Multi-Bandwidth Frequency Selective Surfaces For Near Infrared Filtering: Design and Optimization

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INTRODUCTION

Frequency selective surfaces are widely used in the microwave and millimeter wave regions of the spectrum for filtering signals. They are used in telecommunication systems for multi-frequency operation or in instrument detectors for spectroscopy. The frequency selective surface operation depends on a periodic array of elements resonating at prescribed wavelengths producing a filter response. The size of the elements is on the order of half the electrical wavelength, and the array period is typically less than a wavelength for efficient operation. When operating in the optical region, diffraction gratings are used for filtering. In this regime the period of the grating may be several wavelengths producing multiple orders of light in reflection or transmission.

In regions between these bands (specifically in the infrared band) frequency selective filters consisting of patterned metal layers fabricated using electron beam lithography are beginning to be developed. The operation is completely analogous to surfaces made in the microwave and millimeter wave region except for the choice of materials used and the fabrication process. In addition, the lithography process allows an arbitrary distribution of patterns corresponding to resonances at various wavelengths to be produced.

The design of sub-millimeter filters follows the design methods used in the microwave region. Exacting modal matching, integral equation or finite element methods can be used for design. A major difference though is the introduction of material parameters and thicknesses that may not be important in longer wavelength designs. This paper describes the design of multi-bandwidth filters operating in the 1-5 micrometer wavelength range. This work follows on a previous design [1,2]. In this paper extensions based on further optimization and an examination of the specific shape of the element in the periodic cell will be reported. Results from the design, manufacture and test of linear wedge filters built using microlithographic techniques and used in spectral imaging applications will be presented.

METHODS FOR DESIGN AND ANALYIS OF THE ARRAY

Two different methods are applied in the analysis and design of the frequency selective arrays. The first uses a moment method solution to the electric field integral equation formulation to calculate transmission and reflection coefficients of the filter [3]. In this code (FSS) piecewise basis functions are used to model the metal surface and an impedance boundary condition is applied to model loss in the materials. The layered structure is handled by the appropriate Green's function on the periodic formulation of the problem. The basis functions model induced current on the metal, periodic array deposited on the layered substrate. The key specifications of the design are the filter bandwidth, center frequency and polarization properties which are dependent upon the shape and size of the periodic element. Different element shapes are used for different applications depending on the design specification. In the application outlined in this paper, a narrow bandwidth for random incident polarization is required. This drives the element shape and size of the periodic cell. Additionally, multiple passbands narrowly separated are also required.

The second approach for design and analysis uses a three-dimensional finite element code that models periodic structures [4]. This code (PARANA) couples a Floquet expansion for the fields external to the material structure with a finite element model within the material. The hybrid code then allows frequency selective screens with a substantial thickness to be accurately modeled in comparison to the surface integral equation model outlined above. In the integral equation model the metal layer that forms the element cell is approximated to be of zero thickness. At infrared wavelengths this approximation becomes limiting and the use of the finite element code can examine discrepancies between measurement and predicted transmitted coefficients.

The hybrid finite element model involves the use of a computer aided design package for describing the geometry and a meshing package for creating the finite element mesh throughout the geometry. For this frequency selective surface application, apertures in a metal layer are modeled. In the manufacture of these patterned arrays corners that are designed to be square become rounded and linear dipole elements do not keep perfect shape. The finite element model than is appropriate for modeling the non-perfect shape as well as the thickness as outlined above.

The final component of the design that will be reported is the use of a global optimization method to improve performance. Specifically a genetic algorithm will be applied with the surface integral equation code (FSS) to find new or modified periodic elements that better meet the specifications [5]. A cost function that is the difference between the desired result and the computed result is specified, and the genetic algorithm successively modifies the geometry until the cost function is minimized. The geometry is specified by a binary string that maps to the metal/no-metal portions of the periodic cell. An essential part of this design process is the use of large parallel computers to give meaningful turn-around times in the design process.

Initial Results

Wedge filters covering the 2.5 - 5μm spectral range by patterning thin metal films using the electron beam lithography technique have been manufactured. Arrays of apertures with varying size and pitch were manufactured in a gold layer deposited on a calcium fluoride substrate. This technique produces large area arrays (up to 1.5 cm × 1.5 cm), offers high reproducibility and allows arbitrary tailoring of the bandpass wavelength versus position profile.

The opportunity to specify a particular wavelength versus position sequence to emphasize certain spectral regions is very attractive to both commercial and government agency users.

The electron micrograph of a sample before metal deposition is shown in Fig. 1a and a micrograph of a completed mesh filter is shown in Fig. 1b. A wide area (1 cm^2) single wavelength filter has been produced and measured. In Figure 2 the comparison of the calculated (using FSS) and measured transmittance curves is shown. The measurements were performed using a Beckman IR4250 Spectrophotometer in a f/10 beam [6]. The calculated and measured curves agree well. The filter has very good rejection at wavelengths longer than the center of the pass band. There is an undesirable transmission band on the shorter wavelength side that turned out to be somewhat larger than predicted.

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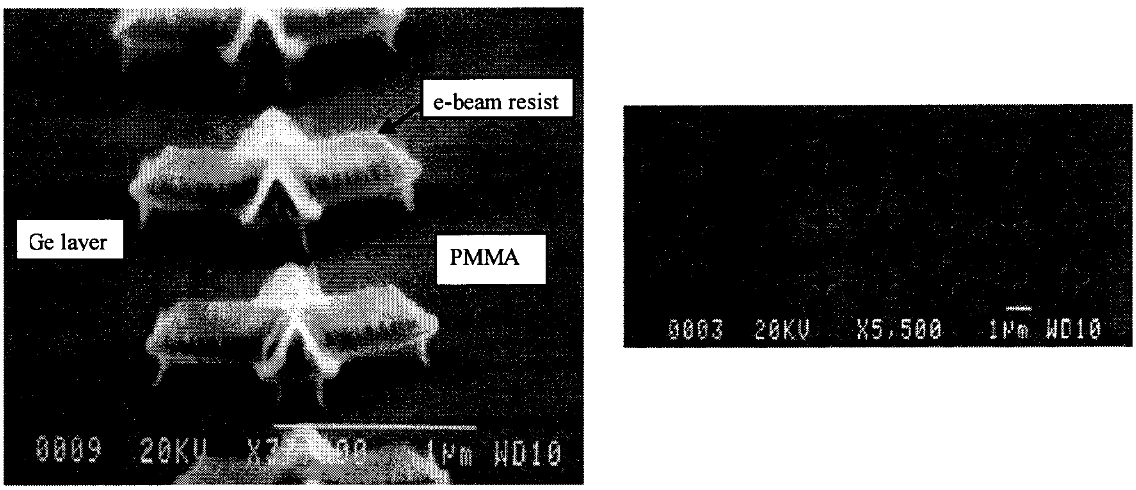

Figure 1. Micrograph of sample periodic screen before metal deposition (left). A portion of the completed mesh filter (right).

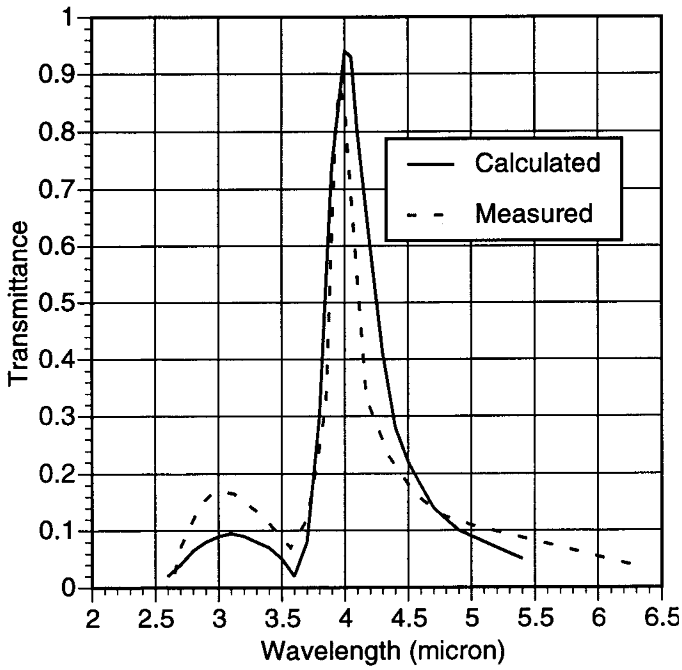

Figure 2. Calculated and measured single filter transmittance.

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