Infrared Frequency Selective Surfaces

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A frequency selective surface (FSS) is designed and fabricated to resonate in the infrared. The FSS is designed via Periodic Method of Moments (PMM) software and is based on circuit-analog resonance of square loop elements. The lithographically composed FSS resonates in absorption of infrared radiation. The spectral characteristics of this surface are studied from 3 to 15μm.

1. Introduction

It is possible to modify a surface's spectral radiation signature by patterning the surface with conducting elements or with apertures in a conducting sheet. This type of structure is known as a frequency selective surface (FSS) and has been in use since the 1960s to control radio frequency radiation [1-4] in applications such as radar cross section reduction. Recent success has been reported to scale FSS to resonate in the infrared [4-8]. This manuscript discusses the design, fabrication and characterization of an infrared frequency selective surface that demonstrates infrared spectral characteristics of a reflecting bandpass filter. FSS measurements show nearly 90% modulation of the reflection spectrum, a substantial improvement on previous IR FSS designs [6-7].

This paper will discuss the steps of square loop FSS composure: modeling, fabrication, and measurement. The design is performed using well-known Periodic Method of Moments (PMM) code. To scale the FSS for infrared operation, it is necessary to fabricate via electron beam lithography (EBL), rather than by conventional photoetching techniques. FSS fabrication by EBL has been demonstrated [5-7], and improvements to these designs are discussed in this writing. The FSS is measured via spectral radiometry.

2. Design

To model an infrared frequency selective surface, the Periodic Method of Moments (PMM) is chosen. This code is well known for design of millimeter wave FSS and is capable of scaling FSS to infrared frequencies. The details of this code are discussed in Refs. 1 and 9.

The square loop FSS design has a circuit analog because of the structure of the elements and the substrate layer. Fig. 1 shows a schematic of the designed square loop FSS, and its analog circuit can be illustrated as follows: the metal loops give to inductance to the FSS as incident radiation excites current in these wires. The 200nm gaps between the metal loops compose capacitors with a dielectric (air) gap. A resistance is present because the FSS loops are lossy metal elements on a substrate. Thus, an analog RLC circuit network can be envisioned for the square loop geometry.

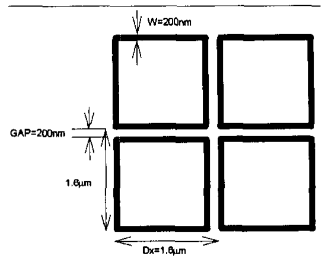

Figure 1 – schematic of the designed IR FSS modeled by PMM

The functional FSS strata consist of a metal ground plane and an amorphous silicon standoff layer on which the patterned FSS layer is written. The PMM code starts the modeling at the ground plane layer. That is, it models a FSS on a dielectric standoff layer atop a ground plane. Between the FSS and its ground plane, a resonant cavity is formed if the thickness of the standoff layer is appropriate. This amorphous silicon standoff layer is tuned such that its thickness is approximately one-quarter wavelength thick at the design wavelength of resonance. The resonant stratified structure enhances the performance of the metal loop FSS

3. Fabrication

The square loop FSS is written on a stratified substrate via EBL in the School of Optics Infrared Systems Laboratory cleanroom. The base of this substrate is a silicon wafer for structural stability during fabrication and testing. A metal ground plane is deposited via thermal evaporation and the amorphous silicon standoff layer is rf diode sputtered.

This substrate is prepared for EBL by spin-coating a bilayer of electron-sensitive resist. Square loop structures are written in this resist via EBL with a JEOL 5900 scanning electron microscope (SEM) converted for EBL. The minimum feature size is 200nm, as shown in Fig. 1. This is well within the resolution of the EBL system. The FSS metal is deposited via thermal evaporation; features are lifted off to reveal the square loop structure. Fig. 2 shows an SEM micrograph of a portion the completed IR FSS. The fabricated FSS covers 25mm^2 and has a total of $2.44 \cdot 10^8$ square loop elements.

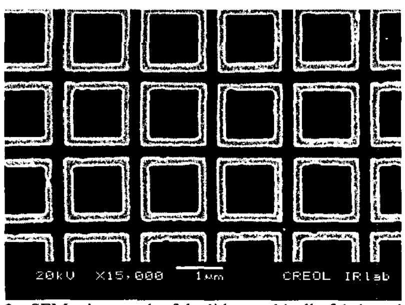

Figure 2 – SEM micrograph of the lithographically fabricated IR FSS

4. Characterization and Results

An infrared spectral radiometer (Infrared Systems Development, Orlando, Florida) is used to characterize the IR FSS from 3 to 15μm. It is used in an imaging configuration in which a 1mm^2 image field is filled by the FSS. The radiometer is designed to collect energy emitted from the FSS and measure the spectral signal using a continuous variable filter. This system is calibrated with a blackbody source at 200°C. The spectral radiance spectra of two different FSS at 200°C are compared to blackbody emission at 200°C in Fig. 3.

To show ability to change the FSS resonant wavelength, two different FSS are composed. Their difference is the thickness of the *a*-Si standoff layer. FSS *A* has a standoff layer thickness of 475nm and resonates in emission at 6.5µm. FSS *B* has a 540nm standoff and resonates at 7.36µm. This shift in resonance is evident in Fig. 3. Maximum contrast is nearly 90% between emission near 4µm and emission at FSS resonance. Also, the shape of their emission spectrum is comparable, because their frequency selective surface layers are identical.

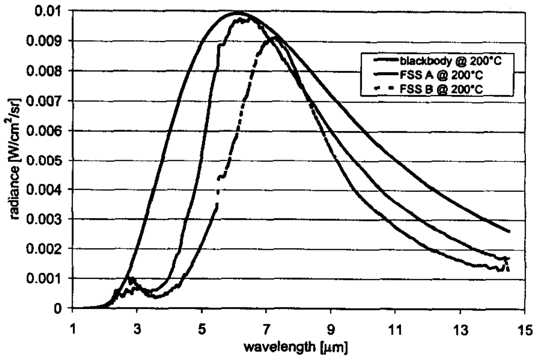

Figure 3 – The spectral radiance of a blackbody, FSS A and FSS B at 200°C. Different FSS to ground plane standoff thicknesses change the resonant wavelength.

To illustrate the validity of PMM in the IR, Fig. 3 compares the results of the PMM model to the experimental data for FSS *A*. Plotted in this figure is the spectral FSS emissivity, the ratio of the FSS radiance to that of a blackbody at the same measurement temperature. Deviations of the experimental data from the model could stem from modeling faults. For instance, PMM is unable to model spectral FSS material permittivity. Also accountable are non-ideal lithographic artifacts, such as stitching errors and intermittent broken metallic loops.

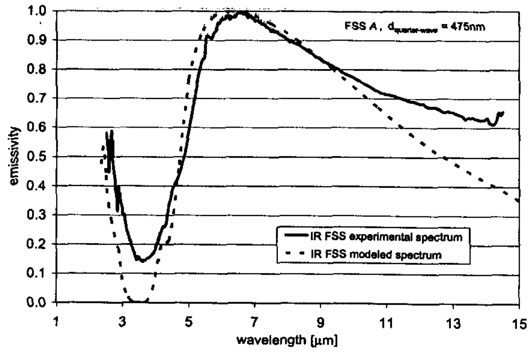

Figure 4 – The spectral radiance of a blackbody, FSS A and FSS B at 200°C. Different FSS to ground plane standoff thicknesses change the resonant wavelength.

5. Conclusions and Future Work

In this study, conducting square loop elements are packed in a tight square grid array to shape the emission spectrum of the resulting frequency selective surface. The versatility of PMM modeling is proven to extend to the infrared spectral region. Nanolithography used to scale the FSS to dimensions necessary for infrared operation has proved successful. Results show infrared resonant FSS behavior, with emission maxima at wavelengths of 6.5μm and 7.36μm for the two FSS studied. Also, out of band emission is 90% less than emission at resonance.

Research is presently being conducted to realize a FSS capable of resonant tuning, i.e., a structure with variable properties such that the wavelength of resonance can be actively changed. The feasibility of such a device is demonstrated here – the physical alteration of the FSS to ground plane standoff distance shifts the resonant location. Also, alternative element structures, element distributions and substrate or superstrate media are being examined in ongoing work. For instance, one method of shaping the FSS resonance is to incorporate a second FSS layer. Another desirable configuration is to fabricate this FSS on a flexible substrate to allow the FSS to be contoured.

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