THE UNIVERSITY OF TOKYO

東京大学が進める光赤外線分野の基礎開発研究

Basic developments on optical-infrared astronomy driven by the University of Tokyo

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酒向　重行 (SAKO, Shigeyuki)

2011/1/18 すばる将来装置計画ワークショップ　国立天文台




Framework of developments in U-Tokyo

Observatory in Atacama, Chile
Oversea base

TAO
miniTAO

6.5-m telescope (future plan)
1.0-m telescope

Staff: 0
TS : 0
PD : 0
ST : 0

Observatory in Kiso, Japan
Domestic base

KISO

1.0-m telescope

Staff: 0
TS : 3
PD : 2
ST : 0

Headquarter in Tokyo

Mitaka(IoA)

Staff: 14†
TS : 1
PD : 3†
ST :25(16)

Hongo

Staff: 9†
TS : 0
PD : 1†
ST:15(9)

Developments of instruments and basic technologies are mainly proceeding at Mitaka and Kiso.

† Including persons on other research fields

Instruments developed by U-Tokyo

- **Development phase**

for TAO 6.5-m and Subaru 8.2-m	**SWIMS**	*NIR camera and spec. with MOS*
	MIMIZUKU	*MIR camera and spec.*
for Kiso Schmitt 1.0-m	**KWFC**	*Wide field CCD imager*
for KyotoSangyo-U 1.3-m	**WINERED**	*NIR high resolution spec.*

- **Observation phase**

on miniTAO 1.0-m	**ANIR**	*NIR camera*
	MAX38	*MIR camera*
on Kiso Schmitt 1.0-m	**2kCCD**	*Wide field CCD imager*
on Hokkaido-U 1.6-m	**NICE**	*NIR mid resolution spec.*
on Hiroshima-U 1.5-m	**DMC**	*15-bands CCD camera*

List of instruments whose PI is in U-Tokyo

New technologies
from the instrument projects

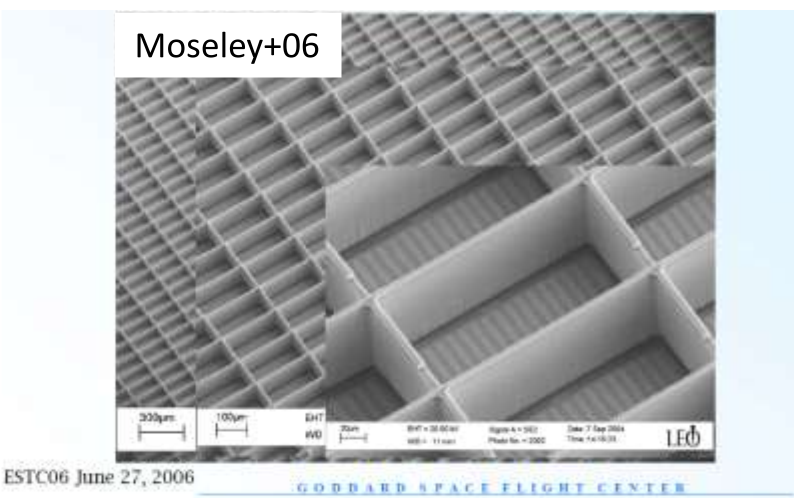
- **SWIMS** → **Micro shutter**
- **MIMIZUKU MAX38** → **Metal mesh filter**
  → **Moth-eye optics**
  → **Cold Tip-Tilt**
- **KWFC** → **CCD controller**
  → **Filter changer with Robotic arm**
- **WINERED** → **Immersion grating**

Electrostatic drive type
Micro shutter array

Motohara et al.

- Micro shutter array
  - Array of small shutters (0.1 to 1 mm size)
  - Can open a shutter at an arbitrary position

    Use as a MOS slit → Simplify a MOS system
- Array for JWST (Goddard) is closest to practical use
  - → scanning with magnets
  - → complex system
- In this study, **Electrostatic drive type** has been developed.



King+05

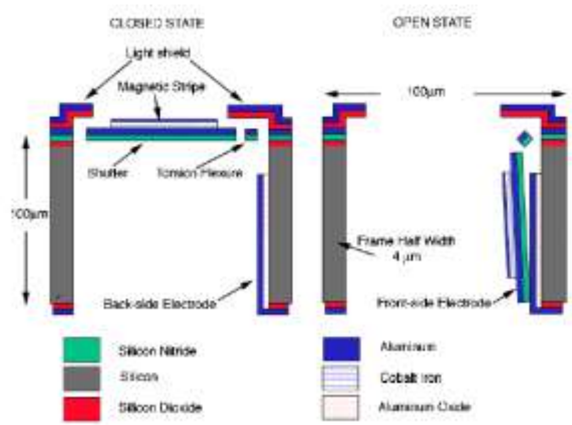
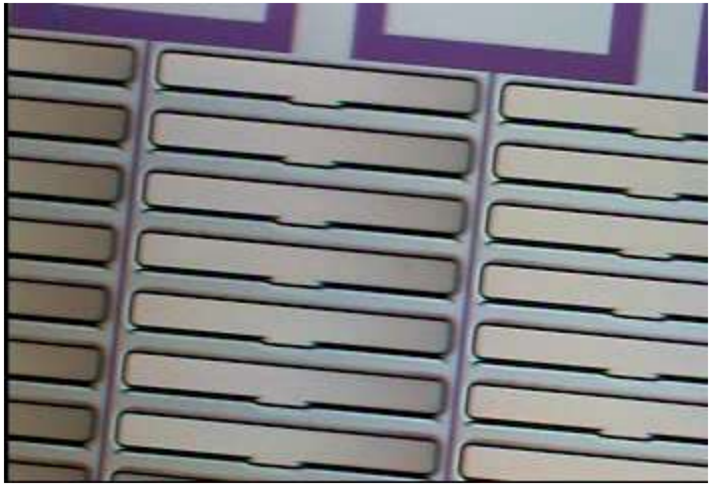


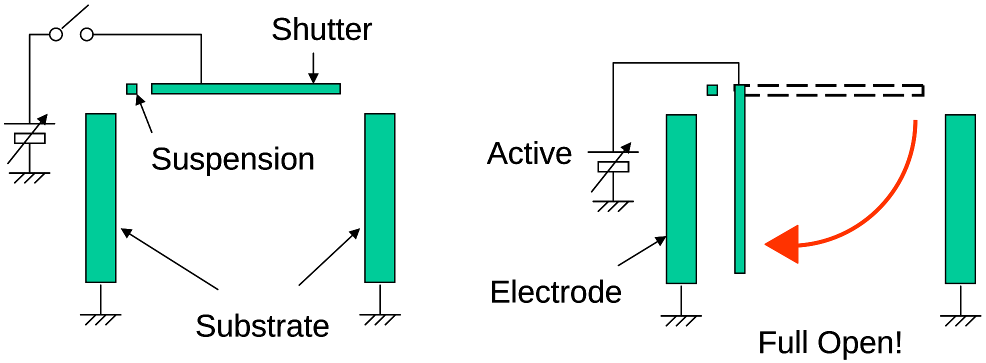
Figure 1. Schematic cross-section of a shutter cell in the closed and open states. Front-side (top) will face light objects in space whose spectra will be determined via NIRSpec placed on the back-side (bottom) of the array.

Electrostatic drive type Micro shutter array

- **IoA, U-Tokyo** + **Institute of Industrial Science, U-Tokyo** + **NAOJ**
- Since 2004
- With **electrostatic force** (>100V is necessary), not magnetic force
- Simple addressing method
- Succeeded in opening and closing shutters.
- Next steps
  - ✓ Structure to prevent light leak
  - ✓ Stable behavior
  - ✓ Larger format



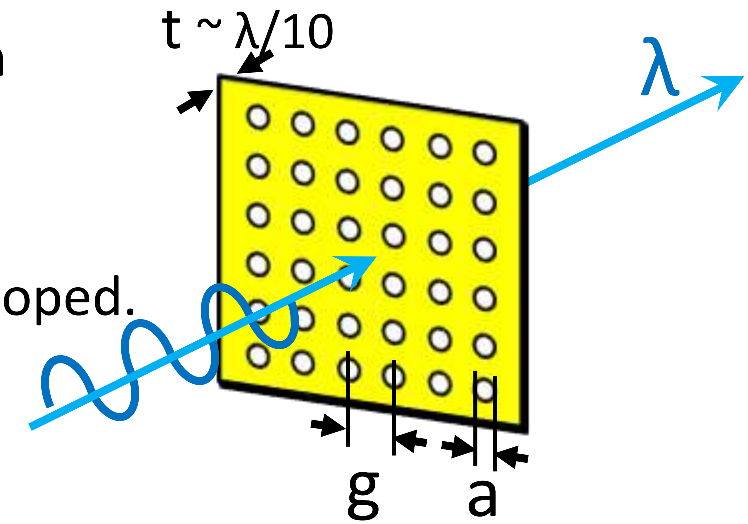
1mm x 0.1mm



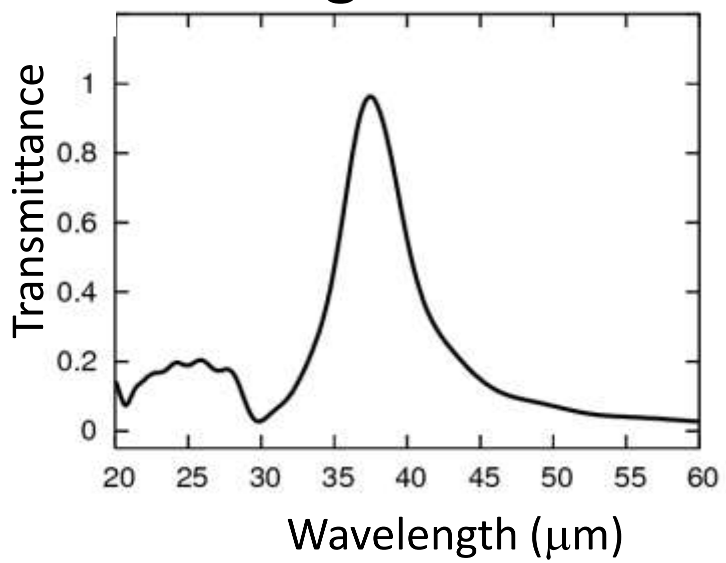
Metal mesh filter

Miyata & Sako et al.

- No good optical filters in 25 - 40 μm
  - No transparent material in 25 – 40 μm
    - ✕ Multi-layer interference method
  - In this study, MIR filters **without transparent material** have been developed.

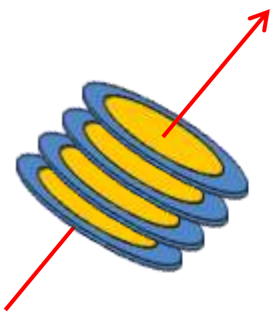


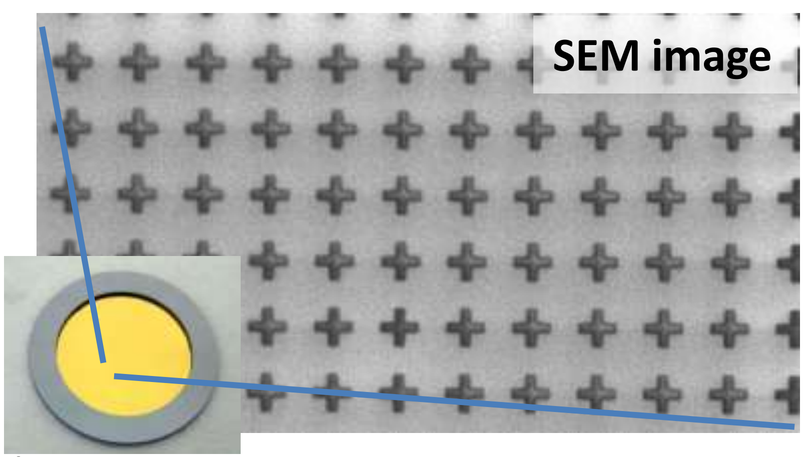
- Metal mesh filter
  - Thin metal film with hole array
  - **Band-pass profile (R~10)**
  - **Peak transmittance** of ~100%
  - Surface Plasmon-Polariton (SPP) effect



Metal mesh filter

- IoA, U-Tokyo + NTT-Advanced Technology + <u>JAXA & NAOJ</u>
- Since 2006.
- FDTD simulation & Photolithography fabrication
- Succeeded in obtaining a peak trans. of > 90% and R~10
- Blocking ratio of < 0.01% by stacking 4 filters
- used in miniTAO/MAX38.
- Next steps → Increase in Strength, Larger aperture

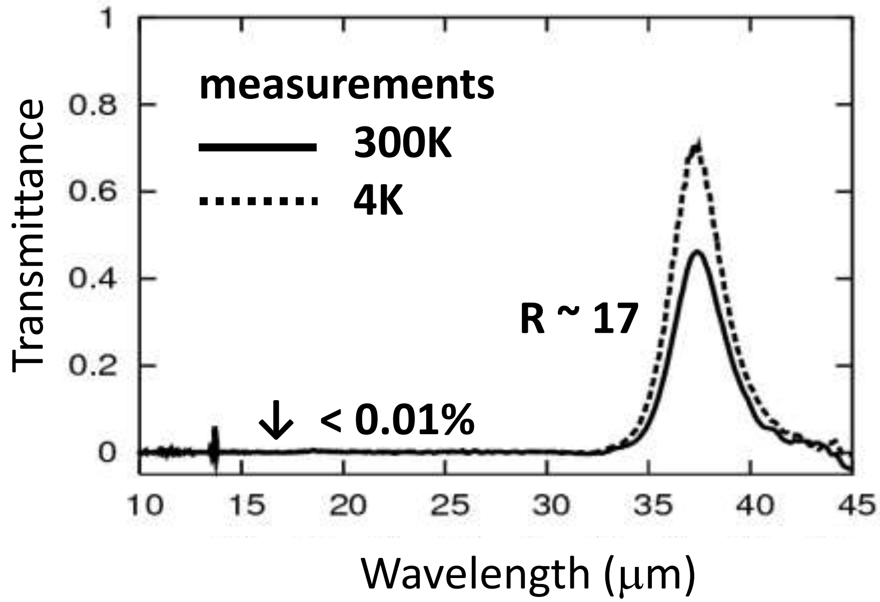




ϕ10mm

29.5 µm pitch cross pattern

stacking 4 filters



Silicon Moth-eye

Sako & Miyata et al.

- ☐ No good optical substrate in 25 - 40 µm
- ☐ **Silicon** is one of the few potential candidates

  Problem

  ・High refractive index (n~ 3.4)

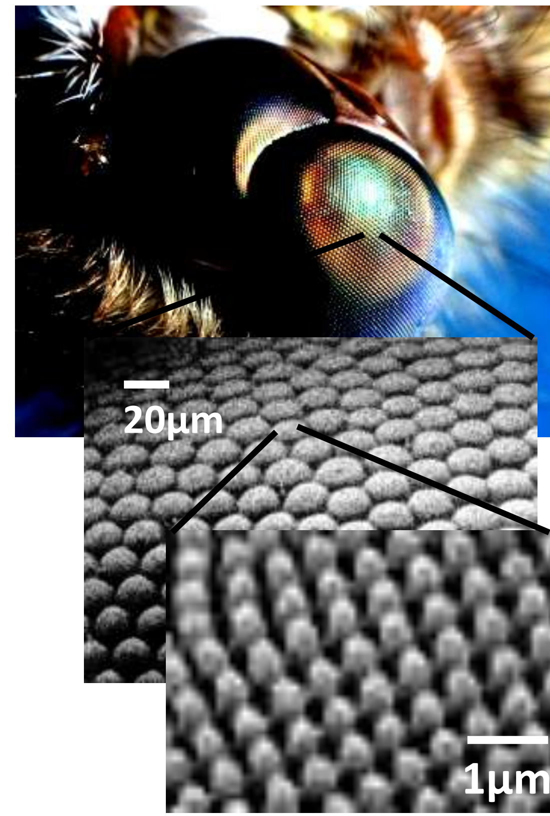
  → **High reflection loss** (30% on one surface)

  ・**AR-coating is not available**

  (the same reason of filters)

- ☐ In this study, AR surfaces **without multilayer interference** have been developed.
- ☐ Moth eye anti-reflection structure
  - Sub-wavelength scale structure
  - Broadband Anti-reflection effect
  - Single material

Compound eye of Moth

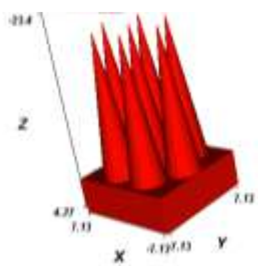


Pillar structures with a pitch of 0.5 – 1µm on the surface of one eye

Silicon Moth-eye

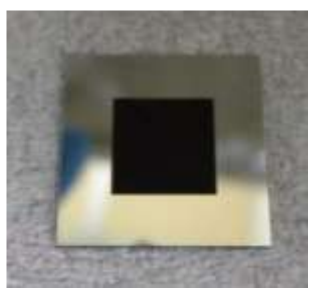
- ☐ IoA, U-Tokyo + NTT-Advanced Technology + **JAXA & KAKENHI**
- ☐ Since 2009
- ☐ RCWA simulation & Photolithography and RIE fabrication
- ☐ Succeeded in obtaining a trans. of **98% in 25 - 40μm** on one surface.
- ☐ Next step
  - ✓ Both side, Moth-eye on Lens, Grism, and window, and for NIR.

Design for MIR

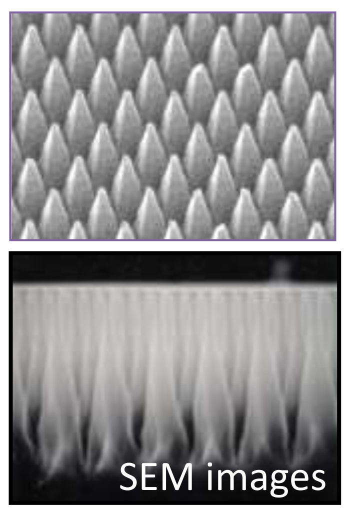


- circular cone
- 60° adjacent
- pitch 5μm
- length 20μm

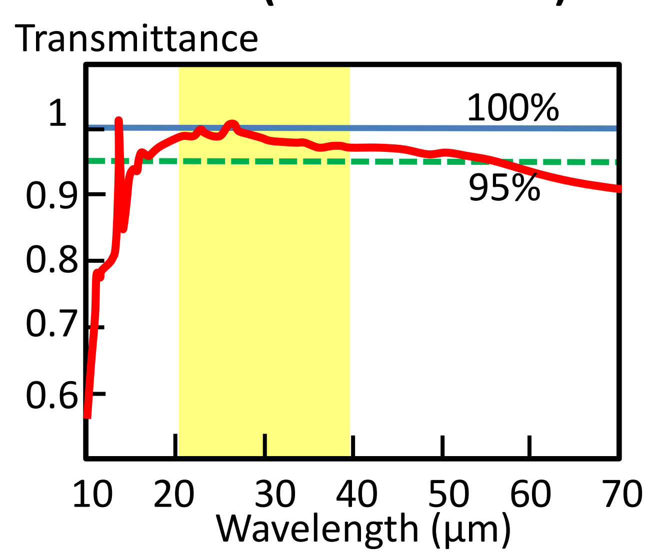
Fabricated Silicon Moth-eye



Overview
10 x 10mm
Visible image



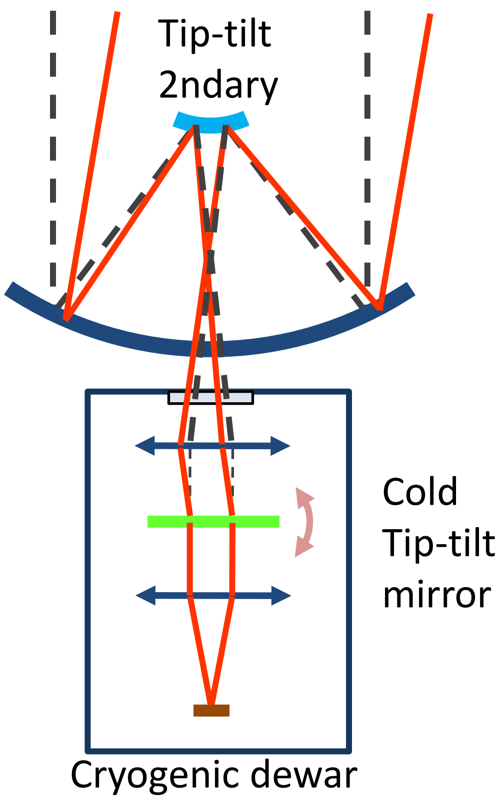
Results (measurement)



Cold Tip-Tilt Mirror

Nakamura et al.

- Cryogenic opt-mechatronics is a key technology in TMT and SPICA era
  → Expand the capability of infrared instruments
- High stability and low power are needed
- In this study, **cryogenic tip-tilt** (chopper) mirror for MIR observations has been developed.
- Cold tip-tilt (chopper) system
  → No need tip-tilt motion of 2ndary mirror
  → Enables tip-tilt observations in space
  (to remove fast vibration generated by refrigerators)



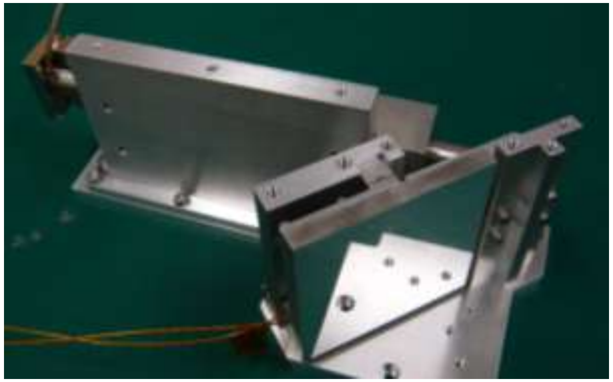
MIR observation with chopping techniques
Typical chopping Freq. is 1 – 10Hz

Cold Tip-Tilt Mirror

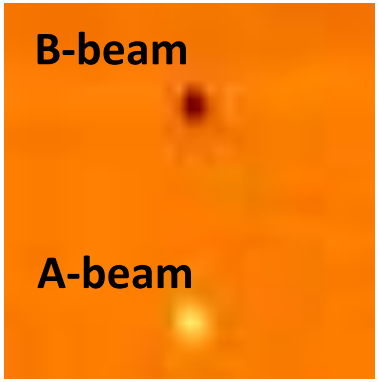
- IoA, U-Tokyo + Fuji ceramics + JAXA & KAKENHI
- Since 2005.
- **Cryogenic piezo actuators** were developed .
  Stroke is extended by a factor of **2.7** at 7K
- Succeeded in driving the chopper with
  max **5 Hz** and **15“** amplitude, and < 100mW at < 20K.
- Used in miniTAO/MAX38
- Next step → 2-axis type, larger amplitude, faster feedback

Driving test of new piezos

Overview of Cold Tip-Tilt system



Observation image

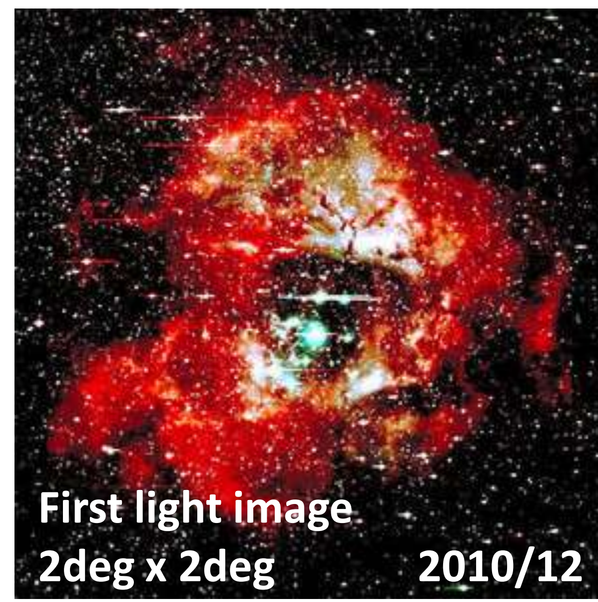


New CCD controller

Sako et al.

- No suitable controller for 1 – 8 CCDs system
- **Almost projects driven by University need small-mid sized system**, not larger like HSC.
- In this study, new CCD controller for small-med sized system (**KAC**: Kiso array controller) has been developed.

- Kiso wide field camera (KWFC)
  - Next generation **open-use** instrument on Kiso 1m telescope
  - Wide F.O.V. (**2deg x 2deg**)
  - 8CCDs of 2k x 4k pixels
  - 4 SITe and 4MIT CCDs from NAOJ
  - Opened in Apr. 2012



New CCD controller

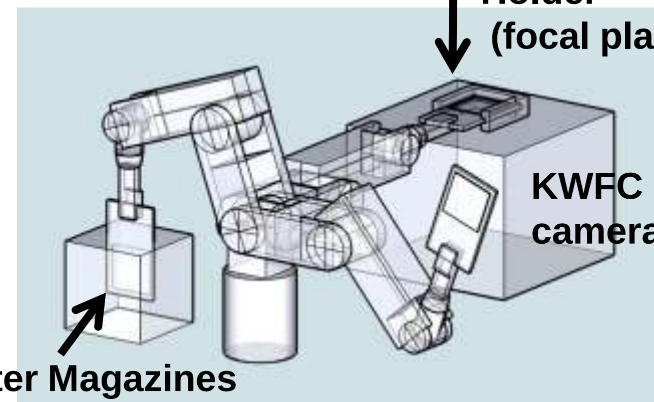
- **IoA, U-Tokyo** + **Several Universities and Institute in Japan** (Hokkaido-U, Kyoto-U, AoyamaGakuin-U, and JAXA) + **NAOJ**
- Since 2009
- Succeeded in taking astronomical images with Kiso/KWFC
- **Welcome participation of this project**

- Development plan
  - Redesign the analog circuit for **Hamamatsu CCDs** (2011/1-8)
  - Installed into
    - → Spectrometer developed by Hokkaido-U and Kobe-U
    - → Kyoto 3D instrument for Subaru
    - → Test systems for Infrared and X-ray satellites

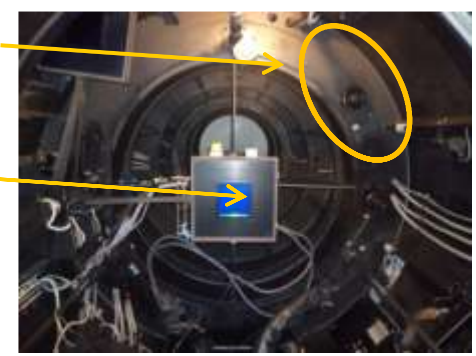
KAC analog boards for 8 CCDs

Filter exchanger with Robotic arm

- IoA, U-Tokyo + Mitsubishi electronics system & service + Sumitomo foundation
- Since 2010
- Filter exchanger is set at the **prime focus** of KISO Schmitt telescope
- Uses an **industrial robotic arm**
- Stores 16 filters (158 x 158 x 15mm) in the magazine box
- Realizes a compact and lightweight system
- **Put an unique ideas to practical use**



The arm and the magazines are placed on a framework of the telescope. The arm is evacuated outside of a beam in observations.



Inside the Schmidt telescope from the primary side

Immersion grating for NIR

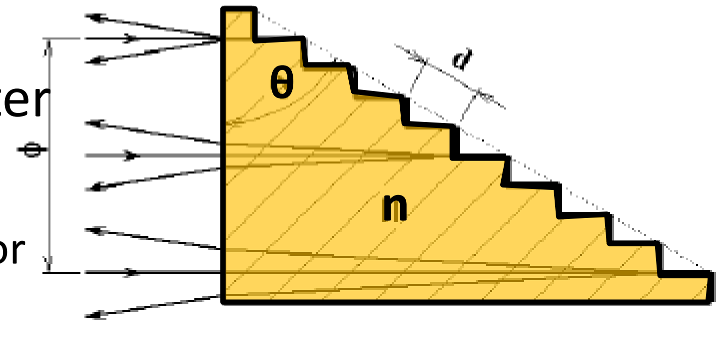
Ikeda and Kobayashi et al.

- ☐ Immersion grating
- ✓ A sort of reflection type grating
- ✓ Diffraction side is filled with '**n**'

- ☐ Resolution and Physical size of spectrometer

$$\phi \propto R \cdot D/n$$

ϕ : beam size
D : diameter of prime mirror
R : spectral resolution



immersion grating

- ☐ High resolution spectroscopy with Large telescope
  - **a size of optics ∝ resolution**

  → large and heavy instrument → high cost

- ☐ Immersion grating with large '**n**' can downsize the optics

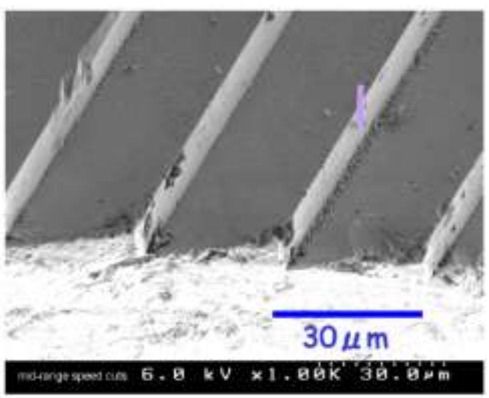
  → In this study, immersion gratings for NIR have been developed.

Immersion grating for NIR

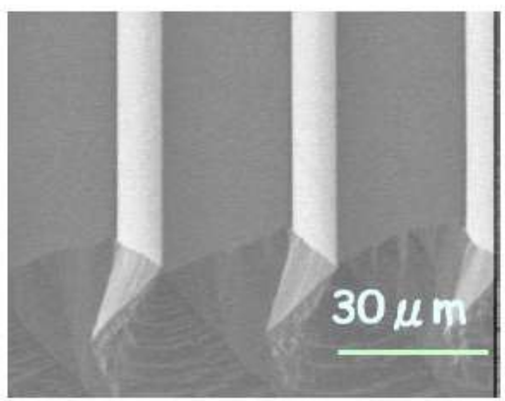
- IoA, U-Tokyo + Photocoding + KyotoSangyo-U + NTT-Advanced Technology +Lawrence Livermore National Laboratory + **JAXA & NAOJ**
- Since 2005
- Two types of substrate : **ZnSe** (broad band), **Silicon** (high **n**)
- Fabrication processes of grooves

  ZnSe → nano precision **fly-cutting** technique (LLNL)

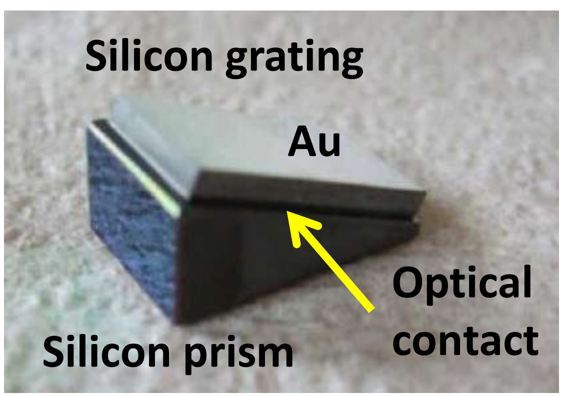
  Silicon → **anisotropic etching** + photolithography (NTT-AT)
- Succeeded in making high quality grooves with both methods
- Next steps: improve diffraction efficiency and assemble the elements



Grooves on ZnSe

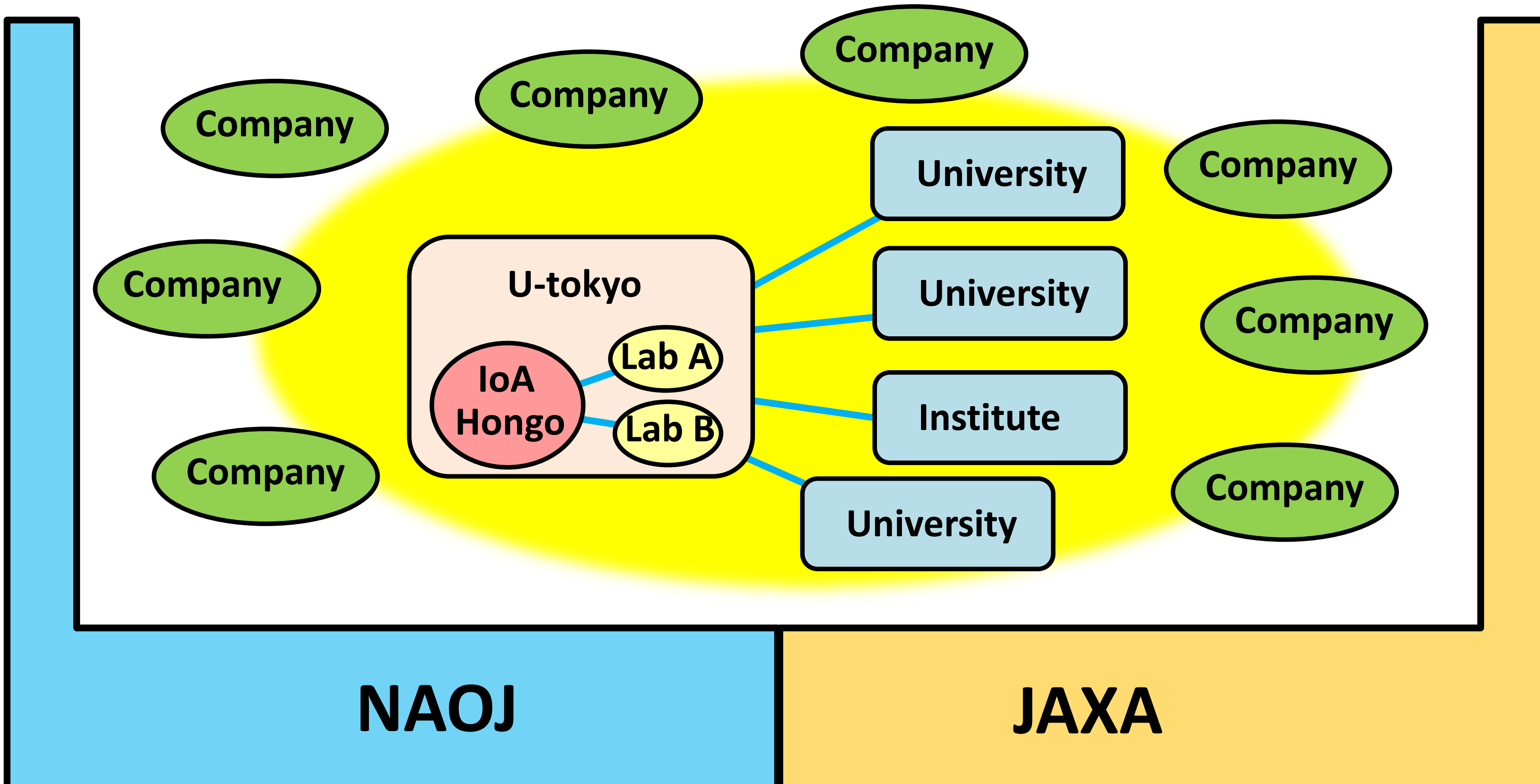


Grooves on Silicon



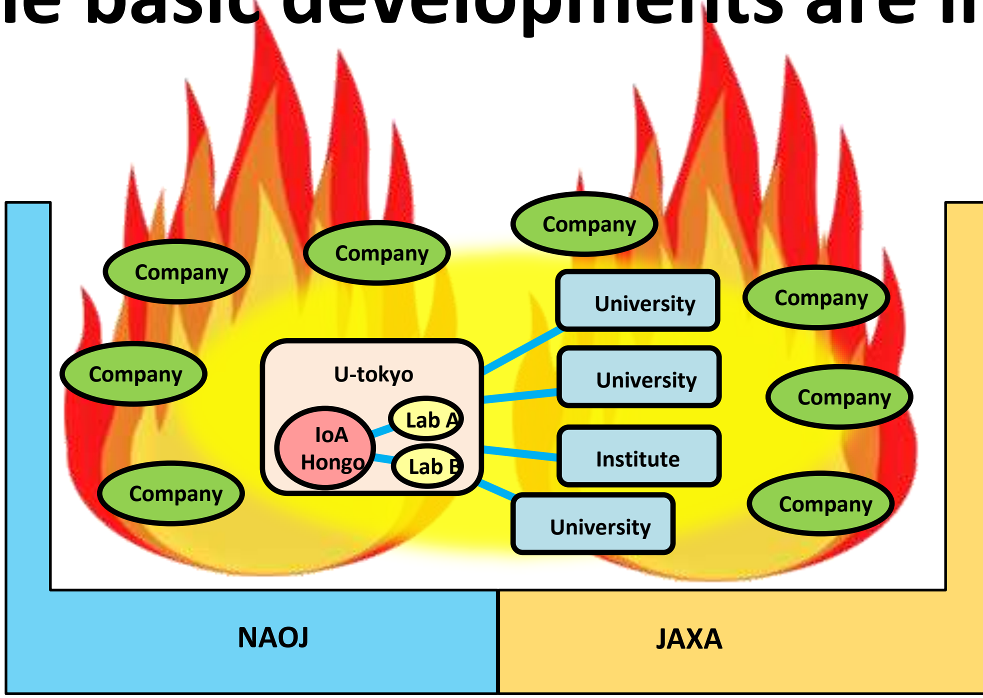
Silicon immersion grating

Basic developments expand community and build a strong foundation



Universities are highly-responsive

- ✓ While energy sources are present, the responses are continued.
- ✓ Continuous and widespread supports to the basic developments are important.



Summary

- U-Tokyo has developed several new basic technologies in promoting mid-small sized instrument projects.
- The basic developments have expanded the community on Japanese astronomy.
- Continuous and widespread supports to the basic development are important to build a strong foundation toward TMT era.
- While energy sources are present, responses between Universities are continued.