Simulated Dielectric Anti-Reflection Coatings

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A.R. Basics

- dielectrics boundaries reflect light

- this effect can be reduced over a finite band width by matching the impedance

- two types of AR coatings
  - lambda / 4 (narrow band)
  - graded index (broad band)
Simulated Dielectrics

What are they?
- tune the effective index of a layer of dielectric by adding sub-wavelength perturbations

Why this is a good idea?
- matched coefficient of thermal expansion
- can achieve any desired index between $n$ and 1
- mechanical robustness
Quarter Wave SDARs

- cut quarter-wavelength deep grooves, holes, posts, ... into a dielectric surface
- Used in DASI, CAPMAP (TRL 4.X)

1 day for ~16k holes
Lambda/4 S.D.-A.R.s

- Work Well over ≈25% band-width
- Cross-polarization
  - grooves ≈ -20dB
  - square array of holes ≈ -45db

from CAPMAP, (HDPE)
Graded index S.D.-A.R.s

- made by tapering the perturbations
  - triangular grooves (APEX / SPT)
  - square base pyramids (UCB, Minnesota)
- achieve > 100% fractional bandwidth
- difficult to machine for some materials
Performance of graded index SD layers

Courtesy S. Hanany, University of Minnesota
SD work I know about:

**DASI** High density poly ethylene (HDPE) meniscus lenses were AR coated using a $\frac{1}{4}$-\(\lambda\) thick (at 32 GHz) SD layer consisting of concentric grooves. Measured reflections were below 1% across 30% bandwidth. The birefringence of these grooves lead a peak cross-polarization of \(-22\) dB. Published polarization science data were taken with this system.

**CAPMAP** Bi-convex lenses made from HDPE were AR coated using a $\frac{1}{4}$-\(\lambda\) thick SD layer consisting of a square grid of holes. Lenses were made for the 40 and 90 GHz band. Measured reflections were below 1% across 20% bandwidth in both cases. The measured cross-polarization of these lenses were below \(-40\) dB. Published polarization science data were taken with this system.

**SPT / APEX** HDPE lenses were AR coated using a wide-band graded index SD layer consisting of concentric triangular grooves. The ratio of the width to depth of these grooves is 1:1. Measurements are not available, but simulations suggest that the peak transmission is 99% at 150 GHz with greater than 98% transmission between 100 and 300 GHz. This design is not optimized for polarization science due to the birefringence of the grooves. This system is currently fielded.

**University of Minnesota** has prototyped a wideband SD-AR consisting of a square grid of square bottom pyramids (see Figure 3) on a flat Rexolite \((n \approx 1.5)\) surface. The height of the pyramids is 500 \(\mu\) and the grid spacing is 250 \(\mu\). Calculations predict a reflectance of less than 0.2% over a band between 100 and 500 GHz. Noise-limited lab measurements at frequencies between 120 and 300 GHz using a fourier transform spectrometer imply the reflection is less than \(\approx 2\)% over the entire bandwidth. No measurements of polarization purity are available.

**UC Berkeley** An attempt to mill a square grid of 4 : 1 (depth to width) square based pyramids on small samples of TMM (plastic) lenses was aborted due to difficulties with machining. Laser and EDM machining in Silicon were considered but not attempted.

**Miller Group** The Miller group at Columbia has considered micro-machining holes into a thin layer of silicon and ‘slumping’ this SD layer onto a silicon optic. This approach is expected to work on a flat substrate, but is believed to be more difficult than direct machining.

Sorry if I left other work out
Technical Readiness

It depends on the dielectric and the choice of geometry

- high 4.xx
  - lambda/4 grooves and holes, tapered grooves in HDPE
- medium 3.xx
  - pyramids in rexolite, pyramids in LDPE
- low 1-2
  - using silicon
What it takes to bring a particular application to a high TRL

- simulate (just a good idea)
- spend time perfecting the fabrication (THE hard part)
- test it (x-pol, reflection)
Advantages of SDs: matched CTE, tunable index, mechanically robust, polarization symmetry is achievable

Disadvantages of SDs: you have to be able to fabricate it which may be difficult for some applications

Mature for some applications, needs work for others