Demonstration of IR absorptive filters using alumina with laser ablated anti-reflection subwavelength structures for ground-based CMB polarization telescopes

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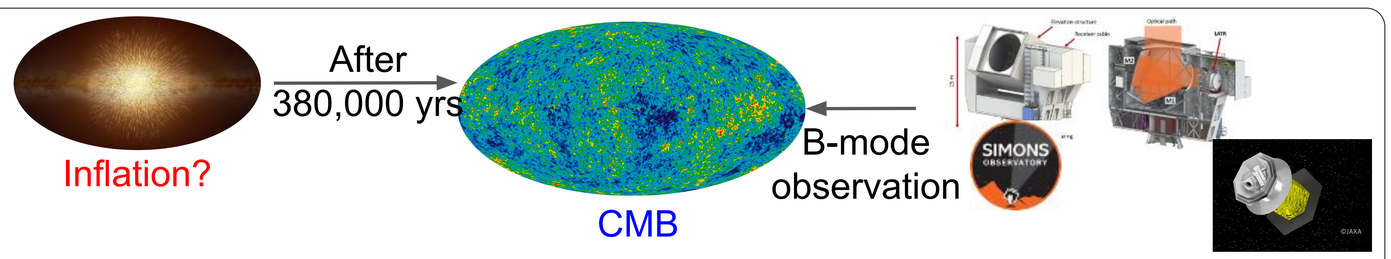
Research purpose and background

- Cosmic inflation is the exponential expansion of the universe at the very beginning (in a scale equivalent to a nucleus expanding to the size of the solar system in 10^{-36} sec).
- Cosmic microwave background (CMB) is the remnant light that emitted at the big bang era, and fills all the space “almost” uniformly and isotropically.
- Inflation generates the primordial gravitational wave, which imprinted the B-mode polarization on the CMB.
- Detecting primordial B modes is an experimental verification of the inflation theory.



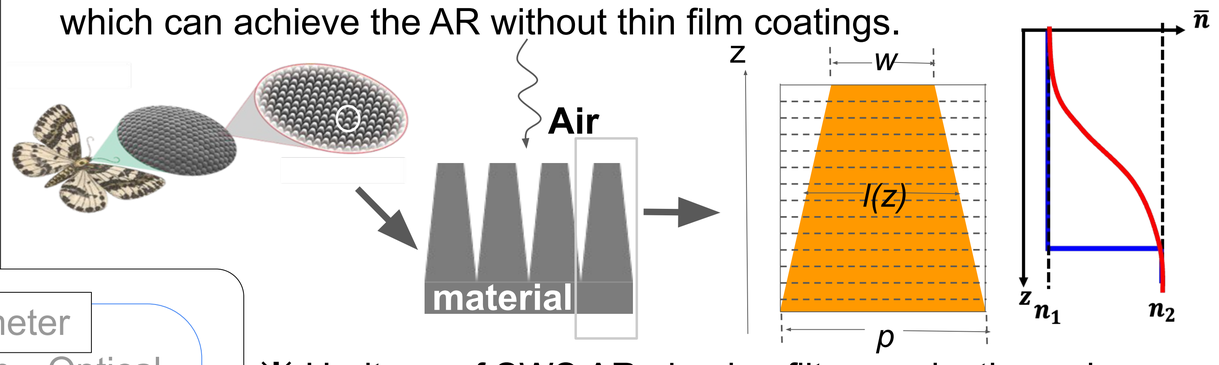
- For higher sensitivity, it is required to develop millimeter-wave optical systems with higher throughput.
- We show the current status of the alumina filter development using a nobel laser machining technique for ground-based telescopes.

Alumina infrared absorptive filter

- Alumina has absorbs infrared wavelength with high thermal conductivity. Many CMB telescopes incorporate them starting with Inoue, et. al (2014).
- One of the challenges with alumina comes from the refractive index of ~3, which leads the needs of anti-reflection (AR).
- Our development goal is to achieve: the high transmittance, the robustness against to the differential thermal contraction, and the realistic production time.

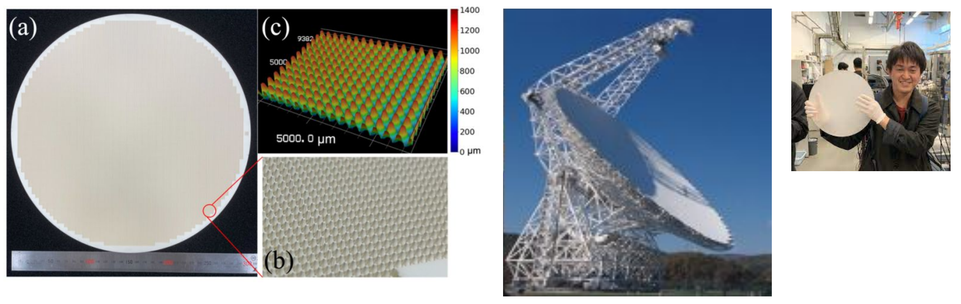
Motheye anti-reflective sub-wavelength structure (SWS)

- We developed motheye AR SWS using ultra-short pulse lasers.
- SWS produces the interim refractive index between air and material, which can achieve the AR without thin film coatings.



※ Heritage of SWS AR alumina filter production using laser machining:

- Alumina filter with D300mm with laser-machined SWS was mounted on MUSTANG2 receiver, Green Bank Telescope, USA.
- Frequency range: 90 ± 15 GHz
- Average band transmittance: 0.98

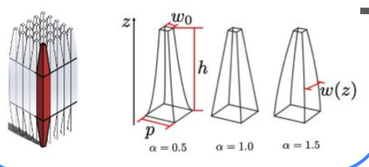


R. Takaku et al. Optics Express (2021)

Development process and the goals

Design

Determining geometric parameters of required structures.



Prototype

- Fabricating small area
- Transmittance simulation →Estimating the appropriate machine parameters and fabricating time

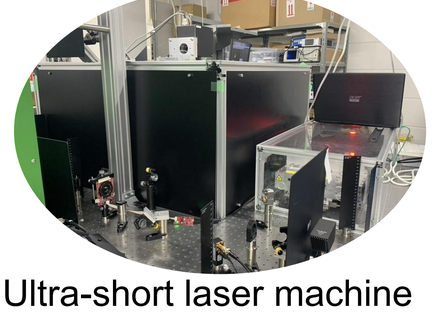
Large diameter

Fabricate D100mm→Optical measurements

↓

Fabricating the actual optical element for ground-based telescopes

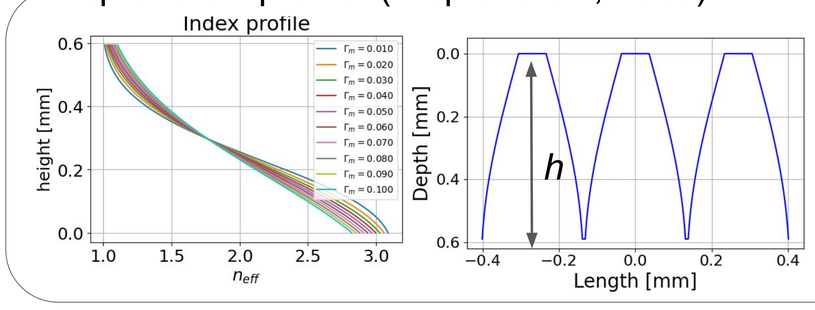
Band name	Central freq. [GHz]	Frequency range [GHz]	Goal average transmittance
Low Freq. (LF)	30, 40	23～45	> 0.98
Mid. Freq. (MF)	90, 150	76～173	> 0.98
High Freq. (HF)	225, 270	190～310	> 0.98



Ultra-short laser machine @IPST, Hongo campus

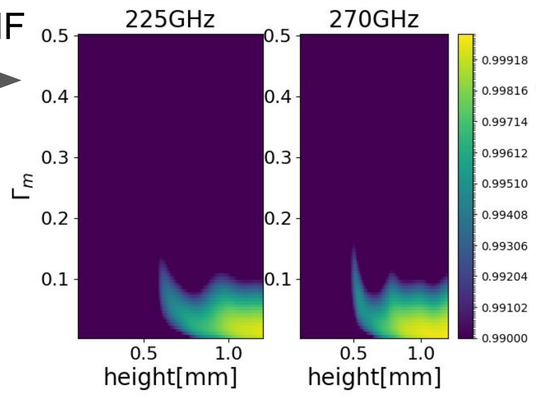
Design: profile and optimization of the height

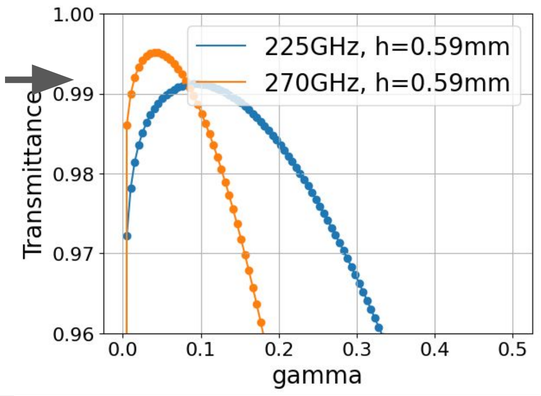
Klopfenstein profile (Klopfenstein, 1956)



Parameter: h, Γ_m

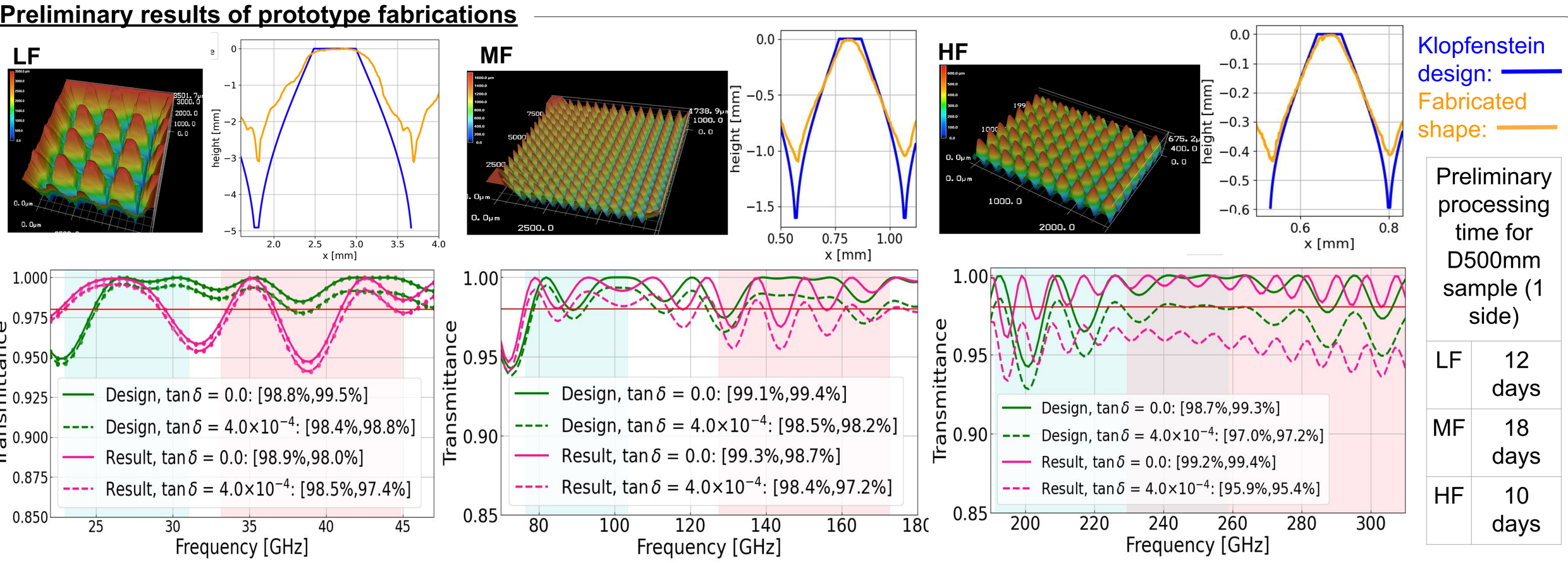
e.g. HF





- Choose minimus h which can exceed 99% of transmittance
- Choose the optimal Γ_m with the constriction of h above.

Preliminary results of prototype fabrications



Klopfenstein design: ——

Fabricated shape: ——

Preliminary processing time for D500mm sample (1 side)	
LF	12 days
MF	18 days
HF	10 days

Summary

Our preliminary results of the average transmittance in each frequency range and estimated fabrication time for D500 mm:

LF: [98.9%,98.0%], 12 days MF: [99.1%,98.8%], 18 days HF: [99.1%,99.2%], 10 days

→ **We obtained the compelling results for the production to the ongoing ground telescopes. We continue optimizing the design and fabrication process for a better performance with fast production.**