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Multipolarized nanoantenna-based infrared pixel

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ABSTRACT

Microbolometers are the detectors most used in infrared imaging systems, these detectors have the disadvantage of being slow and require a bias voltage to operate, which increases the power requirements of the system. The current trend is to transition to low size, weight, and power (low SWaP) imaging systems. Seebeck nanoantennas are resonant elements made of two dissimilar thermoelectric materials tuned at a particular wavelength, when this wavelength is incident on the nanoantenna it induces a current that increases the temperature at the feed of the antenna generating a temperature difference that produces a Seebeck voltage. Due to the small size of the antenna and its low thermal mass Seebeck nanoantennas are considerably faster than traditional bolometers. Also, since the thermoelectric elements provide an output voltage no bias is needed for operation, reducing the power requirements of the whole imaging system. Previous work has reported the use of antennas traditionally used in the microwave region of the electromagnetic spectrum as Seebeck nanoantennas, these antennas are polarization dependent which is not usually desired in infrared imaging systems. In this work a multipolarized Seebeck nanoantenna is analyzed as a potential infrared pixel, their responsivity and detectivity are calculated from Multiphysics simulations for different pixel sizes.

Keywords: Thermoelectric nanoantennas, infrared pixel, Seebeck nanoantennas

1. INTRODUCTION

Antennas are elements that can be used either to receive or to transmit electromagnetic waves [1], when used in reception mode electromagnetic waves induce currents in the antenna elements that can be later detected and used for various applications [2]. Antennas have several unique advantages such as polarization sensitivity, directivity, small footprint, tunability and the possibility of integration into electronic and photonic circuits [3].

The traditional method to recover information from electromagnetic waves through an antenna is by rectifying the induced current, which travels at the same frequency as the incident electromagnetic wave [4], these devices are also referred as rectennas. Due to the high frequencies these rectennas operate their efficiency is low due to the impedance mismatch of the antenna and the rectifying device [5,6].

By using the thermoelectric effect in a bi-material antenna (Figure 1) to convert the increase in temperature due to Joule heating at the feed of the antenna will reduce the antenna mismatch increasing the efficiency of the device by at least a factor of $\times 10^3$ compared to a rectenna, these devices are also known as Seebeck nanoantennas [7].

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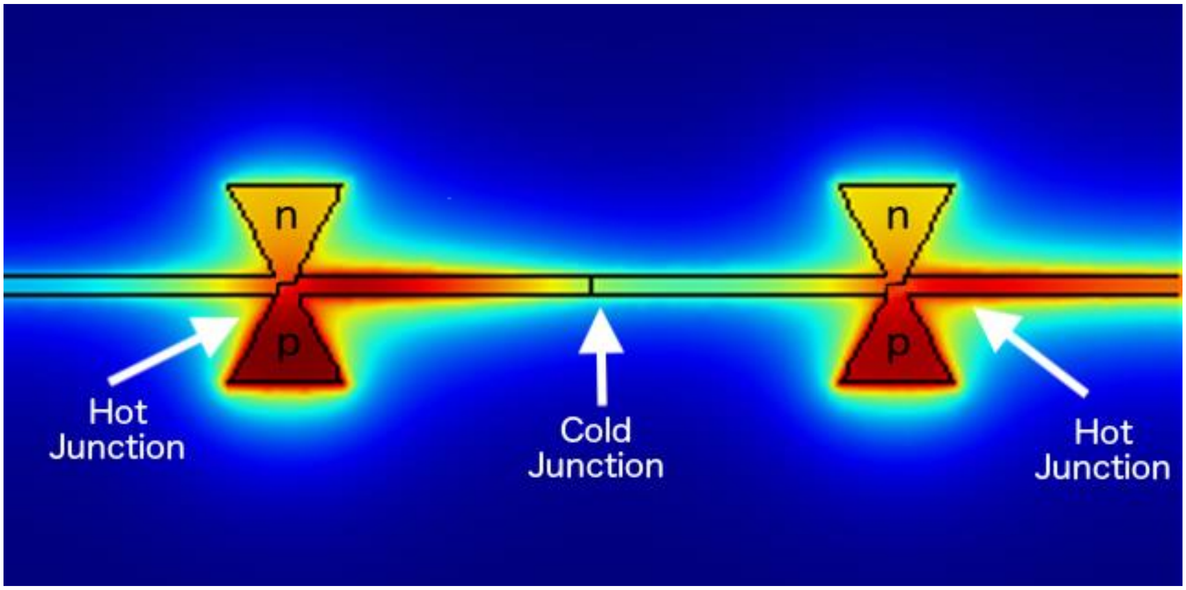

Figure 1. Temperature distribution of thermoelectric antenna under electromagnetic irradiation. Higher temperatures are indicated by red color. Heat is generated by the infrared-induced current in the antenna.

Individual Seebeck nanoantennas may be combined into arrays to create pixel elements if the selected commercial ROICs have sufficiently large dimensions. Multiple nanoantennas may be coupled in series to generate higher voltages, and they may be coupled in parallel to generate higher currents. In this work a dipole-based multipolarized Seebeck nanoantenna is presented (Fig. 2) and numerical calculations are performed on arrays of these multipolarized nanoantennas to cover a pixel area in an infrared imaging system.

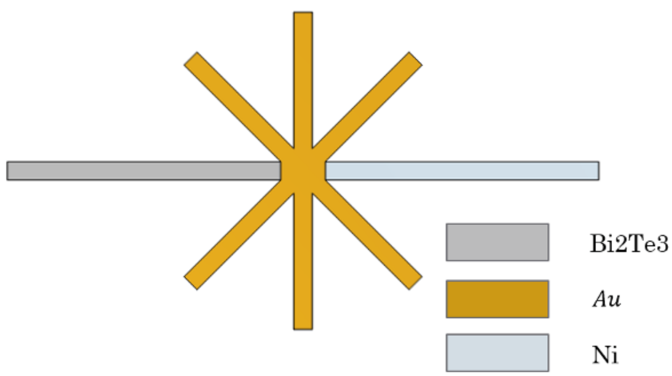

Figure 2. Dipole-based multipolarized Seebeck nanoantenna.

2. METHOD

Seebeck nanoantenna pixels were first evaluated numerically using COMSOL Multiphysics, the simulation procedure consisted in launching a linearly polarized plane wave from the top surface of the simulation volume impinging on the surface of the Seebeck nanoantenna pixel. The irradiance at the antenna plane was set to 1000 W/m^2, simulations were performed by doing a frequency sweep of the incident plane wave from 1 to 120THz. The induced current, the increase in temperature due to Joule heating and the thermoelectric voltage generated were calculated coupling the electromagnetic, heat transfer and thermoelectric modules through a multiphysics approach.

Figure 3(a) shows the analyzed structure and 3(b) shows the simulation volume and the mesh used for the finite element simulations.

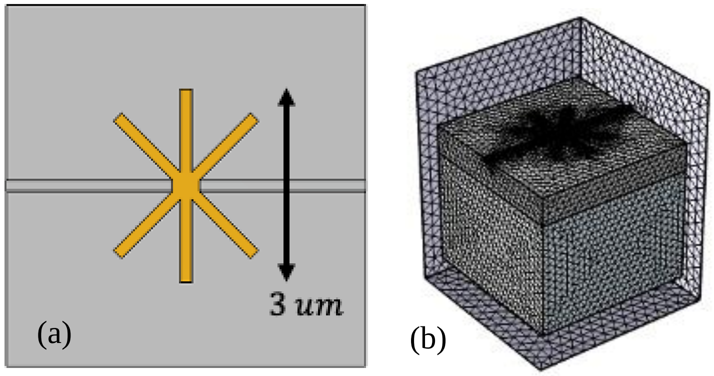

Figure 3. (a) Dipole-based multipolarized Seebeck nanoantenna analyzed, (b) simulation volume and the mesh used for finite element simulations.

Figure 4 shows the simulated structure for a 4×4 multipolarized Seebeck nanoantenna array, in this case the antennas are built as free-standing structures in order to increase thermal isolation of the hot junctions, the substrate used is silicon dioxide grown on a silicon substrate.

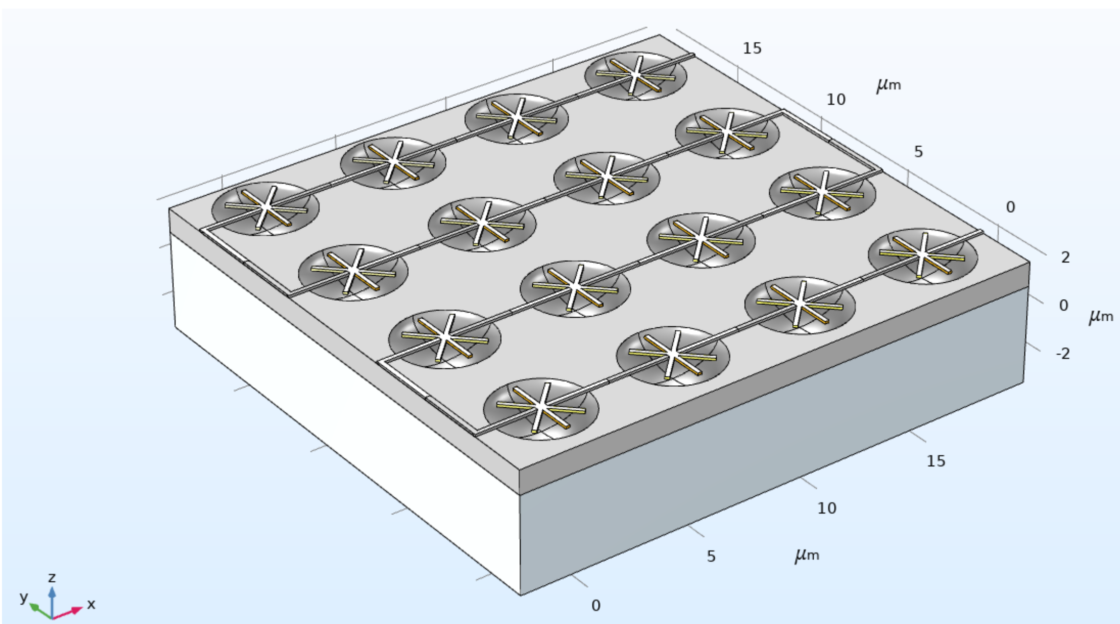

Figure 4. 4×4 multipolarized Seebeck nanoantenna array.

3. RESULTS

Figure 5(a) shows the results of the thermal simulations for a 4×4 multipolarized Seebeck nanoantenna array, the maximum temperature reached at the center of the antenna due to an incident plane wave of 1000 W/m^2 at 40 THz was recorded at 20 μK. Figure 5(b) shows the thermoelectric voltage generated due to the increase in temperature showed in Fig. 5(a), the voltage obtained for a 4×4 array was of 30 μV.

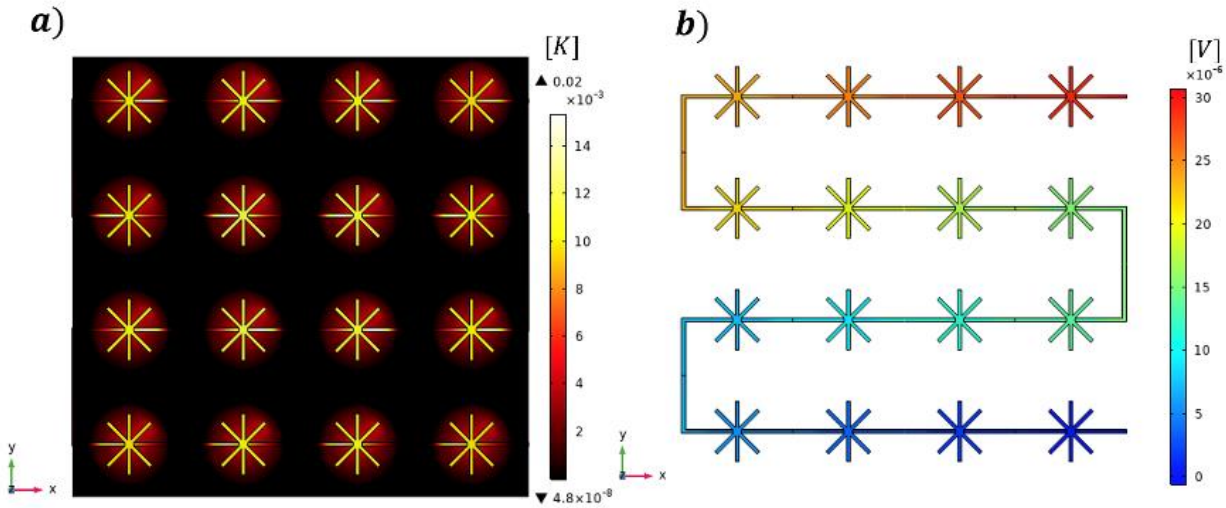

Figure 5. (a) Thermal simulations for a 4×4 multipolarized Seebeck nanoantenna array, (b) thermoelectric voltage generated due to an incident plane wave of 1000 W/m^2 at 40 THz.

Figure 6 shows a parametric study showing the power output of three different pixel arrays as a function of frequency, in this parametric study it can be seen how the output power increases as a function of the collection area and number of elements in the array and that these particular arrays resonate at 40 THz.

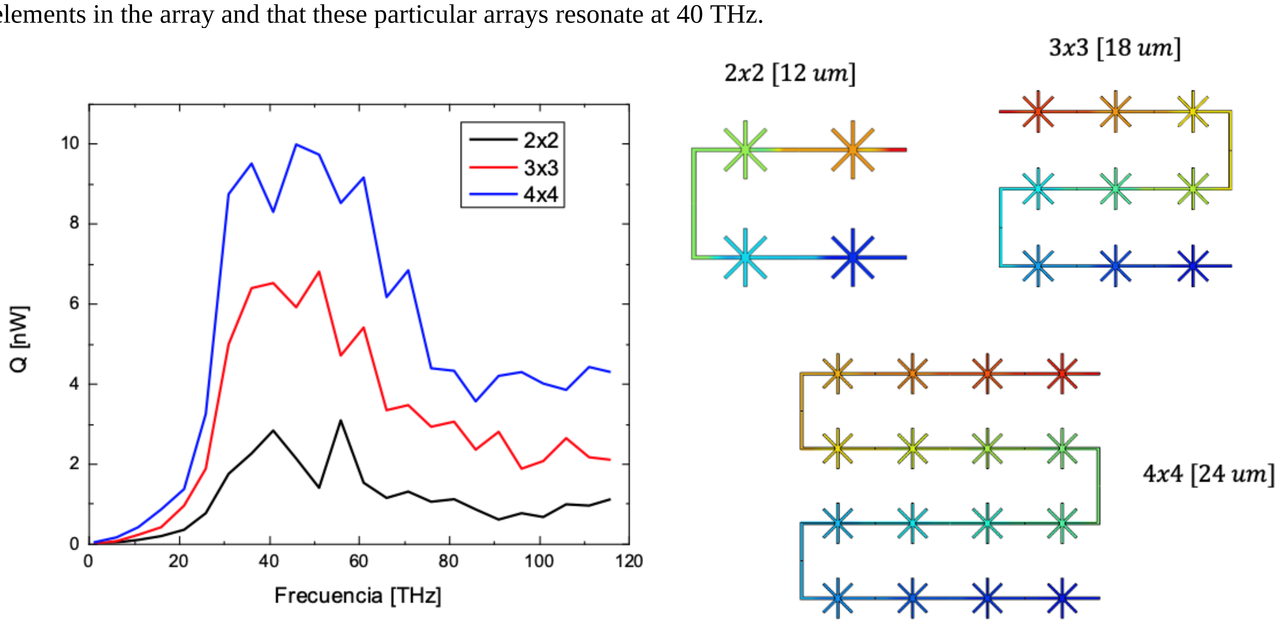

Figure 6. Parametric study showing the power output of three different pixel arrays as a function of frequency.

4. CONCLUSIONS

Seebeck Nanoantenna Pixels are a good alternative for small size, weight, and power (SWaP) imaging systems, numerical simulations show that output voltage in the micro-Volts can be obtained from pixels with pitch size that range from 12μm to 24μm. The design presented in this work does not depend on a particular polarization to optimize its voltage output.

DISCLOSURE

Coauthor Peale has an interest in Truventic LLC and may benefit financially from the results of this research.

REFERENCES

[1] Balanis, C. A, Antenna Theory: Analysis and Design, 2nd ed (Wiley, New York, 1997).

[2] Biagioni, P., Huang, J-S., Hecht, B., "Nanoantennas for visible and infrared radiation," Rep. Prog. Phys. 75, 024402 (2012).

[3] González, F. J., "Optical Antennas," in Wiley Encyclopedia of Electrical and Electronics Engineering, J. Webster (ed.), (Wiley 2015) pp. 1-5.

[4] González, F. J., and Boreman, G., "Comparison of dipole, bowtie, spiral and log-periodic IR antennas," Infrared Phys. and Technol. 46, 418 (2005).

[5] Nagae, M., "Response time of metal-insulator-metal tunnel junctions," Jpn. J. Appl. Phys. 11, 1611 (1972).

[6] Fumeaux, C., Alda, J. and Boreman, G. D. "Lithographic antennas at visible frequencies," Opt. Lett. 24, 1629 (1999).

[7] Briones, E., Alda, J., Gonzalez, F. J. "Conversion efficiency of broad-band rectennas for solar energy harvesting applications," Optics Express, 21(S3), A412 (2013).