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Orthogonal infrared dipole antenna

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Abstract

A dual-dipole structure is demonstrated at 10.6 μm, which facilitates electronic cancellation of the non-antenna-coupled thermal response of an infrared antenna-coupled bolometer. Structures of this type may also find utility in high-spatial-resolution measurement of Stokes parameters of a beam of radiation.

Keywords: Polarization; Infrared antennas

1. Introduction

The polarization response of an infrared antenna-coupled thermal sensor is strongly affected by the thermal and electrical characteristics of the surrounding structures, such as the substrate, lead lines, and bondpads [1–5]. For linearly polarized antennas such as dipoles, bowties, and logperiodics, the co-polarized response is identified with the antenna-coupled signal. The cross-polarized response originates with the electromagnetic coupling of signal extraction structures such as bondpads and leadlines, as well as with the heating of the structural substrate by laser irradiation or by Joule heating of the bolometer by the bias circuitry. However, these additional effects also contribute to the measured co-polarized signal, and a means to accurately remove this portion is desirable. This is especially true in the quantitative assessment of sensor-response mechanisms, when there are a number of response modes operating simultaneously [6].

In this contribution we demonstrate the operation of a pair of infrared dipole antennas, which are aligned orthogonal to each other and whose electrical outputs are wired so as to form a Wheatstone bridge. The combination of the geometrical arrangement of the antennas and their internal and external electrical connections allows the co-polarized response to be isolated as the measured signal. Additionally, it is noted that for the case considered, this recorded signal is directly proportional to the S_1 Stokes parameter [7].

We also discuss briefly some possible extensions of the concept for measurement of additional Stokes parameters.

2. Experimental apparatus

As seen in Fig. 1, the experiment uses an orthogonal arrangement of two antenna-coupled bolometers. Infrared dipole A is oriented horizontally, and dipole B is vertical. They share a common connection at the point labeled V_G in the diagram. The length of the dipole was chosen to maximize response at a wavelength of 10.6 μm [8]. The structure including substrate and bondpads was modeled using Ansoft HFSS. As seen in Fig. 2, a full length of 1.55 μm was chosen as the point where the imaginary part of the dipole impedance goes through a zero.

The devices were fabricated on a high resistivity (3–6 kΩ cm) Silicon wafer using direct-write e-beam lithography. The dipole antenna and bondpads are 75-nm-thick e-beam evaporated gold with a 5 nm Titanium adhesion layer, while the bolometer is 80 nm of e-beam evaporated

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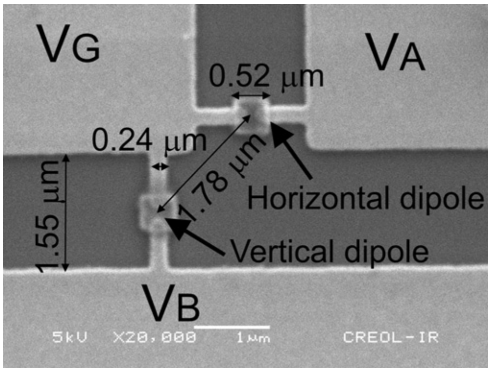

Fig. 1. Scanning electron micrograph of the on-chip arrangement of the pair of orthogonal dipole antennas.

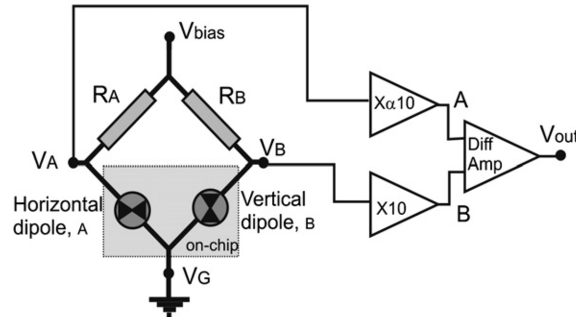

Fig. 3. Schematics of the on-chip and off-chip wiring of the devices. The dipoles are arranged as part of a Wheatstone bridge. The output of the bridge is externally balanced by using a variable gain, α, in one of the amplifiers.

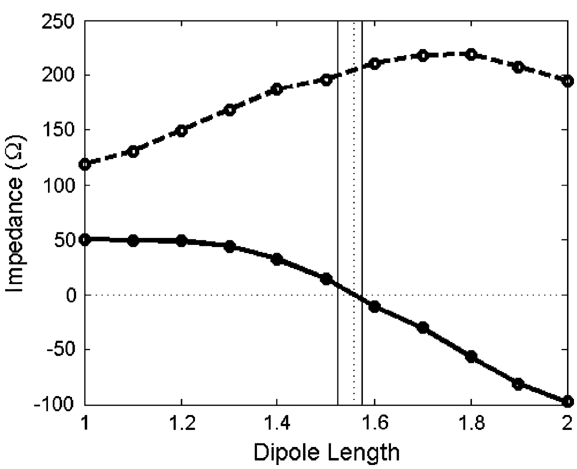

Fig. 2. Real (dashed line) and imaginary (solid line) impedance for the dipole and bondpads arrangement as a function of the length of the dipole. The circles correspond to the values obtained from numerical modeling. The vertical solid lines represent the range of the dipole lengths obtained in the fabrication. The dashed vertical line corresponds with the zero-crossing of the imaginary part of the impedance.

nickel. The distance between the centers of the two orthogonal dipoles was varied (1.33, 1.78, and 2.05 μm in devices 1, 2, and 3, respectively), to examine any influence on the overall behavior of the element. A smaller distance might be expected to exhibit a higher electromagnetic crosstalk, as the price paid for a more compact measurement aperture. The bolometer DC resistance in each device was different because of lithographic differences. These resistances were 40.3, 34.1, and 24.4 ohm, respectively for the studied devices.

Fig. 3 shows that the interconnection between the two antenna-coupled sensors, along with the external biasing electronics, configures a Wheatstone bridge. The response of each sensor consists of several contributions: a substrate-heating thermal response that is not polarization sensitive, residual electromagnetic crosstalk between the antennas themselves and between the antennas and the bondpads, and the dipole-antenna-coupled response, which is the term that we want to extract. The Wheatstone bridge arrangement is able to compensate the thermal response of the elements. Any electromagnetic crosstalk will be the same for both two antennas because of the geometrical symmetry of the layout.

Both bolometers (A and B) are biased using the same voltage, V_{bias} and resistors of equal value, $R_A = R_B$. The DC resistances of the individual bolometers are slightly different, which unbalances the Wheatstone bridge, even when it is not illuminated. The voltage signals V_A, V_B obtained from the bridge are fed to two independent amplifiers. The gain of one amplifier is variable (α), which allows the output of the bridge to be externally balanced, yielding a differential voltage, $V_{\text{out}} = 10 \times (\alpha V_A - V_B)$. A dual-channel lock-in amplifier operating in differential mode is used to measure V_{out}, at a chopping frequency of 2.5 kHz. This configuration allows cancellation of the cross-polarized response of the antenna. The remaining signal will be the dipole-antenna-coupled portion of the response, which should be proportional to the projection of the electric field along the dipole direction.

The light source used for the characterization of the devices is a CO_2 laser emitting at 10.6 μm. The Gaussian full width of the spot at the plane of the antennas is 150 μm ± 20 μm, illuminating the antenna pair quasi-uniformly. The polarization of the laser is linear with an azimuth angle θ, which can be rotated using a $\lambda/2$ wave plate. An incident beam polarized in the horizontal direction is defined as $\theta = 0°$. The total power falling on the devices is adjustable. A reference detector is placed in a separate optical channel to allow calibration of laser-power fluctuations. The differential voltage signal obtained from the detectors, V_{out}, is normalized to the reference laser power, P, to produce the responsivity $\mathcal{R}_{\text{out}} = V_{\text{out}}/P$, having dimensions of [V/W]. To balance the Wheatstone bridge, the polarization of the incident light is set to 45°. Then the gain α of the variable amplifier is adjusted in order to cancel the differential signal.

3. Results and discussion

We measured the three pairs of orthogonal dipoles, for which the distance between the centers of the dipoles was