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New Infrared Photonic Lattice Coating

C.F. Schmidt[1], W.C. Sweatt, I. El-Kady, F.B. McCormick, D.W. Peters, S.H. Kravitz[2], J.C. Verley, U. Krishnamoorthy, D. Ingersoll, W.G. Yelton, G. Subramamia, J.D. Williams

Sandia National Laboratories, PO Box 5800 MS 1082, Albuquerque, NM USA 87185

[1] Compa Industries, [2] Sandia Consultant

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ABSTRACT

In a quest to fabricate large sheets of photonic bandgap material (PBG), we have modeled, fabricated, and tested two “cubic array of cubes” PBG structures, one with a bandgap in the thermal IR and the other operating in the near IR.

Motivation

This work was driven by customer interest in large pieces of full-bandgap, three-dimensional PBG material that can be used to modify the emissivity of surfaces in the thermal IR for energy scavenging and satellite temperature control.

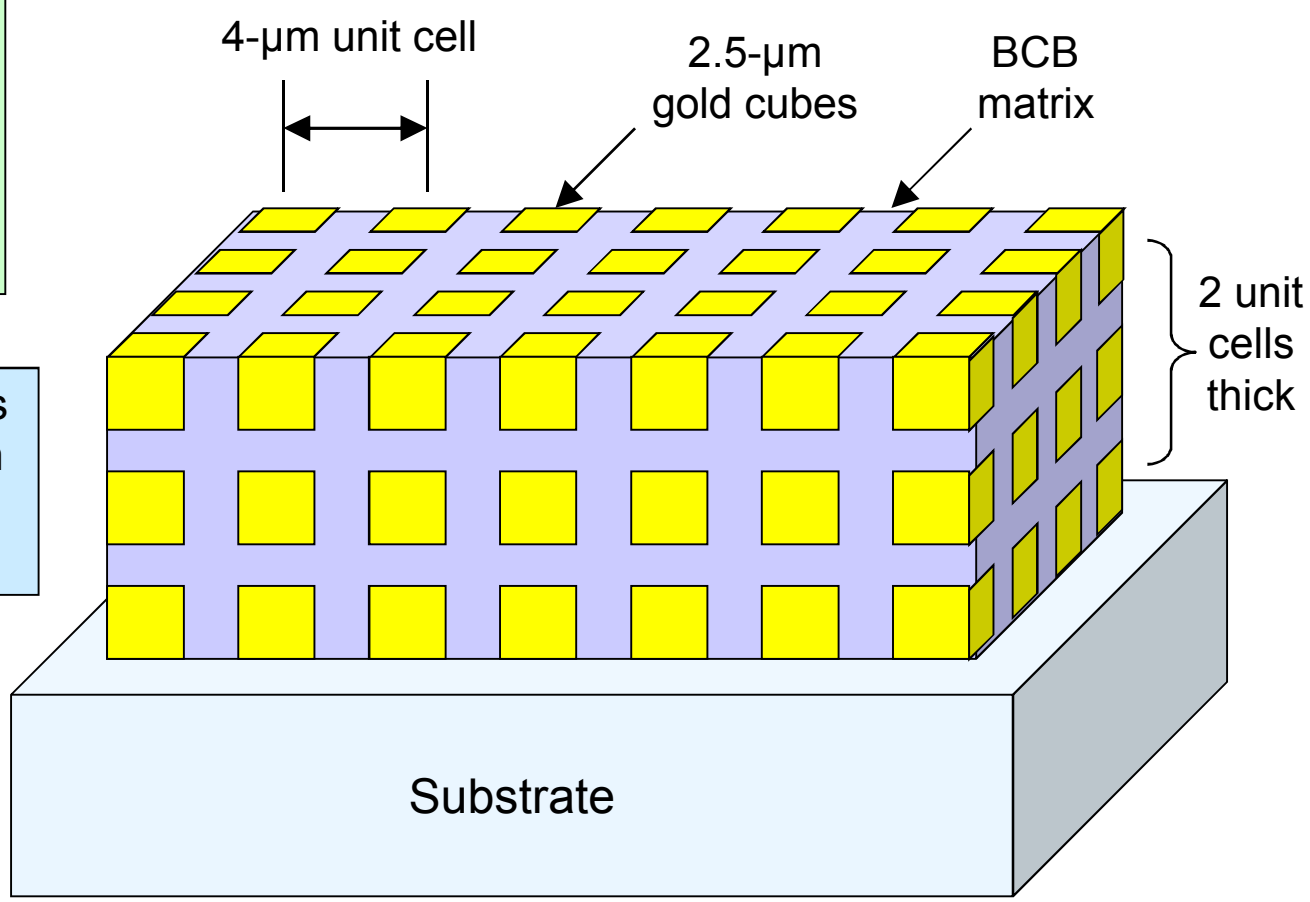
Other customers are interested in our push toward the visible-NIR operating regions for use in photonic circuits and to improve the efficiency of illumination systems.

Note too that these structures have larger features than the standard log-pile structures and require ~3X fewer fabrication steps. Also, the structures are “filled” when completed so they are not affected by rain or dust.

Sketch of a Cubic Array of Cubes PBG

This structure operates in the mid-IR with a cutoff wavelength of $\lambda \approx 7\mu m$

The near IR PBG uses 600-nm gold cubes on 1-μm centers in a polyethylene matrix



PBG Requirements for Fabrication

- Finding a matrix material that is transparent in the visible and IR
- Finding a flexible substrate that is transparent in the visible and IR
- Being able to create multiple layers of alternating matrix and metal materials
- Alignment to submicron accuracy

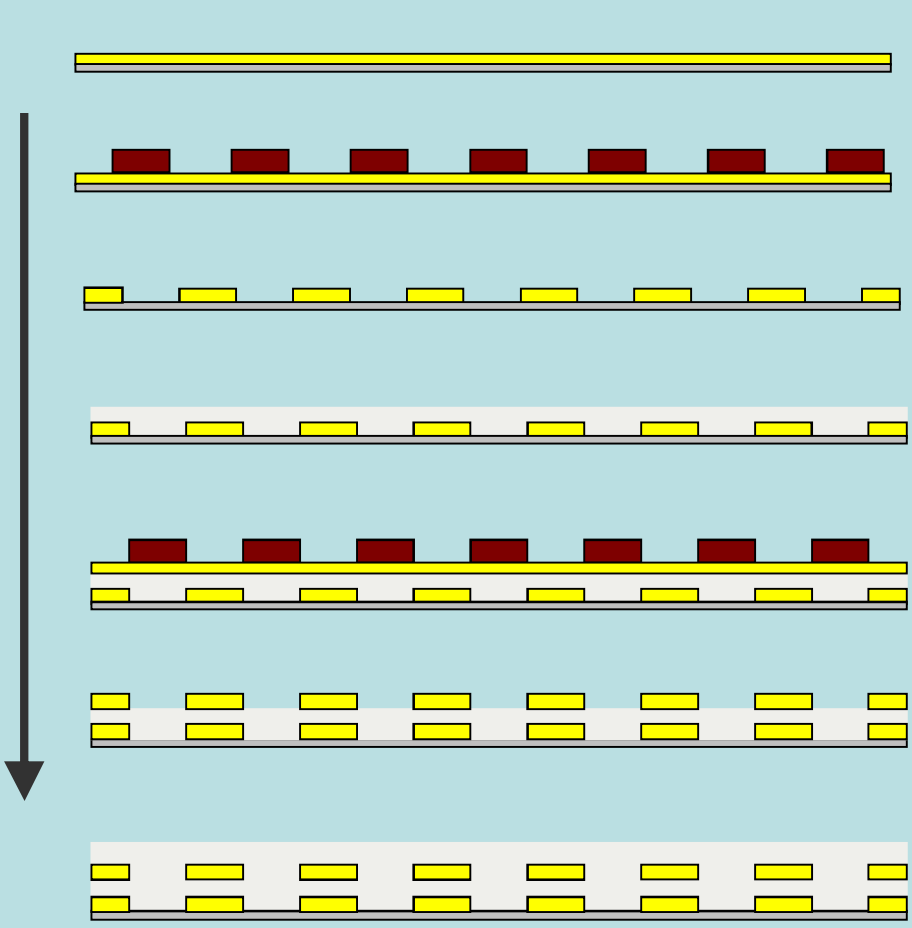
PBG Fabrication Challenges

- Making polyethylene into a spin-castable film by using the ideal combination of solvents
- Photoresist developers were found to affect the polyethylene films
- Metal liftoff evaporation and electroplating were also found to effect the polyethylene films

Advances in PBG Fabrication (An All-Dry Fabrication Process)

- Exxon-Mobil 4033 short chain polyethylene was very transparent in the visible and IR
- Polyethylene was dissolved in a xylene and toluene mixture
- A thermal imprint process was developed to avoid wet photo processing
- E-beam evaporation of Ti/Au was used in conjunction with sputter etching to pattern the PBG

Fabrication Process Flow



Metal layer evaporated onto Si wafer

Imprinted resist for first layer of Cubic Array of Cubes

1st Layer Cubic Array of Cubes after sputter etch

Spin cast Polyethylene Layer

Imprinted resist for second layer of cubes

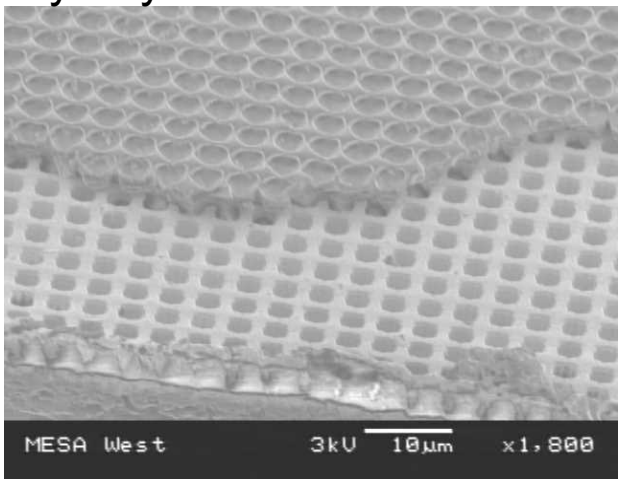
2nd Layer Cubic Array of Cubes after sputter etch

Single Unit cell of Cubes after second polyethylene spin cast

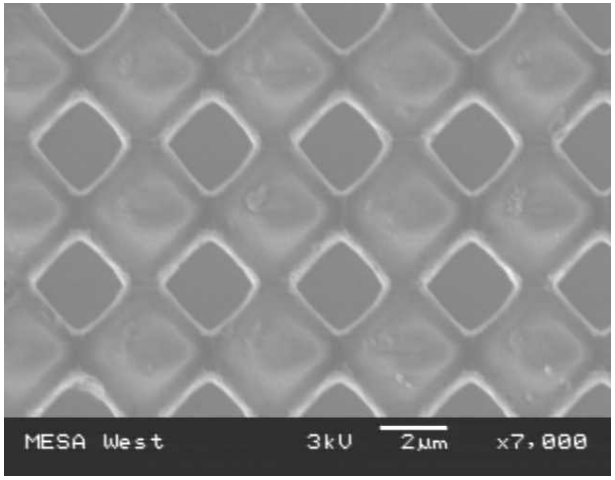
SEMs of the Thermal IR PBG

Scanning electron microscope images show PBG at various stages during fabrication. Panel A- Shows 2 layers of cubes filled with polyethylene. Panel B– Sputter etched gold prior to imprint resist strip. Panel C- Gold cubes after stripping. Panel D– PBG filled with polyethylene.

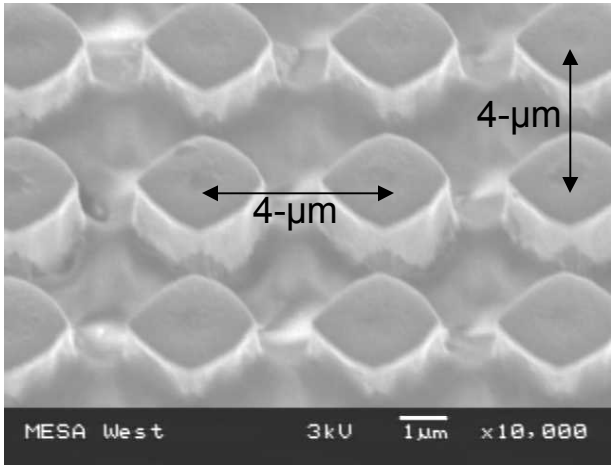
A.



B.



C.



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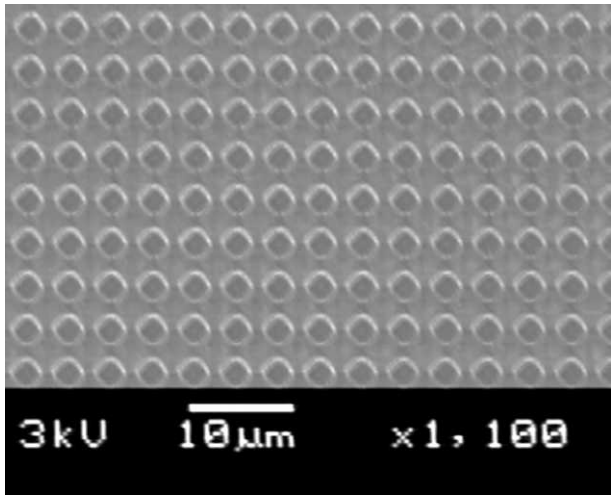
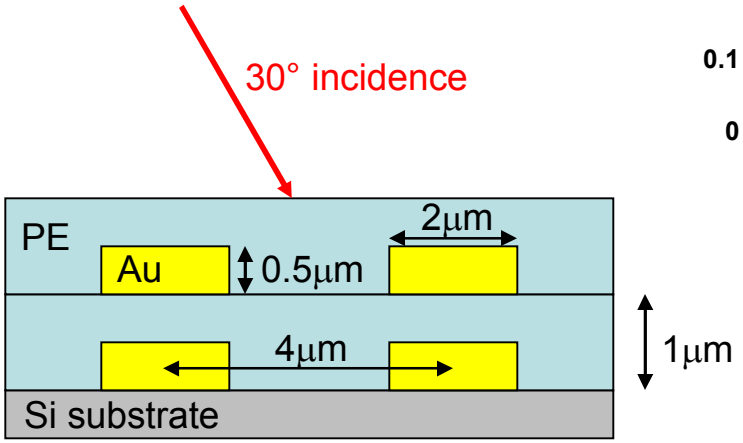


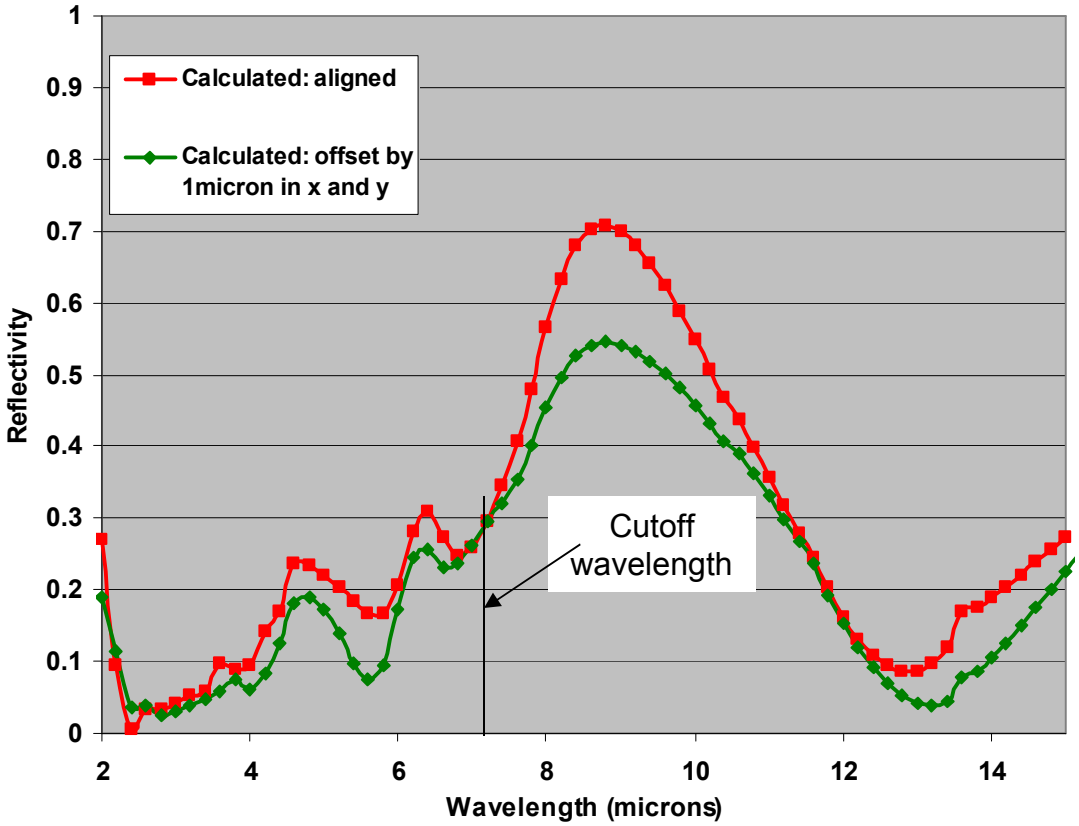
Rigorous Coupled Wave Analysis (RCWA) calculation of the specular reflectance of a 2-layer, mid-IR cubic array of cubes

Cubes are arranged in a diamond pattern as seen in the SEM.

Gold and silicon refractive index values from Palik.

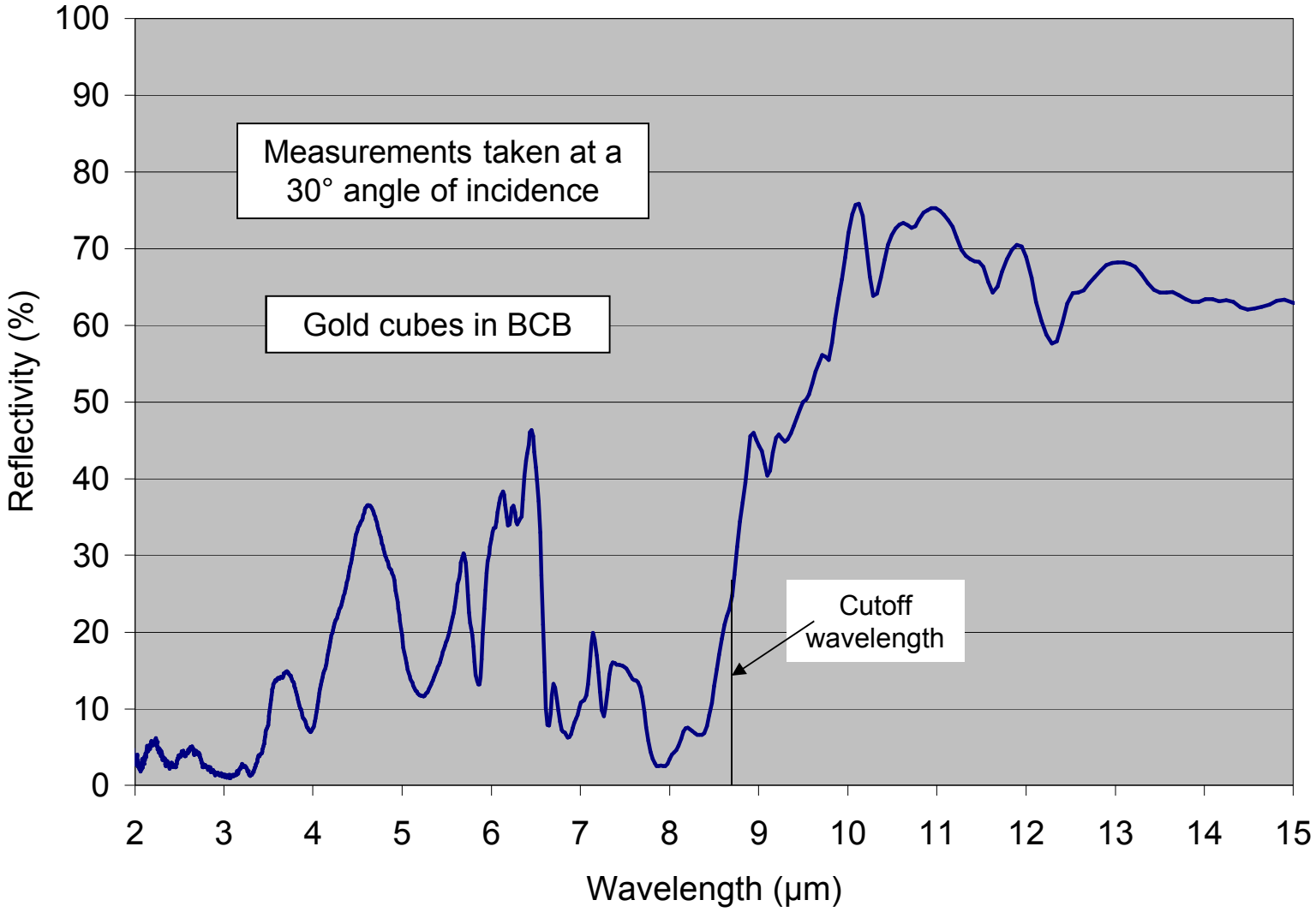
Polyethylene (PE) refractive index assumed to be 1.5 (actual value not yet measured).



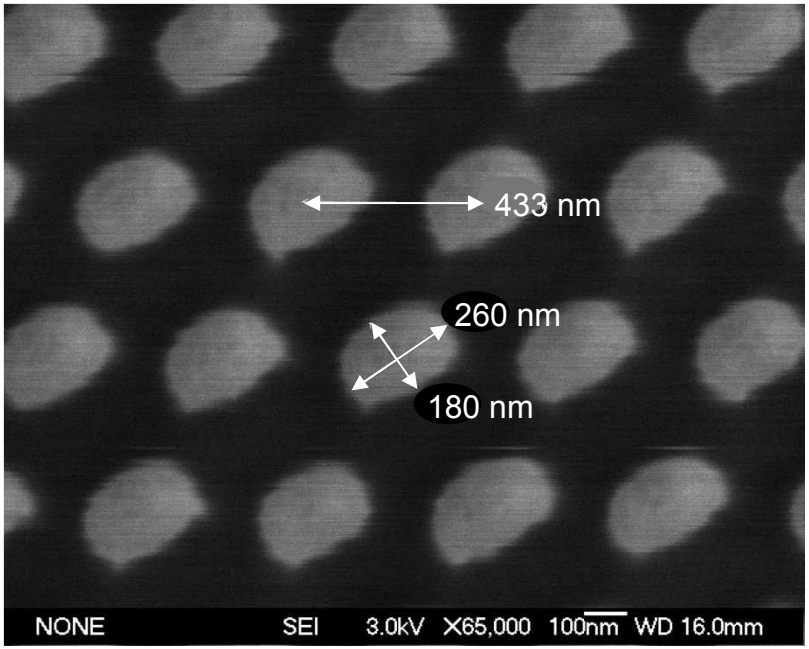


Currently we are uncertain of sample's alignment layer-to-layer. Green curve shows effect of considerable misalignment.

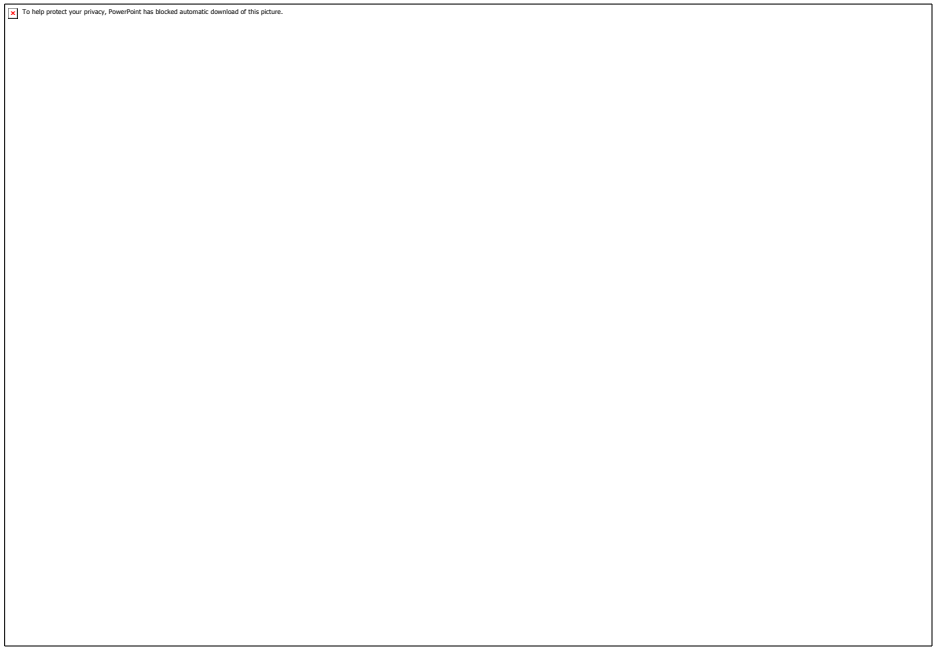
Measurement of the specular reflectance of a 3-layer, Thermal IR cubic array of cubes PBG



Near Infrared Cubic Array of Cubes Mask– “Imprinted Resist” Step in the Process Flow Diagram Above



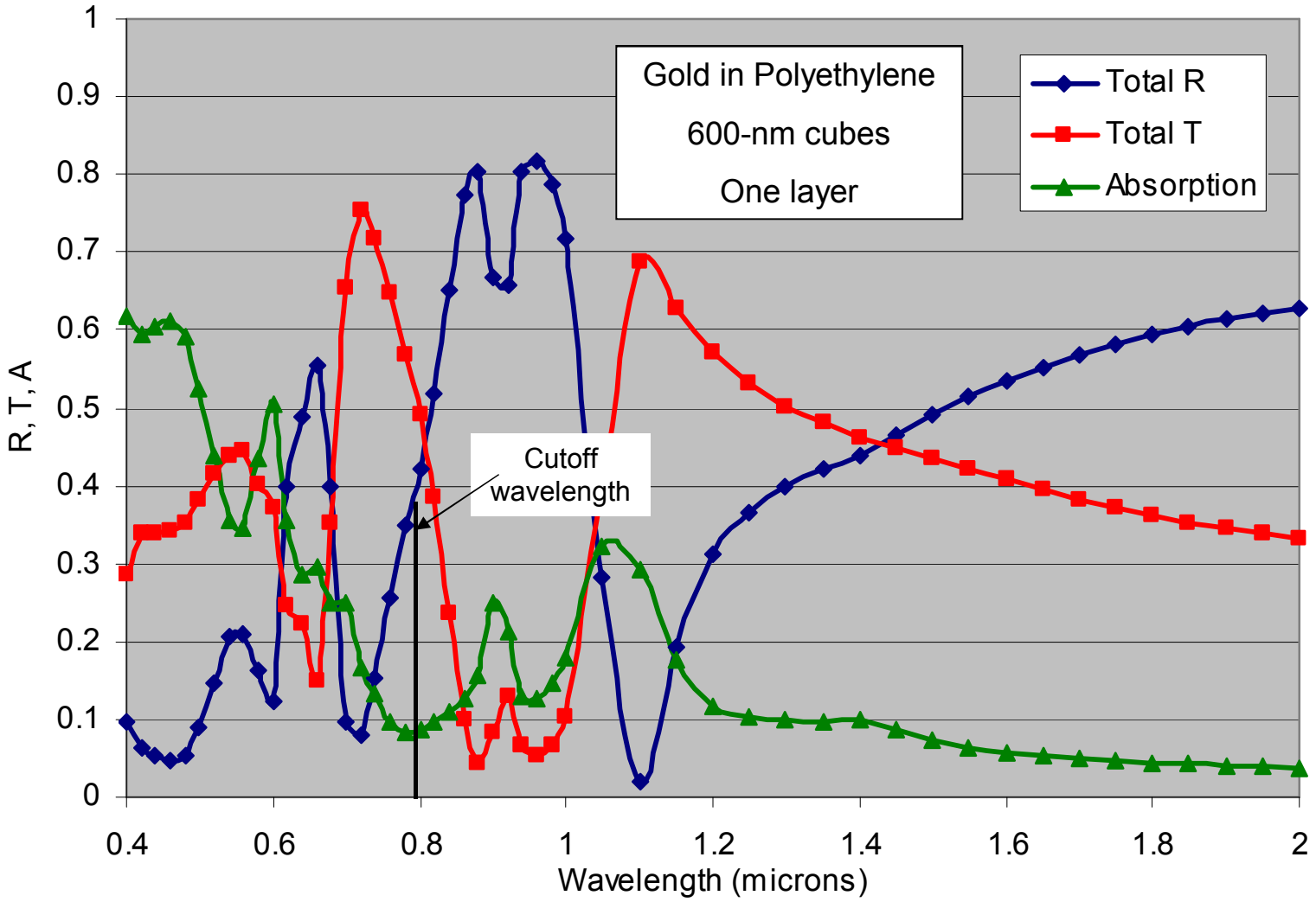
65,000 X



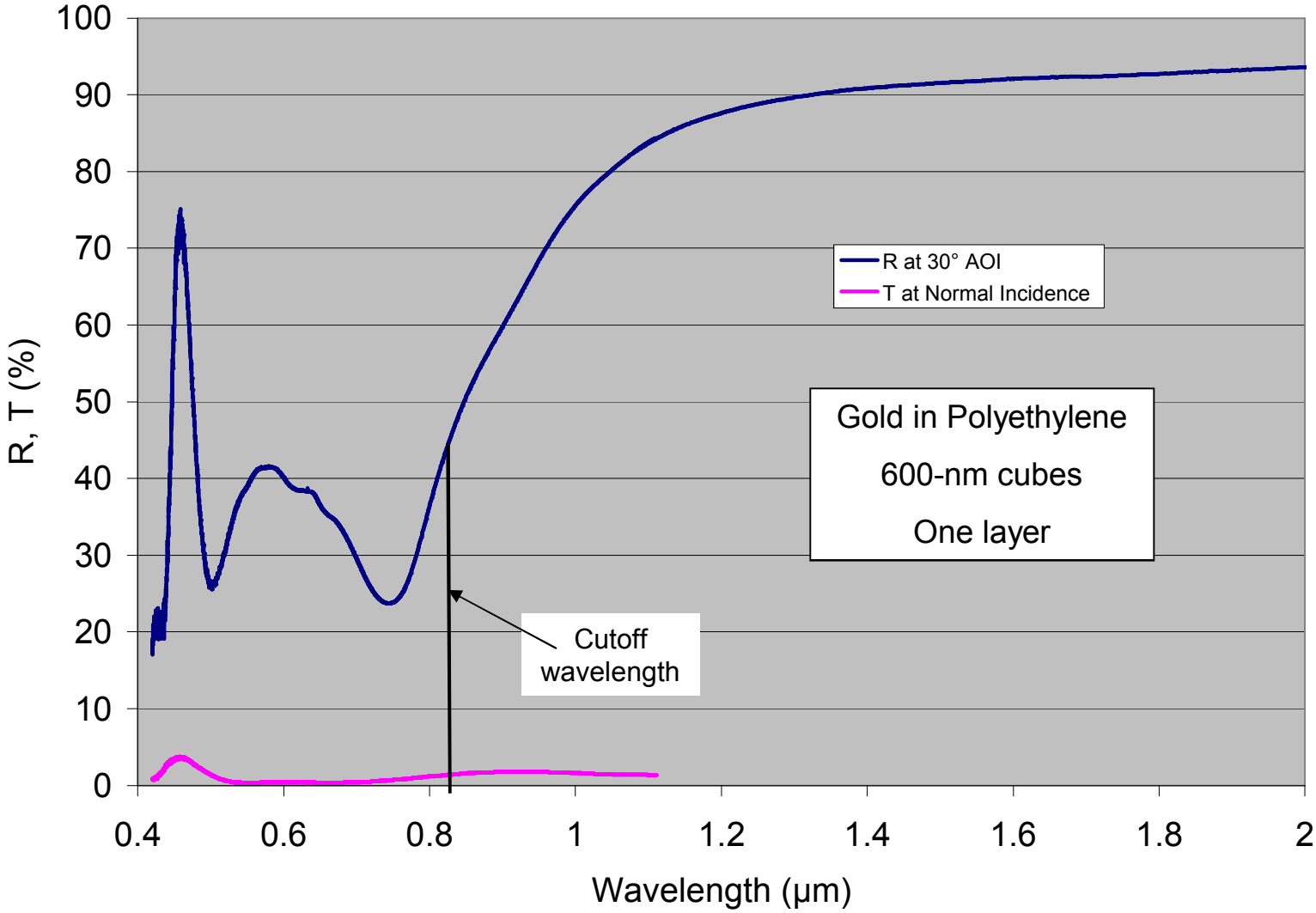
10,000 X

Distance between features is 423 nm

Simulation of Near-IR Cubic Array of Cubes PBG



Measurements of the Near-IR Cubic Array of Cubes PBG: Specular Reflection and Transmission



Measurement Details

- Both CAC measurements were taken with a Thermo-Nicolet Magna-IR 860 FTIR spectrometer.
- For the near-IR CAC sample, a Si detector was used for the 0.42-1.1 μm range, and a MCT-A detector for the 1.1-2.0 μm range. The reflection measurements referenced an Al mirror with a nominal 92% reflectance. The data were corrected for the <100% reflectance of the mirror.
- For the mid-IR CAC sample, a DTGS detector was used for the full 2.0-15.0 μm range. The reflection measurement referenced a Au-coated mirror with an assumed reflectance of 100%.
- The transmission measurements were made at using a focusing mirror at normal incidence, resulting in a small range of AOI.
- The reflection measurements were made at a 30° AOI, also utilizing a focusing mirror.

Conclusions

- **Photonic crystals with a cubic array of cubes architecture have been fabricated**
- **The patterning was done with an imprinter and then “dry” processing was used.**
- **We have shown the capability to fabricate structures with periods of 600nm.**
- **This process has the capability for scaling to large area photonic crystal fabrication.**