Demonstration of a Single Layer Meander Line Phase Retarder at IR

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Introduction

Meander line polarizers are used to convert linearly polarized radiation into circularly polarized radiation. The meander line structure merely acts as a phase retarder for two orthogonal wave components of an incident electric field. These two orthogonal components lie along the meander axis and perpendicular to the meander axis. The meander structure acts as an inductive element along the meander axis and a capacitive element perpendicular to the meander axis in its response to the incident electric field leading to a phase delay. Some efforts have been made in the past to model [1] these types of devices. These results have been applied to the design and manufacturing of meander lines at radio frequencies (RF) and millimeter wave frequencies (mmW) frequencies [2]. We present the extension of these results to the infrared (IR) domain. Currently, circular polarized light has to be produced via birefringent crystals or circular polarizing prisms. Both of these techniques involve a small fabrication tolerance and expensive materials. Meander lines provide a technique to manufacture infrared polarizers with cheaper material costs. The fabrication involves lithographic deposition of metallic structures on silicon wafers. Recent improvements in lithographic processes (UV photolithography) could allow for mass production in the near future.

The main problem for the extension of the previous work to the infrared domain is that all available models and fabrication processes have been made taking into account the material characteristics at RF and mmW. The majority of the results can not be applied to IR due to the wavelength dependence of the structure leading to small size at IR frequencies and various material problems at these frequencies [3]. Moreover, the expected scattering effects due to the meander line structure could be an important factor, decreasing the degree of polarization of the transmitted beam. In this paper we investigate the proof of concept for using meander lines structures at IR to change the state of polarization of incident radiation.

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Experimental Setup and Analysis of Results.

We measure the change in the state of polarization of an infrared laser beam due to the meander line structure. For this purpose we measured the Stokes parameters [4] of the beam with and without the meander line in the setup. The Stokes parameters are determined from four irradiance measurements of the radiation.

Our experimental setup includes a CO_2 laser operating at 10.62μm, two BaF_3 wire grid polarizers, and a quarter wave plate as shown in figure 2. Two thermal detectors were used, one to keep measurements of any fluctuations in laser power and the other for the actual measurements used to determine the Stokes parameters. The incoming beam is linearly polarized. We made two power measurements, one with just an analyzing polarizer rotated through 360 degrees and one with a quarter wave plate with the fast axis horizontal as the analyzing polarizer was rotated. With these measurements the Stokes parameters of the incoming beam were determined [4]. The meander line structure itself was fabricated using electron beam lithography on a high resistivity Silicon substrate. The relative dimension of the meander line structure is shown in figure 1.

The Stokes parameters are determined through a set of four irradiance measurements. The first three power measurements were without the quarter wave plate in the optical train and with the analyzing polarizer at 0° (I_0), 45° (I_{45}), and 90° (I_{90}). The fourth power measurement was with the quarter wave retarder in the optical train and the fast axis at 0° from horizontal and the analyzing polarizer at 45° (I_{r45}).). The first quantity was to verify the retardance in the quarter wave plate by using the measurements taken with the incident polarization at 45° to the fast axis and rotating the analyzing polarizer. The intensity curve as a function of the analyzing polarizer angle is fitted to a periodic function. The relative phase delay (φ) is determined from the curve fit of the data [4] :

$$\cos(\varphi)=(I_{max}-I_{min})/(I_{max}+I_{min}) \qquad (1)$$

where I_{max} and I_{min} are the measured maximum and minimum of the fitted curve. The actual retardance of the quarter wave plate was measured to be 80.78 ± .01 degrees (From the uncertainties in the fitted parameters the uncertainty in the phase delay can be inferred). The Stokes parameters can be calculated as [4]

$$S_0=I_0 + I_{90} \qquad S_1= I_0 - I_{90} \qquad (2)$$
$$S_2=2*I_{45} - S_0 \qquad S_3=(2*I_{r45} - S_0 - S_2*\cos(\varphi))/(2*\sin(\varphi))$$

The Stokes parameters then are used to determine the orientation (ψ) and eccentricity (tan(X)) of the polarization state using

$$\tan(2*\psi)=S_3/S_0 \quad \text{and} \quad \sin(2*X)=S_2/S_1 \qquad (3)$$

From the noise in intensity measurements and uncertainty in the retarder, uncertainties in stokes parameters, eccentricity and orientation can be calculated [5]. Results are shown in Table 1. They show a drastic change in the polarization state of the radiation after passing through the single layer Meander line structure. The eccentricity of the polarization ellipse changed from its initial linear polarization to elliptical polarization with an eccentricity of .398 ± .008 (axial ratio of 2.51) while the orientation of the ellipse changed from 43.5 ± 0.4 degrees to 9.1 ± 0.5 degrees after passing through the meander line. Another interesting aspect is that the degree of polarization of the incident linear polarization was .98 as measured while the degree of polarization after passing through the meander line was 0.88. Therefore the meander line did in fact change the state of the polarization with little degradation of the degree of polarization.

We also determined the phase delay of the meander line structure with incoming linearly polarized beam at 43.5 ± 0.4 degrees, using the same method used for the measurement of the quarter wave retardance. The phase delay, as measured, was 48.89 ± .01 degrees.

Conclusions

To our knowledge this is the first proof of concept of using meander line structures in the infrared domain. We have fabricated a single layer gold meander line on a high resistivity silicon substrate capable of changing the polarization state of the radiation from linear polarization at 43.5 ± 0.4 degrees to elliptical polarization with an eccentricity of .398 ± .008 and an orientation of 9.1 ± 0.5 degrees. This performance shows that the meander line structure can be used in the IR as a planar phase retarder. The phase delay of this single layer meander line was measured to be 48.89 ± .01 degrees. Moreover, the degree of polarization is minimally affected suggesting that the change of polarization is due to the meander line phase delay and not driven mainly by scattering.

Acknowledgements

This work was supported by US Department of Energy, under research contract 00046731 from Idaho National Laboratory, and by a research contract from DRS Optronics, Melbourne FL. Additional support was provided by the Florida High Tech Corridor Council.

References

[1] Bhattacharyya, A.K. , Chwalek, T.J. “Analysis of multilayered meander line polarizer”, *International Journal of Microwave and Millimeter-Wave Computer-Aided Engineering.* Volume 7 Number 6, pg. 442-454. 1997.

[2] Young, L., Robinson, L., Hacking, C. “Meander-line polarizer.” *Antennas and Propagation, IEEE Transactions on.* Volume 21 Issue 3, pg. 376-378. May 1973.

[3] Munk, Ben A. *Finite Antenna Arrays and FSS* (Appendix C). Wiley-IEEE Press. ISBN 0-471-27305-8. July 2003.
[4] Goldstein, Dennis. *Polarized Light 2^{ed.}* Marcel Dekker AG. ISBN 0-8247-4053-X. 2003.
[5] *Guide to the Expression of Uncertainty in Measurement* 2nd ed. (Geneva: International Organization for Standardization.) ISBN 92-67-10188-9. 1995.

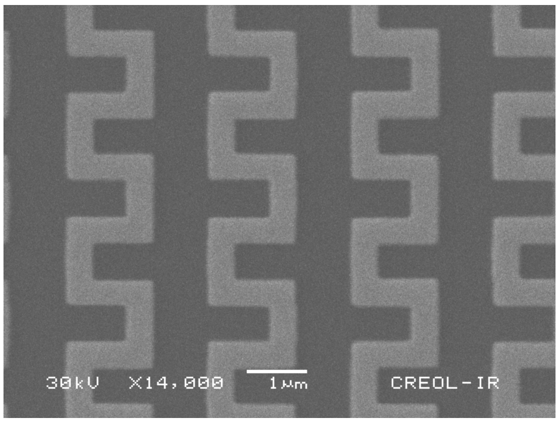

Figure 1: SEM image of the fabricated gold meander line structure on a high resistivity silicon substrate

Stokes parameters	Incident Beam	Transmitted beam
S_0	1.000	1.000
S_1	0.043 ± 0.014	0.546 ± 0.003
S_2	1.007 ± 0.016	0.193 ± 0.010
S_3	-0.019 ± 0.010	0.672 ± 0.011
Ψ (orientation)	43.71° ± 0.39°	9.15° ± 0.44°
χ (eccentricity)	-0.009 ± 0.005	0.398 ± 0.008

Table 1: Stokes parameters and polarization ellipse parameters for the incident and transmitted beam.

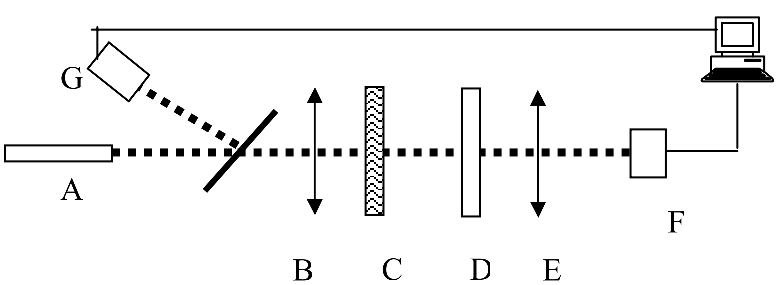

Figure 2: Schematic of the experimental setup: A) CO_2 laser B) Wire Grid Linear Polarizer C) Meander Line D) Quarter Wave Plate E) Analyzing polarizer F) & G) signal and reference detectors connected to a computer for data acquisition