Advances in Microbolometers

D.P. Neikirk, Wayne W. Lam, and D.B. Rutledge
Division of Engineering and Applied Science
California Institute of Technology
Pasadena, Ca. 91125

ABSTRACT

The bismuth microbolometer is a simple, easily made detector suitable for use throughout the far-infrared. A novel photoresist fabrication procedure has made it possible to obtain an electrical NEP of $2.8\times10^{-11}W(Hz)^{-1/2}$ at 100kHz for an air-bridge bolometer. By using a polyimide plastic as an insulator, conventional substrate-supported devices with an NEP of $3.2\times10^{-11}W(Hz)^{-1/2}$ have also been made.

A great deal of effort is being applied to the development of monolithic millimeter and submillimeter receivers. Because of the loss and mechanical complexity of metallic waveguide at these high frequencies, much of this effort is devoted to quasi-optical systems coupled to planar antennas with integrated detectors. Often the integrated detectors have presented real fabrication challenges. There is one antenna-coupled room temperature detector, however, that can provide sensitive detection and speed without requiring elaborate fabrication processes: the bismuth microbolometer.

The microbolometer is a thermal detector, which works well throughout the far-infrared, without the capacitive roll-off that affects Schottky diodes. Because of its small size (typically a few micrometers square and 100 nm thick) the bolometer can have a large thermal impedance, which in turn means it will have a large responsivity. In addition, since the thermal mass is small, the detector can be quite fast. Two basic types of bolometers have been made: the air-bridge microbolometer [1], and the more conventional substrate-supported bolometer [2].

The first microbolometers were substrate-supported devices. In these, an exact solution to the thermal diffusion equation is quite difficult since several conduction pathways are available. The most obvious path is directly into the substrate material, but conduction into the antenna metalization becomes very important for small detectors with large antennas. In order to estimate the thermal impedance Z_t, Hwang et al [2] ignored the presence of the metal antenna, allowing the thermal diffusion equation to be solved. The responsivity of the detector is then given by $\alpha|Z_t|V_b$, where α is the temperature coefficient of resistance of the bolometer material, and V_b is the dc bias voltage across the device. For quartz substrates this approach does describe the frequency response of the detector.

The air-bridge bolometer provides improved performance by suspending the device in the air above the substrate. The only conduction path is now out the ends of the detector into the metal antenna. We can model this bolometer in a simple manner: a bar of material in which power is dissipated uniformly, and whose ends are attached to perfect heat sinks (the metal of the antenna). The thermal impedance for such a detector is

$$Z_t(\omega) = 2\frac{\ell}{twK_b}\left(\frac{L_b}{\ell}\right)^3\left(\frac{\ell}{2L_b} - \tanh\frac{\ell}{2L_b}\right)$$

where L_b is the thermal diffusion length in the bolometer material, $L_b = (K_b/i\omega\rho_b C_b)^{1/2}$, t is the bolometer thickness, w its width, ℓ its length, ρ_b the bolometer material density, C_b its specific heat, and K_s its thermal conductivity. The behavior of the air-bridge bolometer is well described by a thermal equivalent circuit consisting of a resistance $\ell/12K_b tw$ in parallel with a thermal capacitance $\ell tw\rho_b C_b$.

The actual choice of a material for use in the microbolometer is determined by antenna matching requirements. For a matching resistance R_a and material electrical conductivity σ, the device dimensions must satisfy $\ell/tw = \sigma R_a$. We also want to maximize the thermal resistance to increase the detector response. For an air-bridge the thermal resistance is proportional to ℓ/twK_b, but this is just $\sigma R_a/K_b$. Since R_a is fixed we should use a material which gives a large value for σ/K_b. This ratio σ/K, however, is very nearly the same constant for most metals; the two properties are fundamentally related through the Wiedemann-Franz law [3]. Because of this, for fixed device resistance, almost all metals would give the same bolometer thermal resistance.

The other material constant that enters into the responsivity of the detector is the temperature coefficient of resistance α. Once again this is very nearly the same for all metals because the resistivity ρ is proportional to temperature, and so $\alpha = 1/T$ [4]. Semiconductors do have a larger temperature coefficient, but this increase in α is more than offset by a decrease in the material conductivity σ, since the quantity we must really maximize is $\alpha\sigma/K$.

In practice, since the thermal models tell us the smaller the bolometer the

CH1917-4/83/0000-0T61 $0.75 C 1983 IEEE

better, the conductivity should be such that the material resistance per square is roughly R_a. If we assume the device thickness can be no less than 20nm and $R_a = 100\Omega$, then $\sigma < 5 \times 10^3 (\Omega cm)^{-1}$. It is also advantageous to avoid extremely large thicknesses, so a lower bound on σ is roughly $200 (\Omega cm)^{-1}$ for a 0.5μm maximum thickness. An examination of the elements shows very few with a conductivity that will satisfy these restrictions. One material which does cover this range of conductivities is thin-film bismuth.

Both air-bridge and substrate-supported microbolometers have been made using a photoresist bridge technique [5]. Figure 1 illustrates the air-bridge fabrication process. After the evaporation of silver and bismuth the photoresist is dissolved, leaving the bolometer suspended over the substrate. Substrate-supported devices are made in exactly the same way, but the bottom resist layer is omitted. Detectors have been made both directly on quartz substrates and on 2μm thick layers of polyimide. The polyimide has a very low thermal conductivity (0.15W/m K), which greatly reduces substrate conductance.

Unlike many far-infrared detectors it is possible to accurately calibrate the bismuth microbolometer. The dc responsivity is obtained by fitting the detector I-V curve to $V/I = R_0 + \beta IV$. The responsivity is then βI_b, where I_b is the bias point current. The frequency response curve can be obtained using an rf circuit [5], in which the bolometer behaves just as it does in the FIR.

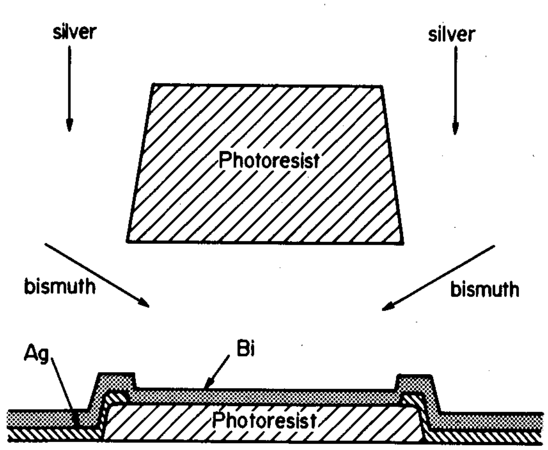


Fig. 1: Fabrication procedure for an air-bridge microbolometer.

Figure 2 shows the responsivity of an air-bridge, glass-supported, and polyimide supported bolometer. All were roughly 3.5μm long and wide, and 100nm thick. Fitted lines using the thermal models are also shown. The low frequency response of the air-bridge is five times larger than the glass-supported device, and 2.5 times larger than the polyimide-supported detector. The noise equivalent powers for these bolometers are given in fig. 3, along with their fundamental fluctuation limited NEP's [6].

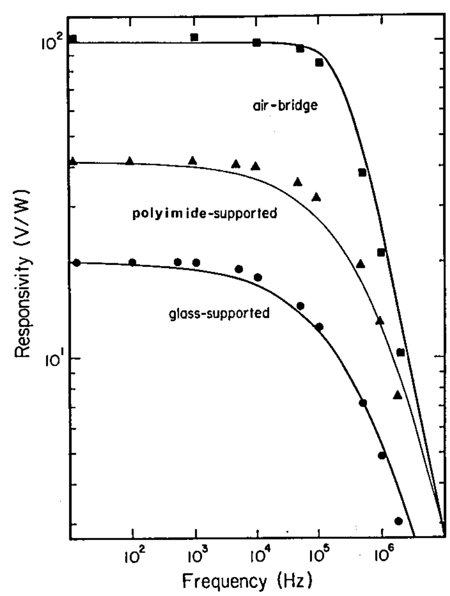
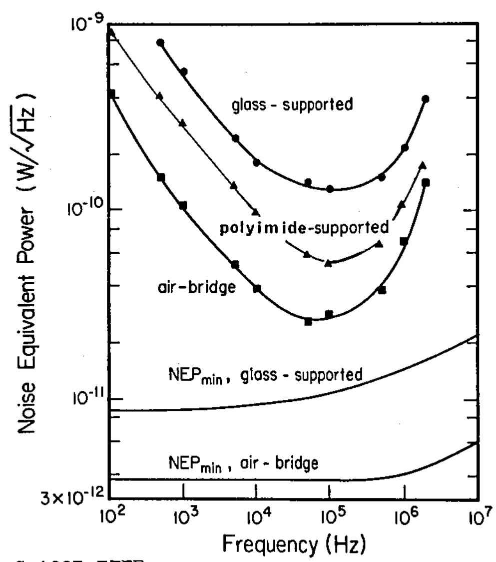


Fig. 2: Responsivity of 3.5μm square bismuth bolometers at 0.1V bias.

Fig. 3: Noise equivalent powers for the bolometers from fig. 2; 0.1V bias.



CH1917-4/83/0000-0T61 $0.75 C 1983 IEEE

In conclusion, we have found the bismuth microbolometer to be a very useful detector. By suspending the detector in the air above its substrate an NEP of $2.8 \times 10^{-11} W(Hz)^{-1/2}$ at 100kHz has been achieved. The air-bridge thermal model also predicts the high frequency response increases like $1/\ell^2$, so a 1µm device should be sixteen times faster than the device above, with no decrease in sensitivity. With a bolometer approximately 2.5µm square, we have also achieved an NEP as good as the air-bridge detector from a polyimide-supported device.

We would like to acknowledge the support of the Department of Energy under contract DEAM03-765F-00010 Task IIA, the Army Research Office under contract DAAG29-82-K-0165, and the Jet Propulsion Laboratory through Dr. M. Litvak.

References

[1] D.P. Neikirk and D.B. Rutledge, 'Air-bridge microbolometer for far-infrared detection,' submitted for publication, Appl. Phys. Lett.

[2] T.-L. Hwang, S.E. Schwarz, and D.B. Rutledge, 'Microbolometers for infrared detection,' Appl. Phys. Lett. **34**, 773 (1979).

[3] N.W. Ashcroft and N.D. Mermin, **Solid State Physics** (Holt, Rinehart, and Winston, New York, 1976), p. 255.

[4] R.A. Smith, F.E. Jones, and R.P. Chasmar, **The Detection and Measurement of Infrared Radiation** (Oxford University Press, London, 1968), p. 85.

[5] D.P. Neikirk, 'Integrated Detector Arrays for High Resolution Far-Infrared Imaging,' PhD thesis, California Institute of Technology, 1983.

[6] Smith et al, p. 211-213.

CH1917-4/83/0000-0T61 $0.75 C 1983 IEEE