Infrared Patch Reflectarray

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Introduction

Reflectarrays are traditionally passive, planar microstrip antenna devices designed for reflected phase manipulation. Initially proposed as a low-cost replacement for bulky parabolic reflectors, reflectarrays have been successfully developed and utilized at both RF [1] and millimeter-wave [2] frequencies. From the stand-point of an optical systems designer, adapting low-frequency reflectarray technology to develop a sub-millimeter and infrared reflectarray (SMIR) would provide a highly desirable alternative to similarly behaved polished or diffractive optical devices. Compared to traditional optics, SMIRs should be cheaper to fabricate, have a smaller physical footprint, allow for utility stacking, and allow for direct integration of aberration correction.

To demonstrate the feasibility of utilizing reflectarray technology at infrared (IR), a simple SMIR has been designed, fabricated, and tested. The SMIR is comprised of three independent arrays or "stripes" of a single size element on a coated optical flat. Actual reflectarray elements consist of variable size patches which exhibit higher operating bandwidths than reflectarrays utilizing other types of elements [3] and are easier to fabricate at small dimensions. For testing, each stripe element has been chosen to exhibit a unique phase shift for measurement using an IR interferometer. The desired operating wavelength of the SMIR is 10.6 μm, however, the device should be scalable to allow operation at other frequencies.

Reflectarray Modeling

Before fabrication of the SMIR, modeling was utilized to determine the range of patch sizes necessary to achieve the desired reflectarray behavior. For the highest accuracy in modeling, each material used in fabricating the device was characterized by an ellipsometer for its optical properties. ZrO_2 was chosen as the device's standoff layer based on the material's low loss and low permittivity at infrared. The low permittivity of ZrO_2 was especially desirable to ensure large patch sizes and reduce the impact of fabrication tolerances. For the SMIR's ground plane and patch elements, gold was chosen due to the material's high reflectivity at IR.

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Two models were consulted when determining patch sizes for the proposed SMIR design. The first model was developed using a commercially available FEM solver, Ansoft HFSS, and, for comparison, a second model was developed using Ansoft's MOM solver, Designer. In both models, the reflectarray was assumed to be an infinite array comprised of a single size patch with material properties identical to the values measured from the ellipsometer. Modeling was realized by calculating the relative phase shift introduced by varying the size of the patch while assuming a 180 degree phase shift of the incident radiation upon reflection in the absence of the patch.

After assuming a stand-off layer thickness of 450 nm and a unit cell size of 5.54 µm, it was now possible to choose patch sizes for the three stripes of the SMIR. From modeled results, patch dimensions to achieve 40, 80, and 120 degrees of reflected phase shift were chosen. The three patch sizes are 2.98 µm (40º), 3.14 µm (80º), and 3.24 µm (120º). Results for both models and the selected patch sizes are summarized in Fig. 1.

Fabrication

To ensure that any measured phase modification was a result of the reflectarray and not a result of a physical material defect, a 2 inch diameter, 0.125 inch thick quartz optical flat was used as the device's substrate. The optical flat was measured to be a quarter-wave flat at visible and, thus, demonstrated no significant aberrations at 10.6 µm. On the polished face of the optical flat, a 300 nm gold ground plane followed by a 450 nm stand-off layer of ZrO_2 was deposited.

Writing of the SMIR pattern (Fig. 3) was carried out using e-beam lithography. A ZEP-PMGI resist bi-layer was spun on the coated flat and the desired patch pattern was written by a Leica EBPG 5000+ EBL system. After resist development, a 150 nm layer of gold for the reflectarray patches was deposited through e-beam evaporation. The process was completed by lifting off the remaining resist and excess gold to expose the desired patch pattern. Upon completion, each stripe on the flat was 0.25 inches by 1.09 inches, separated edge to edge by 0.3125 inches. In total, the reflectarray was made up of 17.9 million elements.

Testing and Results

Testing of the fabricated SMIR device was carried out using a Wyko IR3 interferometer operating at 10.6 µm. In contrast to the fringe pattern of the coated flat (Fig. 4.), the interferogram of the SMIR in Fig. 5 clearly demonstrates distinct fringe shifts introduced by each stripe on the reflectarray. Through post-analysis, the phase shift of each stripe was calculated and the results are summarized in Table 1. Although the measured values are not identical to the predicted values, these results are reasonable considering variation between the models and demonstrate infrared reflectarray behavior .

Table 1. Summary of measured and predicted reflectarray phase shifts.

Patch Size	Predicted Results	Measured Results
2.98 μm	40 °	37 °
3.14 μm	80 °	52 °
3.24 μm	120 °	71 °

Conclusions

A simple SMIR has been successfully fabricated and tested at 10.6 μm. Measured results demonstrate the feasibility of an infrared reflectarray. Continued research will focus on developing SMIR technology for use as a planar focusing element.

Acknowledgements

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References:

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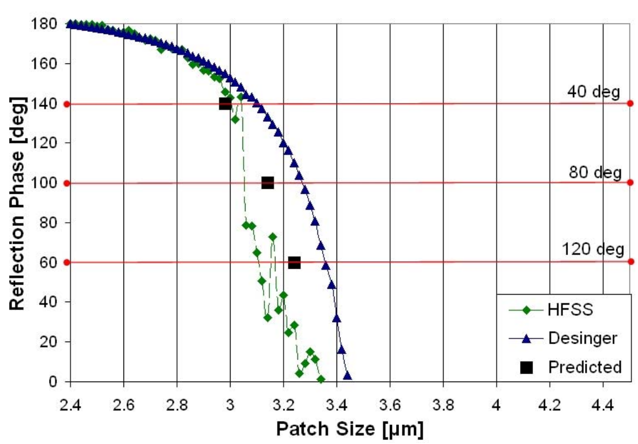

Fig. 1. SMIR modeling results from Ansoft Designer and HFSS, along with predicted values.

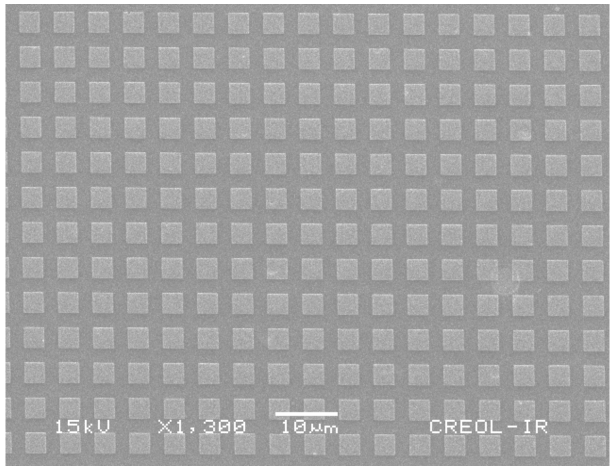

Fig. 2. SEM image of one SMIR stripe.

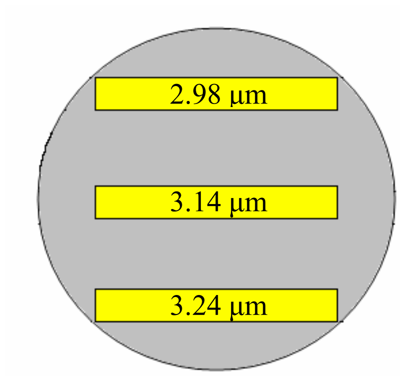

Fig. 3. SMIR layout.

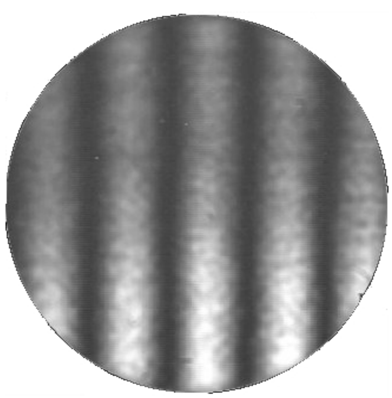

Fig. 4. Interferogram of coated optical flat demonstrating no significant aberrations.

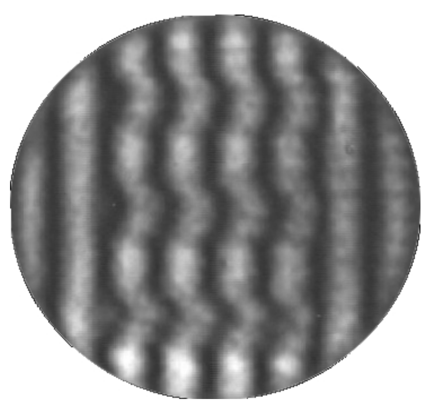

Fig. 5. Interferogram of SMIR demonstrating phase shifts introduced by patch arrays.