Laminate polyethylene window development for large aperture millimeter receivers

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Introduction

Thin windows are required for the next generation of small aperture millimeter wavelength receivers. The need for higher sensitivity pushes requirements for vacuum windows in opposing directions; windows must simultaneously get larger (to accommodate more detectors) and thinner (to reduce in-band emission). We have developed a lamination technique with woven High Modulus Polyethylene (HMPE) and Low Density Polyethylene (LDPE) to generate thin, strong vacuum windows.

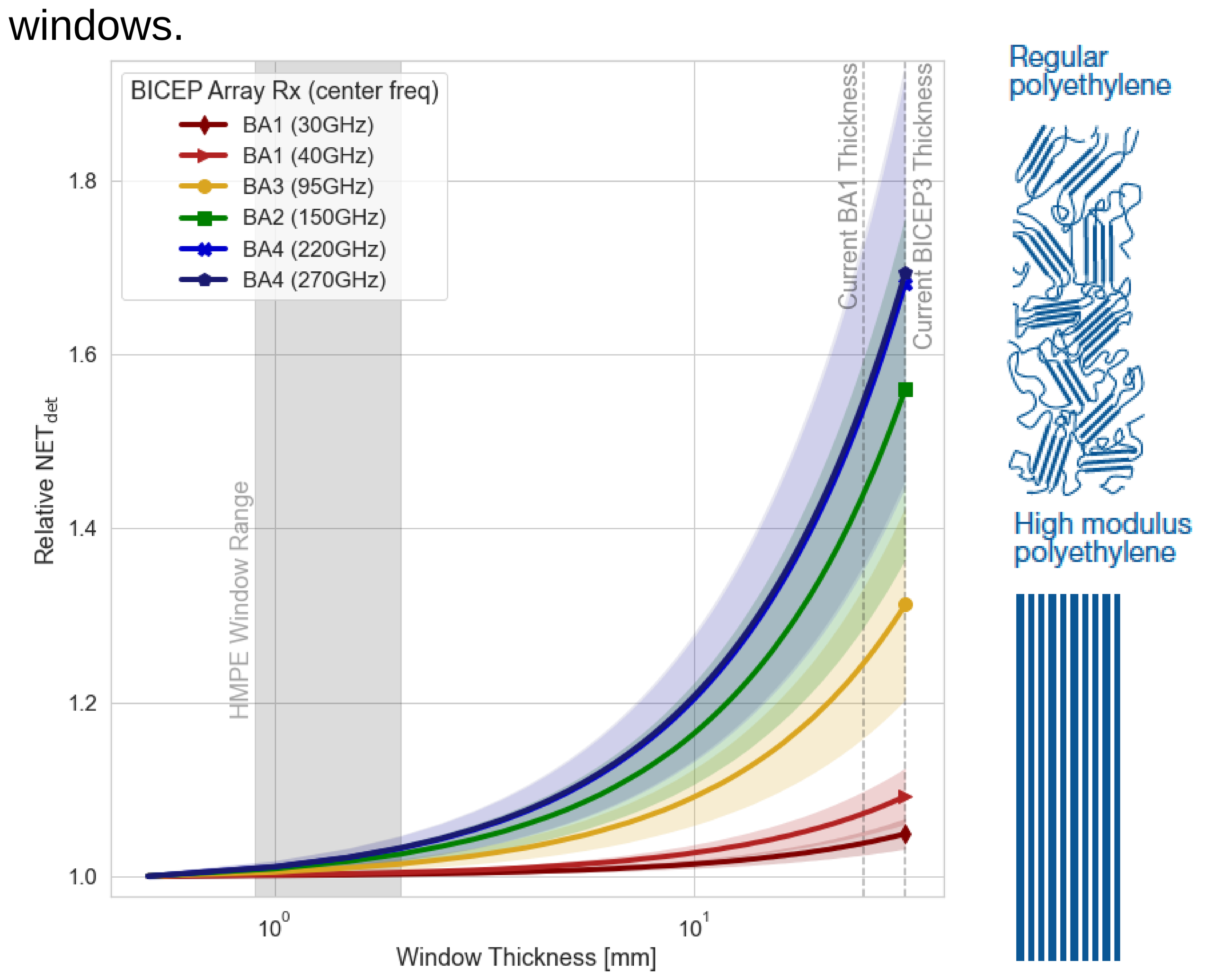
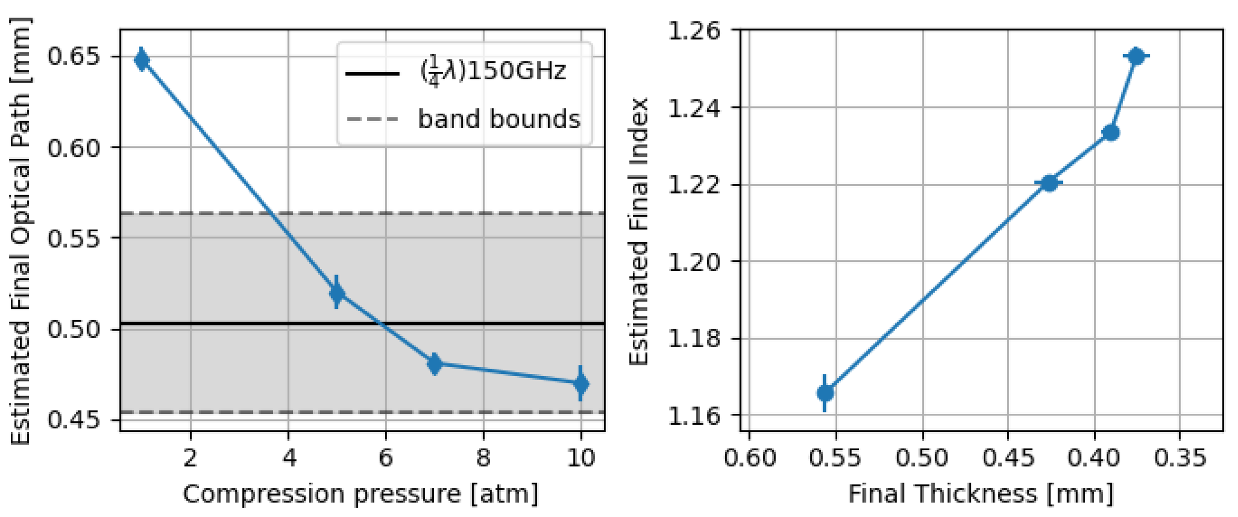


Fig. 1: [Left] Per detector Noise Equivalent Temperature (NET) relative to a BICEP cryostat with no window, for each of the BICEP Array (BA) bands. Colored bands represent transmission loss uncertainty of polyethylene between 2e-4 and 4e-4 [1]. [Right] Molecular structural differences between regular polyethylene and HMPE.

As aperture size grows it is increasingly difficult to source anti-reflection (AR) coatings for polyethylene optics at millimeter wavelengths. We have developed a heat compression technique to control the thickness and index of expanded PTFE which additionally reduces property variability in large ePTFE sheets [2]. The compression pressure can be varied to control the optical path length of the AR coating.



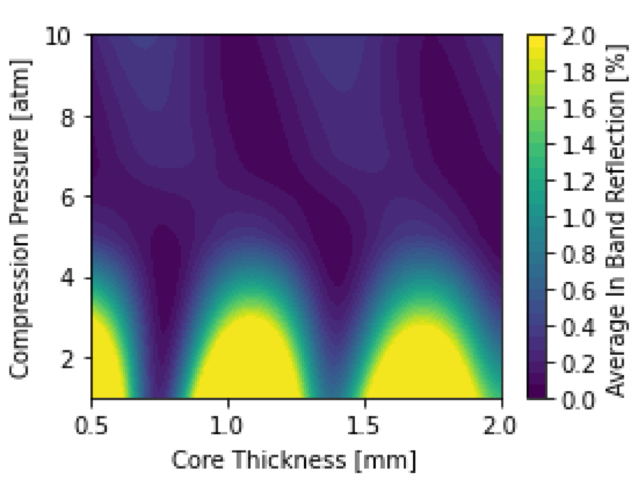


Fig. 2: [Top] Optical path lengths vs compression pressure (left) and final indexes and thicknesses (right) of compressed ePTFE. [Right] Possible in-band average reflection for 150 GHz (133 - 160 GHz) with the heat compressed ePTFE above used as AR coating for thin laminate windows (core).

Optics Autoclave

Table. 1: Temperature and pressure requirements for thin laminate windows and expanded PTFE anti-reflection coatings for both polyethylene optics (windows and lenses) and nylon (infrared filters).

Material	Temperature (C)	Pressure
Thin Laminate Window	130 - 140	>4 atm (207 kPa)
ePTFE (PE and Nylon AR coating)	>130	1 – 10 atm (101 – 1,013 kPa)

To achieve the heat and compression pressure at scale required for both the lamination of HMPE windows and the desired optical path length for the AR coatings, we designed and tested a heated pressure vessel, also known as an autoclave.

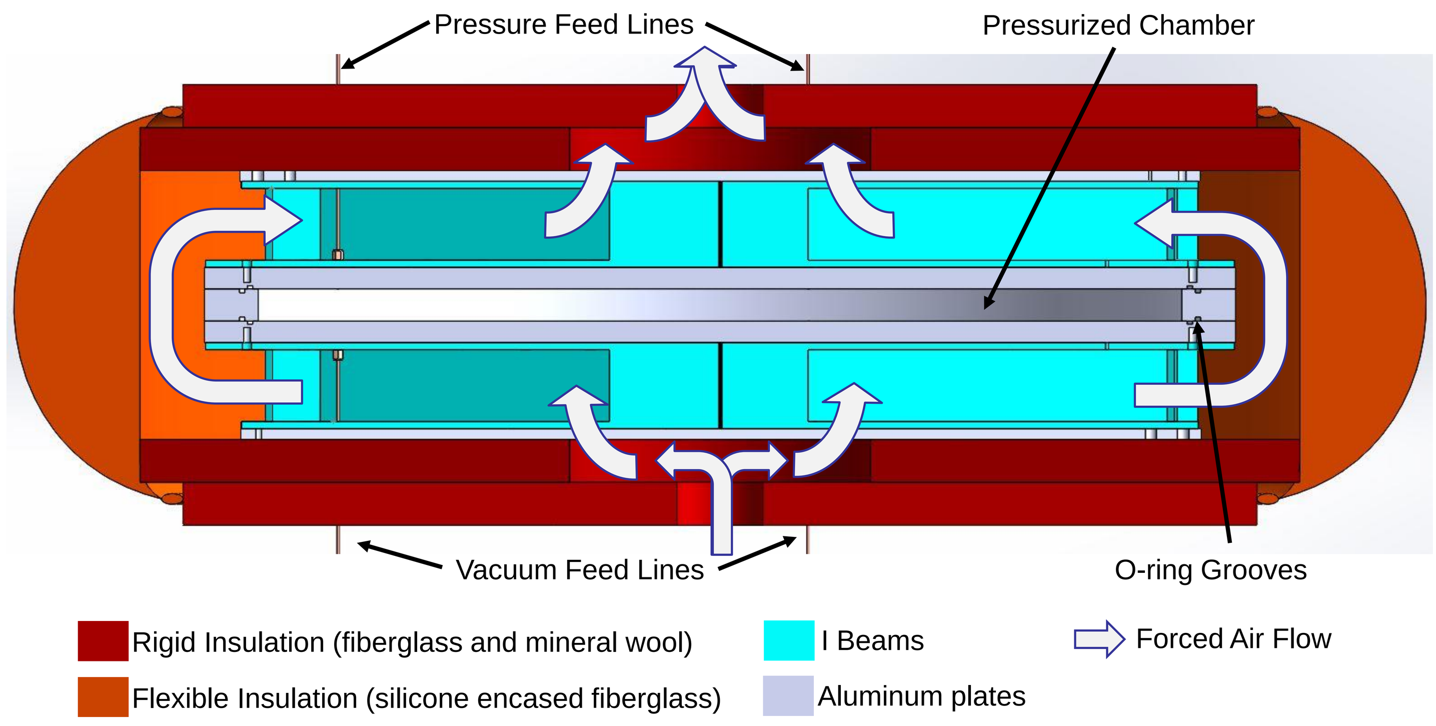


Fig. 3: Rough schematic of the optics autoclave.

The autoclave uses 48 strip heaters attached to the center flange of the supporting I-beams. On both the top and bottom plates twelve I-beams are placed radially, with twelve I-beam arranged around the circumference. The heaters require 9 kW of power to heat the entire vessel to the set temperature within 3 hours, and cools over an additional 8 hours. The outer insulation is a mix of rigid fiberglass and mineral wool panels (top and bottom) and a flexible silicone encased fiberglass fabric, with a fiberglass insulation core, around the edge. Pressure is achieved with pressurized nitrogen. Optical materials are placed under a vacuum bag to prevent bubbles or wrinkles. At the maximum pressure (10 atm), the top and bottom plates are under approximately 1 million Newtons (266,000 lbs or 120,655 kg) of force, and the center deflects nearly 5 mm (1/4").

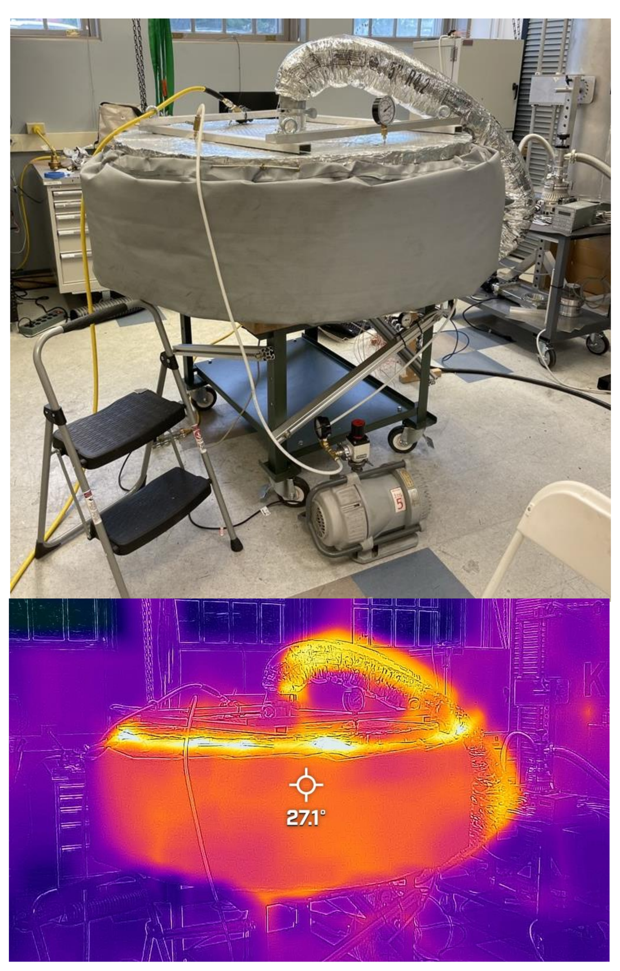
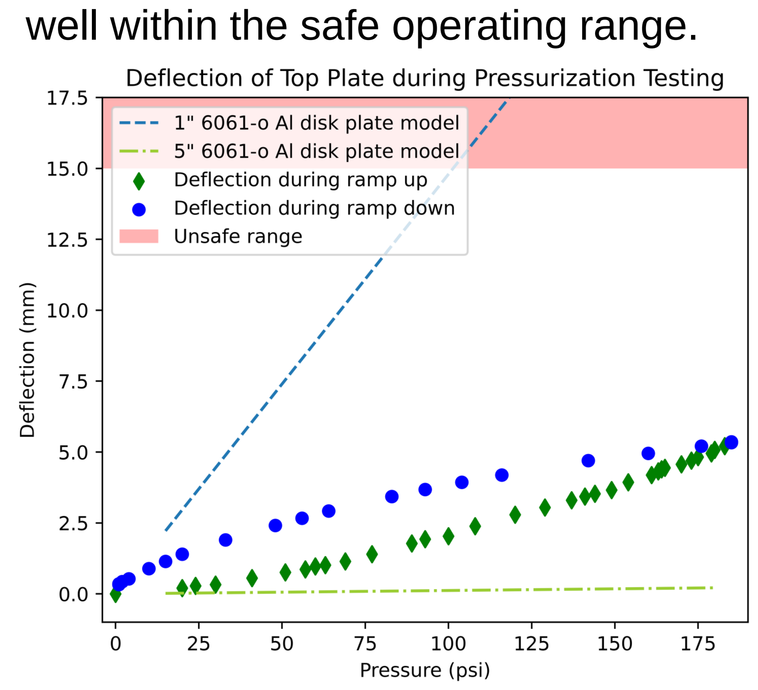
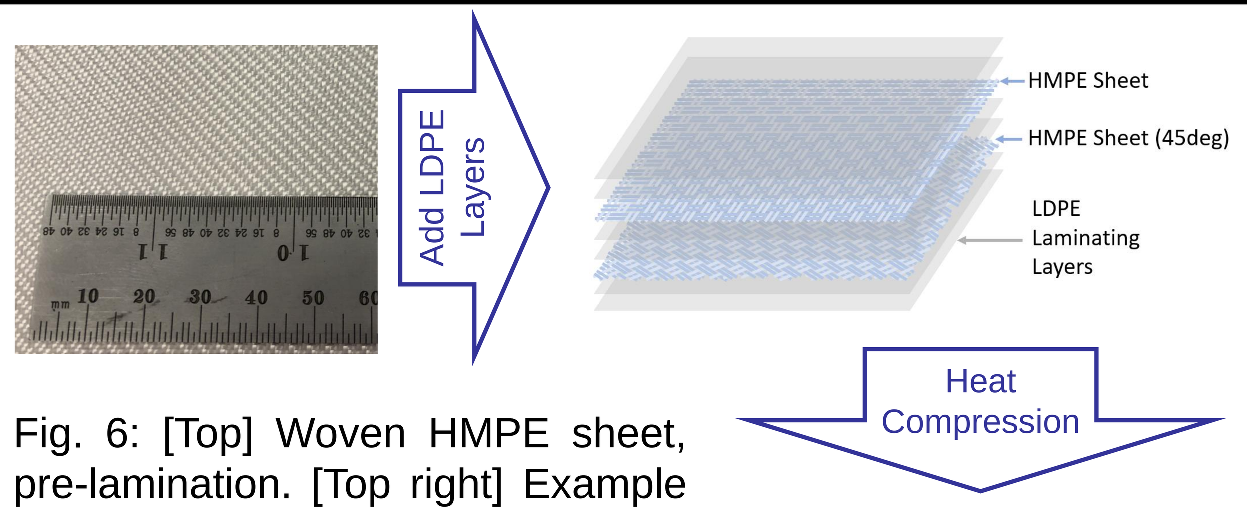


Fig. 4: [Left] Optical and thermal image of the optics press in operation.

Fig. 5: [Bottom] Center deflection measurements during initial hydrostatic pressure testing. Deflection showed some hysteresis but remains well within the safe operating range.



Results



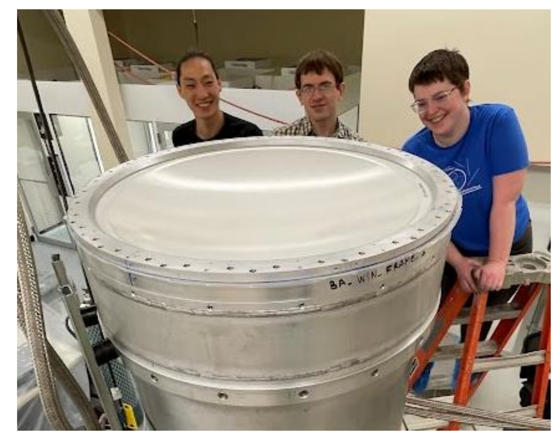


Fig. 6: [Top] Woven HMPE sheet, pre-lamination. [Top right] Example layer stack of HMPE and LDPE. Varying the amount of LDPE varies the thickness of the final laminate window. [Right] Laminate window on a BICEP Array cryostat, with people for scale. Reflection measurements of a sample version of that window (with AR coating) is shown in Fig. 7 below.

The combination of thin windows and heat compressed ePTFE can be used to generate multiple reflection nulls in-band. We measured the reflection out of band in the W-band (75 – 110 GHz) to get a higher signal measurement for a window meant for the 150 GHz (133 – 160 GHz) BICEP Array receiver.

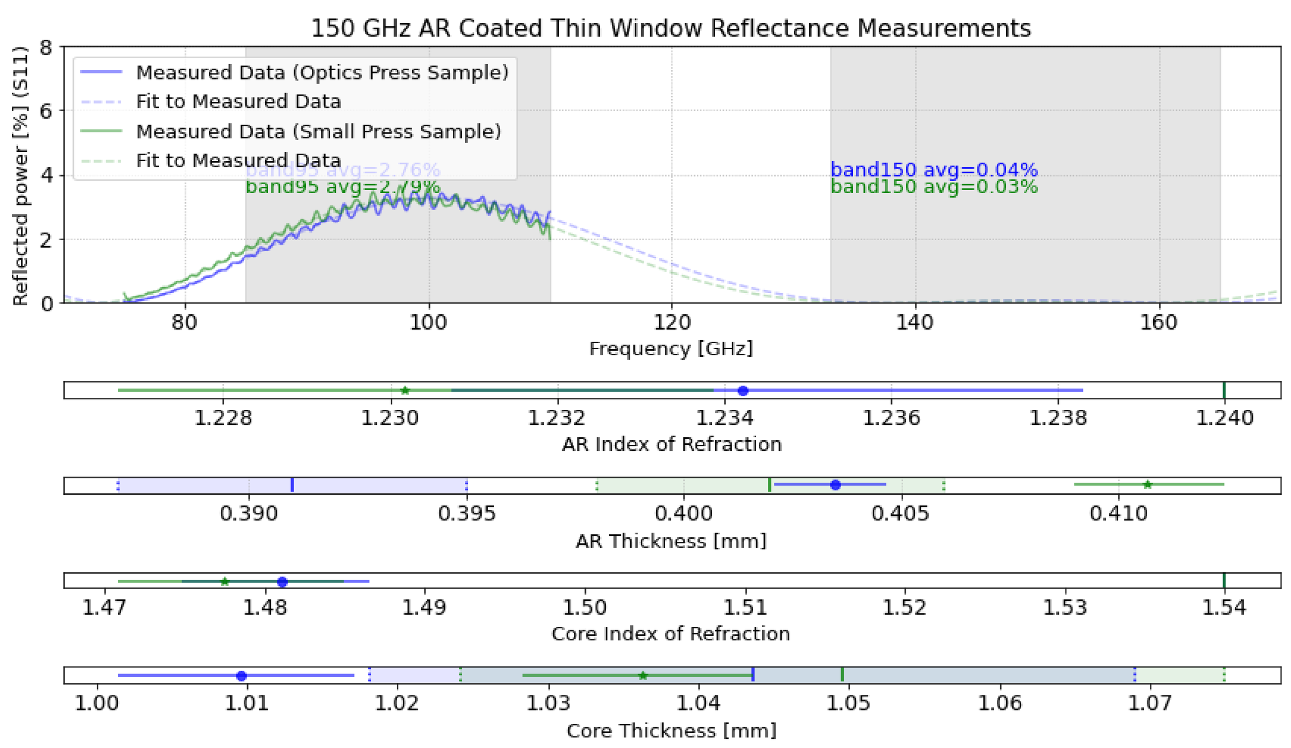


Fig. 7: [Top] W-band (95 GHz) vector network analyzer (VNA) S11 measurements of thin window samples anti-reflection coated for the 150 GHz band. [Bottom] Fit parameters and uncertainties to the reflection measurements. Solid lines are starting parameters; dotted lines are measurement uncertainties on thicknesses.

Conclusions

1. **Thin laminate windows and large scale ePTFE AR coatings require heat compression.**
2. **We have developed a large optics autoclave to produce these optical components.**
3. **The optics autoclave works produces thin windows and AR coatings that perform well mechanically and optically.**
4. **We plan to deploy thin laminate windows on the next telescopes sent to South Pole for the BICEP Array.**

References

1. Lamb, J. W. [1996] International Journal of Infrared and Millimeter Waves 17, 1997, doi:10.1007/BF02069487. *Miscellaneous data on materials for millimetre and submillimetre optics*
2. Dierickx, M. et al. [2021] Low Temperature Detectors Proceedings, https://doi.org/10.48550/arXiv.2111.14751. *Plastic Laminate Antireflective Coatings for Millimeter-wave Optics in BICEP Array*

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Many thanks to the generous work provided by undergraduate students, including those participating in Astronomy 191 at Harvard. Though their names may not appear in this work as direct contributors, their labor has proven invaluable for the completion and characterization of these materials.