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Vertical-via interconnection for infrared antennas

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The authors present fabrication process details and test data for a vertical-via interconnection suitable for low-frequency signal extraction from infrared antenna-coupled sensors. Electrical readout of the signal from an antenna-coupled bolometer was accomplished using two 300 nm diameter Au via structures that extended 300 nm in the vertical direction. These vertical vias passed through two isolation layers of SiO_2 and through a $1500 \times 600\ nm^2$ cutout in a ground plane. Electromagnetic isolation of the antenna from its associated electrical-readout bondpads at 28.3 THz in the infrared was demonstrated by mapping the two-dimensional spatial response of the antenna and comparing it to spatial response data from a similar structure without the intervening ground plane. © *2006 American Vacuum Society.* [DOI: 10.1116/1.2366613]

I. INTRODUCTION

Infrared (IR) antennas[1] are used to collect incident electromagnetic radiation and to supply an oscillating field at the feedpoint of the antenna, connected across the terminals of a sensing element with dimensions much smaller than the wavelength. Various sensors can be used as square-law detectors for the IR-frequency electrical currents induced on the antenna, including microbolometers,[2] metal-oxide-metal diodes,[3] and Schottky diodes.[4] The terahertz frequency signal is demodulated to a low-frequency baseband signal by the action of the square-law sensor, so the signal-extraction structures required for electrical readout operate at low frequencies. Dimensions of infrared antennas are on the order of one wavelength, which presents challenges in the design of associated low-frequency signal-extraction structures, e.g., leadlines and bondpads, whose functionality dictates larger dimensions. Leadlines and bondpads often act as long-wire antennas themselves and interact electromagnetically with the antenna, adversely affecting the angular, spatial, spectral, and polarization responses of the sensor. It is also desirable to avoid direct illumination of the signal-extraction structures, since the materials from which they are made have a temperature coefficient of resistance, which can compete with the response from a bolometric sensor.

This article describes the fabrication of a dipole-antenna-coupled bolometer connected to bondpads through vias which pass vertically down through two isolation layers of SiO_2 and through a ground plane (Fig. 1), which removes the electrically large bondpads away from the plane of the antenna. A bolometer is a thermal detector, in which the temperature rise caused by the incident radiation induces a change in the electrical resistance, which in turn produces a measurable change in voltage across the bolometer. In the present case investigated, the bolometer coupled to the Au dipole antenna is also made of Au. Thus, the dipole antenna is continuous, and the voltage signal is read out across a Au connection at the feedpoint of the antenna. In reference to Fig. 1, it is important to note that the antenna is designed to be illuminated through the Si substrate[5] (up from the bottom in the diagram).

II. FABRICATION

The device was fabricated using a Leica EPPG5000+ direct-write e-beam lithography system operating at 50 kV. The substrate used was low-resistivity Si wafer with thermally grown 1.19 μm thick SiO_2 coated on either side. The process flow diagram for the fabrication is shown in Fig. 2. The first step was to pattern the dipole antenna, of dimensions $3.4 \times 0.6\ \mu m^2$, designed for half-wave resonance at a 10.6 μm free-space wavelength. The resist used was a bilayer consisting of polymethyl glutarimide (PMGI SF7) and ZEP520A-7. First PMGI SF7 was spun at 300–700–3000 rpm for 15–5–80 s followed by 3 min softbake at 180 °C, resulting in a 450 nm thick film. Next, ZEP520A-7 was spun at 300–700–3000 rpm for 15–5–80 s and softbaked for 4 min at 180 °C, giving a 250 nm thick film. The dipole antenna was patterned with a dose of 125 $\mu C/cm^2$ and 8 nA beam current and developed in xylene for 90 s and rinsed with isopropanol, followed by 20 s development in tetramethyl ammonium hydroxide (TMAH) developer (2.3%), and finally a de-ionized-water rinse. The antenna pattern was then metallized with e-beam evaporated Ti–Au (10 nm/150 nm), followed by lift-off.

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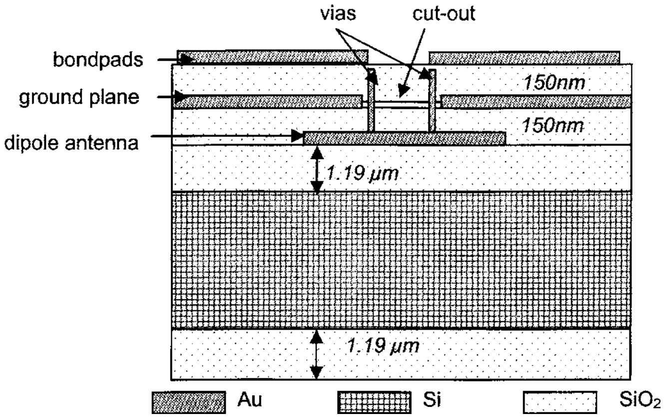

FIG. 1. Cross-sectional view of device with vias through two isolation layers and through a ground plane.

The first SiO_2 standoff layer ($h_1 = 150$ nm) was then deposited using a Plasma Therm 790 series system. This system is a two-chamber unit for plasma enhanced chemical vapor deposition and reactive ion etching (RIE). The following process parameters were used for the deposition process giving the deposition rate of 50 nm/min: 1050 mTorr pressure, 400 SCCM (SCCM denotes cubic centimeter per minute at STP) SiH_4, 827 SCCM NO_2, and 25 W rf power. The two 300 nm diameter vias were patterned next, with a dose of 145 $\mu C/cm^2$ and 8 nA beam current. Then followed a development in xylene for 40 and a 10 s TMAH development. The SiO_2 to be removed to accommodate the vias was plasma etched in the RIE chamber of the Plasma Therm 790 system with the following process parameters giving an etch rate of 50 nm/min: 75 mTorr pressure, 5 SCCM O_2, 45 SCCM CF_4, and 175 W rf power. The first-layer vias were then metallized with Ti–Au (10/150 nm) using e-beam evaporation and lift-off process.

The next step was to pattern the ground plane (250 $\times 250$ μm^2) with a 1.5×0.6 μm^2 cutout. For patterning the ground plane, a single layer of ZEP520A-7 was spun using the above mentioned recipe. The ground plane consisted of two parts, a small 10×10 μm^2 inner square containing the cutout and a larger outer square annulus. Both regions were patterned at the same time but with different doses and currents: 75 $\mu C/cm^2$ and 8 nA beam current for small inner piece and 140 $\mu C/cm^2$ and 25 nA beam current for large outer region. Development followed for 30 s in xylene. The finite ground plane was metallized so that it had a Ti adhesion layer both on the top and at the bottom of 150 nm Au film to ensure adhesion to the first SiO_2 layer beneath as well as the second SiO_2 layer to be deposited on top of the ground plane.

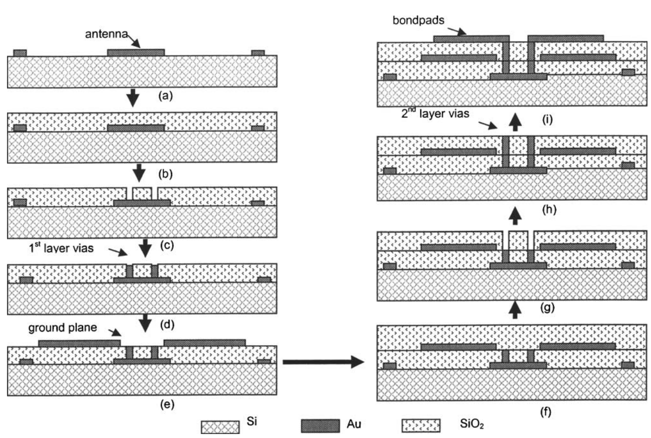

FIG. 2. Fabrication process flow diagram.

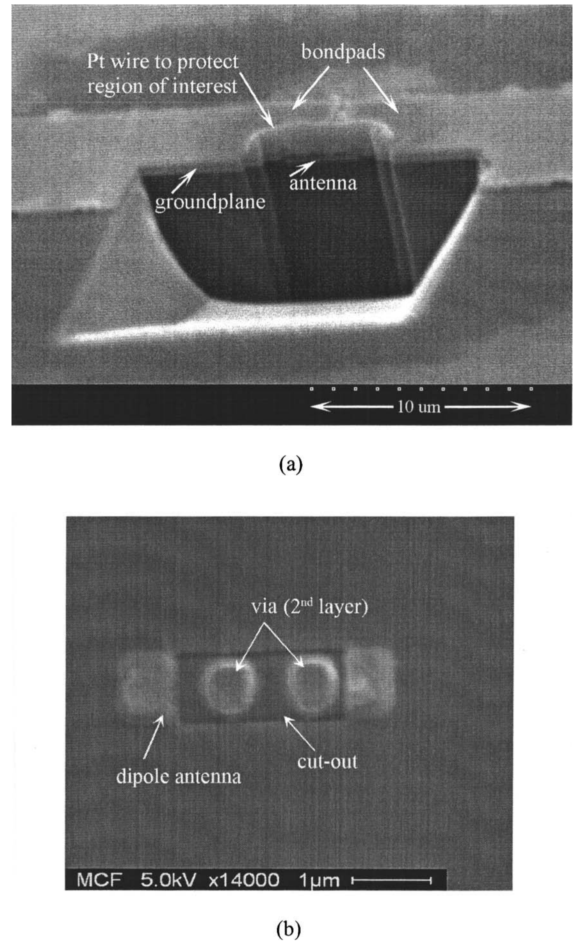

FIG. 3. (a) Focused ion beam (FIB) cross section of the fabricated device. (b) Top view of device corresponding to fabrication step of Fig. 2(h).

Next, second layer of SiO_2 ($h_2 = 150$ nm) was deposited using the same process mentioned above and then the 300 nm diameter vias were patterned, etched, and metallized as mentioned above. Finally, the bondpads (250 $\times 250$ μm^2) were patterned and metallized.

To see the cross section of the structure, a portion of substrate near the device was cut using focused ion beam (FIB) FEI 200TEM having 30 kV Ga-ion source, and the cross-sectional view of the fabricated device [corresponding to the fabrication step of Fig. 2(i)] is shown in Fig. 3(a). Figure 3(b) shows the top view of the device corresponding to the fabrication step of Fig. 2(h).

III. RESPONSE MEASUREMENT

We measured the response of this device with the CO_2-laser beam at 10.6 μm focused by an $F/1$ optical train,

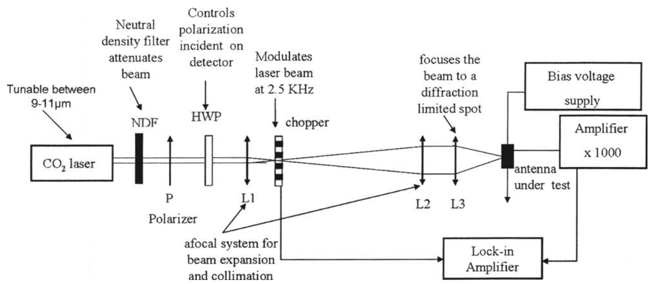

FIG. 4. Test setup for response measurement.

using the apparatus shown in Fig. 4. Using substrate-side illumination where the laser beam is incident from the backside of wafer,[5] a two-dimensional spatial response map[6] of the electromagnetically isolated antenna-coupled sensor was obtained with a scan step size of 1 μm. We also measured a spatial response with the device layout of Fig. 5. In this case, the dipole antenna is connected to the bondpad through a lead line configured such that the antenna, lead line, and bondpad are on the same plane.[7] We used benzocyclobutene as an isolation layer between the ground plane and the antenna. In this case, the bolometer is formed by a vertical connection between the ground plane and the antenna. The two-dimensional scans corresponding to the electromagnetically isolated and nonisolated cases are shown in Figs. 6(a) and 6(b). Comparing the spatial scans, it is noted that the isolation provided by the vias and the ground plane yields a sensor spatial response that is compact and symmetric, which is characteristic of the antenna alone,[8] while the spatial response of the device configuration of Fig. 5 yields the unwanted response from the lead lines (seen as a faint streak to the right of the main peak) along with the desired antenna

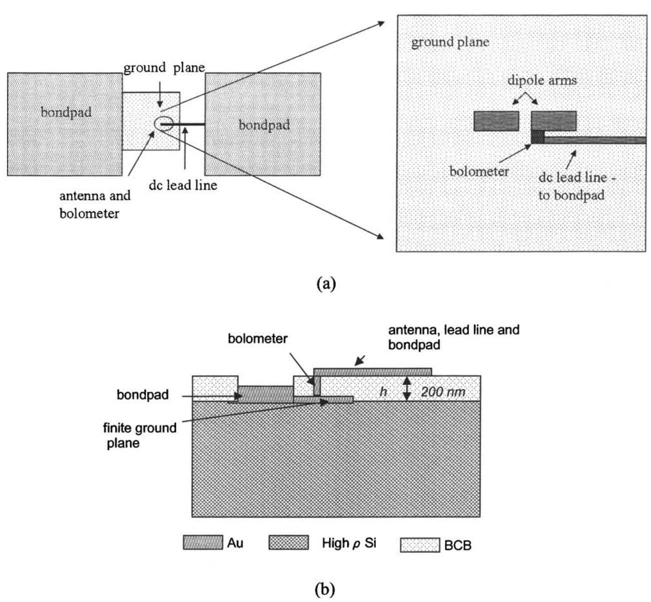

FIG. 5. (a) Layout of a dipole antenna having lead line and bondpad on the antenna plane. (b) Cross-sectional view of a dipole antenna having lead line and bondpad on the antenna plane.

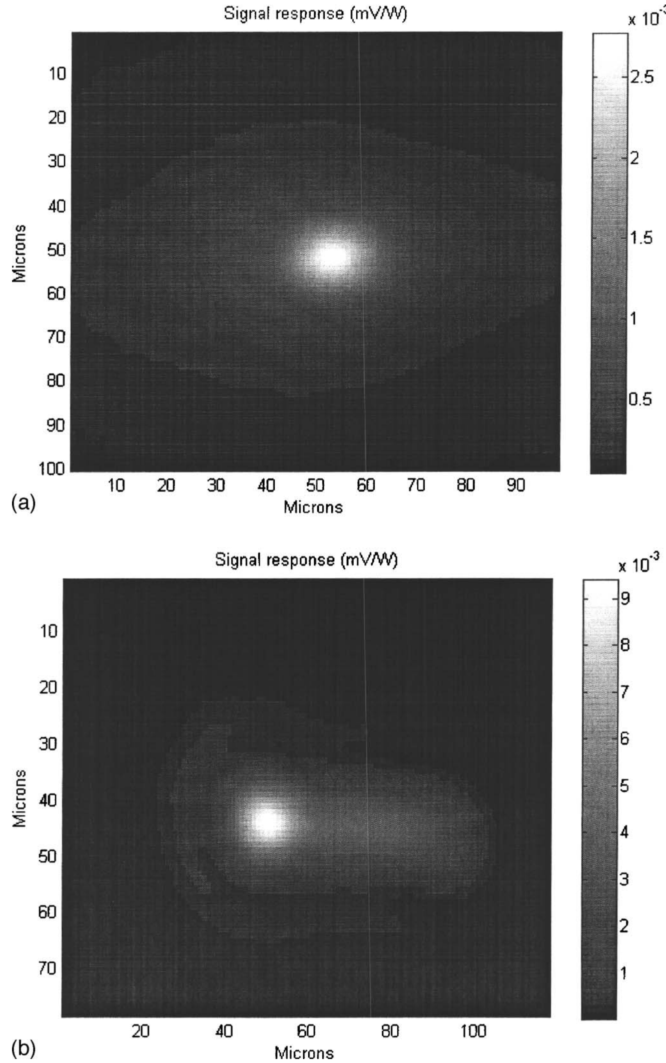

FIG. 6. (a) Measured spatial response map of the electromagnetically isolated device. (b) Measured spatial response map of dipole antenna having lead line and bondpad on the plane of the antenna.

response. Thus, having the signal-extraction structures in the same plane as the antenna contributes a significant broadening and asymmetry to the spatial response.

IV. CONCLUSION

We demonstrated a vertical-via interconnection suitable for low-frequency signal extraction from infrared antenna-coupled sensors, which consisted of a pair of 300 nm diameter Au structures, which passed vertically through a ground plane. Spatial response measurements at 28.3 THz in the infrared demonstrated that the isolation eliminated undesired response from the bondpads. This type of interconnection will be useful for detailed studies of electrically small antennas, where accurate determinations of antenna pattern, spatial response, or frequency-dependent impedance are desired.

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