Opening a Cryostat to Light

Towards Detector Testing for the Advanced ACTPol Experiment

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Introduction

McMahon Lab is a cosmology group that has been developing new cryogenic detectors to soon be deployed in the Atacama Cosmological Telescope (ACT). The telescope's receiver has three optics tubes: two containing 150 GHz frequency band detector arrays, which have already been deployed, and one containing a 90/150 GHz multichroic detector array, which will be deployed by the end of the year. These optics tubes, along with the detectors, are housed within a cryostat.

My work in McMahon Lab under the University of Michigan Physics REU involved developing a vacuum window for the lab's multistage cryostat. This cryostat window would allow the group to send mm-wave signals into the cryostat in order to test their 90/150 GHz multichroic detectors before deployment in the ACTPol receiver. The window design was similar to the cryostat window that would be used in the actual telescope.

Set-up and Methods

Multistage cryostats can achieve millikelvin temperatures by lowering the internal temperature in stages. These types of cryostats contain a series of shells, each lowering the temperature of the cryostat environment to reach the coldest temperature at the central shell. Thus, in order to build a vacuum window for a multistage cryostat, one must build a window for each shell—or each temperature stage of the cryostat.

The shells within the cryostat are normally closed to light; therefore, replacing material of each closed shell with window material that will allow some wavelengths to pass through can thermally load the coldest stage, resulting in a higher temperature than desired at the coldest stage and saturation of the detectors. An approximation of the thermal loading onto one stage of the cryostat from the next warmer stage is given by

$$P_e = \varepsilon\sigma\int_0^a r[T(r)]^4\,dr, \tag{1}$$

where r is the radial distance from the center of the window, a is the radius of the window, σ is the Stefan-Boltzmann constant, ε is the emissivity of the window material, and $T(r)$ is the temperature of the window at radial distance r. The temperature of the window is given by

$$T(r) = T_e + \frac{q_o'}{4kT}(a^2 - r^2), \tag{2}$$

where T_e is the temperature at the edge of the window, T is the temperature of the next warmer stage, k is the thermal conductivity of the material, and q_o' is the power per unit area absorbed at the window.

We can attempt to minimize the thermal loading on the final stage of the cryostat by choosing the right materials. In order to minimize thermal loading, allow the desired mm-wavelengths through, and survive the extreme conditions within the cryostat, the window materials must meet the following criteria:

- Have minimal absorption and reflection in the mm-wavelength range.
- Be highly absorptive in the infrared wavelength range, as this radiation causes the most thermal loading.
- Have a high thermal conductivity at low temperatures such that any heat absorbed by the material can quickly escape through the cryostat shell.
- Have a low dielectric constant.
- Cannot be too brittle (must be able to withstand cryostat temperatures).
- Have a low index of refraction in the mm-wavelength range and/or an anti-reflection (AR) coating.

Since many materials will not meet all of the criteria, an AR coating (mentioned in the last criterion) can be used to lower the index of refraction of the window as a whole and therefore reduce reflection of mm-waves. A good AR coating has an index of refraction

$$n_{coating} = \sqrt{n_{window}}\,. \tag{3}$$

A significant part of my project involved developing a new method of AR-coating the cryostat windows. Previously, AR coatings were adhered to the window material using Stycast epoxy glue. The glue layer would ideally be thin and even enough as to not interfere with any radiation passing through the window or alter the index of refraction of the window significantly.

However, it was very difficult to achieve a thin, even layer of glue using this method, so we switched to using a thin layer of LDPE for a more controlled adhesive layer. I built a press apparatus that allowed us to clamp the AR coating down to the window material, with a 0.6 mil thick layer of LDPE in between. The press then went into a vacuum oven at 135° C, allowing the LDPE layer to melt and adhere the coating to the window material.

In order to test the effectiveness of the AR coatings, we used a set-up consisting of a mm-wave signal emitter and receiver. A signal was directed towards the AR-coated window, where part of the signal would be reflected by the window and part would be absorbed or pass through. By knowing the intensity of the original signal at each frequency, we could compare it to the intensity of the reflected signal detected by the receiver to determine the percentage of the signal that was reflected.

Results

AR coating tests showed that the presence of an AR coating indeed significantly reduced the reflection of mm-waves by the window. Figure 1a shows the percentage of a mm-wave signal that was reflected by a 1/32" thick sheet of uncoated nylon. Figure 1b shows the percentage of the signal reflected by the same sheet of nylon coated with 0.020" thick PTFE Teflon, which has an index of refraction very close to $\sqrt{n_{nylon}}$. We can see that the percentage reflection for uncoated nylon is very rarely below 10%, while the percentage reflection for AR-coated nylon is nearly 0% around 130 GHz, and below 5% in the 120 – 140 GHz range.

In order to minimize the thermal loading at the 1K stage of the cryostat and maximize signal transmission, we chose the following materials for windows at each stage:

- 300 K: 5.5" thick Zotefoam (uncoated)
- 70 K: 1" thick PTFE Teflon coated with 0.015" thick Porex
- 4 K: 1/32" thick nylon coated with 0.020" thick Zitex
- 1 K: 3/4" thick Eccosorb MF coated with 0.020" thick PTFE Teflon

The Teflon-coated Eccosorb at the 1-Kelvin stage was chosen to act as a neutral density filter (NDF), which would attenuate the signal so as to not saturate the detectors.

The thermal loading from each of these windows was estimated to be in the milliwatt range, so we do not expect any problems to arise with excess loading on the detectors.

After installing the window for the first time and trying to bring the cryostat down to 1K, we found that the 4-Kelvin stage was not getting cold enough. We inspected the window components after the first run and found that some of the AR coatings had peeled off, and there were gaps in the window components that may have allowed excess heat flow between the cryostat stages.

We reapplied the damaged AR coatings, closed the gaps, and reinstalled the window. We do not yet have results from the second run. Once we can confirm that the cryostat is able to reach the desired temperature, IR-blocking filters will be installed at the 70-Kelvin stage and we can try sending a signal through the window.

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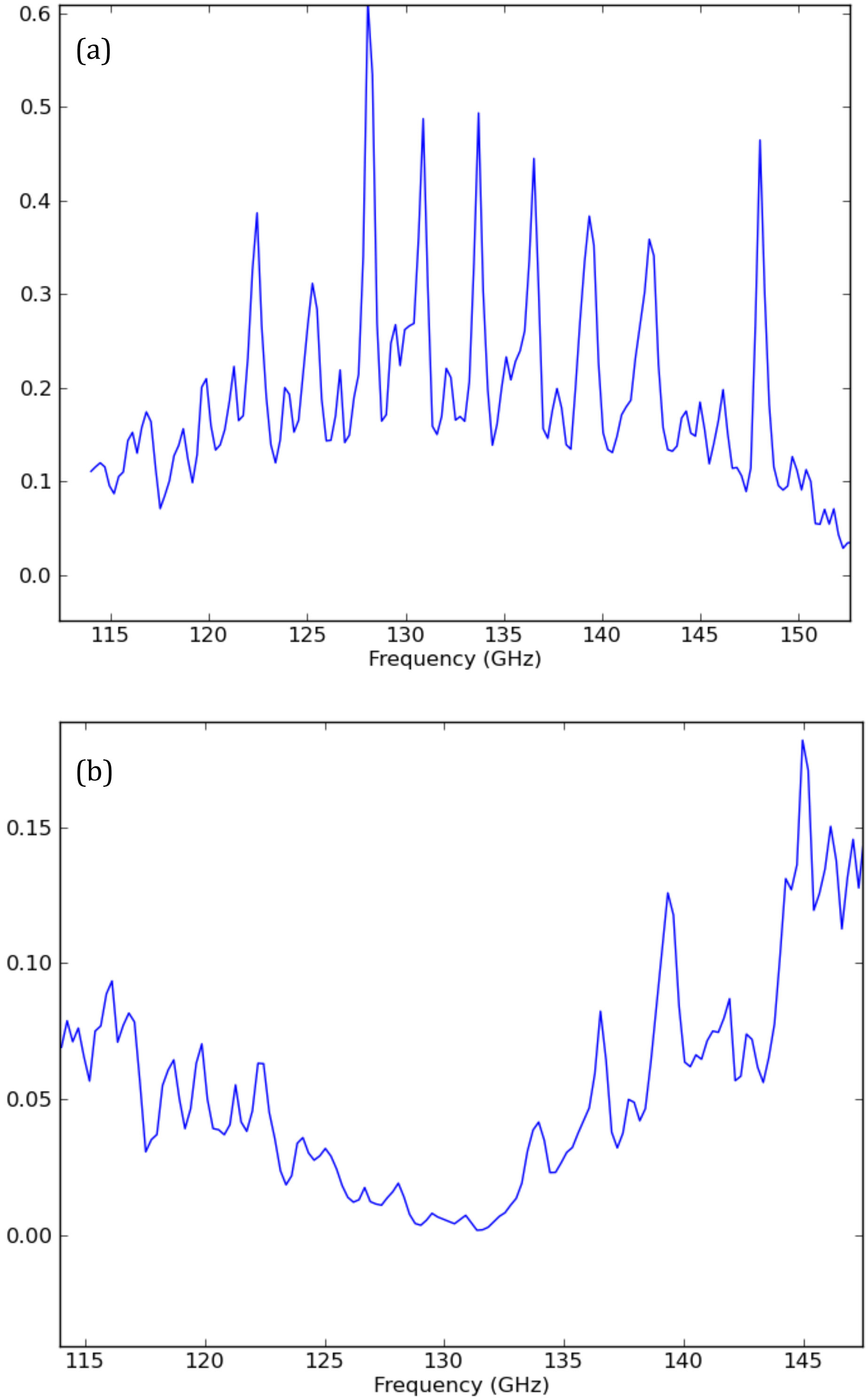

Figure 1. Percentage of original signal reflected from (a) uncoated 1/32" thick nylon sheet; (b) 1/32" thick nylon sheet coated with 0.020" thick PTFE Teflon.