Transmittance Analysis of Silicon Vacuum Window with Antireflection Subwavelength Structure for Wideband Submillimeter Receivers

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We are developing cryogenic receivers for submillimeter-wave astronomy which cover a wider frequency band including the ALMA Band 10 (787–950 GHz). The vacuum window of receivers is one of the components to be upgraded to extend the target band. Silicon is a promising material for receiver vacuum windows, suitable to apply antireflective (AR) sub-wavelength structures (SWS) on its surface. AR SWSs on silicon for optical components are actively studied for broadband applications (e.g. [1-2]). We developed AR designs for a band centered at 850 GHz using plane-parallel homogeneous multi-layer models and electromagnetic simulations. AR SWSs on silicon surface were fabricated at Advanced Technology Center (ATC) using deep ion-reactive etching (DRIE). To make the thickness of the AR layers uniform, silicon on insulator (SOI) wafers with buried oxide (BOX) layers are employed since each BOX layer works as an etch stopper.

Transmittance of AR silicon samples were measured with a terahertz time-domain spectrometer (THz-TDS) system. Analysis with a plane-parallel homogeneous multi-layer model is useful to know the effective refractive index and the effective thickness of the SWS layers. However, it is not simple to determine model parameter values in general, because the fit result depends on the fit range which can be set arbitrary, and because the actual value can have frequency dependence. To make the situation clear, we made fits on ranges with a fixed center, changing the fractional bandwidth (Fig. 1). The five models used have different sets of fixed parameters. Parameter behavior on fit ranges narrower to wider can be seen with this method.

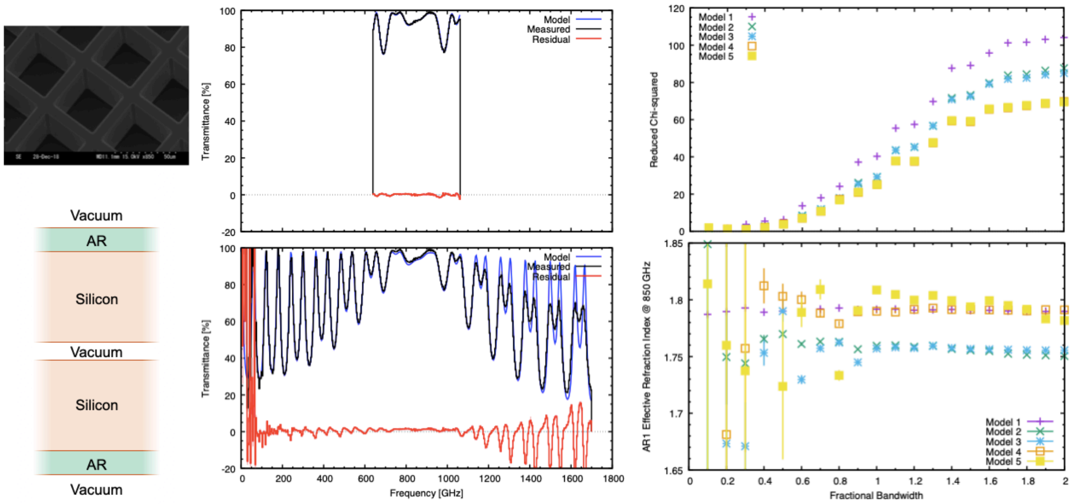

Figure 1. Fit results to a transmittance of two silicon wafers with one-layer AR on one side joined back-to-back without glue. (Top left) SEM image of the AR SWS. (Bottom left) Schematic of the fit model. (Top middle) Example of fit on a range of fractional bandwidth 0.5 centered at 850 GHz. (Bottom middle) Example of fit on a range of fractional bandwidth 2.0. (Top right) Reduced chi-squared of five models vs. the fractional bandwidth of fit range. (Bottom right) Effective refractive index of the AR layer given by the fits.

References

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[2] T. Hasebe, et at., "Development of Multi-Layer Anti-Reflection Structures for Millimeter-Wave Silicon Optics Using Deep Reactive Ion Etching Process," *Journal of Low Temp. Phys*. **199**, 339–347 (2020).