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 x 10^-11 W/(Hz)^1/2 at 100 kHz for an air-bridge bolometer. By using a polyimide plastic as an insulator, conventional substrate-supported devices with an NEP of 3.2 x 10^-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 waveguides 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 rolloff 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 metallization becomes very important for small detectors with large antennas. In order to estimate the thermal impedance Zt, 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 α Zt i Vb, where α is the temperature coefficient of resistance of the bolometer material, and Vb is the dc bias voltage across the device. For quartz substrates this approach does not 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 the other end is attached to perfect heat sinks. Since the thermal mass is small, the detector is the temperature coefficient of resistance α, and so

\[ Z_t = \frac{\beta}{\pi a K_b} \left( \frac{a}{2 a R_a K_b} \right)^{1/2}, \]

where Lb is the thermal diffusion length in the bolometer material, Lb = (Kb/iwρCp)1/2, t is the bolometer thickness, ρ its length, ρb the bolometer material density, Cp is its specific heat, and Ks its thermal conductivity. The behavior of the air-bridge bolometer is well described by a thermal equivalent circuit consisting of a resistance 1/12 twKb in parallel with a thermal capacitance twKbwCb.

The actual choice of a material for use in the microbolometer is determined by antenna matching requirements. For a matching resistance Ra and material electrical conductivity σ, the device dimensions must satisfy \( \frac{1}{tw} = \frac{\sigma a}{K_b} \). We also want to maximize the thermal resistance to increase the detector response. For an air-bridge the thermal resistance is proportional to 1/twKb, but this is just αRa/Ks. Since Ra is fixed we should use a material which gives a large value for αKs. This ratio αKs, 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 α = 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 ασ/Ks.

In practice, since the thermal models tell us the smaller the bolometer the
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 $c < 5 \times 10^{-3}(\text{ohm} \cdot \text{cm})^{-1}$. It is also advantageous to avoid extremely large thicknesses, so a lower bound on $c$ is roughly $200(\text{ohm} \cdot \text{cm})^{-1}$ for a 0.5$\mu$m 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 2$\mu$m 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 $\beta I_b$, 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.

Figure 2 shows the responsivity of an air-bridge, glass-supported, and polyimide supported bolometer. All were roughly 3.5$\mu$m 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].

![Figure 1: Fabrication procedure for an air-bridge microbolometer.](image1)

![Figure 2: Responsivity of 3.5$\mu$m square bismuth bolometers at 0.1V bias.](image2)

![Figure 3: Noise equivalent powers for the bolometers from fig. 2; 0.1V bias.](image3)
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 $2.8 \times 10^{-11} \text{W(}\text{Hz})^{-1/2}$ at 100 kHz has been achieved. The air-bridge thermal model also predicts the high frequency response increases like $1/t$, so a 1 μm device should be sixteen times faster than the device above, with no decrease in sensitivity. With a bolometer approximately 2.5 μm square, we have also achieved an NEP as good as the air-bridge detector from a polyimide-supported device.

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