Bandwidth Variations in Conformal Infrared Frequency Selective Surfaces

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Introduction

Infrared Frequency Selective Surfaces (FSS) have been demonstrated to control the spectral emissivity and reflectivity of a surface in the 3-6 μm band. These structures were designed using rigid substrates and with radiation only at normal incidence [1]. Previous research has demonstrated conformal FSS transmission filters in the mid-infrared band [2]. This paper will show the design and testing of an infrared FSS for control of spectral emissivity and reflectivity, and operating in the 3-6 μm band. The FSS performance will be demonstrated at angles of incidence from 0 to 30 degrees. Both square loop and loaded cross elements will be considered. The bandwidth of the loaded cross is shown to vary significantly with variation in angle of incidence while the bandwidth of the square loop is more stable.

Design

A structural schematic of the infrared FSS is shown in figure 1. It is similar to previous designs [1] with the addition of the flexible substrate. Standoff layer materials were chosen such that the entire structure is conformable around a cylindrical axis. While the structure's resonant frequency is determined in part by the thickness and permittivity of the standoff layer, the dielectric slabs in contact with the FSS can also have an effect on the bandwidth variation with angle of incidence [3]. Because of this, the same standoff layer (1.3 μm thick, $\varepsilon_r = 3.03$) was used for both element types. Material dispersion issues involved with the standoff layer have been previously addressed [4].

The square loop and loaded cross elements were chosen because they are common in infrared FSS research, and because they have been shown to have wide spectral bandwidths. It has also been hypothesized that the square loop elements in general would show little bandwidth variation with angle of incidence due to their symmetry [1]. The loaded cross was expected to have similar bandwidth and performance to the square loop given the same periodicity, but more angular variation is expected.

HD Microsystems liquid polyimide is applied to a Si wafer to serve as the flexible substrate. The FSS elements are fabricated using E-beam lithography and have dimensions as shown in figure 2. Once processing is complete, the liquid polyimide is peeled off of the wafer and made to conform to the test surface. An example of a conformal FSS with elements fully populating a 10 cm diameter circle is shown in figure 3.

Simulation

All simulations were computed using Ohio State's Periodic Moment Method (PMM) software. In the initial models presented in this paper the ground plane is considered to be a perfect electric conductor (PEC). Since the structures use a low-loss polymer standoff layer, a complex permittivity was used in the simulation. The permittivity was taken from an IR-VASE ellipsometer measurement [3] performed at 8 μm. Again using ellipsometry, the finite conductivity of a gold film at a wavelength of 8 μm was measured. The associated sheet resistance was included in the model. Simulation results for the square loop are shown in figure 4 and for the loaded cross in figure 5. Both structures showed resonance bands in reflectivity around 4 μm.

Testing and Results

An IR spectral radiometer [1] was used to measure the emissivity of the structures. The FSS is placed on a 180 °C hot plate in the focal plane of the radiometer and tilted to measure at off-normal incidence. Equating emissivity with absorptivity by Kirchoff's Law, it can be shown by conservation of energy that unity minus the emissivity is equivalent to reflectivity since the groundplane makes the overall structure opaque. The measured data is also shown in figures 4 and 5 referenced against the simulated data.

The square loop element FSS simulation had a 1.65-μm full width half max (FWHM) bandwidth. At a 30 degree angle of incidence the simulation had a 1.39-μm FWHM bandwidth. The measured FSS had a 1.4-μm and 1.1-μm FWHM bandwidth at normal and 30 degree incidence respectively. The decreased bandwidth at normal incidence is likely due to increased element spacing in the fabricated FSS as compared to the simulation, but the magnitude of decrease in bandwidth with angle of incidence is consistent with the model. This discrepancy could be corrected with further characterization of the lithography process. The simulated loaded cross FWHM bandwidth decreased from 2.8 μm to 1.76 μm, and the measured FWHM bandwidth decreased from 3.1 μm to 2.0 μm with angle of incidence variation from 0 to 30 degrees.

Although both structures produce a similar response at normal incidence, the loaded cross bandwidth is reduced by 35% at 30 degree incidence. The square loop demonstrated a superior performance with only a 21.5% decrease in bandwidth at 30 degree incidence.

References:

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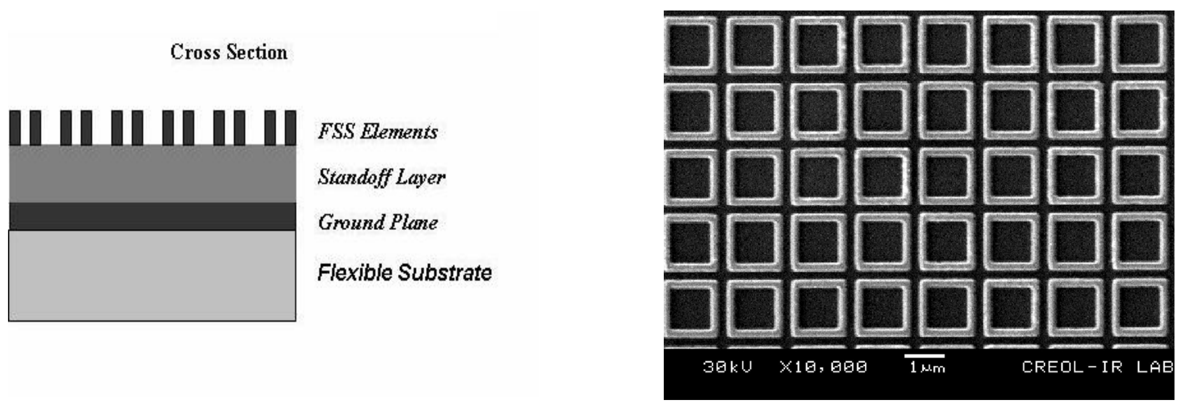
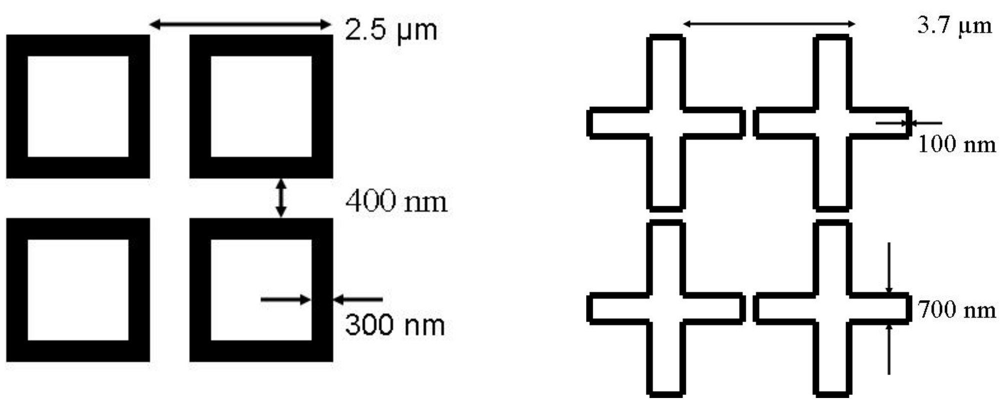


(a) (b)

Figure 1: FSS structural schematic with cross section (a) and top view (b).



(a) (b)

Figure 2: FSS element unit cells for square loop (a) and loaded cross (b).

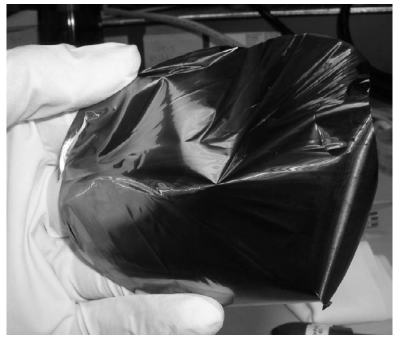


Figure 3: Conformal FSS with elements fully populating a 10 cm circle.

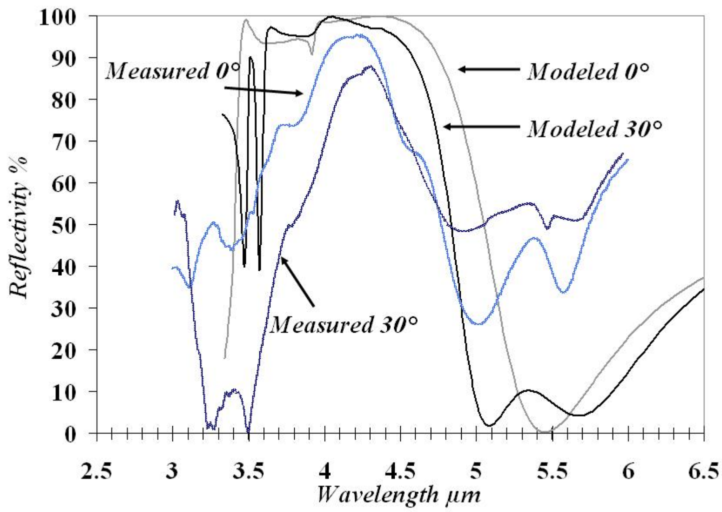


Figure 4: Square Loop Elements, angle of incidence indicated.

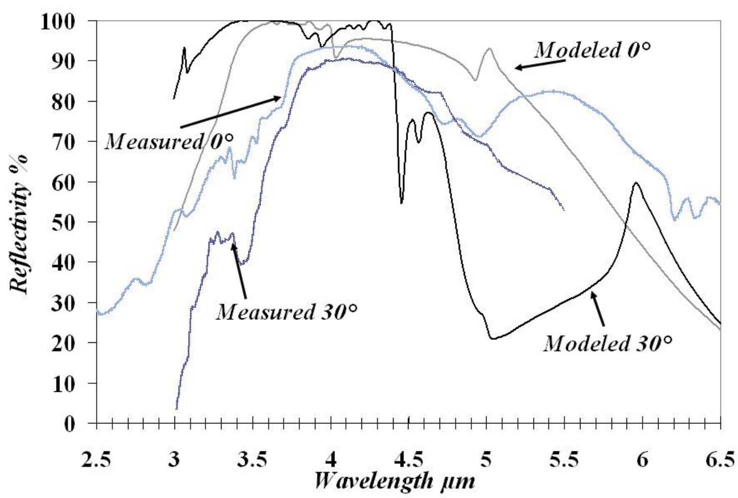


Figure 5: Loaded Cross Elements, angle of incidence as indicated.