Antenna-coupled MOM diodes for dual-band detection in MMW and LWIR

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ABSTRACT

An antenna-coupled metal-oxide-metal (MOM) diode for dual-band Infrared (IR)-millimeter wave (MMW) detection is presented. Electron-beam lithography and conventional sputtering techniques were used to fabricate a Ni-NiO-Ni diode coupled to an Infrared slot antenna at 28 THz and a coplanar waveguide (CPW)-fed MMW twin slot antenna at 94 GHz; simultaneous dual-band detection was tested and verified.

Keywords: MOM diodes, slot antennas, dual-band response.

1. INTRODUCTION

Millimeter-wave (MMW) imaging systems offer a good complement to infrared (IR) imaging systems. High resolution IR systems suffer high attenuation in cloudy and foggy atmospheres, while MMW systems will penetrate through clouds and fog offering an excellent all-weather imaging system. In our application, we aim at integrating both MMW and IR detection capabilities in one sensor and thus combining the advantage of high resolution and all-weather detection capabilities.

Antenna-coupled metal-oxide-metal (MOM) diodes have been used in the past for detection and mixing in the IR [1] and MMW [2] portions of the spectrum. A MOM diode with low enough junction capacitance, corresponding to a small enough junction area, to rectify IR radiation will also rectify MMW radiation; thus is a good candidate for this application. Slot antennas were successfully coupled to Schottky diodes [3] and SIS mixers [4] for detection in the MMW region and to bolometers for detection in the IR region [5].

In this work, we integrate a MMW CPW-fed twin slot antenna with an Infrared slot antenna and couple both antennas to a Ni-NiO-Ni diode for dual-band detection at 94GHz and 28THz.

2. SENSOR OPERATION

The sensor configuration is shown in Fig.1. Two MMW slot antennas are etched in a 5mm×5mm Au ground plane. A CPW is utilized to feed coupled MMW radiation to the MOM sensor located at the center of the CPW. The CPW is modified as shown in Fig.2 to accommodate an Infrared slot antenna. DC cuts are made in both the MMW slot ground plane and the modified central area of the CPW to allow for sensor bias. The MOM diode is connected to an IR slot antenna as shown in Fig.3. The diode contact area is $0.0144 \mu m^2$. The length of the MMW slot is $0.31\lambda_0$, its width is $8\times10^{-3}\lambda_0$ the CPW strip width is 40μm corresponding to a characteristic impedance of 51Ω. The IR slot was designed as a one-wavelength slot for operation at 28 THz; its length is $0.75\lambda_0$ and its width is $0.085\lambda_0$. The cut-off frequency of a MOM diode junction is described by [6]:

$$f_c = \frac{1}{2\pi R_A C_D} , \qquad (1)$$

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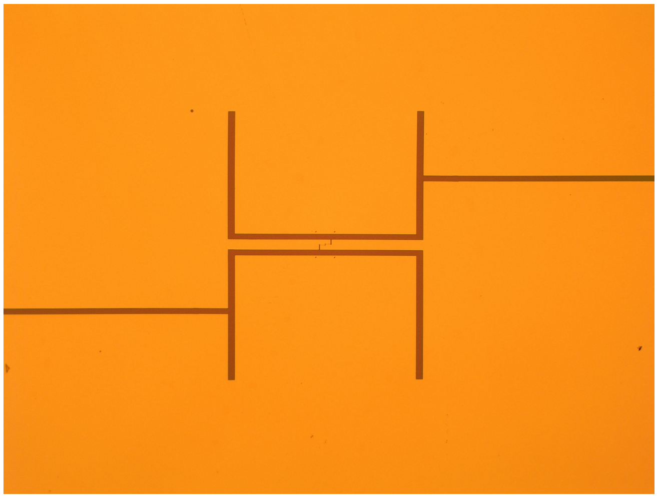

Fig. 1: MMW twin slot

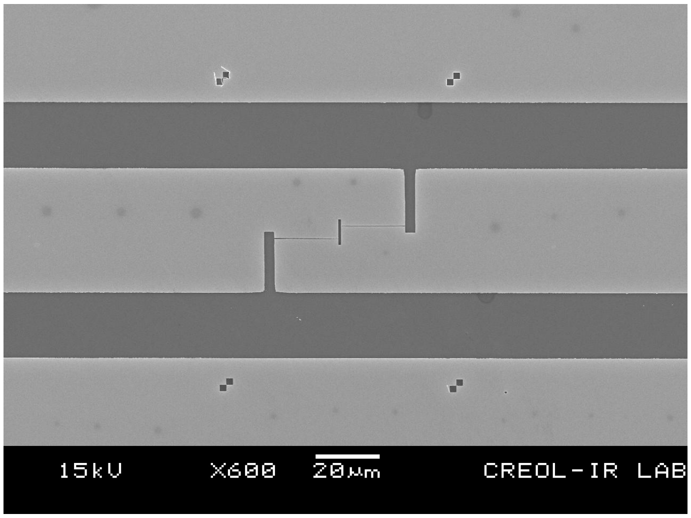

Fig. 2: CPW and IR slot antenna.

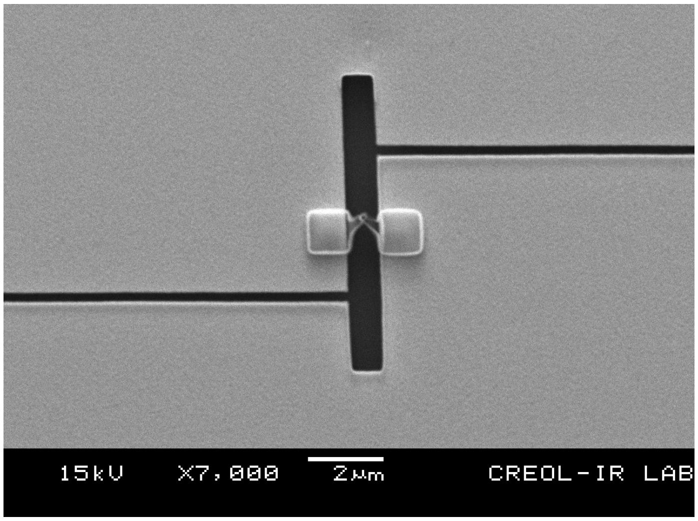

Fig. 3: IR slot coupled to MOM diode

Where R_A represents the resistance of the antenna, and C_D is the capacitance of the diode which is described by

$$C_D = \frac{\varepsilon_0 \varepsilon_r A}{d}\ , \qquad (2)$$

Where ε_r is the relative permittivity of the oxide, A is the contact area between the two metal electrodes and d is the thickness of the oxide layer. The fabricated diode contact area in this work is 0.0014μm^2 which corresponds to a contact area of 120nm×120nm, and the oxide layer thickness was measured to be 3.5nm with a relative permittivity of 3.24. Based on those measurements, the capacitance of our diodes is estimated to be 117aFarads.

The infrared slot antenna was designed to operate a one-wavelength slot. The design was based on one-wavelength slot theory for wavelengths below 120μm [7]. The infrared slot antenna was simulated by IE3D [8], and the simulation predicts a resonance at 11.7μm with an antenna impedance of 35Ω. The MMW slot antenna was designed based on [9] where a twin slot antenna on a Si substrate is predicted to have an admittance of ~$17\times10^{-3}\Omega^{-1}$ which corresponds to an impedance of ~ 58Ω.

Based on the above antenna impedance simulations and substituting in equation (1), the cutoff frequency for a 58Ω MMW twin slot antenna coupled to 117aFarads MOM diode will be 23THz and for a 35Ω IR slot antenna is 38THz. Therefore, the device is expected to operate above the cutoff frequency in both bands.

3. SENSOR FABRICATION

The device is fabricated on a high resistivity Si substrate coated with a 500nm layer of SiO_2 for electrical isolation. The substrate was coated with a 15nm layer of Cr and 120 nm layer of Au. The CPW-fed twin slot structure was then patterned in electron beam positive resist and sputter etching was used to etch the slots into the Au ground plane. The bottom MOM diode electrode was defined and a Ni layer of 140nm was then deposited using DC magnetron sputtering. The top electrode was patterned. A NiO layer of 3.5nm was then deposited using RF diode sputtering followed by another 140nm Ni layer deposited using DC magnetron sputtering.

4. EXPERIMENTAL RESULTS

I-V plots for the device were measured using an HP4145B parameter analyzer. A typical plot is shown in Fig.4. The plot shows the typical non-linear relation between the tunneling current and the bias voltage of the diode. The device shown in the plot has a zero-bias resistance of 61Ω and a maximum sensitivity (S) of 2.75V^{-1} at 150mV of bias.

For testing THz response as in Fig. 5, the detector was irradiated by a CO_2 laser at 10.6μm. An F/1 lens is used to focus the beam into a diffraction limited spot onto the device. A mechanical chopper was used to modulate the laser beam at a frequency of 2.6 kHz. For testing in the GHz region as in fig. 6, radiation from a 92.5 GHz Gunn oscillator at 25mW of output power was input into a PIN diode switch that is modulated at 3 kHz using a function generator and finally a horn antenna was used to irradiate the device. The modulated detector response signals were amplified and then captured using a lock-in amplifier. Fig.7 shows a plot for the IR response and the second derivative of the I-V characteristic curve vs. bias voltage of the diode. The Infrared voltage response follows the second derivative of the I-V curve which indicates that tunneling is the dominant detection mechanism [10]. The sensor was measured to have a Noise equivalent power (NEP) of 180 pWatt/Hz$^{0.5}$ in the IR. For simultaneous response verification, IR and MMW radiation were modulated at 2.6 and 3 kHz respectively and made simultaneously incident on the device. An image of the spectrum analyzer output, Fig.8, verifies simultaneous dual-band operation of the device.

5. CONCLUSIONS

The simultaneous response to 94 GHz and 28 THz radiation using a dual-band antenna coupled MOM diode was verified. MMW response can be further improved by using a substrate lens for reducing surface-wave coupling. IR response can be further improved by decreasing the junction which will decrease the junction capacitance and therefore increase the cut-off frequency of the device; in addition, a CPW-fed twin slot Infrared antenna is an improved alternative to the single slot feed structure.

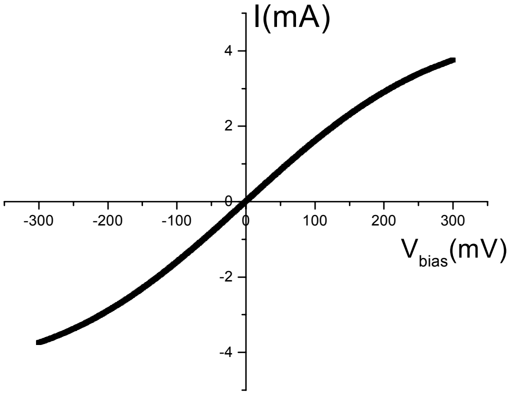

Fig. 4: I-V characteristic curve for MOM diode.

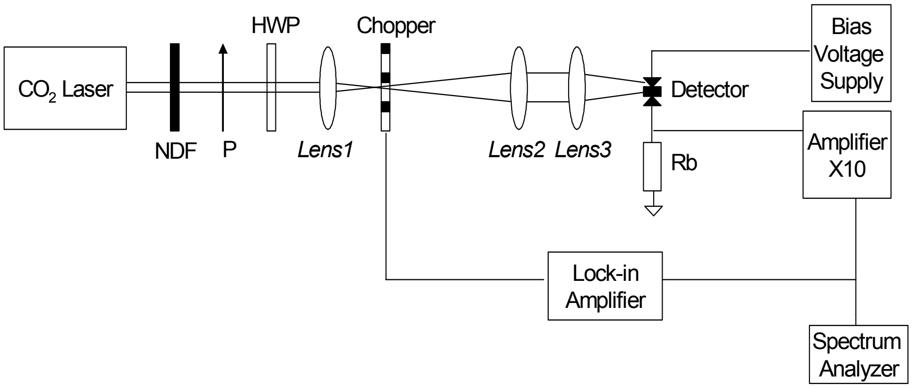

Fig. 5: THz test setup.

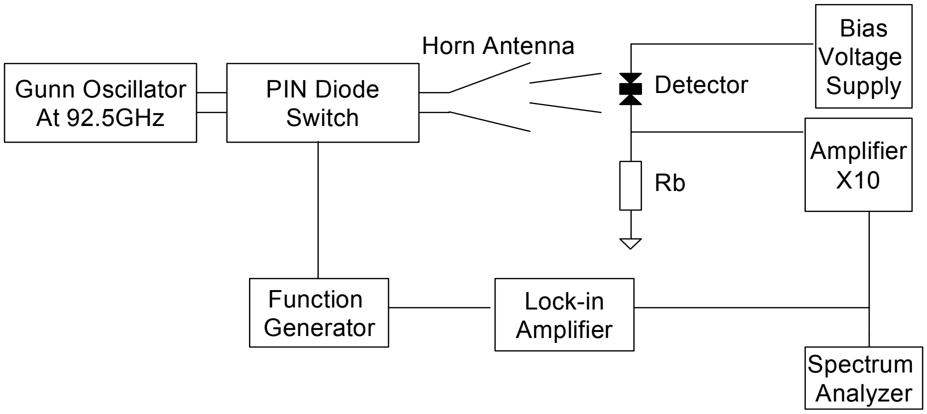

Fig. 6: GHz test setup.

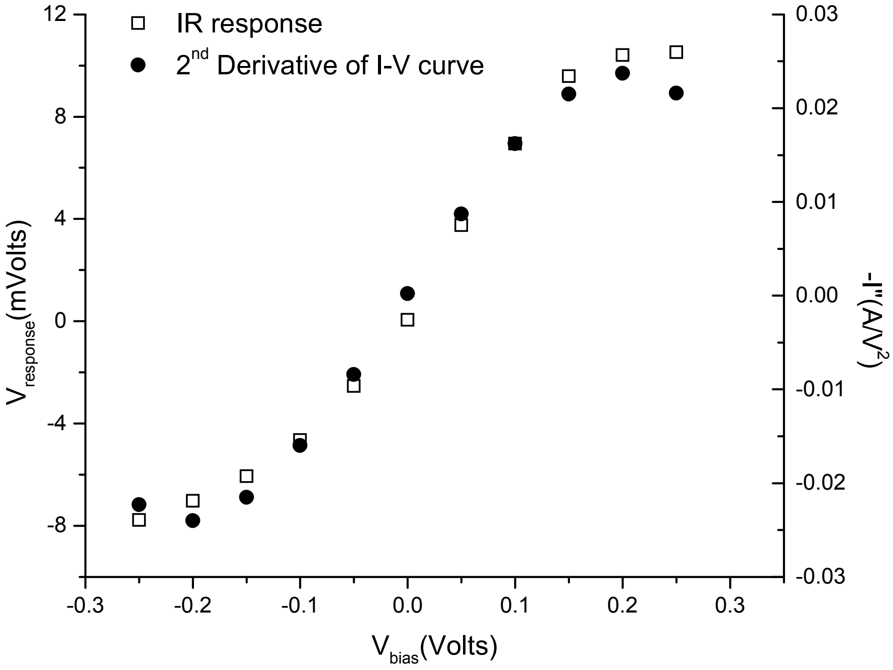

Fig.7: Voltage response at LWIR and second derivative of MOM diode I-V curve.

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REF -25.0 dBm                 MARKER 2 751.0 Hz
10 dB/DIV     RANGE -25.0 dBm      -123.9 dBm
START 2 250.0 Hz                   STOP 3 250.0 Hz
   RBW 30 Hz         VBW 100 Hz      ST 2.4 SEC
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Fig. 8: Simultaneous response at LWIR and MMW.

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References

1. Fumeaux, C., Herrmann, W., Kneubühl, F.K., and Rothuizen, H., "Nanometer thin-film Ni-NiO-Ni diodes for detection and mixing of 30 THz radiation", *Infrared Physics and Technology*, **39**, 123-183, 1998.
2. Dees, J.W., "Detection and harmonic generation in the sub-millimeter wavelength region", Microwave Journal, **9**, 48-55, 1966.
3. Gearhart, S., and Rebeiz G., "A Monolithic 250 GHz Schottky-diode receiver", *IEEE Transcations on Microwave Theory and Techniques*, **42**, 2504-2511, 1994.
4. Zmuidzinas, J., "Quasi-optical slot antenna SIS mixers", *IEEE Transcations on Microwave Theory and Techniques*, **40**, 1797-1804, 1992.
5. Yasuoka, Y., Hashimoto, S., Abe, Y., and Gamo, K., "Fabrication of thin film slot antenna arrays for receiving 28 THz-CO_2 laser radiation", *Microelectronic Engineering*, **61-62**, 1049-1054, 2002.
6. Sanchez, A., Davis Jr., C.F., Lui, K.C., and Javan, A., "The MOM tunneling diode: Theoretical estimate of its performance at microwave and infrared frequencies", *Journal of Applied Physics*, **49**, 5270-5277, 1978.
7. Abe, Y., and Yasuoka, Y., "Operating Properties of Thin-Film Slot Antennas at 2.5-THz Submillimeter Wave Band", *Electronics and Communications in Japan*, **85**, 8-15, 2002.
8. Eleftheriades, G., and Rebeiz, G., "Self and Mutual Admittance of Slot Antennas on a Dielectric Half-Space', *International Journal of Infrared and Millimeter Waves*, **14**, 1925-1946, 1993.
9. Zeland Software Inc., IE3D simulator, 2004.
10. Gustafson, T.K., Schmidt, R.V., and Perucca, J.R., "Optical detection in thin-film metal-oxide-metal diodes", *Applied Physics Letters*, **12**, 620-622, 1974.