FAR-INFRARED COMPOSITE MICROBOLOMETERS

Stuart M. Wentworth and Dean P. Neikirk

Microelectronics Research Center, Department of Electrical and Computer Engineering

The University of Texas at Austin

Austin, Texas 78712

ABSTRACT

Composite microbolometers for use as broad band far-infrared radiation detectors have been constructed. These novel devices utilize nichrome load elements which can be impedance-matched to a planar antenna. The load elements are thermally coupled to tellurium detectors. We achieved room temperature responsivities of 120 V/W, and noise equivalent powers of 6.7 x 10^{-9} W/$\sqrt{\text{Hz}}$.

BACKGROUND

Microbolometers are infrared radiation detectors that are relatively simple to fabricate and calibrate. They have been used with a variety of planar antennas (1)(2)(3) for far infrared radiation measurements, at wavelengths ranging from 3 mm to 100 μm. Since these are thermal detectors, they work well throughout the far-infrared spectral region without the capacitive roll-off associated with Schottky detectors.

A bolometer owes its operation to a temperature sensitive resistance. As radiation is absorbed, the temperature of the bolometer changes and the resulting change in resistance can be measured. Conventional bolometers directly absorb the radiation to be detected, thus requiring an area on the order of a wavelength squared and a thickness of at least an absorption length. These restrictions can be avoided by using a planar antenna as a coupling element. The detector now appears as a lumped-element load for the antenna, and is thus very small (i.e., a microbolometer). This small size yields enhanced responsivity and high speed operation (1)(2).

COMPOSITE MICROBOLOMETER

Bismuth has been the material of choice for microbolometers in the past, primarily because its thin film resistivity is conducive to impedance-matching with planar antennas. Tellurium has been suggested as a bolometer candidate since thin film Te has a high value of dR/dT (4), and Te microbolometers have attained responsivities 100 times that of Bi microbolometers (5). But the resistance of Te is too high to simply match with typical planar antenna impedances of 100-200 Ω. One solution to the mismatched load problem is to separate the load from the detector in a composite microbolometer structure, as shown in Fig. 1. The load, which is impedance-matched to the antenna, is in intimate thermal contact with, but is electrically isolated from, the detector element. Changes in load temperature will be quickly followed by changes in detector temperature, and hence by changes in detector resistance.

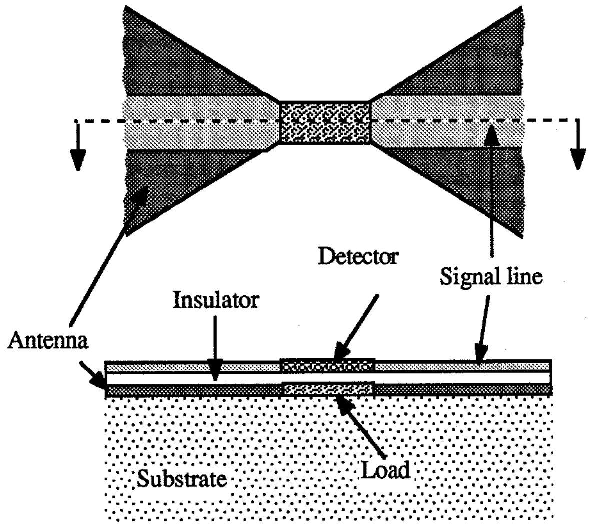

Fig. 1: Top-view and cross-section of a composite microbolometer. The load is impedance-matched to the bow-tie antenna, and is thermally coupled to a detector.

Composite microbolometers have been fabricated consisting of nichrome as the load, Te as the detector, and SiO_2 as the insulator. These devices were fabricated on a glass slide substrate upon which gold contact pads had been electroplated. Gold was also used for both the antenna leads and the signal line. Both device layers were produced using a photoresist bridge technique(6) and vacuum deposition. The 80% Ni-20% Cr load was approximately 1500 Å thick, in contact with a 1500 Å thick gold bow-tie antenna. An 1800 Å thick layer of SiO_2 was formed by plasma-enhanced chemical vapor deposition. The Te detector was about 1200 Å thick, contacted to a 2000 Å thick gold signal line. NiCr and Te elements were roughly square, with side lengths ranging from 4.5 to 5.0 μm.

To measure speed of response, two 220 MHz rf sources were beat together at an adjustable frequency, and fed to the NiCr load element through the antenna leads. The signal drawn off the Te detector was monitored by an oscilloscope for beat frequencies ranging from 100 Hz to 200 kHz. The responsivity of the device is the ratio of this signal voltage to the power dissipated in the load element. This dissipated power is difficult to measure directly. However, if we know the dc responsivity $\mathbf{r}_{dc}$, we can determine power dissipated in the NiCr element by dividing the low frequency signal voltage by $\mathbf{r}_{dc}$. All signal voltages are then divided by the dissipated power term to obtain responsivity as a function of frequency.

For an ideal bolometer, resistance is a linear function of dissipated power. Thus, the dc responsivity $\mathbf{r}_{dc}$ of a microbolometer can be written

$$r_{dc} = \frac{V_{bd}}{R_d}\frac{dR_d}{dP_l}$$

where V_{bd} is the bias voltage across the detector, R_d is the detector resistance, and P_l is the power dissipated by the load element. The slope dR_d/dP_l can be extracted from the R-P plot shown in Fig. 2. At V_{bd} = 0.75V, r_{dc} = 120 V/W. Using this r_{dc}, the responsivity curve is generated for Fig. 3. This figure also shows the noise voltage measured across the Te detector element biased at 0.75V. We used a PAR 124A lock-in amplifier with a 117 preamp, and measured noise over a bandwidth of 10% of the selected center frequency. Since the Johnson noise floor is about 10^{-8} V/$\sqrt{Hz}$, it is clear that a 1/f-type noise is dominant. The NEP is calculated from the plots in Fig. 3, and is shown to have a minimum value of 6.7×10^{-9} W/$\sqrt{Hz}$ in Fig. 4. For comparison, a Bi microbolometer typically has an r_{dc} of 20 V/W, and minimum NEP of 10^{-10}W/$\sqrt{Hz}$.

CONCLUSIONS

We have for the first time demonstrated a composite microbolometer. This structure utilizes NiCr load elements thermally coupled to Te detectors. The sensitivity and speed of these devices have been measured, and these results are being used to formulate a thermal model for aid in designing an optimum composite structure. Although a conventional Bi microbolometer has a reasonable NEP, its low responsivity makes detection of low power levels difficult. The higher responsivity of our composite structures may make it easier to detect these low levels, and could therefore ease amplification requirements in receiver systems.

The sensitivity of our composite microbolometers could probably be improved by using thinner Te detectors with higher responsivity. Another way to increase device responsivity might be to use a thinner separating layer between the load element and the detector, or by using a high thermal conductance material, such as diamond thin film, for the separating layer. Finally, sensitivity could be improved by decreasing 1/f noise in the Te detectors.

ACKNOWLEDGEMENTS

The authors would like to thank D. Miller for his assistance with device testing. This work was supported by the National Science Foundation under grant #ECS-8552868.

REFERENCES

(1) T.-L. Hwang, S.E. Schwarz, and D.B. Rutledge, "Microbolometers for infrared detection," APPL PHYS. LETT. Vol. 34, No.11, pp. 773-776: 1 June 1979.

(2) D.P. Neikirk, D.B. Rutledge, M.S. Muha, H. Park, and C.X. Yu, "Far-Infrared Imaging Antenna Arrays," APPL. PHYS. LETT. Vol. 40, No. 3, pp. 203-205: 1 Feb 1982.

(3) S.M Wentworth, R.L. Rogers, D.P. Neikirk, and T. Itoh, "A Twin Slot Antenna Structure on a Layered Substrate for Millimeter Wave Imaging Arrays," 14TH INT. CONF. IRMM WAVES, M. von Ortenberg, Editor, SPIE Vol. 1240, pp. 399-400: Oct. 2-6, 1989.

(4) B.H. Billings, W.L. Hyde, and E.E. Barr, "An Investigation of the Properties of Evaporated Metal Bolometers," J. OPT. SOC. AM. Vol. 37, pp.123-132: 1947.

(5) S.M. Wentworth and D.P. Neikirk, "Far Infrared Microbolometers Made with Tellurium and Bismuth," ELECTRONICS LETTERS Vol. 25, No. 23, pp. 1558-1560: 9 Nov. 1989.

(6) D.P. Neikirk, W.W. Lam, and D.B. Rutledge, "Far-Infrared Microbolometer Detectors," INT. J. IR MM WAVES Vol. 5, No. 3, pp. 245-278: Mar 1984.

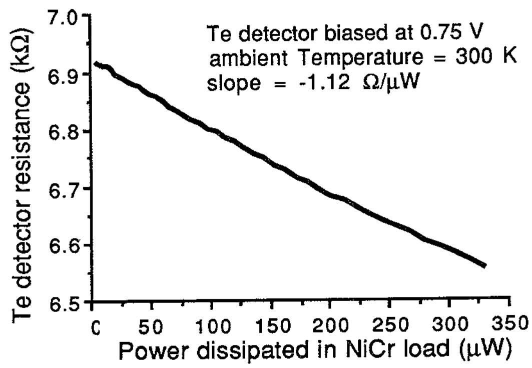

Fig. 2: The tellurium detector resistance is plotted versus power dissipated in the nichrome load element for a 0.75V Te element bias. The slope of the plot is used to calculate dc responsivity.

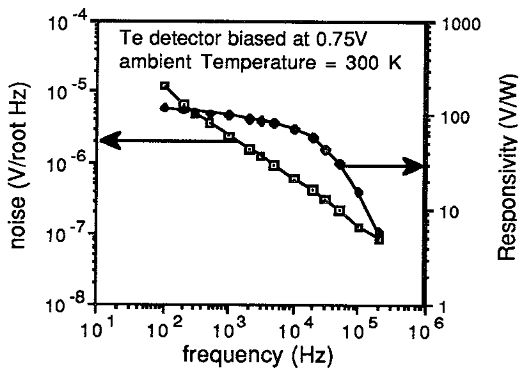

Fig. 3: Noise and responsivity are plotted versus beat frequency for a composite microbolometer with the Te detector element biased at 0.75V.

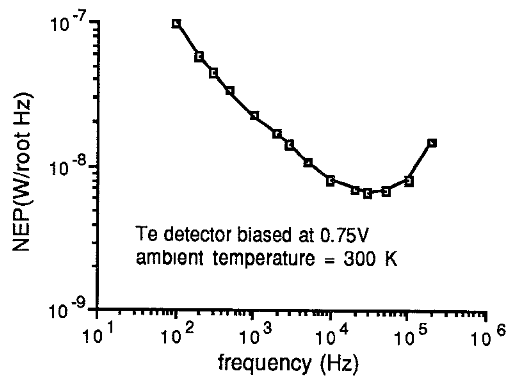

Fig. 4: Sensitivity for the composite microbolometer versus beat frequency, with the Te detector element biased at 0.75V. Best performance occurs at about 30 kHz, where NEP = 6.7×10^{-9} W/$\sqrt{Hz}$.