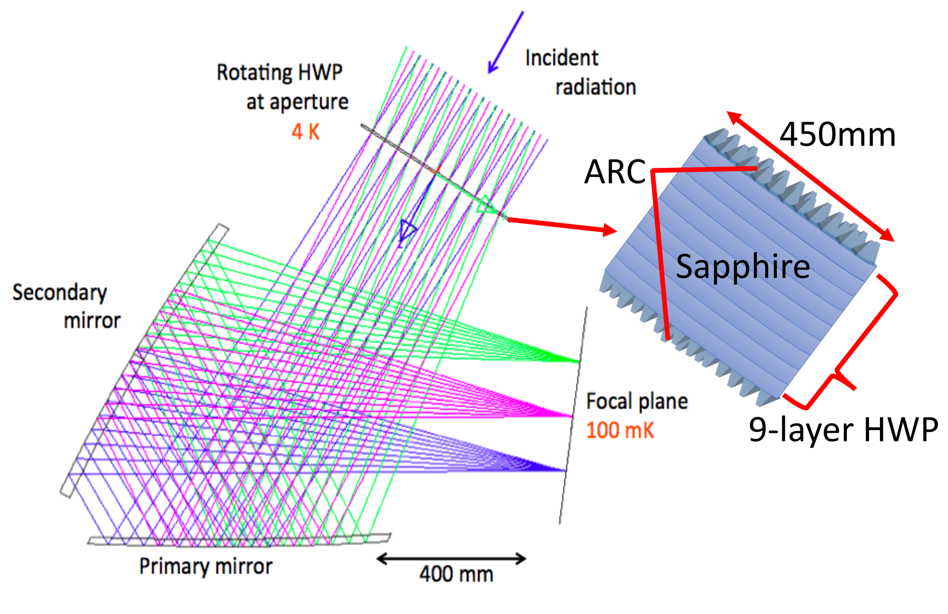
Anti-reflection coating using moth eye structure

R. Takaku[A], H. Imada[B], T. Matsumura[C], Y. Sakurai[C], N. Katayama[C], H.Ishino[D], K. Komatsu[D], S. Hanany[E], K. Young[E], Q. Wen[E],
M. Kuwata-Gonokami[F], J. Yumoto[F], K. konishi[F], H. Sakurai[F], Y. Kobayashi[F]
Yokohama National University[A], JAXA/ISAS[B], Kavli IPMU[C], Okayama University[D], University of Minnesota, Twin Cities[E], The University of Tokyo[F]

Introduction

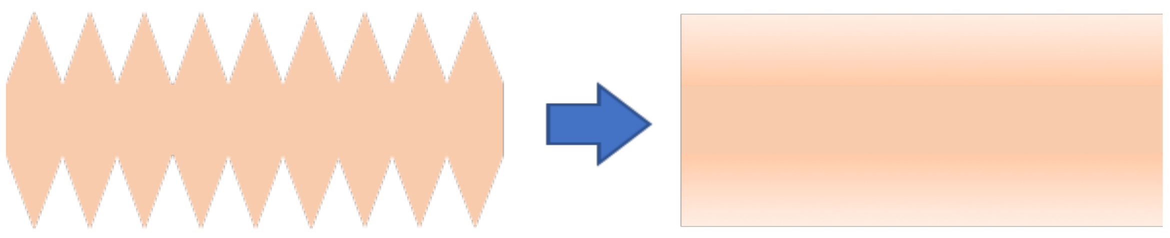


Crossed dragon telescope

The low frequency telescope of LiteBIRD, a proposed space mission to map the polarization of the CMB, operates between 34 and 270 GHz. The first element of the optical system is a sapphire-based achromatic half-wave plate.

We present a study aimed at optimizing the shape of sub-wavelength structures that serve as anti-reflection coating for the half-wave plate. We extend the laser ablation work of Matsumura et al.[1] and Young et al [2] and demonstrate a laser-ablated sapphire prototype that has more than 90% transmittance over the low frequency telescope's bandwidth.

Moth eye structure as broad band AR

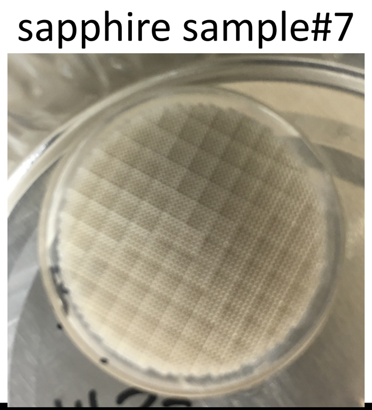


We imitate the moth eye structure by using an array of a very small pyramidal structure. When wavelength is much larger than the structure pitch, the moth eye structure is regarded as a material with the effective refractive index that gradually increases along the incident.

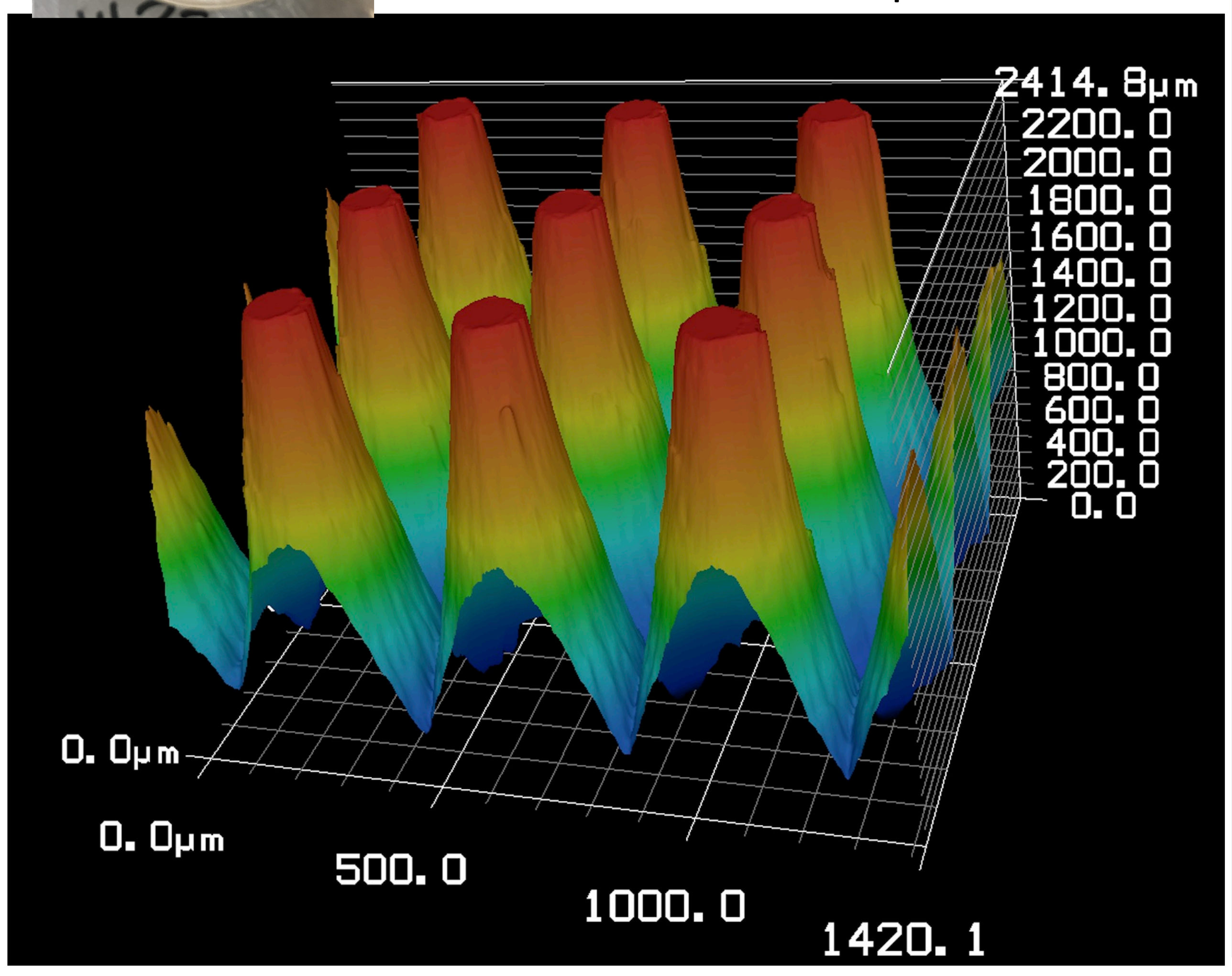
SWS AR fabrication and sapphire

1) Sapphire sample by laser ablation

IPMU mini-master SWS sapphire sample#7



- The diameter of 1 inch sapphire
- Structure height ≅ 2.3mm
- Structure pitch ≅ 0.4mm
- The machining time is about 80 h for 21 mm diameter area.
- The structure is measured using a confocal microscope.

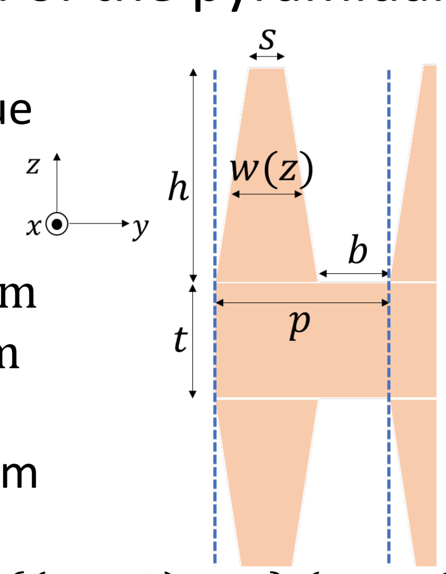


Simulation using RCWA

Parametrization of the pyramidal structure

Nominal value

$s = 80\ \mu m$
$h = 2000\ \mu m$
$p = 300\ \mu m$
$b = 0\ \mu m$
$t = 1000\ \mu m$
$\alpha = 1.0$

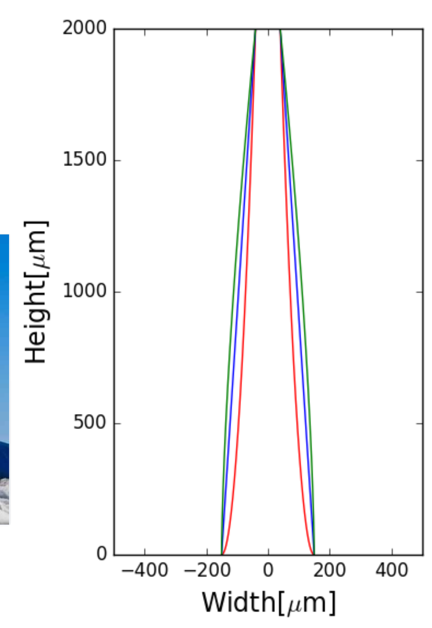


$w(z) = s + \{(p-b) - s\}(1 - z^{\alpha})$

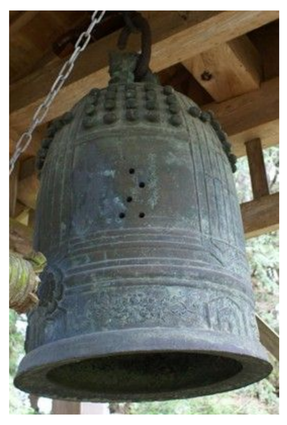
- z is normalized to 1
- $\alpha = 1.0$ corresponds to straight line.

Modelling the non-linear shape

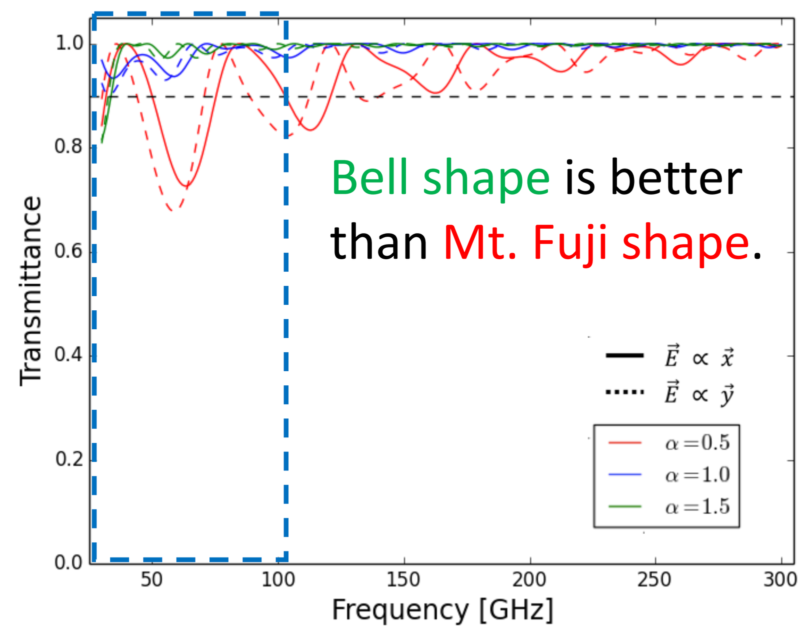
$\alpha = 0.5$
Mt.Fuji shape



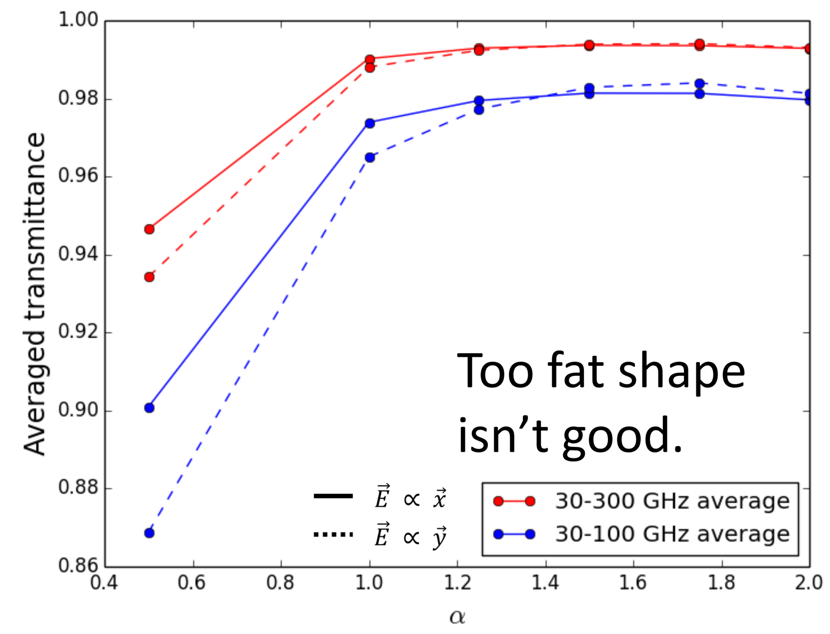
$\alpha = 1.5$
Bell shape



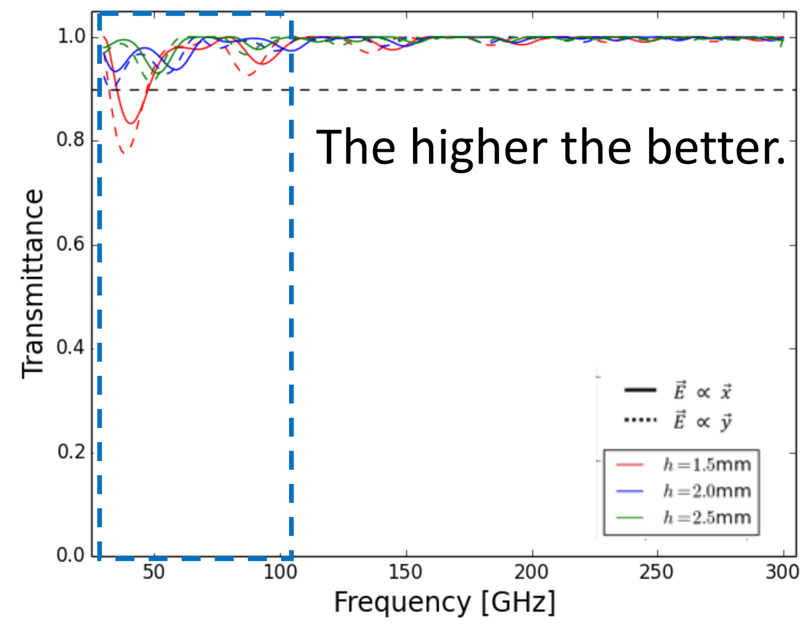
Result by changing the shape with α



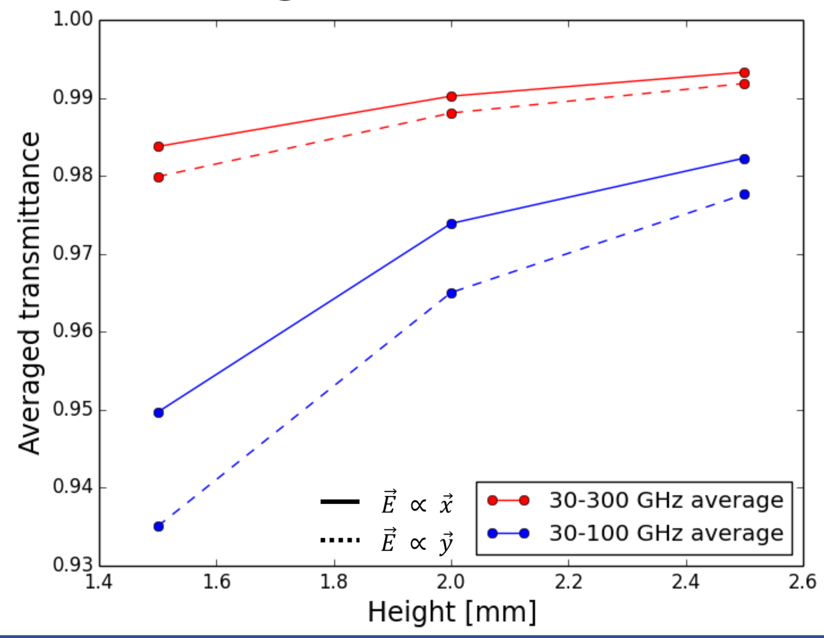
Averaged transmittance



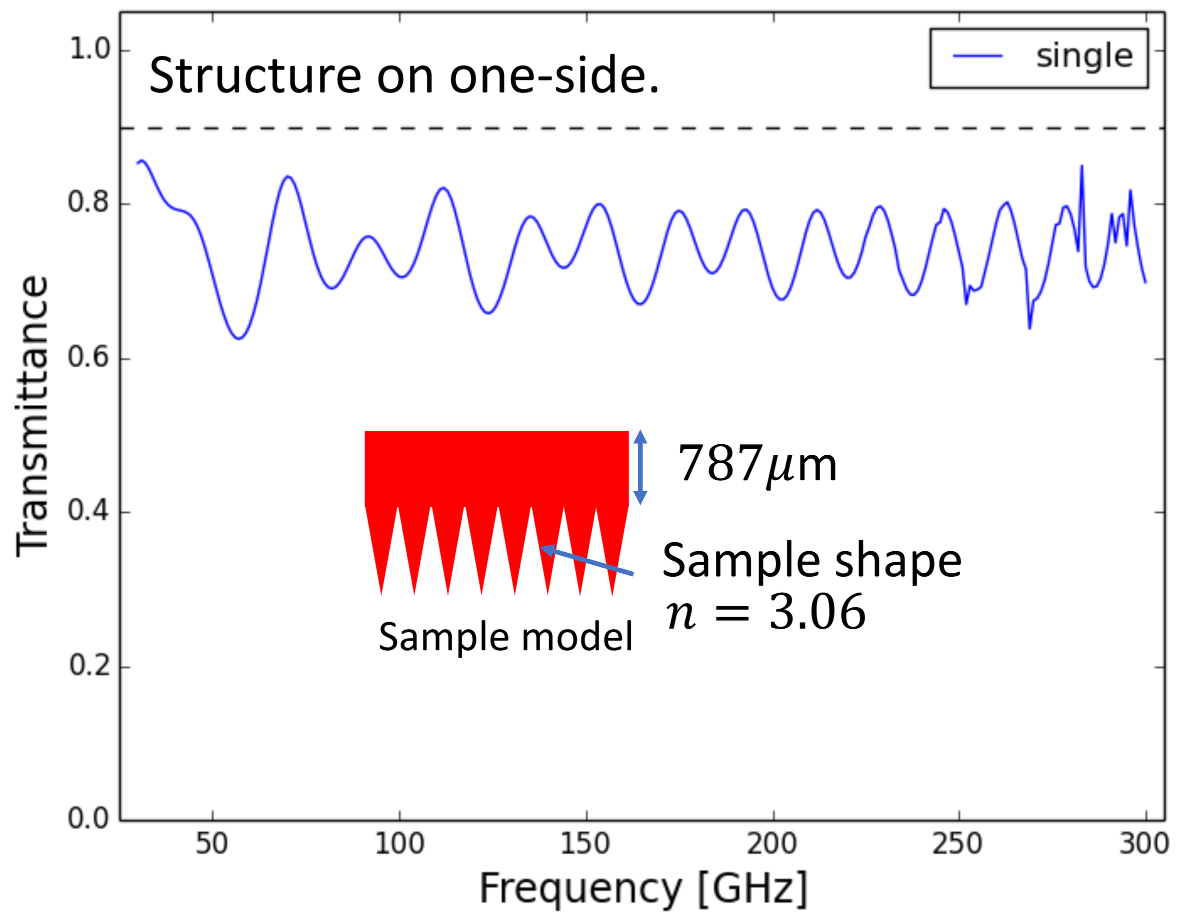
Result by changing height h

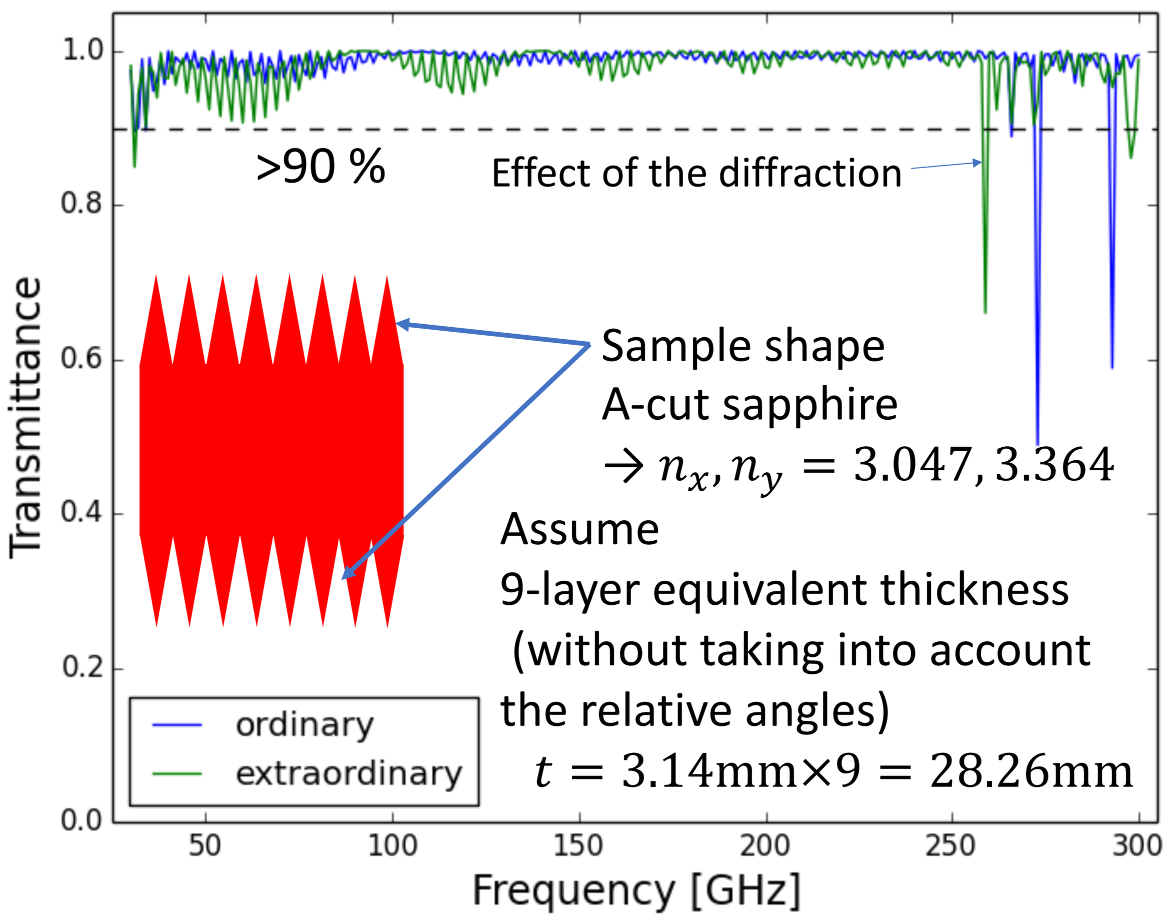


Averaged transmittance



2) The prospective performance from the prototype sample using RCWA





The previous studies [1,2] have demonstrated the correspondence between the measured SWS shape and the optical performance at millimeter wave.

[1] T. Matsumura, "Millimeter-Wave Broadband Anti-Reflection Coatings Using Laser Ablation of Sub-Wavelength Structures", Appl. Opt. 55, 3502 (2016).
[2] K. Young, "Broadband millimeter-wave anti-reflection coatings on silicon using pyramidal sub- wavelength structures", Journal of Applied Physics 121, 213103 (2017)

Summary

- We conducted the design optimization and the prototype fabrications.
- The structure shape is desired to be a bell shape rather than a Mt.Fuji shape to achieve high transmittance. The optimal range of the parameter is broad.
- We fabricated the prototype sample and simulate the result. We achieved above 90% transmittance using the SWS AR over the LFT observing band.