Development status of the millimeter wave transmittance measurement system at LN2 temperature

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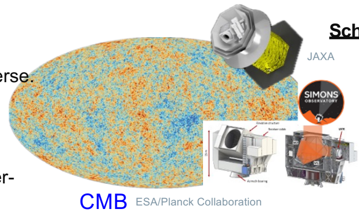
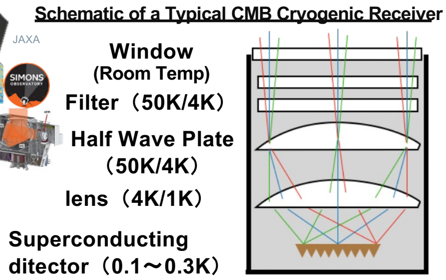
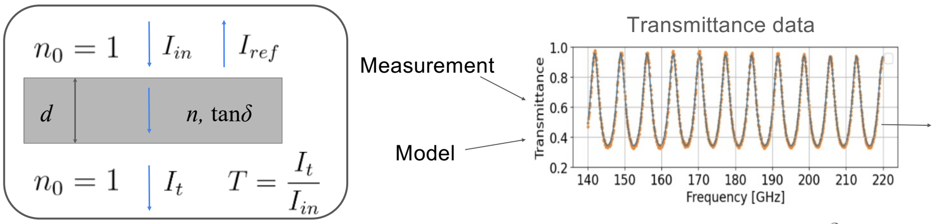
Introduction

- The Cosmic Microwave Background radiation (CMB) is the afterglow of the Big Bang, characterized by blackbody radiation at 2.725 K.
- The cosmic inflation is a hypothesis of exponential expansion of space at the early universe.
- That can be tested by observing the CMB polarization.
- Many ground-based, satellite and balloon-born CMB polarization telescopes have been developed in the world and several ground-based observation are ongoing.
- To enable precise CMB polarization measurements, it is critical to evaluate the millimeter-wave properties of optical elements in low-temperature environments.
- However, while many measurement setups exist for room temperature, environments capable of evaluating millimeter-wave properties at low temperatures are scarce.
- In this study, we aim to construct an environment capable of evaluating these millimeter-wave properties at liquid nitrogen temperature (77K) as a first step.





Method



Estimating parameters

- Refractive Index n
- Loss tangent tanδ

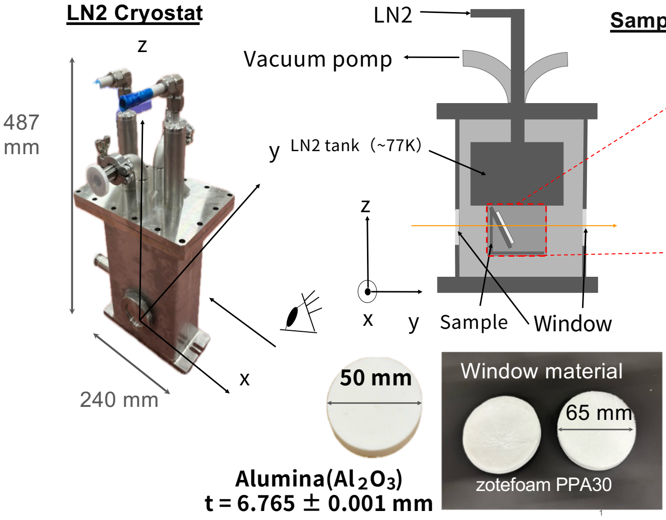
By fitting the obtained transmittance data, the parameters (n, tanδ) are estimated.

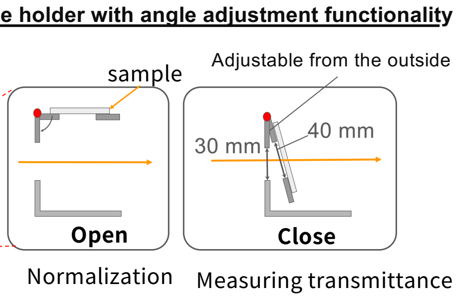
- Optical measurement: Transmittance
- Temperature: 95 K
- Measurement bandwidth: 140~220 GHz
- Sample: Alumina（Al_2O_3）D 50 mm

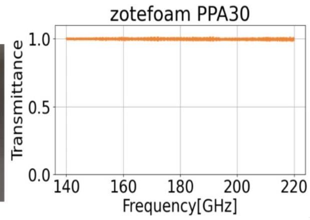
$$T = \left| \frac{2n(1-i\frac{\tan\delta}{2})}{n(1-i\frac{\tan\delta}{2})\cos x - i\sin x - n^2(1-i\frac{\tan\delta}{2})^2 i\sin x + n(1-i\frac{\tan\delta}{2})\cos x} \right|^2 \qquad x = \frac{2\pi\nu n(1-i\frac{\tan\delta}{2})d}{c}$$

This equation does not include incident angle dependency, but it is accounted for in the model.

Experimental procedure





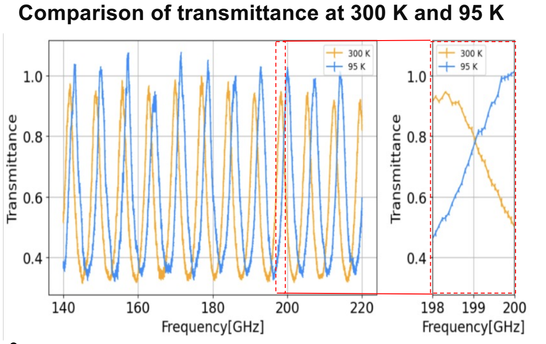


$$T = \frac{I_c}{I_o}$$

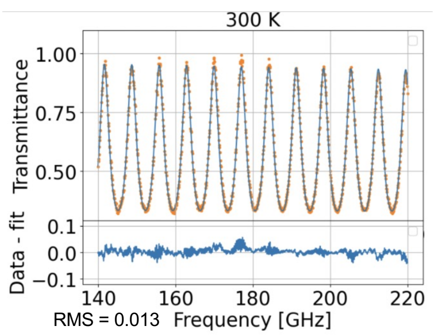
- This cryostat is equipped with a window designed to allow millimeter waves to pass through, using a high-transmittance material for millimeter waves (Zotefoam PPA30).
- The sample holder includes an angle adjustment mechanism to set the angle of the optical sample. It can also switch the sample in or out of the light path.
- This mechanism enables transmittance measurements without opening the cryostat lid. The transmittance is determined by the ratio of the output with the holder closed to that with the holder open (I_C / I_O).

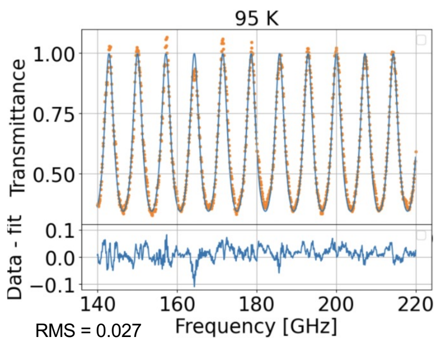
Transmittance measurement and parameter estimation results

Comparison of transmittance at 300 K and 95 K



- The results of 10 measurements were averaged, and the error bars represent the standard deviation calculated from the 10 measurements.
- The spectral differences are considered to be due to changes in the refractive index and dielectric loss.





	300 K	95 K
n	3.130±0.001	3.102±0.001
tanδ	(4.3±0.6)×10^{-4}	< 1.6×10^{-5} (68%)

- The error analysis is currently in progress.
- The fit residuals increased at lower temperatures.

Conclusion

We built a millimeter-wave transmittance measurement system for a liquid nitrogen environment. We conducted transmittance measurements with alumina at 300 K and 95 K, and estimated parameters to determine the refractive index and dielectric loss.
In the future, we will focus on improving accuracy at low temperatures and developing a measurement system at 10 K.

Acknowledgement

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