Development of silicon lens array for MKID camera

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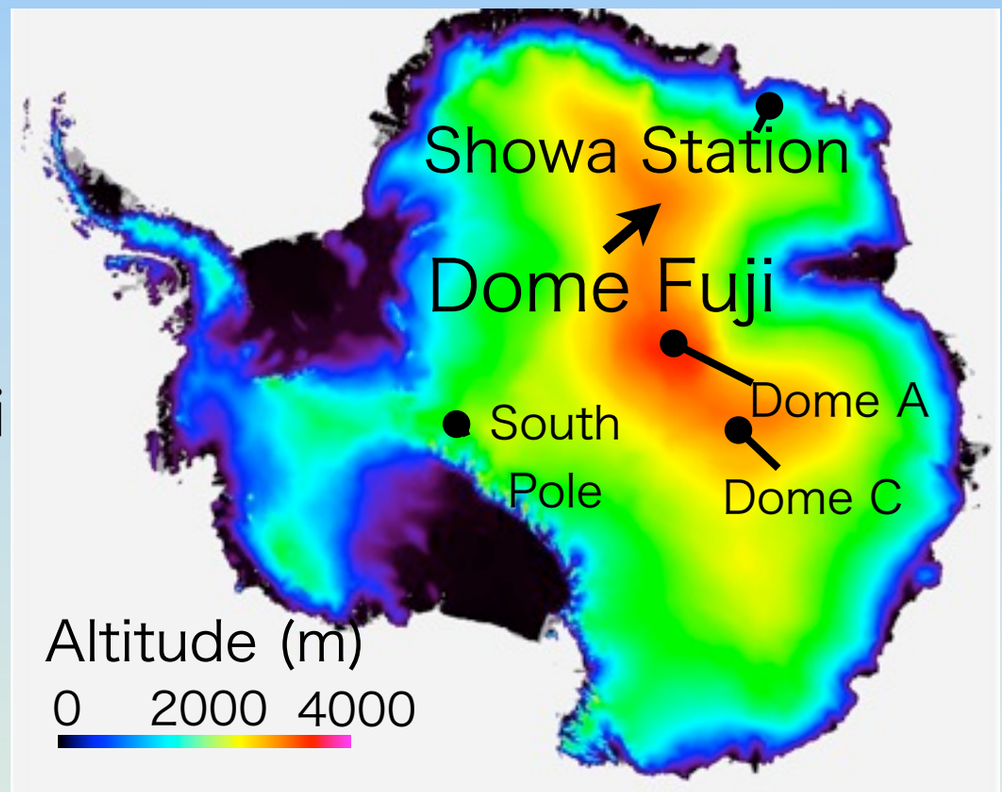
Table of Contents

Motivation

- Wide-field sub-millimeter camera
  - survey of the distant galaxy
- The Dome Fuji Station

Tsukuba University planning to construct the 7m submillimeter telescope at the Dome Fuji

	Temperature	Altitude
・Average：	−54 ℃	
・Minimum：	−79 ℃	3810 m



- Comparison of 220 GHz optical depth (Ishii et al , 2010)

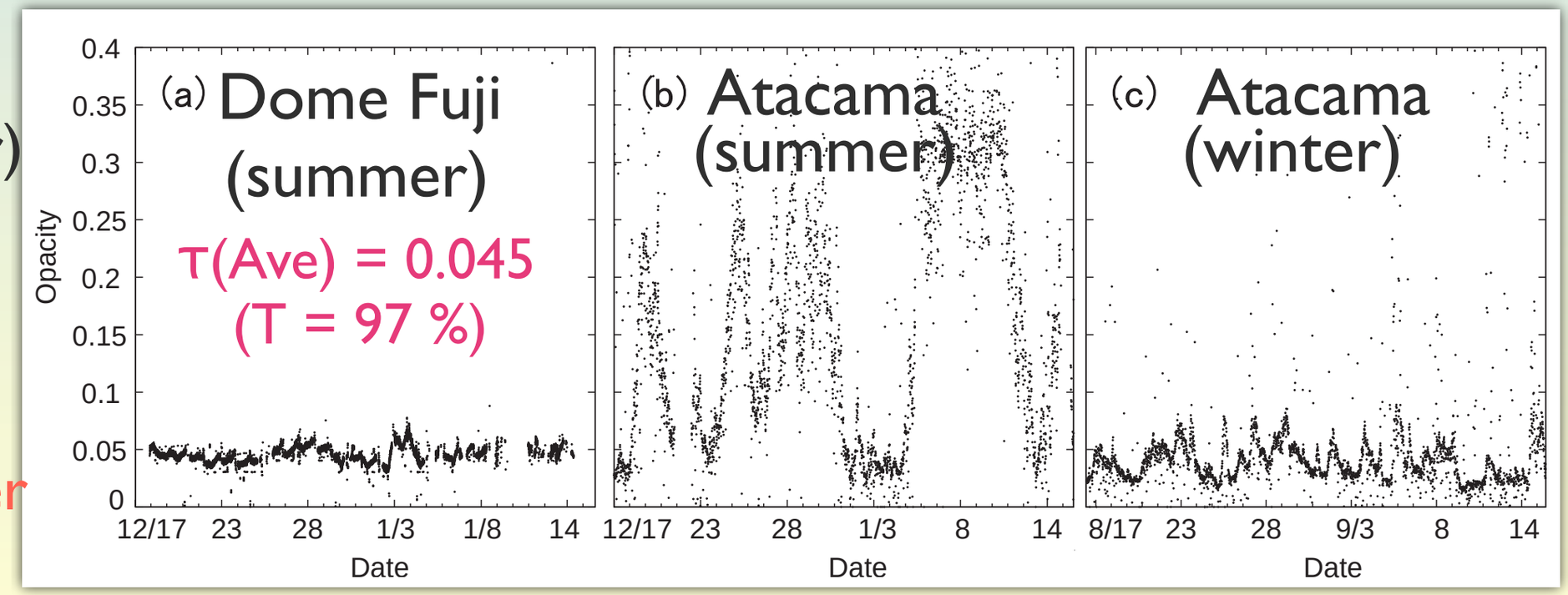
- Transmittance

  Dome F (summer)

  Atacama (winter)

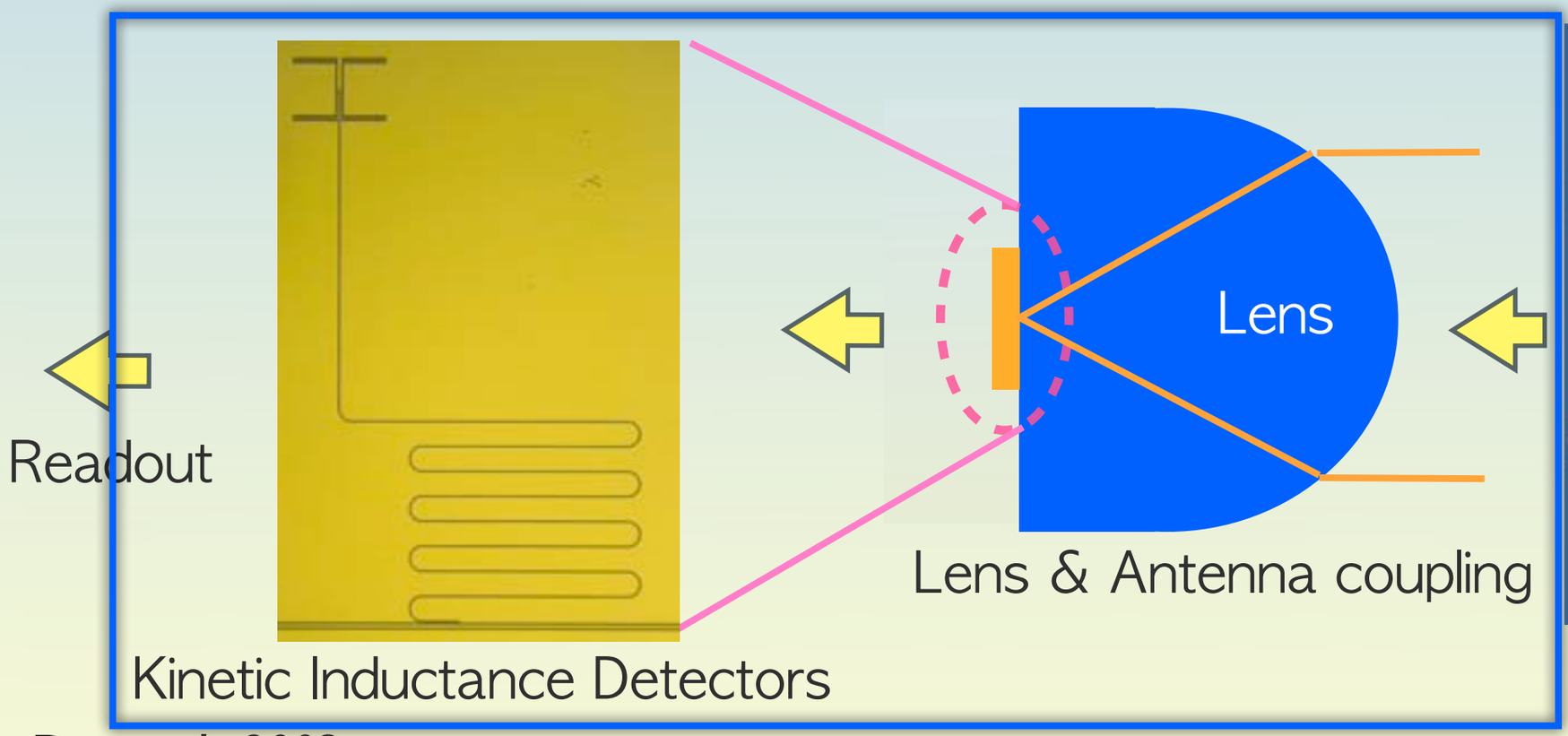
  →same value
- very stable
- Dome F in winter

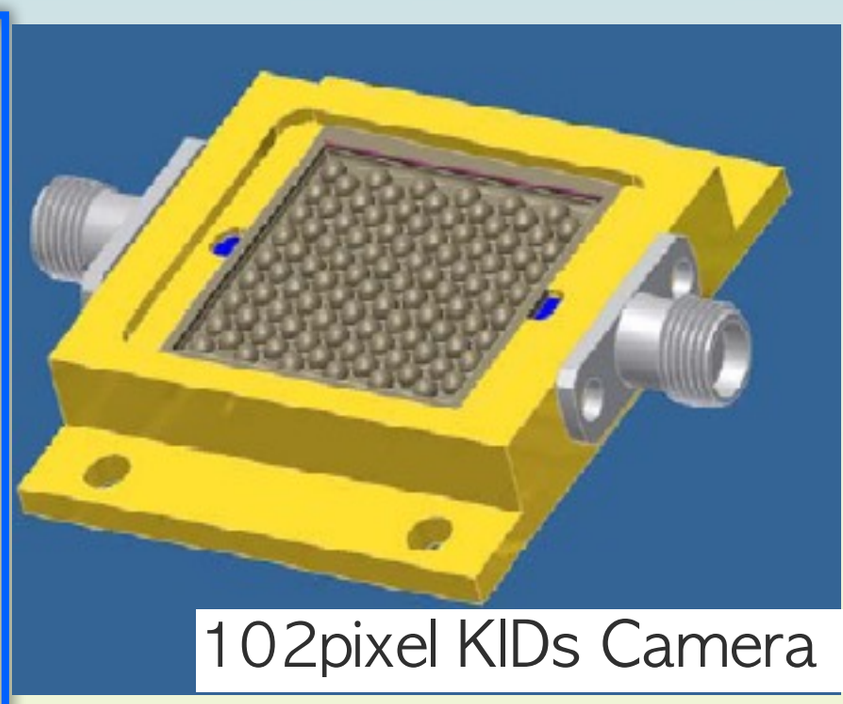
  →expect to better transmittance



NAOJ Camera Design

- Target Frequency
  - 220 GHz & 440 GHz
- number of pixel
  - 220 GHz → 9 pixel demo camera
  - 440 GHz → 102 pixel camera
- Camera design





Day et al , 2003
Yates et al , 2009
Neto et al , 2009

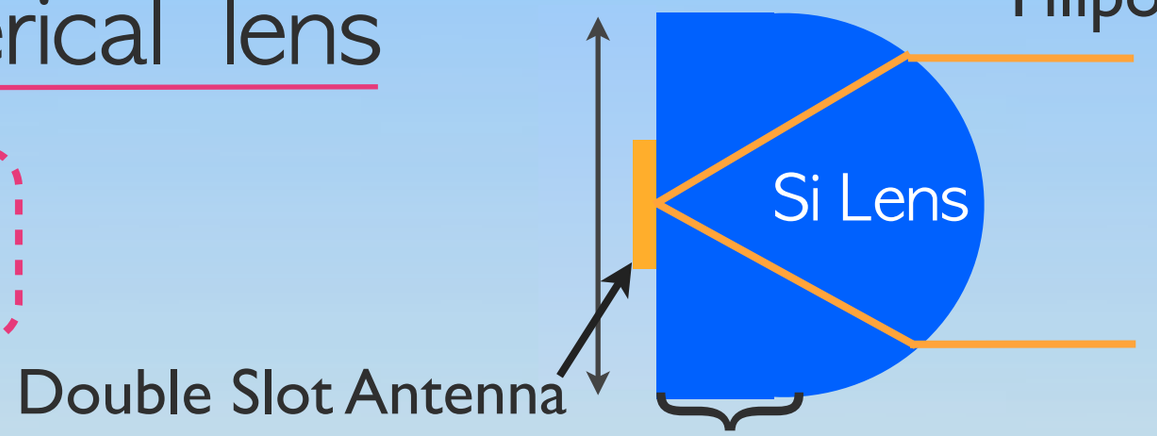
Development of Silicon lens array

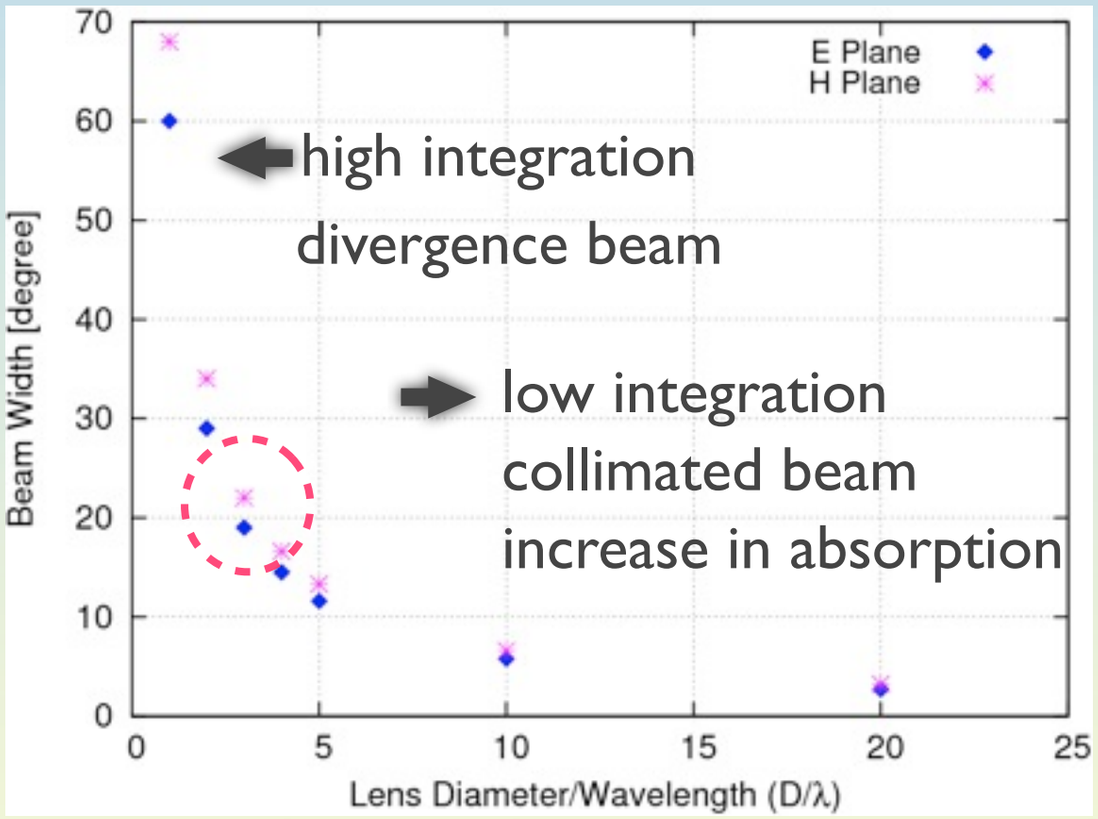
Lens Design with Double Slot Antenna

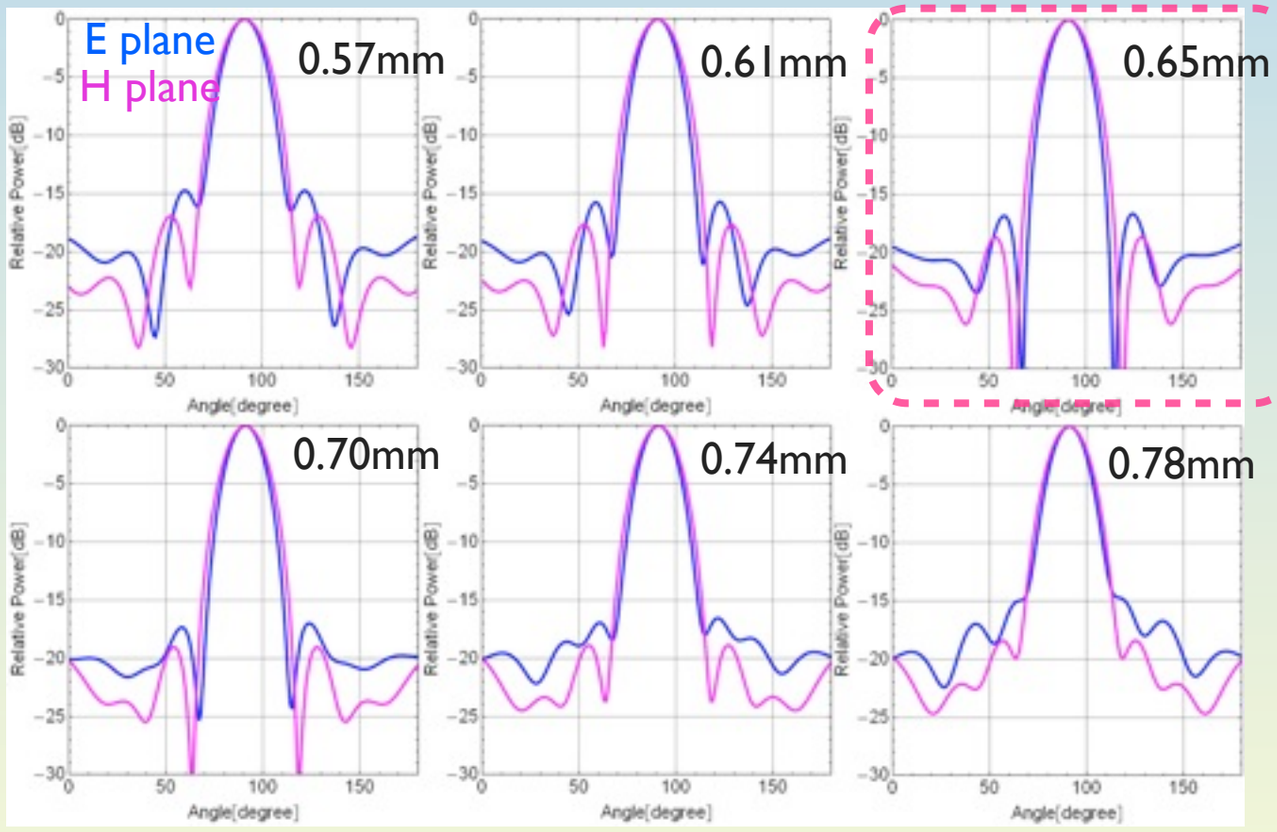
✳ Extended hemispherical lens

- Lens Diameter
- Extension Thickness

Filipovic et al , 1993



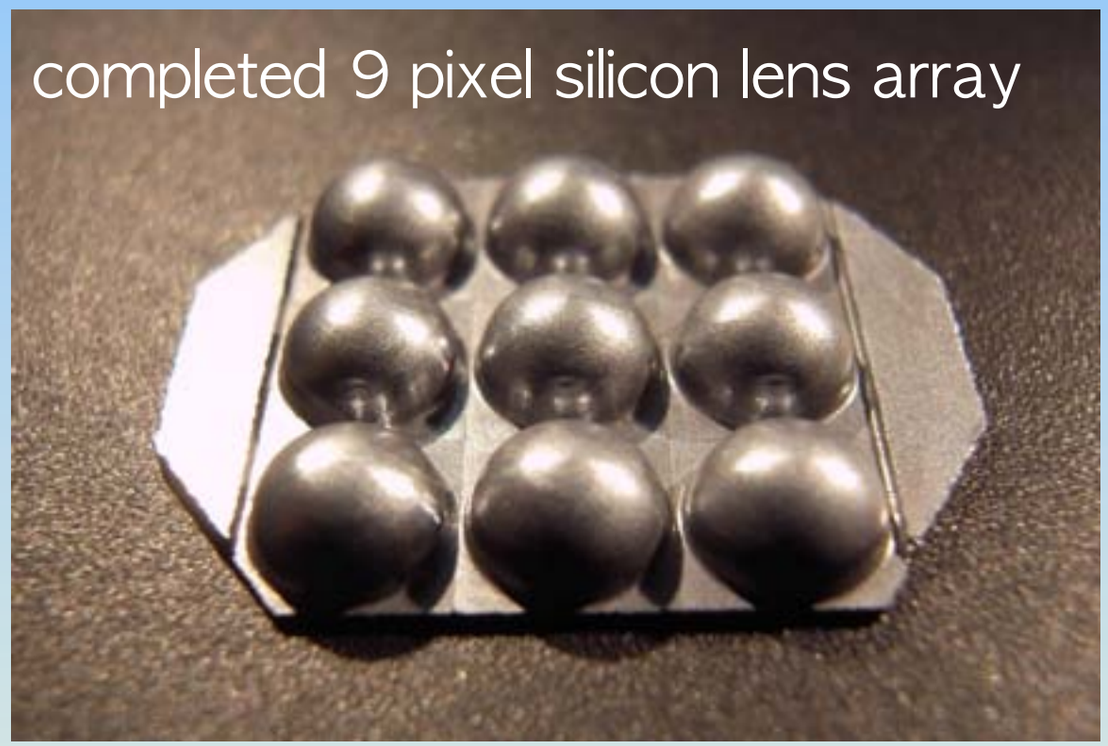




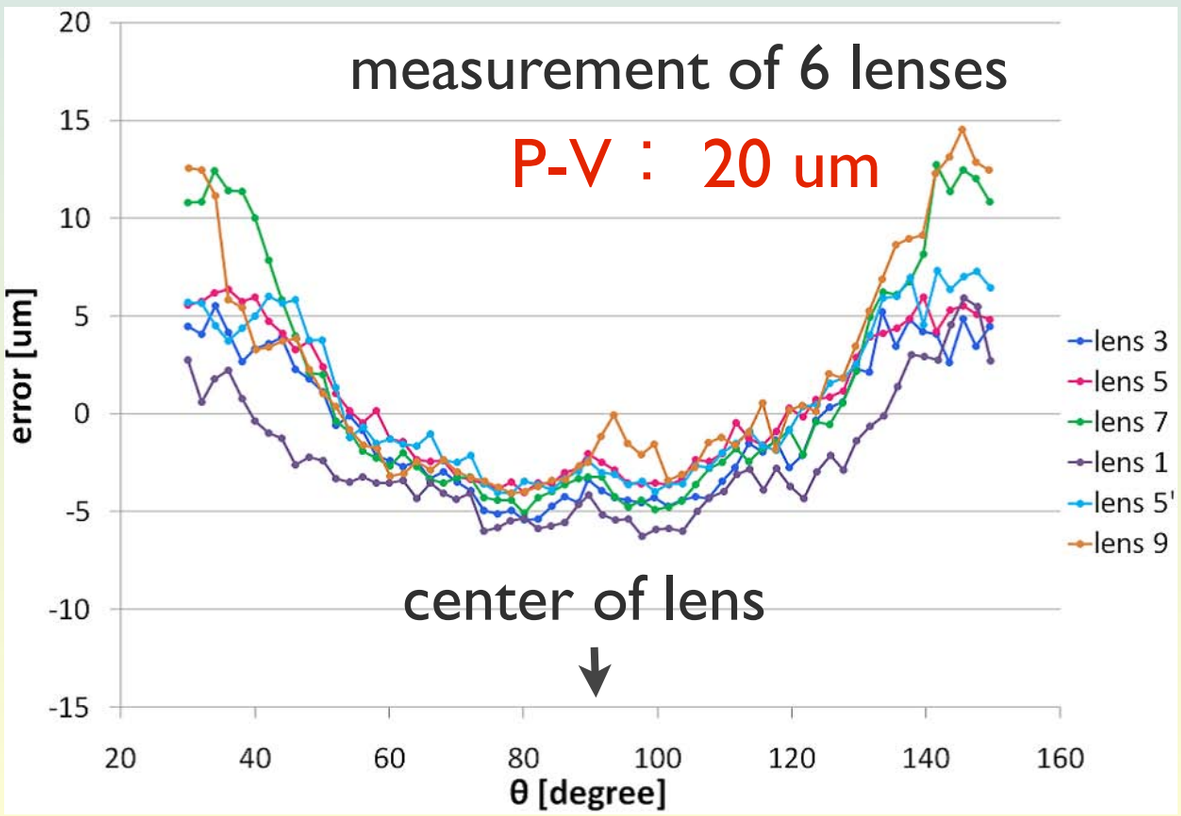
- considering the integration and dielectric loss, we decided to D = 3λ
  - Lens diameter : D = 3×1.36 mm (=220GHz) = 4.09 mm
- Symmetrical beam pattern and low side-lobe level
  - Extension thickness : Ext = 0.65 mm

Machining by High-speed spindle

- Prototype 220 GHz Silicon Lens Array
  - 3×3 array
  - lens diameter : D=4.09 mm
  - Extension thickness : L=0.35 mm
  - machining time
    → 9 hours for machining 1 pixel
  - R0.15 mm TiAlN coated ceramic end-mill

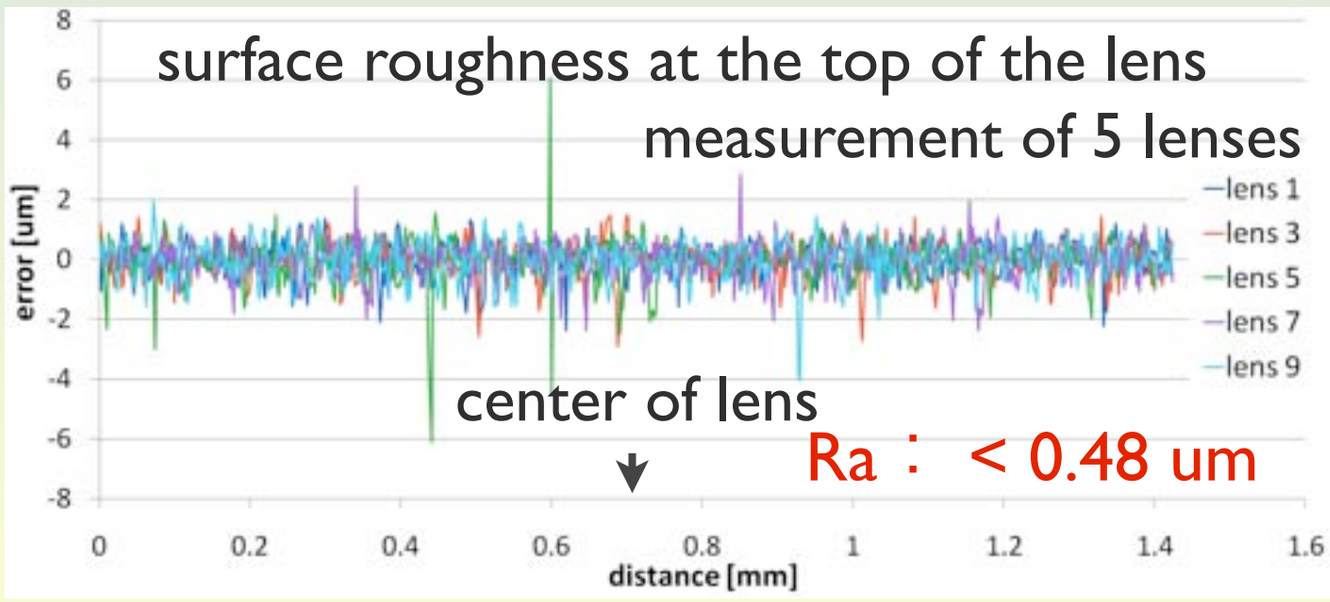


- Error from the radius of lens (R=2.045mm)



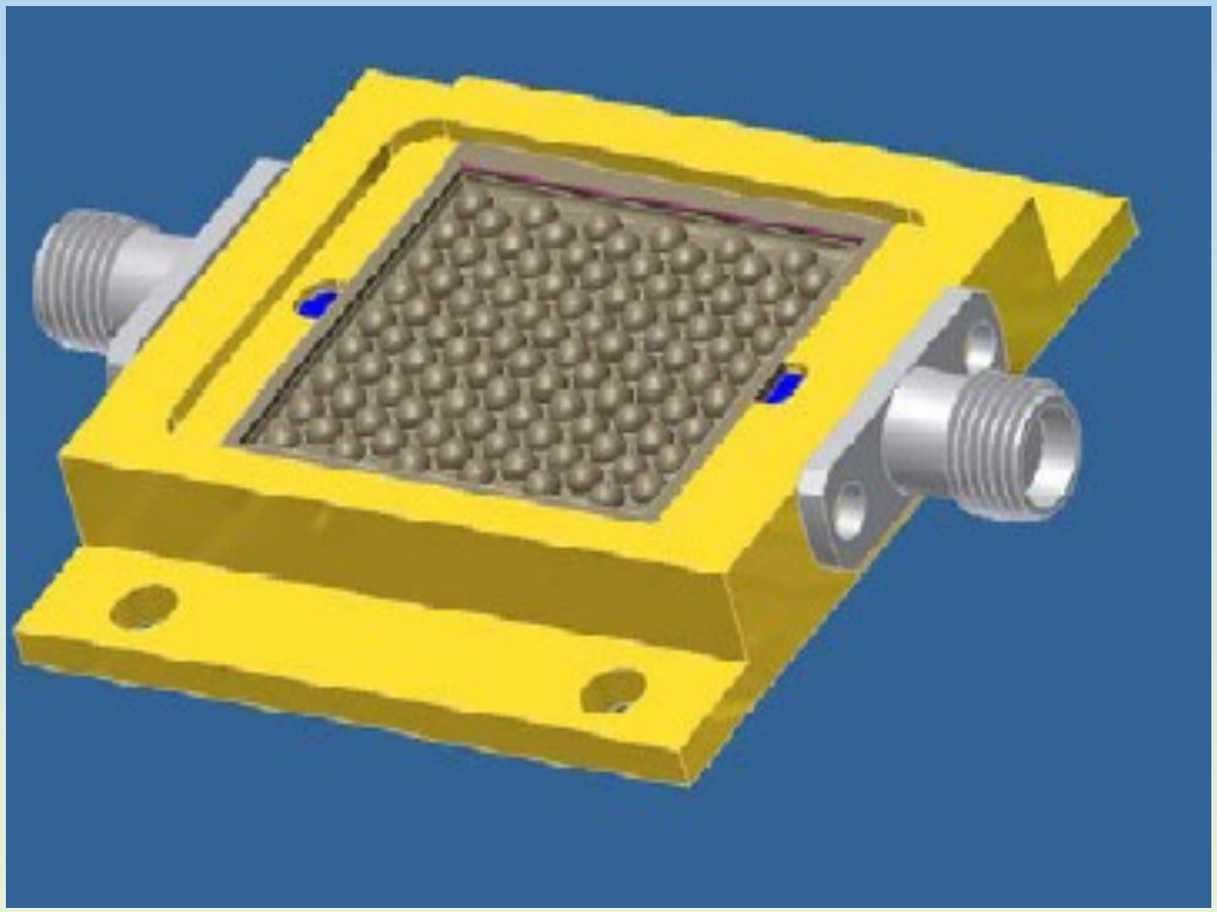
- Surface roughness

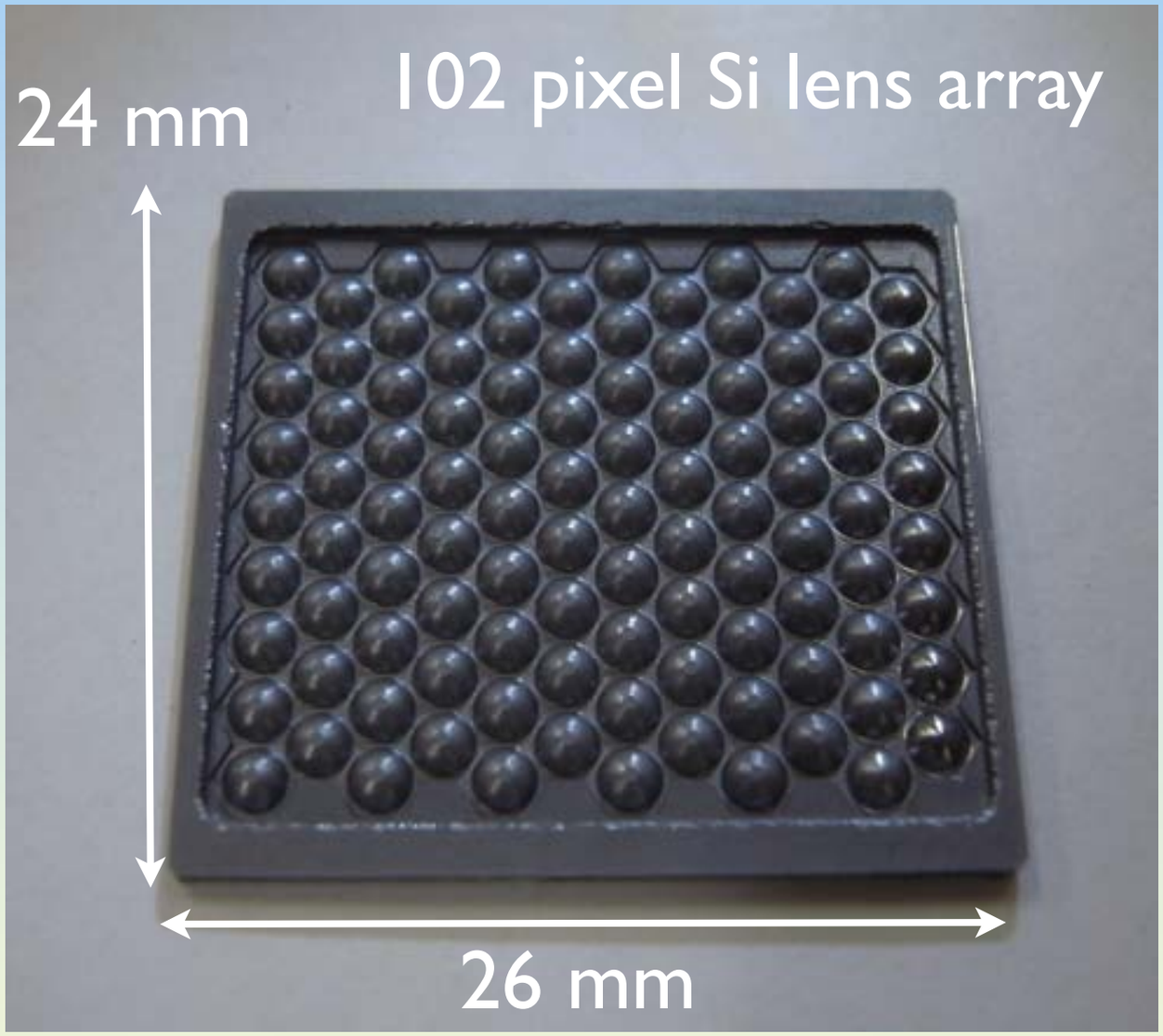
→ non-contact measurement of the He-Ne laser



Development of 440 GHz lens array

✳440 GHz 102 pixel camera design





✳ Lens Diameter : 2.04 mm

✳ Extension thickness : 0.2 mm

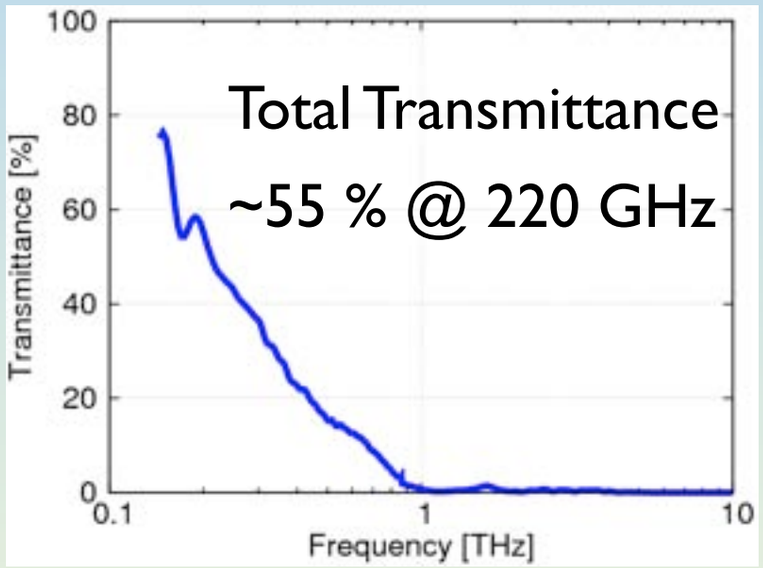
✳ Machining Setup : high speed-spindle & R0.1 mm TiAlN coated ceramic end-mill

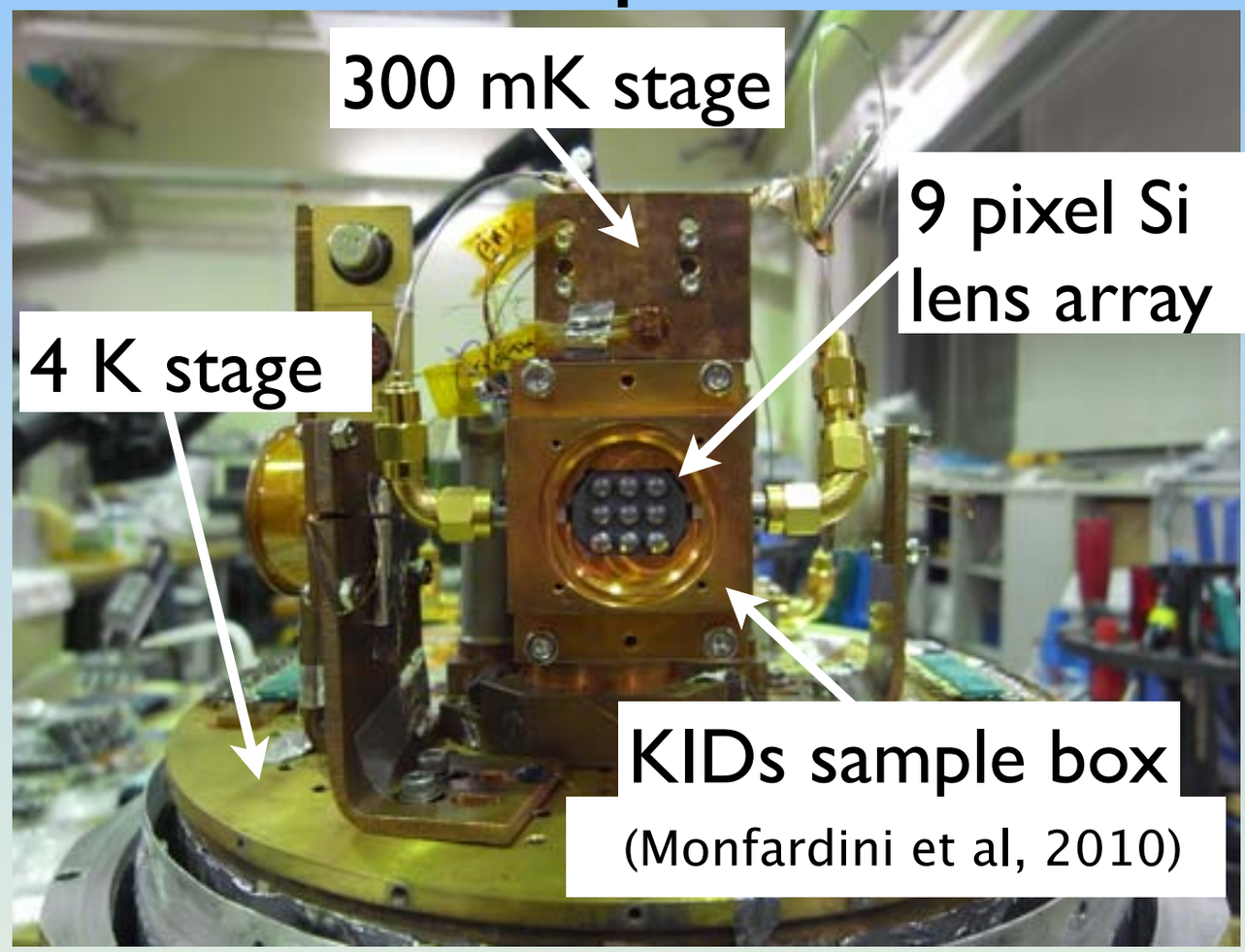
✳ Machining Time : 1 hour for machining 1 pixel

Beam pattern measurement of Antenna coupled KID

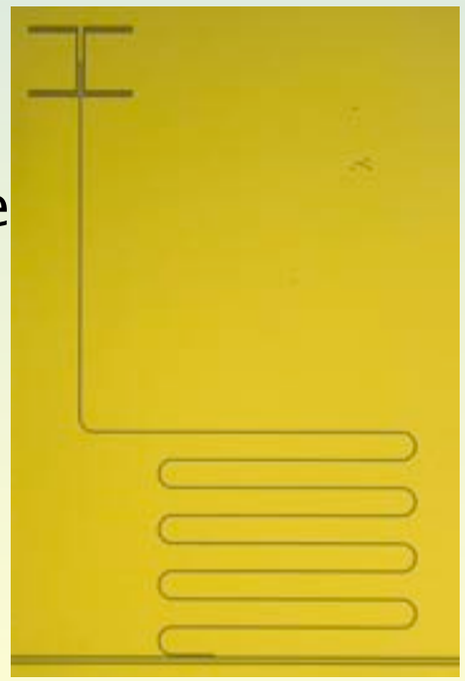
Measurement Setup

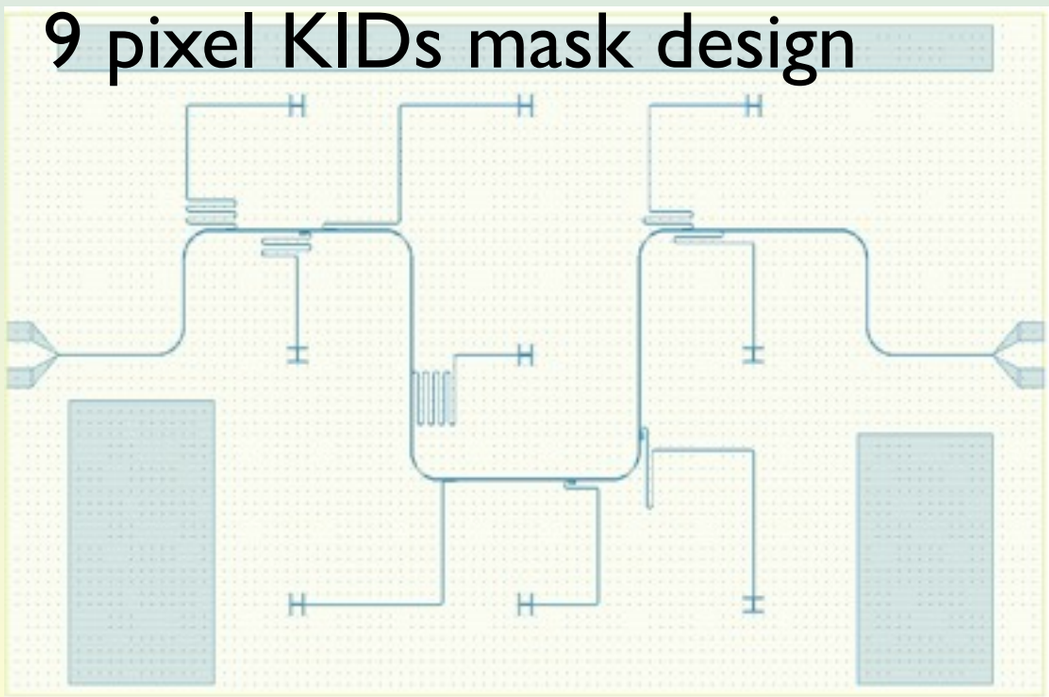
- He3 sorption cooler
  - Tmin : 300 mK
  - hold time : about 10 hours
  - IR filter





- Antenna Coupled KIDs
  fabricated by M.Naruse
  - 9 pixel Al KIDs
    --film thickness : 150 nm
  - silicon substrate
  - double slot antenna

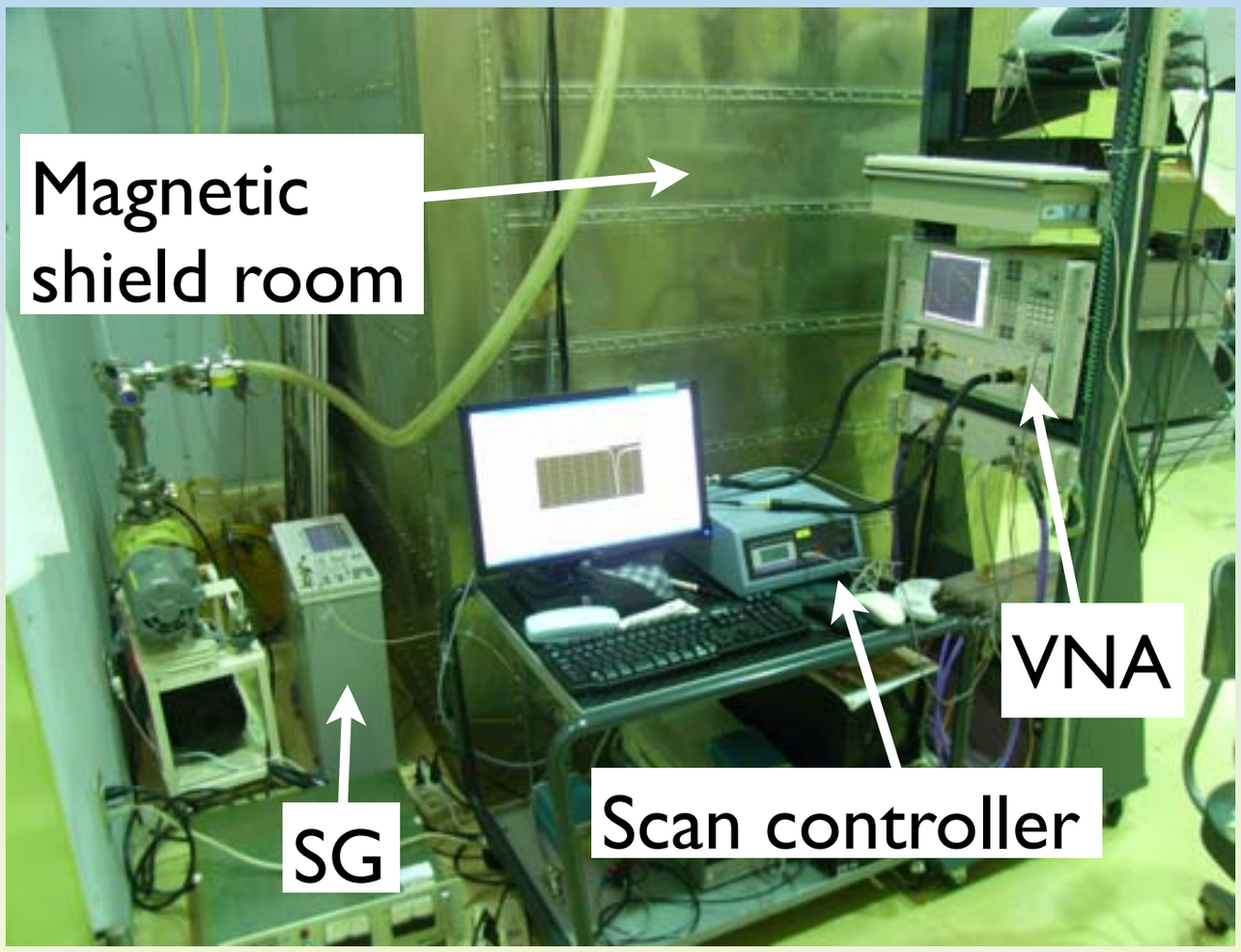




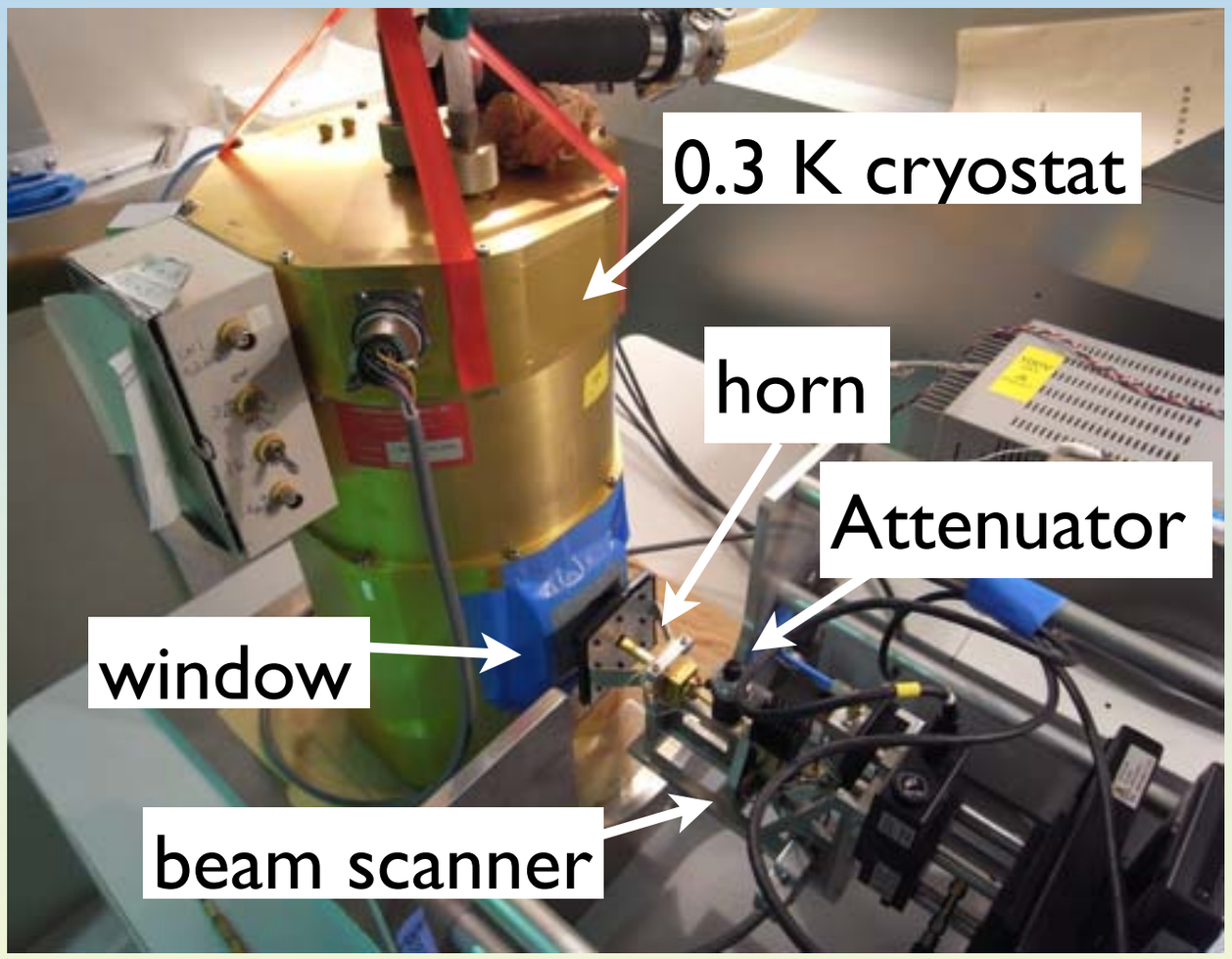
Measurement Setup

- beam pattern measurement
  - measurement at magnetic shield room

outside of the shield room



inside of the shield room

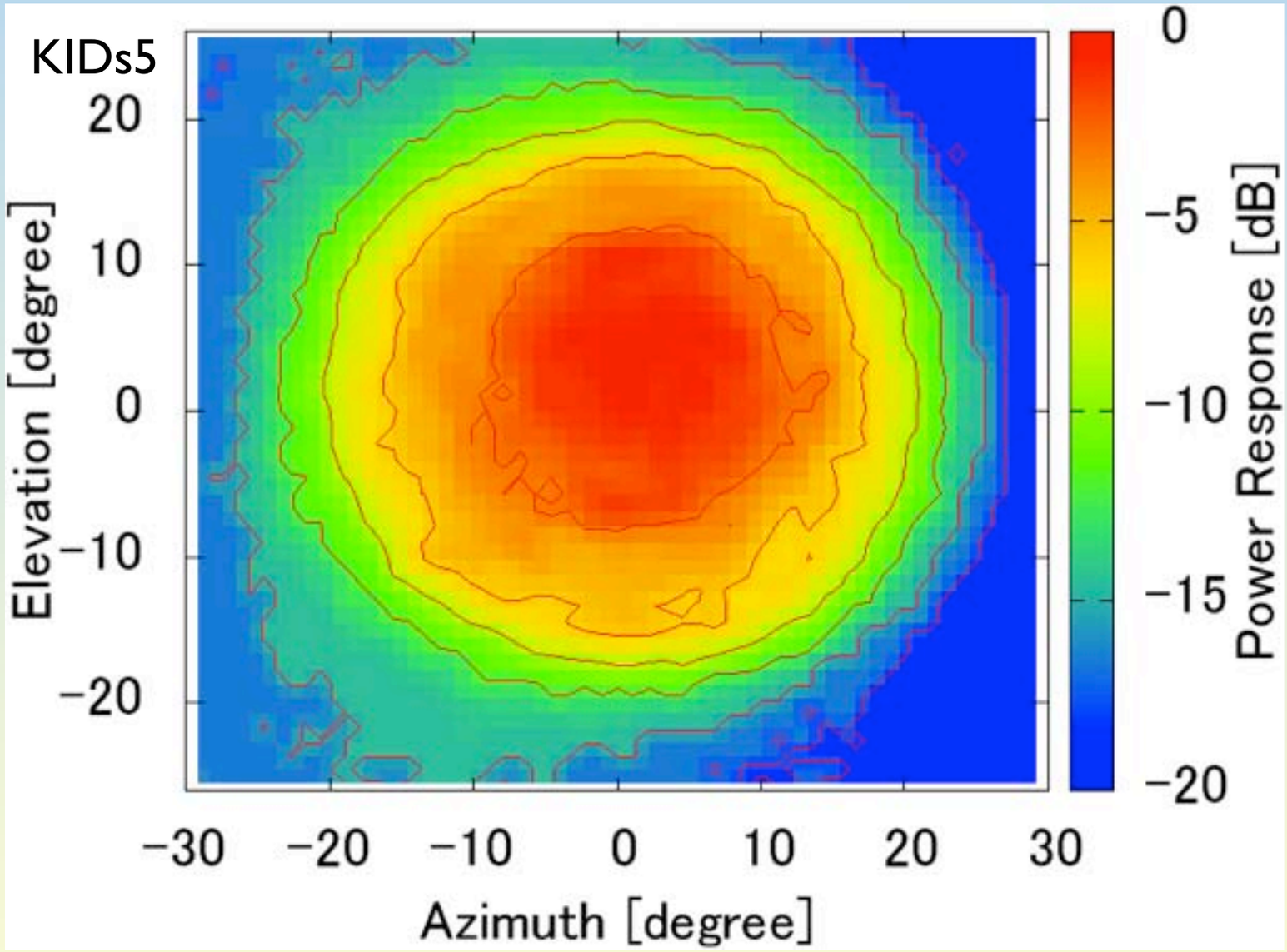


- 220 GHz radiation source was scanned around the window
- recorded the amplitude variations of the S21 response

Beam Pattern Measurement

- Far-field beam pattern

  - frequency : 220 GHz
  - dynamic range : 20 dB
  - contour : 3 dB step



Future Work

Antireflective Structure

Raguin and Morris , 1993
Grann et al , 1995

✶ Antireflection coating

- conditions for zero reflectivity

$$n_{AR} = \sqrt{n_{air} \cdot n_{Si}} = 1.84 \qquad d = \frac{\lambda}{4 \cdot n_{AR}}$$

- AR coating could separate from lens in thermal cycling .

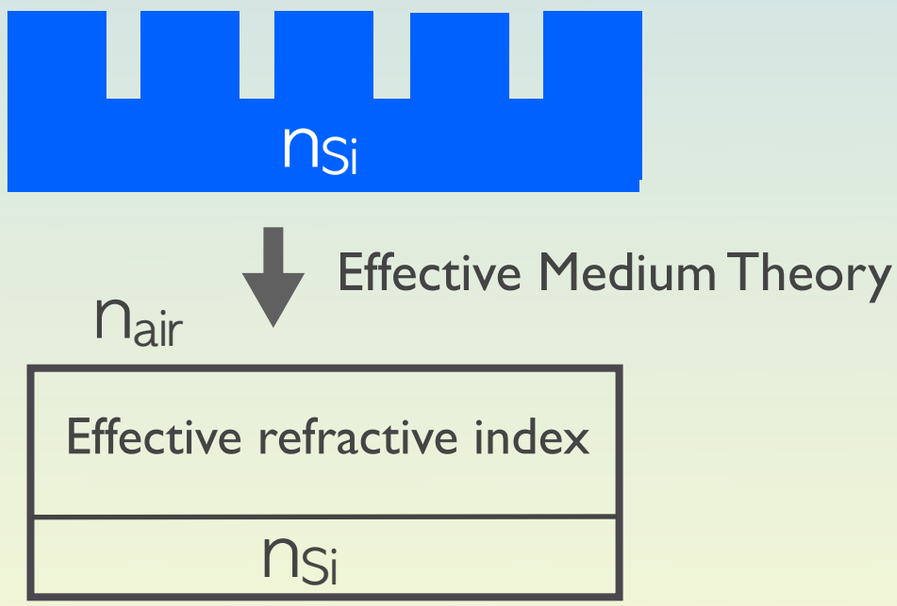
	refractive index	thickness@220GHz
Kapton-JP	1.84	185 um
TMM3	1.81	188 um
Parylene N	1.66	205 um
Stycast1266	1.68	203 um

Tran & Page , 2009

✶ Antireflective structure

Form a cyclic structure smaller than
the target wavelength on the silicon surface

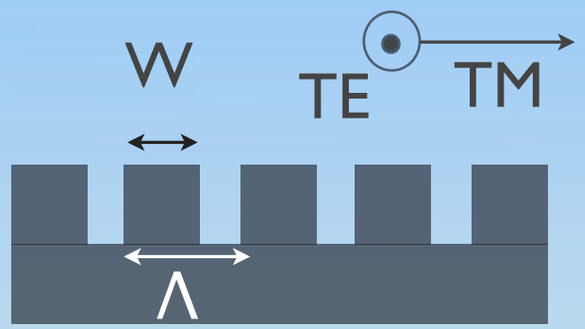
→ Possible to replace the ARS with
the effective medium of the refractive index
(Effective Medium Theory)



→same effect of one layer AR coating

✶ It is possible to get an anti reflective effect with only one material

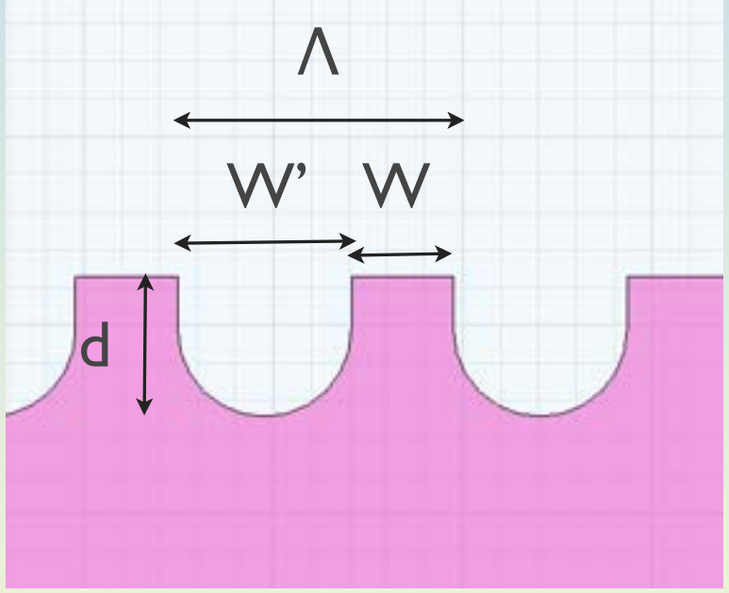
Groove Structure



✳groove has polarization dependence

→Because the structure is different at the vertical or horizontal direction of the groove.

✳ Groove Design of 220 GHz band



Λ = 0.36 mm

W = 0.14 mm

W' = 0.22 mm

d = 0.185 mm

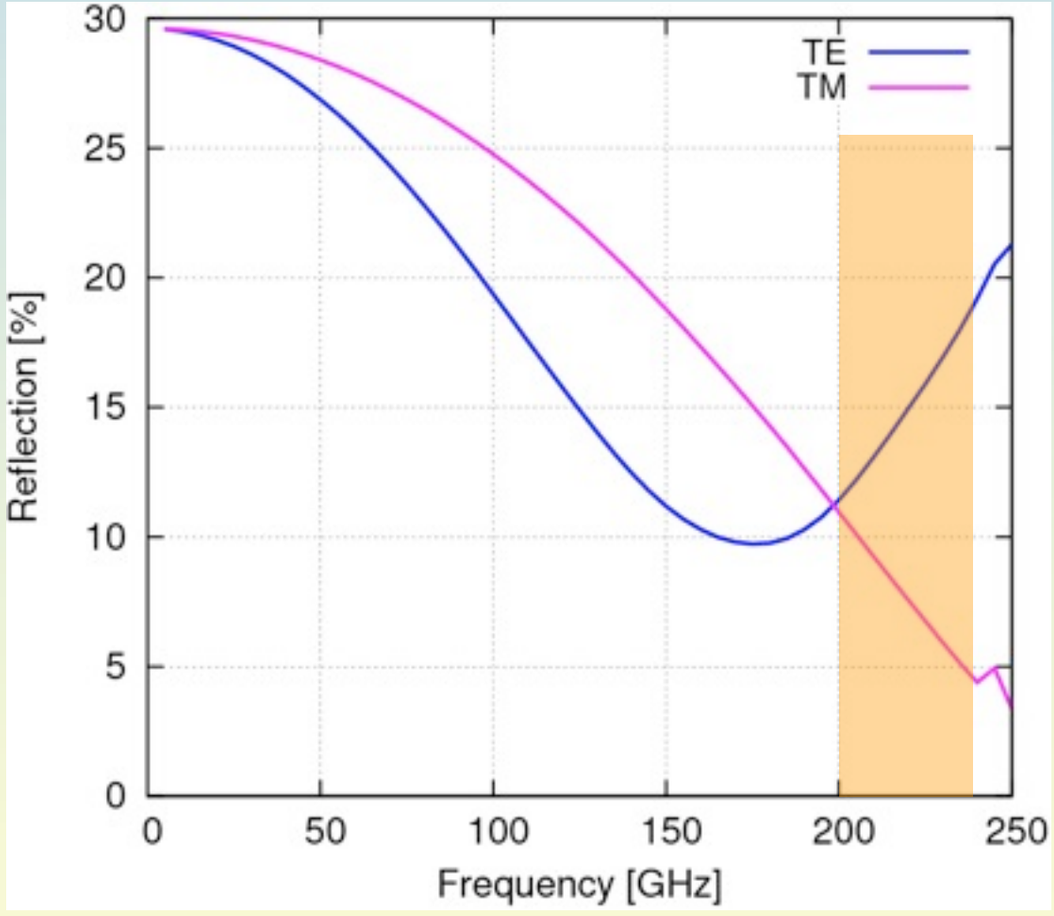
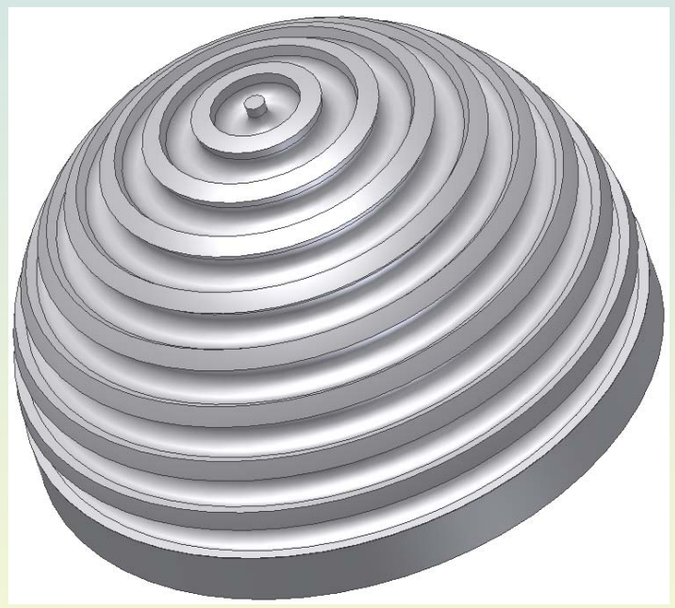


image of groove lens



average reflectance between 200 - 240 GHz is about 12 % .

Summary

1. Development of Si lens array for MKID camera

- 9 & 102 pixel silicon lens array was machined with the high-speed spindle at NAOJ
- measurement of 9 pixel lens' shapes
  - shape error : ~20 um(P-V)
  - surface roughness: ~0.48 um(Ra)

2. Beam Pattern measurement of antenna coupled KID

- measurement of 220 GHz beam pattern using antenna coupled Al KID
- Simulation and measurement are well conformed

3. Future work

- fabricate the AR structures on the lens surface
- beam pattern measurement of 102 pixel KIDs array