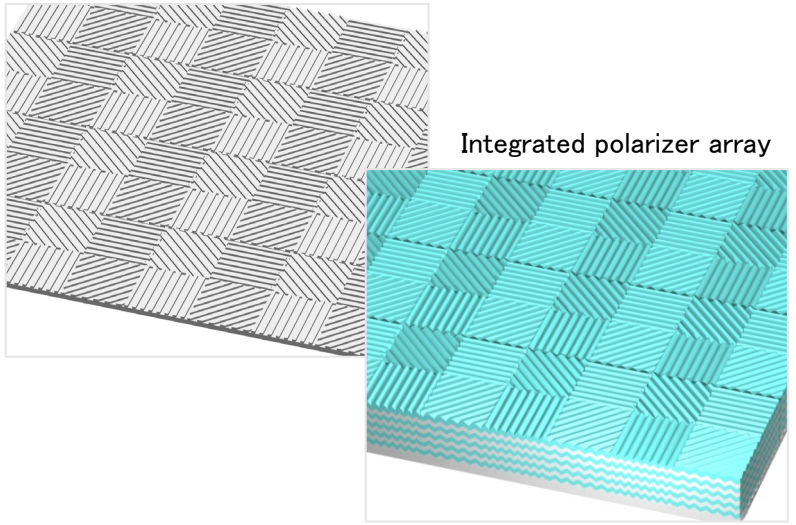
【 Issue 】
Rotary mechanism is necessary.

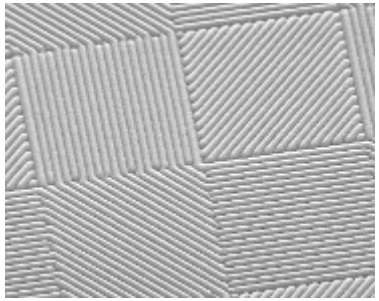
Measurement time.

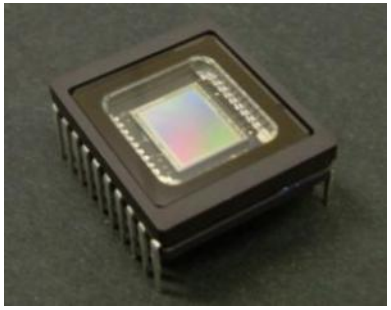
Alignment is difficult as rotating filter is not typically perfectly perpendicular to its rotation axis.

→ Point measurement is common.

Structure of polarization imaging sensor, using integrated photonic crystal array

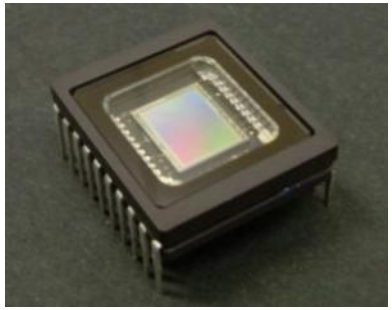




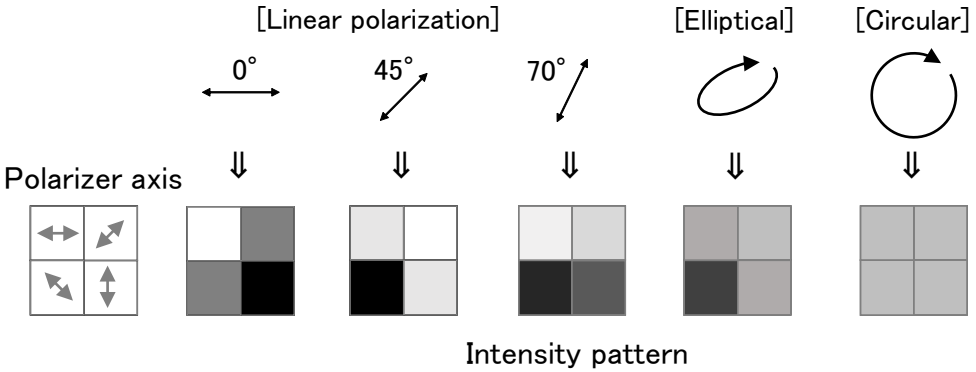


Arrayed polarizing filter made of photonic crystal is placed in front of a CCD image sensor.
→ Comparing brightness values in each set of 4 adjacent pixels allows recovering polarization information.

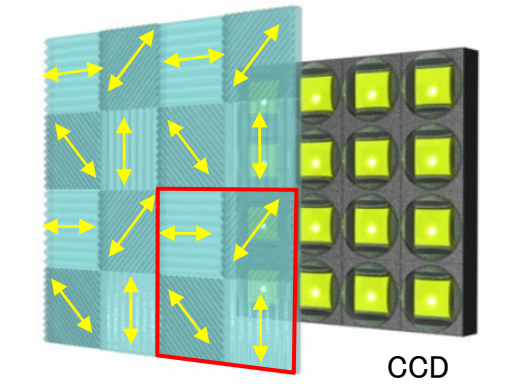
[Picture of an actual **polarization imaging sensor**]



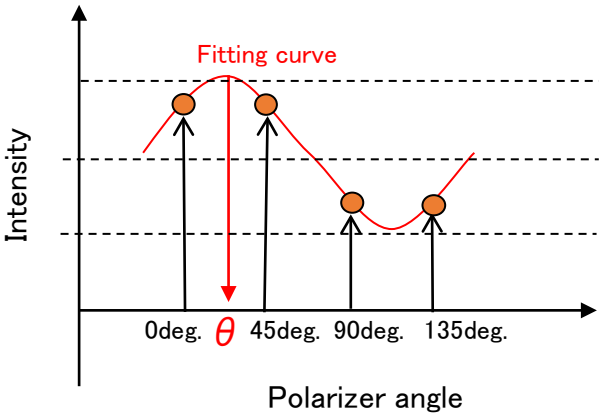
[Relation between input polarization and intensity pattern]



[Schematic view of polarization imaging sensor]



[Computation principle]



Intensity is supposed to describe a sinusoid.
By knowing only 4 points on the curve, it is possible to recover the whole set of information for any input polarization

Polarization imaging camera

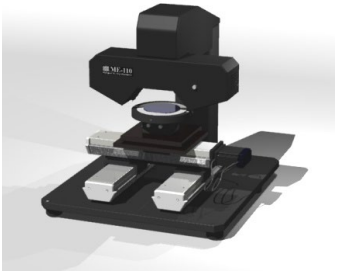
PI/WPI Series

2-D Birefringence measurement system

PA/WPA Series

Thin film thickness / Refractive index ellipsometry measurement

ME/SE Series



It unfolds from technology development to applied products.

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