Wafer-bonded Antireflection Layers for Silicon optics

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Abstract— Many applications in astronomy from tens of GHz to THz frequencies, on the ground and in space, would benefit from silicon optics because silicon's high refractive index and low loss make it an ideal optical material at these frequencies. Silicon can also be used for ambient temperature vacuum windows, however, it's large refractive index necessitates an antireflection coating. Moreover, multilayer antireflection treatments are necessary for wide spectral bandwidths, with wider bandwidths requiring more layers. To this end, we are developing multilayer coatings for silicon by bonding together wafers individually patterned with deep reactive ion etching (DRIE).

While a standard approach to antireflection coating is to deposit or laminate dielectric layers of appropriate refractive index, it is difficult (but not impossible) to find low loss dielectrics with the correct refractive index and other properties to match silicon well, especially if more than one layer is required, operation up to THz frequencies is desired, and/or the optic will be used cryogenically. Textured surfaces are an attractive alternative to dielectric antireflection coatings. For millimeter wavelengths, multi-layer antireflection textures with up to 4:1 bandwidths have been cut successfully into silicon lens surfaces with a dicing saw, but this technique becomes unusable at frequencies of 300 GHz and higher given the saw dimensions. Laser machining is being explored but demonstrations are not yet available. DRIE works well on flat surfaces (and has been demonstrated for narrowband windows to THz frequencies), but there are limits to the depth and aspect ratio of the features it can create. Furthermore, etching has not been adapted to large, curved optics.

We are pursuing a hybrid approach to this problem: construct a silicon optic by stacking flat patterned wafers. The starting point is a multilayer optical design incorporating both an axial gradient in the refractive index for antireflection and a radial index gradient for focusing. For each optical layer, a hole or post pattern is used to achieve the required effective index of refraction. Using a novel multilayer etching procedure, several layers of the optical structure are fabricated on a flat wafer. Several individually patterned wafers are stacked and bonded together to produce the completed optic. This approach can thus address the aspect ratio limitations of DRIE, and it obviates etching on curved surfaces.

We present our results to date, which include simulations, fabrication and measurements of 2- and 4-layer coatings with wafer-bonding, on high resistivity silicon wafers, at 75-330 GHz. The good agreement between the simulations and the test results validates the fabrication and test setup, and allows us to continue the development of larger bandwidth and more efficient coatings. Our near-term goal is to produce a 10-cm lens with a 7-layer coating providing 5.5:1 bandwidth from 75 to 420 GHz, with less than 1% reflection, eventually scaling up to 15-cm, 30-cm, and larger elements.