Metamaterial Based Terahertz Detector

Andrew C. Strikwerda[1], Hu Tao[2], Emil A. Kadlec[3], Kebin Fan[4], Willie J. Padilla[5], Xin Zhang[4], Eric A. Shaner[3], Richard D. Averitt[1]

[1]Boston University, Department of Physics, 590 Commonwealth Avenue, Boston, Massachusetts 02215, USA
raveritt@physics.bu.edu
[2]Tufts University, Department of Biomedical Engineering, 4 Colby St., Medford, Massachusetts 02155, USA
[3]Sandia National Laboratories, P.O. Box 5800, Albuquerque, New Mexico, 87185, USA
[4]Boston University, Department of Mechanical Engineering, 110 Cummington Street, Boston, Massachusetts 02215, USA
[5]Boston College, Department of Physics, 140 Commonwealth Avenue, Chestnut Hill, Massachusetts 02467, USA

Abstract: We present a metamaterial based terahertz (THz) detector. The detector design, which combines metamaterials and MEMs, is frequency selective, and we have fabricated and tested detectors at 95 GHz and 693 GHz with noise equivalent powers of 1.13 x 10^{-8} W/√Hz and 2.96 x 10^{-8} W/√Hz and responsivities of 16,500 V/W and 6,800 V/W, respectively. These values were achieved at room temperature and pressure.

OCIS codes: (230.0040) Detectors; (040.2235) Far infrared or terahertz; (160.3918) Metamaterials.

1. Introduction

Though progress in THz detector sensitivity over the past quarter century has been impressive, it is mostly accredited to improvements in thermometer sensitivity. Inefficient absorption of THz radiation - which yields a low heat-induced temperature variation - remains the performance bottleneck. Furthermore, most THz microbolometers show broadband response, which can be undesirable for applications such as spectroscopic detection of materials with unique THz responses. Here we present a THz detector based on metamaterial resonators. These metamaterials show high absorption, and their sub wavelength nature enables their use as a focal plane array (FPA) to image near the diffraction limit. Furthermore, their narrow band resonance is a salient feature for spectrally selective detection applications. Consequently, metamaterials hold great promise for facilitating the development of a "versatile" THz detector which can a) strongly absorb THz radiation; b) operate at room temperature with decent responsivity and sensitivity; c) be scaled up to function as a multi-pixel array for imaging applications; d) operate selectively at any frequency in the THz regime; and e) be lightweight and low cost.

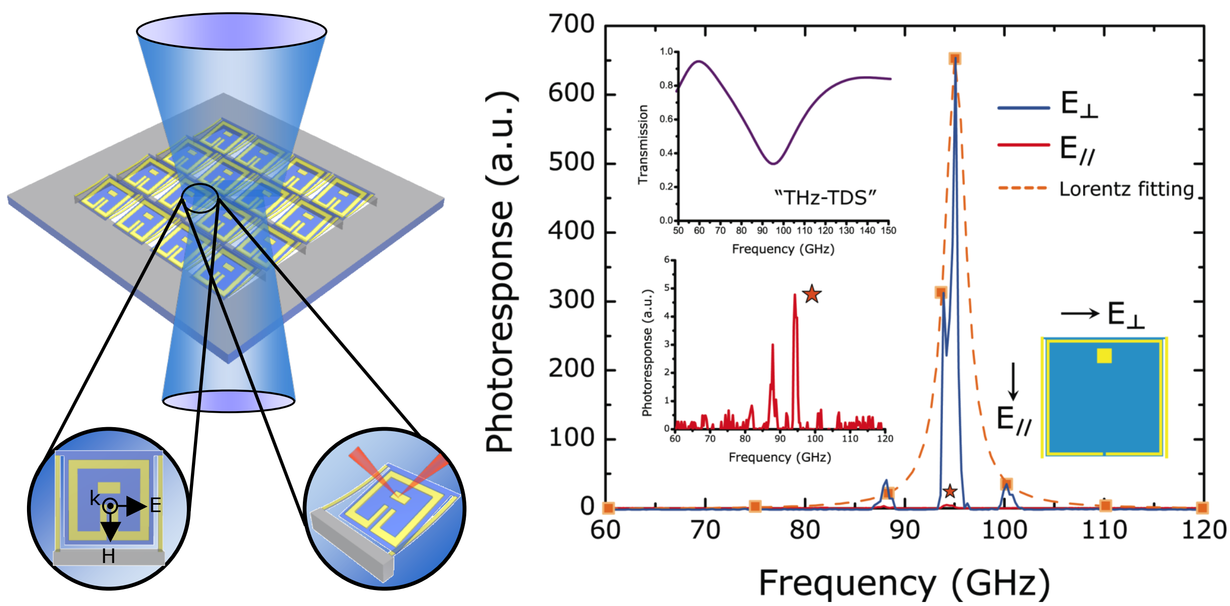

Fig. 1. The picture on the left shows the basic principle of detector operation. The figure on the right shows the polarization sensitivity of the SRR and fits a Lorentz model to the photoresponse of the 95 GHz detector. Note that the troughs on either side of the peak signal (~89-93 GHz and 96-99GHz) correspond to standing waves in the emitted power spectrum. For brevity, the 693 GHz results are not shown in this submission.

2. Detector Operation

The samples are split ring resonators (SRR) that have been fabricated on thin SiNx and are supported by bi-material cantilever legs [1]. The materials in the cantilever legs have different coefficients of thermal expansion, which cause the legs, and subsequently the SRR, to deflect with a change in temperature. This change is induced by strong absorption in the SRR upon exposure to the appropriate radiation. To detect this deflection, a small reflecting pad has been fabricated in the interior of the SRR (Fig. 1). A HeNe laser beam is focused upon this pad and the reflected beam is aligned to a position sensitive photo-detector.

3. Characterization

The structures were simulated using CST Microwave Studios and tested using THz Time Domain Spectroscopy. In addition, the 95 GHz source was tested using a Yttrium iron garnet (YIG) CW oscillator tuned between 60 - 120 GHz (Fig. 1) for polarization both parallel and orthogonal to the SRR gap. The results, shown in Figure 1, clearly demonstrate the increased absorption due to the SRR. A strong resonant peak can be easily seen at 95 GHz when the polarization is aligned with the SRR gap. There are several other observed peaks and valleys in the photoresponse, but these correspond to standing wave interference within the wave-guide between the source and the lens, and as a result a Lorentz response has been fitted to the data as a visual aid. At 95 GHz, a responsivity of 16,500 V/W with a minimum noise equivalent power (NEP) of 1.13×10^{-8} W/√Hz was measured. The 693 GHz detector was tested using a far-infrared laser (FIRL) based on formic acid lines, and was found to have a 6,800 V/W responsivity and 2.96×10^{-8} W/√Hz NEP. For brevity, only the data for the 95 GHz detector is shown.

4. Discussion

While the performance of these first-generation detector lags behind commercial methods, there are several distinct advantages. These MM based detectors are naturally in array form and are relatively inexpensive. Furthermore, it is possible to combine multiple SRRs geometries to create multicolor pixels, enabling frequency-sensitive THz imaging. Finally, it is worth mentioning that the detector performance could be improved appreciably due to the fact that all characterizations were conducted at room temperature and pressure. Both detectors have similar noise levels, which mainly comes from the optical readout system and could be further improved by using a more stable laser, higher sensitivity PSD, and reducing the environmental vibration or using alternative signal addressing methods such as thermo-capacitive and thermo-resistance readouts.

5. Conclusion

In conclusion, we have fabricated and tested a frequency selective THz detector using metamaterials. This new technique for detecting THz radiation enables detection at room temperature and pressure, is scalable to large multi-pixel arrays, and is lightweight and low cost.

6. References

[1] Hu Tao, A. C. Strikwerda, K. Fan, W. J. Padilla, X. Zhang, and R. D. Averitt, "Reconfigureable terahertz metamaterials," Phys. Rev. Lett. **103**, 147401 (2009).