A Long Wave Infrared Polarization Sensing Detector with Wide Dynamic Range

Elham Mohammadi and Nader Behdad
Department of Electrical and Computer Engineering
University of Wisconsin, Madison, WI 53706, U.S.A.
{emohammadi, behdad}@wisc.edu

***Abstract*—We present the design, fabrication, and characterization of a polarization sensing detector in long wave infrared (LWIR) frequency band. The detctor is composed of two orthogonal slot antennas coupled to nickel microbolometers, which are sensitive to thermal radiation. The detector's topology is optimized to maximize its dynamic range. A prototype is fabricated and characterized. The detector has a measured dynamic range of 26 dB for the power ratio of the two antennas when the polarization of the incident wave is rotated from 0° to 90°.**

I. Introduction

Design and development of infrared imaging systems has been the focus of many research efforts for the past few decades. These imaging systems are used in many military and scientific areas such as night vision, target tracking, and non-contact temperature measurement. The available devices use the irradiance of the incoming wave at the long or mid wave infrared (LWIR or MWIR) regime and neglect the other attributes of electromagnetic (EM) wave such as frequency, angle of incidence, and polarization [1]. These characteristics of the EM wavefront contain important information, which can be exploited in performing non-traditional sensing and imaging, especially in highly degraded environments. Conventional infrared imaging devices capable of sensing polarization use additional optical components such as wire grid polarizer [2]. However, these external components attenuate the incident wave amplitude and also result in bulky devices.

Previously, infrared detectors using antennas coupled to various IR sensing elements such as thermocouple [3] and metal–insulator–metal diodes [4] have been studied for potential application as polarization sensing LWIR sensors. Although the responses of these systems are sensitive to the wave polarization, these responses are either amplitude dependent or adversely impacted by the presence of DC bias line in the vicinity of the antenna-based detector. In this paper, we use two orthogonal slot antennas coupled to microbolometers as a polarization sensing LWIR detector. By measuring the ratio of the absorbed power in each antenna, we are able to determine polarization angle and eliminate the sensitivity to wave amplitude. Also, the slot antennas are directly connected to large biasing pads without a strong polarization preference, which improves sensitivity of the device.

This work is based upon the materials supported by the Office of Naval Research under ONR Award No. N00014-14-1-0300.

II. Polarization Sensing Detector Design

We use two orthogonal slot antennas each loaded with two microbolometers as a polarization sensing detector. The slots are resonant at 10.6 μm (28.3 THz). The resistance of microbolometers used in this design are in the range of few ohms. Therefore, to transfer maximum power from antenna to the load, the microbolometers should be placed close to the edges of the slot. Furthermore, we have used two microbolometrs at each edge to maintain design symmetry. The conventional structure of a slot antenna has a continuous ground plane, which does not provide isolation between the IR currents induced on the ground plane of the slot and the DC current that needs to be measured to sense the changes in the resistances of the bolometers. However, since the microbolometers are metallic, they can provide DC and RF path simultaneously. Therefore, we have used the slot antenna design shown in Fig. 1(a) instead of the conventional connected slot antenna design. The difference between the two designs is that the DC path area beyond the microbolometers are removed. Consequently, all DC current must pass through the two microbolometers, which allows for sensing their resistance change as a result of absorbing the incoming IR radiation.

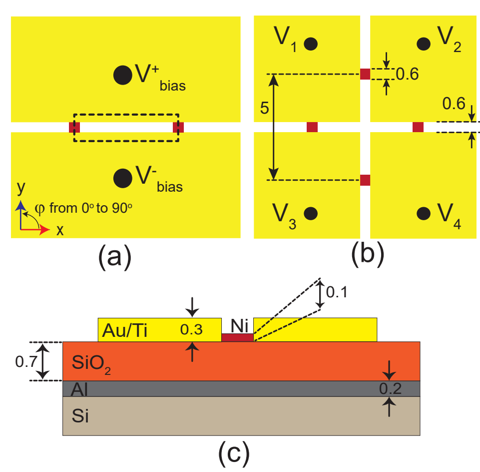

Fig. 1. (a) Schematic of a slot antenna with maximum received power for the $\hat{y}$ polarization. (b) Top view of two perpendicular coupled slot antennas for optimal polarization detection. (c) Cross section view of the detector. All dimensions are in μm.

The antenna shown in Fig. 1(a) absorbs maximum radiation when the polarization angle of the incident wave is along the $\hat{y}$ direction. We use another identical antenna with 90° rotation to detect incoming waves whose polarizations are aligned with the $\hat{x}$ direction. The final detector design and the dimensions are shown in Fig. 1(b). If the incoming wave has the polarization between 0° and 90°, each antenna receives a portion of incoming radiation and the ratio of the absorbed power in each slot antenna is only a function of the polarization direction. The absorbed power in each antenna is converted to thermal energy in the respective bolometers and change their resistance. We characterize the resistance variations by applying a DC voltage and measuring the change in the DC current. Therefore, by monitoring the ratio of the current variation passing through the bolometers for each slot antenna, $\frac{\Delta I_{\varphi=0}}{\Delta I_{\varphi=90}}$, we can detect the polarization of the incident wave.

The polarization sensing detector is fabricated on a silicon wafer covered by 200 nm-thick aluminum and 700 nm-thick silicon dioxide (SiO_2) layers. The aluminum layer acts as the ground plane and silicon dioxide is the dielectric layer which are deposited by DC plasma sputtering and electron-beam evaporator, respectively. A patterned layer of 100 nm thick nickel is used for fabricating the bolometrs. We use a 250 nm of gold on top of a 50 nm of titanium for the body of the slot antennas. The cross section view of the detector is shown in Fig. 1(c). The entire device is patterned using two levels of electron-beam lithography followed by lift-off process. To ensure discontinuities between deposited metal film on the resist and substrate layers, a bi-layer positive resist consist of MMA/PMMA is used. Fig. 2 shows the SEM image of the fabricated LWIR detector connected to measurement pads.

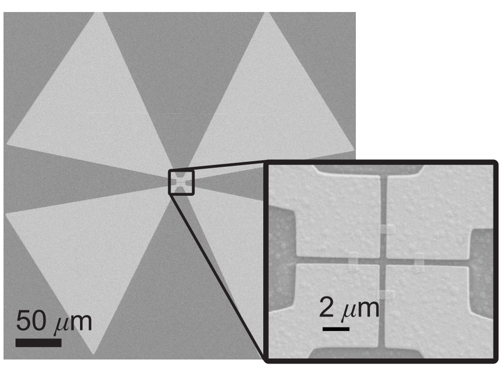

Fig. 2. SEM image of the fabricated prototype device. The detector is at the center of the figure which is connected to four large triangular pads that are used for the DC biasing of bolometers. The inset shows a magnifide picture of the fabricated detector.

III. Results

CST Microwave Studio was used to simulate the designed structure. In this simulation, a plane wave with different polarization angle is incident on the modeled device and the ratio of absorbed power in bolometers is monitored.

The measurement setup consists of an infrared laser, wire grid polarizer, mechanical chopper, current preamplifier, and a lock-in amplifier. A CO_2 laser beam with 10.6 μm wavelength illuminates to the detector. The laser beam passes through a rotational wire grid polarizer which produces the desired polarization angle. Then, a mechanical chopper which is connected to the lock-in amplifier modulates the laser beam at 400 Hz. The responses of each antenna is measured by applying a DC voltage and monitoring the currents passing through the microbolometers. The output currents are amplified by using a current preamplifier, which is fed to the lock-in amplifier. The lock-in amplifier extracts the desired output signals from the noisy signals. The two final output signals represent the current change in microbolometers and we look at their ratio for detecting the polarization angle. Fig. 3 shows the simulation and measurement results. We note that a good agreement is observed between the two in general, and measurement results show a 26 dB dynamic range of response.

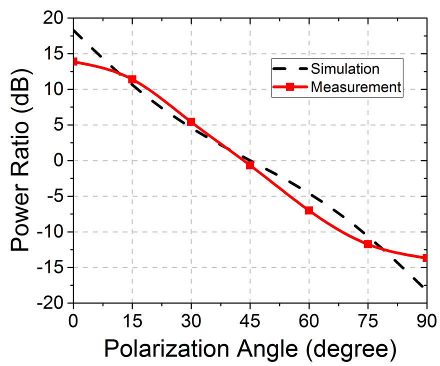

Fig. 3. Simulation and measurement results of the detector

IV. Conclusion

In summary, we showed design and fabrication of a polarization sensing detector by using two perpendicular slot antennas coupled to microbolometer loads. The polarization of the incoming EM wave is detected through monitoring the ratio of variations in the conductivity of the microbolometers. The proposed device offers a considerably wider dynamic range compared to previous antenna-based LWIR polarization sensing detectors.

References

[1] F. Gonzalez and G. Boreman, "Comparison of dipole, bowtie, spiral and log-periodic ir antennas," *Infrared Physics Technology*, vol. 46, no. 5, pp. 418–428, 2005.

[2] G. Niehues, S. Funkner, D. S. Bulgarevich, S. Tsuzuki, T. Furuya, K. Yamamoto, M. Shiwa, and M. Tani, "A matter of symmetry: terahertz polarization detection properties of a multi-contact photoconductive antenna evaluated by a response matrix analysis," *Optics express*, vol. 23, no. 12, pp. 16 184–16 195, 2015.

[3] G. P. Szakmany, A. O. Orlov, G. H. Bernstein, and W. Porod, "Novel nanoscale single-metal polarization-sensitive infrared detectors," *IEEE Transactions on Nanotechnology*, vol. 14, no. 2, pp. 379–383, 2015.

[4] J. A. Bean, B. Tiwari, G. Szakmány, G. H. Bernstein, P. Fay, and W. Porod, "Antenna length and polarization response of antenna-coupled mom diode infrared detectors," *Infrared Physics & Technology*, vol. 53, no. 3, pp. 182–185, 2010.