Infrared Antenna-Coupled Thermocouple

Peter M. Krenz[1], Glenn D. Boreman[2], and Wolfgang Porod[1]
[1]Department of Electrical Engineering, University of Notre Dame, Notre Dame, IN 46556 USA
[2]Department of Physics and Optical Science, UNC at Charlotte, Charlotte, NC 28223 USA
e-mail: pkrenz@nd.edu

ANTENNA-COUPLED THERMOCOUPLE

Infrared antenna-coupled thermal detectors operate by receiving infrared radiation, which induces antenna currents. These currents are dissipated as Joule heat causing a temperature increase in the thermal detector, which is located at the feed-point of the antenna. The antenna design controls the directional, spectral, and polarization sensitivity of the detector, while the sub-micrometer sized thermal detector provides a fast response time due to its small thermal volume [1]. The type of thermal detector used in this experiment is a thermocouple.

Generally, a thermocouple consists of two dissimilar wires with Seebeck coefficients S_A and S_B. As shown in Fig. 1, the wires are only joined at one end. An open-circuit voltage can be measured between the open ends of the wires by inducing a temperature difference ΔT between the joined and open ends

$$V_{OC} = (S_A - S_B)\Delta T\,. \qquad (1)$$

For antenna-coupled thermocouples, the two wires are joined at the antenna, which locally increases the temperature. To predict the response of such a device, a simulation is required to take into account the electromagnetic and thermal interactions.

EXPERIMENT

To demonstrate the accuracy of the simulation of antenna-coupled thermal infrared detectors, impedance matching was investigated as a method to improve the response of a bowtie antenna-coupled thermocouple. A transmission line of different lengths was inserted between the antenna and thermocouple and the response was measured. One of the fabricated devices is shown in Fig. 2. The bowtie antenna has a large input impedance of $Z_{ANT} = 285.28 - j20.36\ \Omega$, while the impedance of the thermocouple is smaller, $Z_{TC} = 2.47 + j8.88\ \Omega$. The transmission line has a characteristic impedance of $Z_0 = 125.60 + j11.83\ \Omega$, an attenuation constant of $\alpha = 0.18\ \mu\text{m}^{-1}$, and a propagation constant of $\beta = 1.14$ rad/μm. The response of the devices was measured with a CO_2 laser operating at 10.6 μm and polarized along the axis of the bowtie antenna. The measured responses are shown in Fig. 3.

The device can be described by a microwave circuit model, shown in Fig. 4, from which the power dissipated in the thermocouple can be determined as a function of the transmission line length [2]. This calculated quantity, which is proportional to the response of the device was normalized to the measured data and is also shown in Fig. 3.

SIMULATION

COMSOL Multiphysics was used to compute the temperature increase of the thermocouple in response to an incident electric field. This temperature increase is shown for a device without a transmission line, Fig. 5, and for a device with a transmission line, Fig. 6. The simulated temperature increase and measured Seebeck coefficients are used in (1) to calculate the response. The simulated responses, which are in great agreement with the measured data, are shown in Fig. 3.

CONCLUSION

Excellent agreement was shown between the simulated and measured responses of bowtie-antenna coupled thermocouples that incorporated a transmission line of various lengths. This experiment demonstrated a response increase by improving the impedance match between the antenna and thermocouple.

REFERENCES

[1] F. González and G. D. Boreman, *Comparison of dipole, bowtie, spiral and log-periodic IR antennas*, Infrared Phys. Technol. **46** 418 (2005).
[2] D. Pozar, *Microwave Engineering* (J. Wiley, Hoboken, 2005), p. 77-82.

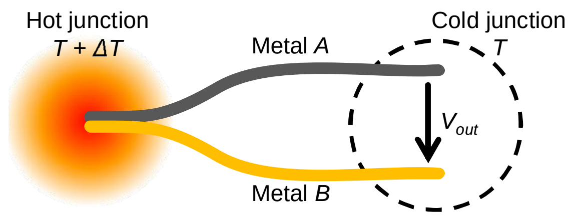

Fig. 1. Schematic of general layout and operation of a thermocouple.

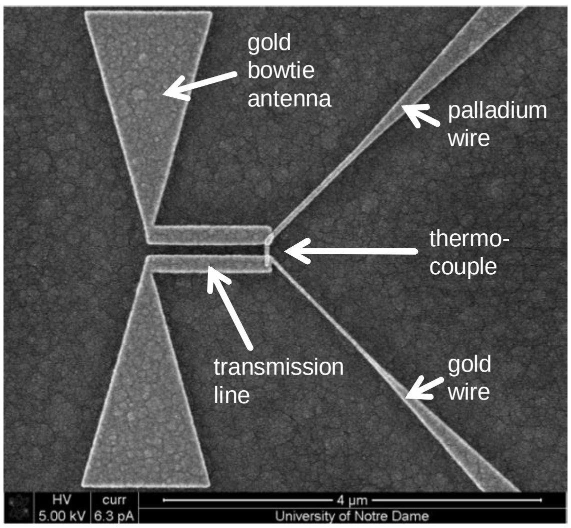

Fig. 2. Scanning electron micrograph of a bowtie antenna-coupled thermocouple with transmission line of length 1.3 μm located on a SiO_2 substrate.

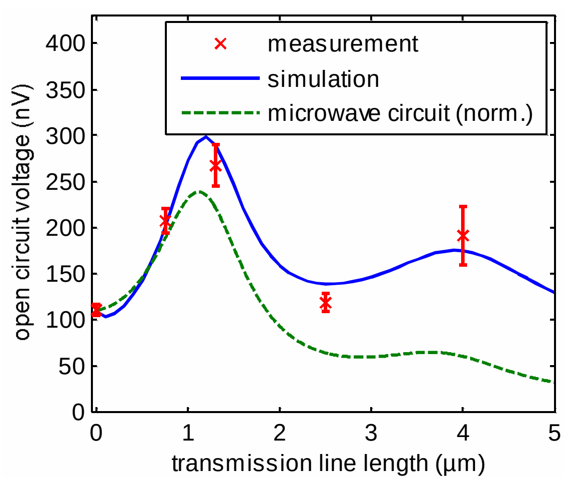

Fig. 3. Comparison of measured device responses, COMSOL simulation, and response calculation using a microwave circuit representation of the detector

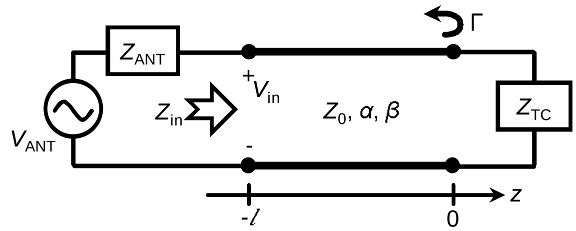

Fig. 4. Microwave circuit representation of antenna-coupled thermocouple. The impedance of the thermocouple is connected with a transmission line of length l to the antenna.

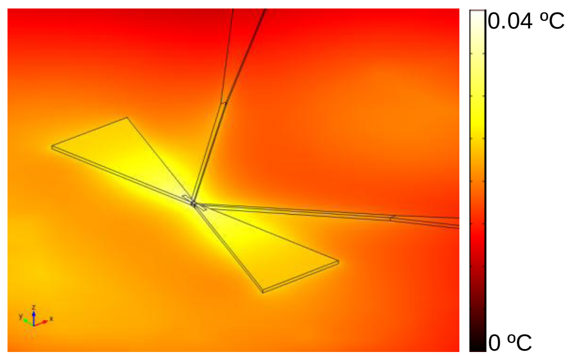

Fig. 5. Simulated temperature increase of a bowtie antenna-coupled thermocouple in response to an incident electric field.

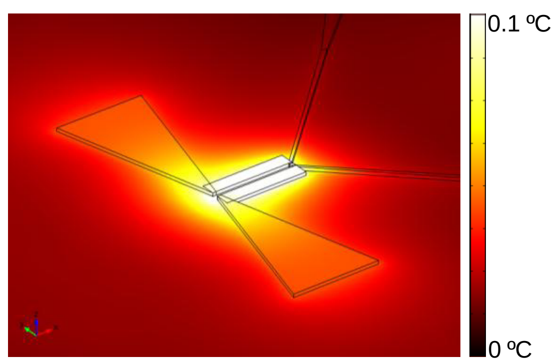

Fig. 6. Simulated temperature increase of a bowtie antenna-coupled thermocouple with a transmission line in response to an incident electric field. Note the larger temperature increase in the thermocouple compared to Fig. 5.