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Tunable Antireflection Layers for Planar Bolometer Arrays

Ari-David Brown, David Chuss, Edward Wollack, James Chervenak, Ross Henry, and James Wray

It remains a challenge to obtain high-efficiency coupling of far-infrared through millimeter radiation to large-format detector arrays. The conventional approach of increasing detector coupling is to use reflective backshorts. However, this approach often results in excessive systematic errors resulting from reflections off the backshort edge. An alternate approach to both increasing quantum efficiency and reducing systematics associated with stray light is to place an antireflective coating near the front surface of the array. When incorporated with a resistive layer and placed behind the detector focal plane, the AR coating can serve to prevent optical ghosting by capturing radiation transmitted through the detector.By etching a hexagonal pattern in silicon, in which the sizes of the hexes are smaller than the wavelength of incident radiation, it is possible to fabricate a material that has a controllable dielectric constant, thereby allowing for simple tunable optical device fabrication. To this end, we have fabricated and tested tunable silicon "honeycomb" AR layers and AR/resistive layer devices. These devices were fabricated entirely out of silicon in order to eliminate problems associated with differential contraction upon detector cooling.

Tunable Antireflection Layers for Planar Bolometer Arrays

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Ari-David Brown* (Code 553), David Chuss (PI, Code 665), Edward Wollack (Code 665), James Chervenak (Code 553), Ross Henry (Code 551),
and James Wray (2006 NASA Academy)

Introduction:

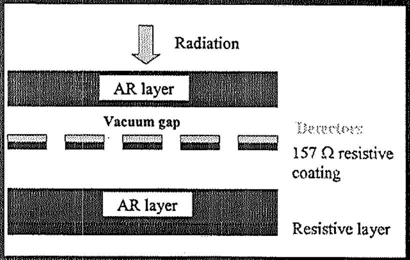
It remains a challenge to obtain high-efficiency coupling of far-infrared through millimeter radiation to large-format detector arrays. The conventional approach of increasing detector coupling is to use reflective backshorts. However, this approach often results in excessive systematic errors resulting from reflections off the backshort edge.

An alternate approach to both increasing quantum efficiency and reducing systematics associated with stray light is to place an antireflective coating near the front surface of the array. When incorporated with a resistive layer and placed behind the detector focal plane, the AR coating can serve to prevent optical ghosting by capturing radiation transmitted through the detector.

By etching a hexagonal pattern in silicon, in which the sizes of the hexes are smaller than the wavelength of incident radiation, it is possible to fabricate a material that has a controllable dielectric constant, thereby allowing for simple tunable optical device fabrication.

To this end, we have fabricated and tested tunable silicon "honeycomb" AR layers and AR/resistive layer devices. These devices were fabricated entirely out of silicon in order to eliminate problems associated with differential contraction upon detector cooling.

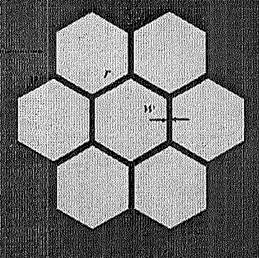
Envisioned Absorber/AR Coating Strategy:



A vacuum gap is added between the detectors and AR coating so as to preserve the thermal properties of the detectors.

The backside absorber, consisting of AR and resistive layers, is used instead of a backshort, which requires precise positioning.

Si Dielectric Honeycombs as AR Coatings:



Antireflection conditions:

1. $t = (\lambda_0/4)\,\varepsilon_{AR}^{-0.5}$
2. $\varepsilon_{AR} = \varepsilon_{Si}^{0.5}$

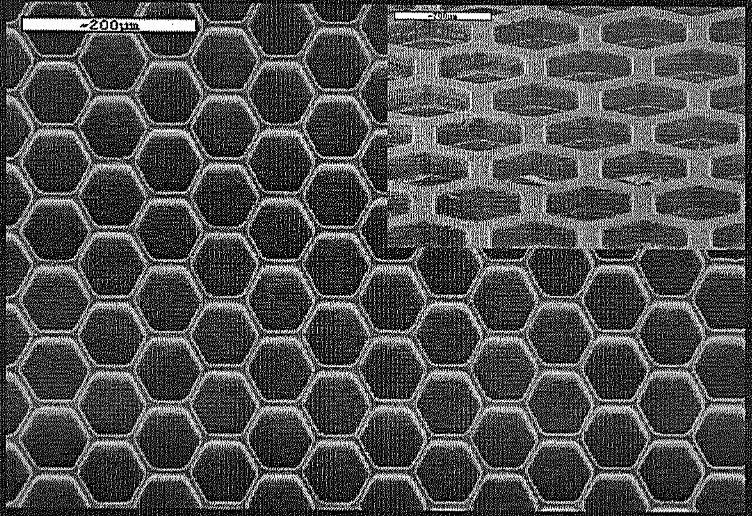
Effective medium theory* ($r << \lambda_0$) :

$$\varepsilon_{eff} = \{(\varepsilon_x, 0, 0), (0, \varepsilon_y, 0), (0, 0, \varepsilon_z)\};$$

$$\varepsilon_x = 1 + (w/r)(0.7375\varepsilon_{Si} - 0.521)$$

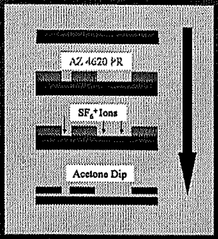
$$\varepsilon_y = 1 + (w/r)(0.6715\varepsilon_{Si} - 0.4615)$$

λ_0 is the wavelength of incident radiation; t is the AR coating thickness; ε is dielectric constant.



Plan view SEM micrograph of silicon dielectric honeycombs, w = 13 microns, r = 40 microns, and t = 300 microns. INSET: w = 40 microns, r = 121 microns, and t = 40 microns. In both cases, the honeycomb array extended over a 1cm x 1cm area.

Si Dielectric Honeycomb Fabrication:



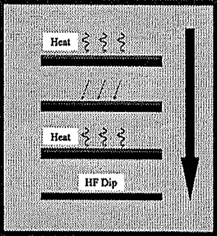
Bond to Backing Wafer

Pattern via Photolithography

Deep Reactive Ion Etch

Release Parts

Si Backside Absorber/Resistive Layer Fabrication:



Thermal Oxide Growth

[illegible] Implantation

Implant Activation

Thermal Oxide Strip

Implantation Recipe:

We constructed an implantation model in order to establish recipes for obtaining backside absorbers possessing a desired sheet resistance. The ion energy and dose, as well as oxide (used as a diffusion barrier) thickness were inputs, and were used to obtain a implant concentration profile. We then input activation temperature and time, and modeled implant diffusion using Fick's second law in order to obtain a post-activation concentration profile. Finally, sheet resistance could be calculated.

$$R_{sheet} = \{e\int c(x)\mu(x)dx\}^{-1}$$

$$dc/dt = D\,(d^2c/dx^2) + (dD/dx)(dc/dx);$$
$$D = \alpha D_0 + \beta(A + Bc + Cc^2)^*$$

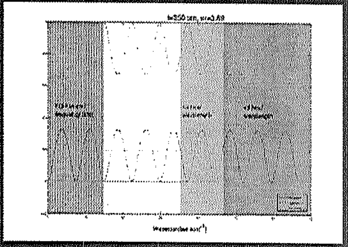
R_{sheet} = sheet resistance, e = electronic charge, x = implant depth, c = [illegible] concentration, μ = electron mobility**, t = time, D = diffusion coefficient, α, β [illegible], D_0 = low concentration "tail region" diffusion constant, A = interstitial diffusion constant, B and C = impurity-vacancy (divacancy) diffusion constants.

*S. K. Ghandhi (1983).

**Dorkel, J. and Leturcq, P., Solid State Electronics (1981).

Expected AR Coating Performance:

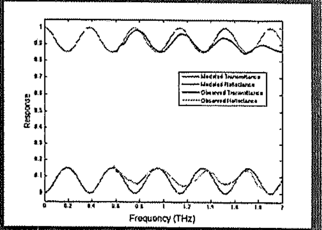
We designed devices that were expected to have several transmittance and reflectance fringes within the narrow FTS measurement band – depicted in white – in wavenumber space.



Observed AR Coating Performance:

Best-fit model:
t = 270 microns
ε = 2.3

Anticipated
t = 300 microns,
ε = 2.5



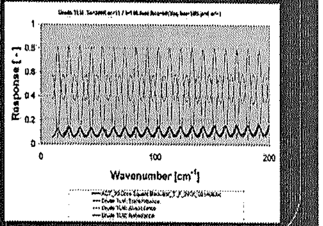
➡ Sidewall profile might be tapered, and, consequently, new model needs to be constructed.

Optical Measurement of Implanted Silicon Resistance:

Target sheet resistance:
30 Ω/sq (T = 0.4 K)

Measured sheet resistance:
60 Ω/sq (T = 295 K),
~ 30 Ω/sq (cold)

➡ Implant recipe works.



Future Work:

- Further investigation of micromachined silicon features possessing steep sidewall profiles.
- Further development of much more accurate models of the reflectance and transmittance data.

Acknowledgments:

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