

Microstrip Reflectarray Design at MWIR and NIR

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Introduction

Reflectarrays are conventionally defined as a quasi-periodic array of passive antenna elements arranged for the purpose of reflected phase manipulation or focusing [1]. A mature technology at microwave frequencies, the feasibility of these devices has only recently been explored at frequencies above 1 THz, specifically at the LWIR [2]. Reflectarrays are a potentially disruptive technology in the field of optics due to their small physical footprint and lower production costs when compared to analogous diffractive or refractive elements. In addition, the reflectarray's unique resonant nature holds a strong potential for aberration correction applications. This paper continues the development of the high frequency reflectarray by establishing the challenges and issues that limit infrared reflectarray design. Taking into account these limitations, reflectarray elements were developed and measured for the first time in the MWIR (3.39 μm) and NIR (1.55 μm).

Infrared Development Challenges

Numerous unique challenges exist in the design of reflectarrays for use in the infrared. Often neglected in microwave reflectarray design, the inclusion of frequency dependent metal conductivity in modeling plays a major factor in the accuracy of high frequency reflectarray models. The additional loss inherent in the metal antenna elements at higher frequencies results in a deQ-ing of the design [3] and a subsequent loss in phase variation range. Similarly, the conductivity of the groundplane will further degrade the strength of the resonance and negatively impact reflection efficiency. Generally, all of these issues can be accounted for with the proper modeling and accurate optical properties.

Unfortunately, the impact of metal non-idealities is not limited to normal Drude dispersion. Additional metal features which cannot be easily numerically modeled can lead to further changes in conductivity - such as grain boundary size, substitutional lattice impurities, oxide layers, surface roughness, and film non-uniformities. An additional consideration in the infrared is that the skin depth of most metals is on the order of the electron mean free path. This is particularly true for the noble metals, (Au, Cu, Ag, Al), which have long intrinsic mean free

paths. The result is an anomalous skin effect [4] at room temperature which alters the conductivity compared to the value that is expected from the Drude model at infrared frequencies.

Fabrication tolerances must also be accounted for in the development of a practical infrared reflectarray design. The cost of long write times and the practical resolution of most nano-fabrication equipment prohibit the employment of small features in the design of infrared reflectarrays, such as stubs or concentric rings. Broadening of device dimensions from overdevelopment is also a major concern due to the high phase sensitivity of reflectarray elements to defects at small wavelengths. For reflectarray stand-off layers, spin on dielectrics like Benzocyclobutene (BCB) or Spin on Glass (SOG) have gained in popularity as a cheaper and more efficient alternative to deposition of non-polymer materials such as Zirconium Dioxide or Silicon Dioxide. These films become increasingly more difficult to employ at higher frequency and require thinning or etching to achieve necessary film thicknesses. Thinning of the dielectric prior to spinning will also increase the chance of streaking and height non-uniformity.

MWIR Reflectarray Design

With the infrared reflectarray limitations established, it was now possible to begin development of a reflectarray with operation in the MWIR, or specifically 3.39 μm . To minimize small device features, a simple patch geometry was chosen to serve as the elements making up the array. Patch elements achieve variable phase responses by altering their physical dimensions to shift their resonant wavelengths [4]. Thus, an increase in dimension of the patch will result in an increase in phase delay of an incident wave upon reflection. Aluminum was chosen for use in the patch elements and the groundplane due to the metal's high reflectivity and conductivity at 3.39 μm and the patch's thickness was selected to be 40 nm (4 times the skin depth) to limit the impact of the anomalous skin effect. The stand-off layer was made up of low loss BCB at a thickness of 350nm and the overall unit-cell length for each patch was 1.5 μm . Modeling of the elements was carried out using Ansoft Designer, a Method of Moments solver, while incorporating in-situ measured optical properties of each material in the design.

Fabrication of the test design followed a standard electron-beam lithography process: initial deposition of the ground plane and stand-off layer, spin-on of a resist, patterning of the resist, development of the resist, deposition of the patches, and a final lift-off stage. The actual layout of the reflectarray elements was similar to the stripe configuration used in [5]. Instead of an optical flat, the reflectarray substrate comprised of a prime grade wafer to reduce write complexity and cost. Also, due to thickness required, the BCB solution had to be diluted prior to spin, but no streaking or surface deviation was observed.

Testing of the device, using the same approach as in [3], employed a Twyman-Green interferometer utilizing a HeNe laser tuned for operation at 3.39 μm and,

due to the low power of the laser, a PtSi camera. Images of two stripes of the device are presented in Figure 1 and measured data are plotted against modeled results in Figure 2. The device exhibited behavior in strong agreement with the modeled results and only slight surface deviation due to the substrate was observed during testing.

NIR Reflectarray Design

Similarly, a NIR, or 1.55 μm , reflectarray was developed and tested. The materials and overall layout of the array remained identical to the MWIR reflectarray. The thickness of the patches were reduced to 30nm to prevent phase errors due to the height of the patch and the unit cell was reduced to 0.8 μm to prevent the appearance of grating lobes. The BCB stand-off layer was reduced to 200 nm, which forced additional dilution of the BCB solution. Modeling was still carried out using Ansoft Designer and the fabrication process was identical to the MWIR design.

Testing of the device once again employed a Twyman-Green interferometer utilizing a 1.55 μm diode laser and an InGaAs camera. Images of two stripes of the device are presented in Figure 3 and measured data are plotted against modeled results in Figure 4. Film streaking was observed only on the edges of the device, but surface deviation was only significant due to the substrate. Further prototyping in the future with an optical flat substrate will be required to mitigate these issues, however; the feasibility of reflectarray behavior in the NIR has been demonstrated.

Conclusions

The infrared reflectarray is an emergent technology with numerous potential applications. In the paper, an outline was presented of the challenges facing high frequency reflectarrays and preliminary results are presented for reflectarrays operating in the MWIR and the NIR.

Acknowledgements

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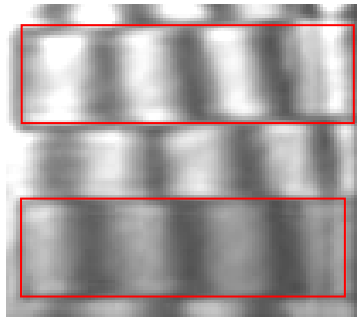


Fig 1. Two stripes (marked by boxes) of 3.39 μ m reflectarray prototype demonstrating unique fringe shifting at each stripe.

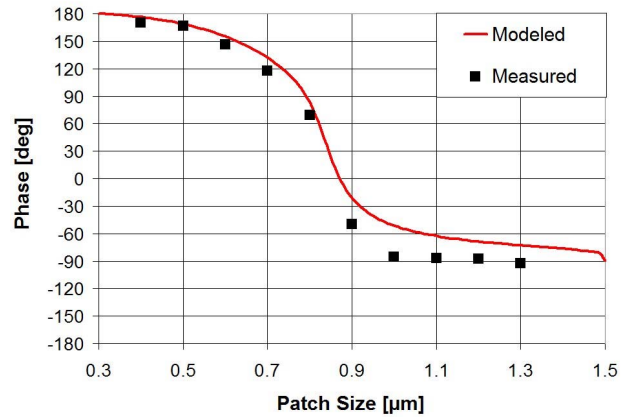


Fig 2. Measured and modeled results for 3.39 μ m reflectarray prototype.

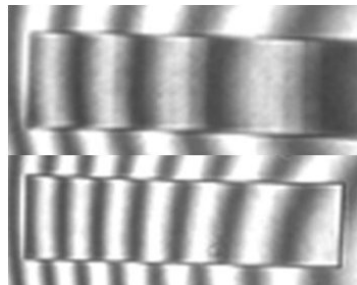


Fig 3. Two stripes of 1.55 μ m reflectarray prototype.

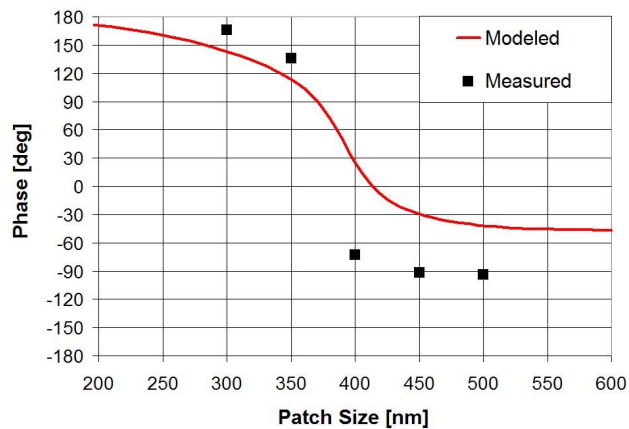


Fig 4. Measured and modeled results for 1.55 μ m reflectarray prototype.