Distributed Loading Effect for Infrared FSS

J. C. Ginn*(1), D. J. Shelton(1), J. S. Tharp(1), B. A. Lail(2), and G. D. Boreman(1)
(1) University of Central Florida, College of Optics and Photonics/CREOL
4000 Central Florida Blvd. Orlando, FL 32816
(2) Florida Institute of Technology, Department of Electrical and Computer Eng
150 West University Blvd. Melbourne, FL 32901

Introduction

Frequency selective surfaces (FSS) are traditionally resonant periodic antenna structures patterned on a surface for the purpose of spectral filtering. At infrared (IR) frequencies, FSS structures have been successfully demonstrated as both transmission filters [1] and surface emissivity modifiers [2]. While FSS design is extremely mature at longer wavelengths, infrared FSS efforts have been consistently impeded by one major limitation: geometry restrictions due to fabrication. Thus, it is of great interest to investigate any techniques that may allow for easily fabricated FSS elements to exhibit tuned behavior, such as bandwidth expansion, without significant variation in the element's geometry. At longer wavelengths, this has been accomplished through loading of FSS elements with lumped loads or introducing tuning stubs. However, this approach is not practical in the IR given the difficulty of individual element loading on microscale elements. Instead, it is proposed that a similar effect could be achieved at IR by loading the entire FSS element with a distributed load in the form of lossy metals.

Rather than loading an element at a discrete point, distributed loading is realized by using low conductivity metals for FSS elements to introduce a distributed loss throughout the entire element. Distributed loading has been used in surface emissivity designs previously for maximizing absorption bandwidth [3], but the concept can also be expanded to arbitrary bandwidth transmission filters or absorbers. In the simplest embodiment, all pure metals at IR would make ideal distributed loads as they are both lossier than at longer wavelengths and demonstrate significant variations in conductivity depending on the wavelength of operation and the metal. With the high range of conductivities available, and with proper incorporation of material properties in modeling [4], it is possible to design simple distributed loaded infrared FSS elements, such as patches, crosses, and loops, with arbitrary bandwidths and minimal changes in fabrication. Furthermore, future designs may also use surface roughness, contamination, or layer intermixing to selectively introduce arbitrarily loaded FSS elements with bandwidths that would not be possible with pure metals alone.

FSS Loading Materials and FSS Layout

The proposed distributed loading effect will be investigated using four pure metals as distributed loads: aluminum (Al), gold (Au), nickel (Ni), and titanium

1-4244-0878-4/07/$20.00 ©2007 IEEE

(Ti). The four materials were chosen due to their wide variation in conductivity in the long wave IR (5 – 12 μm) and their capability to be easily deposited with e-beam evaporation. Film thickness of the FSS elements was chosen to be approximately 75 nm, well above the skin depth of all four materials. As for the FSS structure, a symmetric, unloaded cross transmission FSS was developed due to the element's narrow notch reject behavior [5] and high potential for significant bandwidth modification due to loading. A unit cell schematic of the FSS is presented in Fig. 1 with fabricated dimensions. A high resitivity silicon (Si) wafer was employed for the FSS substrate due to its low attenuation and typical uncoated transmission of -3 dB.

Material Characterization and FSS Modeling

Before modeling and optimization of the FSS devices, witness samples were prepared of each metal and tested on a J.A. Woollam infrared variable angle spectroscopic ellipsometer (IR-VASE). In characterization of the materials no attempt was made to suppress or isolate metal intermixing, native oxide layers, or chamber contaminants leading to measured results that would very closely illustrate the behavior of the films used in actual fabrication of the cross FSS. Measured values of each metal are presented in Fig. 2. All metals were deposited directly onto Si except for Au, which required a 5 nm Ti adhesion layer to adhere properly to the substrate.

Modeling of the cross transmission FSS device was carried out using a commercially available finite element modeler, Ansoft HFSS. Material values for each of the loading metals, as measured from the ellipsometer, were directly imported into the software as frequency dependent materials. From a practical standpoint, it is not possible to model the complete device, given the depth of the substrate and the size of the array fabricated. The primary limitation of this approach is the inability to account for backside reflections from the rear air-Si boundary and the lack of finite array characterization. However, modeling successfully demonstrates the principle of distributed element loading with wide modulation of the developed FSS center frequency and bandwidth. Results are presented in Table 1 with Q factor calculated assuming bandwidth was determined between the two points 3 dB above the center of the notch.

Measurement and Results

In total, four FSS arrays with dimension of 4 by 4 mm were fabricated, each using one of the four different FSS loading metals. The filters were then tested using a Perkin Elmer Fourier transform infrared (FTIR) spectrometer at normal incidence. Transmittivity results for the four devices are presented in Fig. 3 and summarized in Table 1. A decrease in bandwidth is observed between modeled and measured results due to non-collimated illumination from the FTIR. In addition, a perturbation in the spectrum is seen around 8 μm that is most likely due to internal error in the instrument.

Conclusions

A simple cross FSS filter has been developed and demonstrated to have significant bandwidth sensitivity to distributed loading by several pure metals. This sensitivity gives rise to the potential of bandwidth tuning of infrared FSS elements and reduced fabrication tolerancing.

References

[1] T. Schimert, M. E. Koch, and C. H. Chan, "Analysis of scattering from frequency-selective surfaces in the infrared," *Journal of Optical Society of America A*, vol. 15, pp. 1545–1553, 1990.

[2] I. Pusçasu, W. L. Schaich, and G. Boreman, "Resonant enhancement of emission and absorption using frequency selective surfaces in the infrared," *Infrared Physics and Technology*, vol. 43, pp. 101-107, 2002.

[3] B. Monacelli, J. Pryor, B. A. Munk, D. Kotter, and G. D. Boreman, "Infrared frequency selective surface based on circuit-analog square loop design," IEEE Transactions on Antennas and Propagation, vol. 53, no. 2, pp. 745-752, 2005.

[4] J. Ginn, B. Lail, D. Shelton, J. Tharp, W. Folks, and G. Boreman, "Modeling Infrared Frequency Selective Surfaces with Frequency Dependent Materials," *22nd International Review of Progress in Applied Computational Electromagnetics (ACES 2006)*, pp. 307 - 311, 2006.

[5] B. A. Munk, *Frequency Selective Surfaces: Theory and Design*, New York: Wiley, 2000.

Table 1: Bandwidth Response of Modeled/Measured Cross Transmission FSS

FSS Metal	**Center Wavelength (µm)**	**Q**
Aluminum (Al)	8.50/7.59	5.56/16.79
Gold (Au)	9.30/8.00	3.37/7.74
Nickel (Ni)	10.08/9.07	2.21/2.91
Titanium (Ti)	11.30/10.2	< 1/ < 1

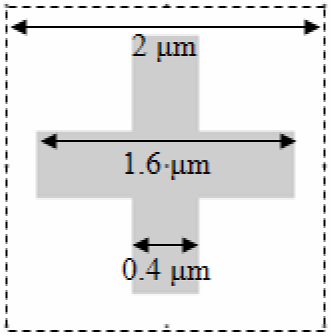

Fig. 1: Cross Transmission Filter Unit Cell Schematic

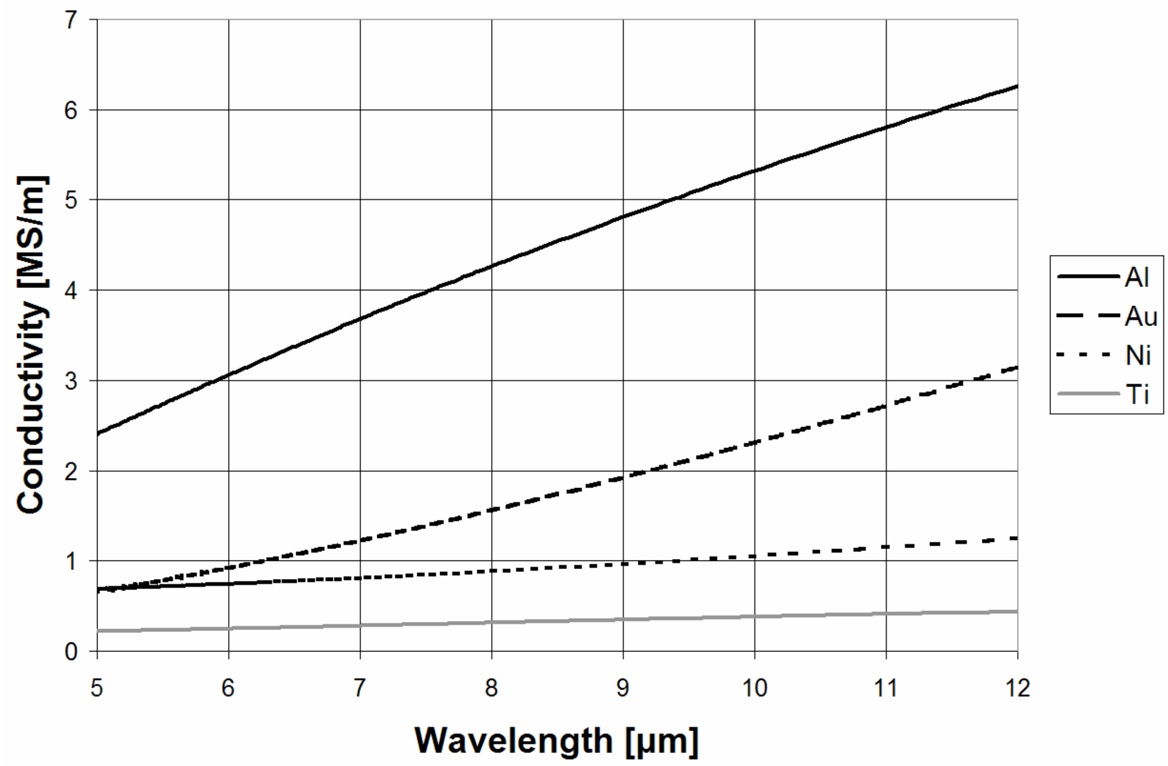

Fig. 2: Measured Conductivity for Four Metals Used in Fabrication

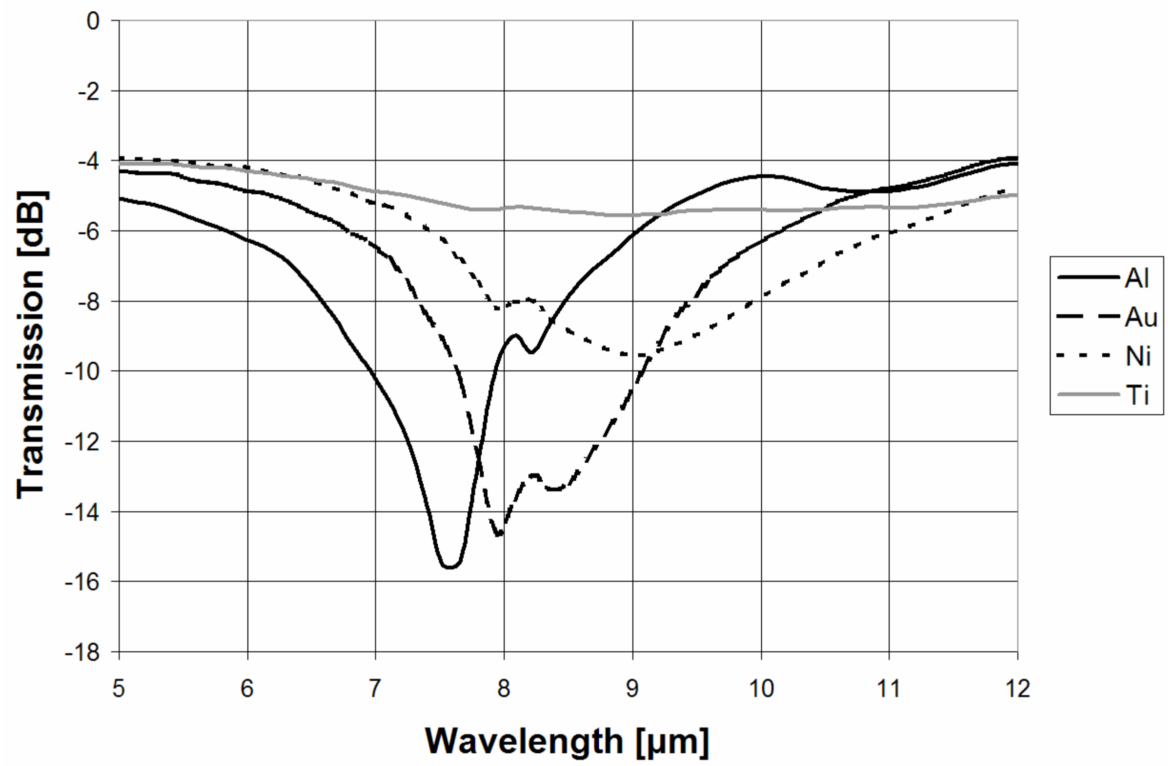

Fig. 3: Measured Cross Transmission FSS Transmittivity