Demonstration of a Multilayer Meanderline at IR

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Introduction

Meanderline polarizers are used to convert linearly polarized radiation into circularly polarized radiation. The specific function of the meanderline is as a phase retarder [1]. Both orthogonal components of an incident electric field act as an AC source for an equivalent RLC circuit. In this manner, the components can be treated as electrically independent when considering the interaction with the meanderline phase retarder. There are two distinct axes in the meanderline, one of which is along the meanderline and the other which is perpendicular [2]. The difference in the phase between the orthogonal re-radiated field components is due to the different impedances and gives the meanderline its retarder functionality. Another aspect of the meanderline is that the spectral phase delay between the two field components remains fairly constant over rather large bands of interest and gives the meanderline the possibility of functioning as a wide band circular polarizer. Previous work has been done to demonstrate the proof-of-concept for the meanderline polarizer for infrared wavelengths. The demonstration showed that a single-layer-meanderline fabricated for radiation at 10.6μm would function as a phase retarder [3].

The present work extends these initial efforts and attempts to increase the transmission and bandwidth by using multiple meanderline layers. A new ellipsometric method of characterization allows spectral measurements from 6 – 14 μm [4]. The use of multiple layers reduces impedance mismatches at each meanderline layer. Therefore less reflection is seen at each interface. A dielectric superstrate layer is also deposited so that an anti-reflection coating may be used to increase the overall transmittance.

Design

The design of the mulitilayer meanderline retarders were modeled in Ohio State's Periodic Method of Moments (PMM). After developing the input file for the multilayer meanderline designs, an external MATLAB code was used to call PMM and incorporate measured frequency-dependent permittivity and conductivity values for the dielectric and metal layers used.

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The geometry of the meanderline, along with the electrical environment, determines the complex impedance that the incident radiation will experience. The geometrical design parameters are the line width (w), pulse width (pw), pulse height (ph), and periodicity (dx) as shown in figure 1. To begin the design process, approximations were made which include perfectly conducting metals and lossless dielectric media. These approximations are valid starting parameters since the addition of finite-conductivity metals and isotropic low-loss dielectrics do not severely impact the polarization parameters of interest. With these approximations made, PMM was used to determine the reflection coefficients from which the impedance was computed. The impedance for each polarization was then easily inverted and realized on an admittance Smith Chart. Since the design was then lossless, the Smith Chart was well suited to visualize complex field reflection coefficients through meanderline layers and lossless dielectric layers. The Smith Chart was then used to determine the ideal dielectric thickness for impedance matching [5]. Using this graphical analysis, the geometries of both meanderline layers should have identical geometries.

With the initial geometric parameters determined using the ideal approximations, PMM was then used along with the measured frequency-dependent material properties to optimize the performance by maximizing the efficiency, defined as the percent of initial optical power transmitted in the desired polarization state. Several dielectrics were characterized for use as a dielectric standoff layer, but evaporated silicon was chosen since it is essentially lossless in the long-wave IR. Although silicon's high permittivity ($\varepsilon_r \sim 11.5$) was not desired for bandwidth considerations, it allowed for thinner dielectric layers for the same effective propagation distance (ideal from a fabrication perspective.) The optimized meanderline geometry was: w = 0.225 μm, pw = 0.6 μm, ph = 0.5 μm, and dx = 1.2 μm. The ideal dielectric standoff thickness was 0.890 μm. The model with these parameters showed an axial ratio ≤ 1.5 from 8 – 12 μm; however the design was remodeled after fabrication to include the as-fabricated dimensions.

Fabrication and Analysis of Results

The fabrication of the multiple layer meanderlines began with the design parameters for the bottom layer being written using a Leica 5000+ electron beam writer onto a 3" high resistivity silicon substrate. This first meander layer was developed and later metallized using aluminum. After metallization, high-purity silicon was deposited using electron-beam evaporation to a thickness of half the design thickness. Since e-beam evaporation is a conformal method of deposition, the film was then planarized using a spin-on dielectric to produce a roughness (±5 nm as measured using an atomic force microscope) acceptable for ebeam lithography and the remaining silicon was evaporated. The second meanderline layer was then fabricated in a similar fashion. This procedure kept silicon in contact with the meander structures resulting in an identical electrical environment for each meanderline layer.

The measurement of the meanderline performance was done using a spectroscopic ellipsometer in transmission mode and at normal incidence. The ellipsometer directly measured the spectral phase delay and the power transmission coefficients along and perpendicular to the meanderline axis. This design showed an axial ratio of ~2 from 8 - 12 μm and an average measured transmission of 22%. The measured axial ratio and phase delay are shown along with the modeled results in figure 2. From the measured results, it is observed that the phase delay and axial ratio remain fairly flat from ~9 μm to 14 μm. The peak in the phase delay seen at 8.3 μm seems to be due to the Fabry-Perot resonance set up within the silicon superstrate layer. This is plausible because after fabrication, more silicon was deposited onto the superstrate to determine its effects. The peak in phase delay shifted to longer wavelengths as the thickness of silicon increased. Therefore, it is feasible to consider that if the superstrate layer is at an appropriate thickness, the peak can be at a substantially higher frequency that will allow for very flat phase response and axial ratio performance in the band of interest.

To our knowledge this is the first multilayer meanderline retarder designed, fabricated, and characterized for infrared radiation. When the meanderline is coated with an antireflection coating, it will have a transmission of 45% which is double the previous measured transmission of a single layer meanderline retarder.

Acknowledgements

This research was supported by a contract from DRS Optronics, Melbourne FL. Additional support was provided by the Florida High Technology Corridor Council.

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Figure 1: SEM image of a fabricated meanderline structure on a high resistivity silicon substrate with the geometric parameters labeled

Figure 2: Plot of modeled and measured phase delay and axial ratio for double layered meanderline

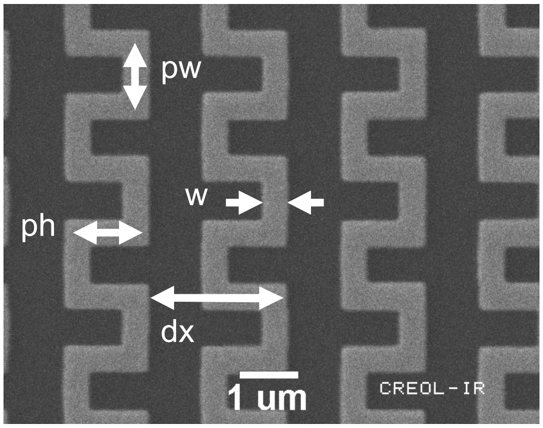

Figure 1

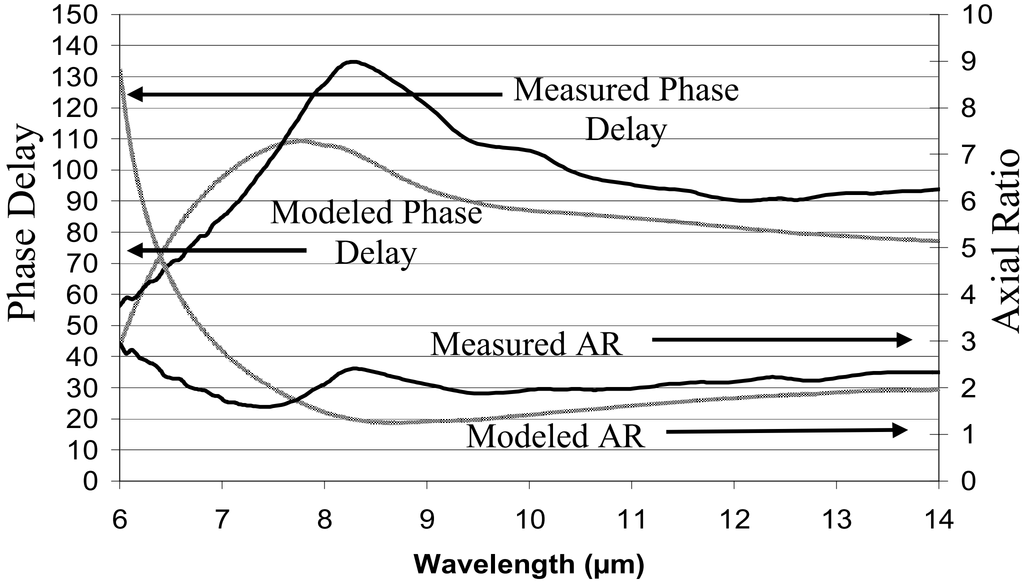

Figure 2