Efficiency of a microwave reflectometry for readout of a THz multipixel Schottky diode direct detector

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Abstract. In this paper we report on the results of investigation of efficiency of a microwave reflectometry for readout of a terahertz multipixel Schottky diode direct detector. Decent capabilities of the microwave reflectometry readout were earlier justified by us for a hot electron bolometric direct detector. In case of a planar Schottky diode, we observed increase of an optical noise equivalent power by a factor of 2 compared to that measured within a conventional readout scheme. For implementation of a multipixel camera, a microwave reflectometer is to be used to readout each row of the camera, and the row switching is to be maintained by a CMOS analog multiplexer. The diodes within a row have to be equipped with filters to distribute the probing microwave signal properly. The simultaneous use of analog multiplexing and microwave reflectometry enables to reduce the camera response time by a factor of its number of columns.

1. Introduction

Nowadays, gallium arsenide is in vast demand in the monolithic microwave integrated circuit receiver technology including development of power amplifiers, frequency multipliers, coherent and direct detectors for both scientific and civilian purposes [1, 2]. Planar Schottky diode (PSD) based on gallium arsenide wafer can successfully act as a key element for the development of sources and detectors of electromagnetic radiation. In this paper we report on the results of investigation of efficiency of a microwave reflectometry for readout of a terahertz multipixel Schottky diode direct detector. Decent capabilities of the microwave reflectometry readout were earlier justified by us for a hot electron bolometric direct detector [3]. New experiments suggest that the simultaneous use of microwave reflectometry and analog multiplexing enables to reduce the response time of a Schottky diode array by a factor of its number of columns. This can be achieved at the cost of twofold decrease of pixel sensitivity.

2. PSD samples

For our studies, we used off-the-shelf quasioptical diodes fabricated within a technological route similar to that previously employed by us in [4]. Figure 1 (a, b) provides SEM images of a PSD structure and the inner part of a spiral antenna integrated with it; the following notation are employed: 1 – SI-GaAs, 2 – n_+-GaAs, 3 – n-GaAs, 4 – SiO_2, 5 – ohmic contact, 6 – anode suspended bridge, 7 – circular Schottky contact (under the cap), 8 – alignment marks to “insert” PSD structure, 9 – planar spiral antenna arms. The thickness and dopant profile of n_+/n-GaAs (t_{n+}/t_n and N_{d+}/N_d), the SiO_2 thickness (t_{SiO2}) and the Schottky contact diameter ($ø_a$) were chosen to fabricate diodes with certain crucial parameters. Table 1 provides the values of ideality factor (η), barrier height (Φ_{bf}), series resistance (R_s) and total parasitic capacitance (C_{tot}) of a typical PSD sample fabricated.

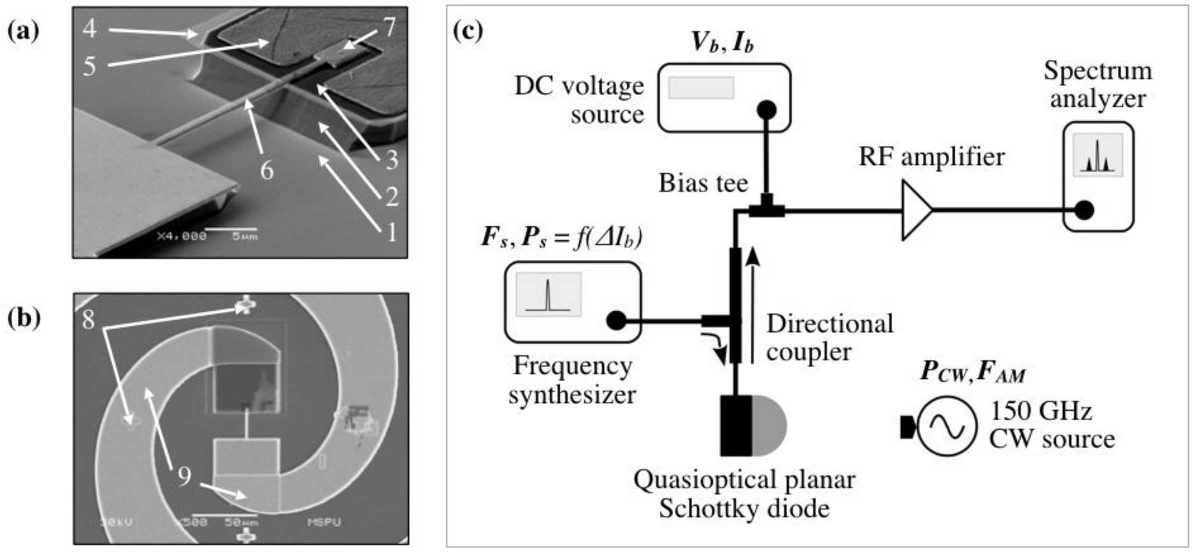

Figure 1(a, b, c). (a) SEM image of a PSD structure. **(b)** Inner part of a self-complementary spiral antenna. **(c)** Experimental setup.

Table 1. Parameters of a typical PSD sample.

t_{n+}/t_n [nm]	N_{d+}/N_d [cm^{-3}]	t_{SiO2} [nm]	$\o_a$ [μm]	η	Φ_{bf} [eV]	R_s [Ω]	C_{tot} [fF]
2000/60	$5\times10^{18}/4\times10^{17}$	250	1-3	1.4	0.76	20	4

3. Experimental setup and results

Referring to Figure 1(c), the microwave reflectometer is employed to readout the response of a terahertz planar Schottky diode to incident AM radiation produced by the 150 GHz CW source. The source modulation frequency (F_{AM}) is fixed to a constant value. A weak probing signal is injected into the diode through the directional coupler at certain frequency (F_s), and the probing signal power (P_s) is chosen to cause an increase of the diode bias current (ΔI_b) of 5 %. The diode is operated at bias voltage (V_b) of ~0.6 V corresponding to bias current (I_b) of 210 μA. Signal-to-noise ratio (SNR) at F_s+F_{AM} is measured by the spectrum analyzer whose resolution bandwidth (B) is set to 100 Hz. The 150 GHz CW source power (P_{CW}) incident onto the optical input of the diode is calibrated by the VDI Erickson power meter, when the source modulation is turned off. The value of an optical noise equivalent power (NEP) is further calculated as

$$NEP = P_{CW}\cdot B^{-0.5}\cdot SNR^{-1}. \quad (1)$$

If $P_s = 0$, the setup transforms into a conventional scheme for readout of a THz PSD direct detector, and SNR is measured at F_{AM}.

As shown in Figure 2(a), we measured an input dynamic range (IDR) of ~30 and 40 dB for the diodes with the corresponding Schottky contact diameters of 1 and 3 μm within a conventional readout scheme. For PSD2, the linear response formed by the reflected probing signal was also confirmed at F_s = 1.5 GHz, F_{AM} = 100 кHz and P_{CW} = 1 μW. The measurement also revealed that input power of

1 µW is close to the linearity upper limit. Since the noise floor of -84 dBm was observed for both PSD samples, we deduced that bigger $ø_a$ is preferred for the diode intended to detect relatively weak signals at 150 GHz.

To enable the use of a microwave reflectometry for readout of a two pixels direct detector, each pixel has to be equipped with a band-pass filter (BPF). Moreover, the readout efficiency is determined by the output line losses at F_s. Figure 2(b) provides the output intermediate frequency (IF) power measured at local oscillator frequency (F_{LO}) of 150 GHz for the diodes without (PSD1) and with embedded filter (PSD2). As one can clearly see, F_s = 2.5 GHz is to solely readout PSD1, and $F_s \notin$ (1.5 GHz, 4 GHz) can be used to readout both PSD samples.

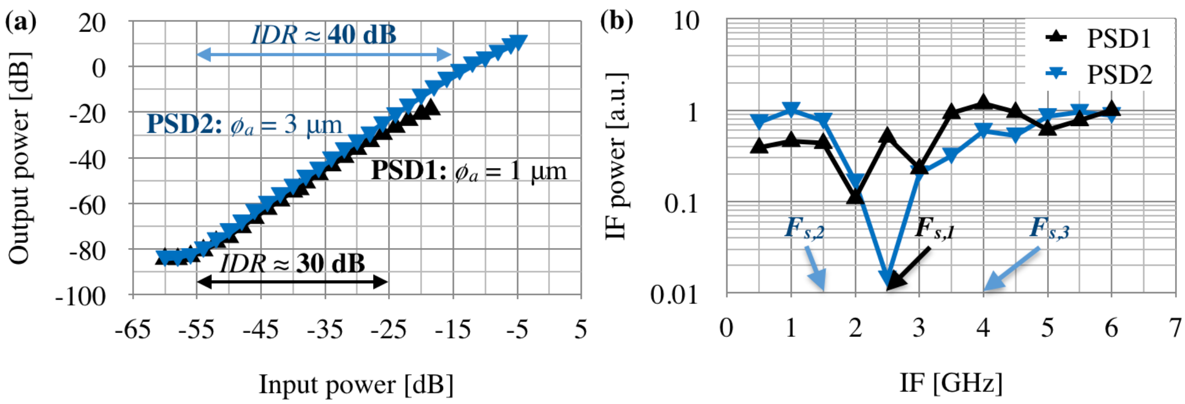

Figure 2(a, b). (a) Linearity curve of a PSD with no microwave power injected. **(b)** PSD's output IF power measured at F_{LO} = 150 GHz.

Since bigger $ø_a$ was considered beneficial, sensitivity measurements were conducted for PSD2 only. We observed the *NEP* value of 160 pW·Hz$^{-0.5}$ within a conventional readout scheme. *NEP* = 13 nW·Hz$^{-0.5}$ was measured with the aid of a microwave reflectometer at F_{AM} = 100 kHz. The change of F_{AM} to 4MHz resulted in the decrease of *NEP* to 320 pW·Hz$^{-0.5}$. This effect was due to the carrier frequency noise reduction. The experimental values were obtained at F_s = 4 GHz and P_{CW} = 1 µW to insure linear response of the diodes within both readout schemes.

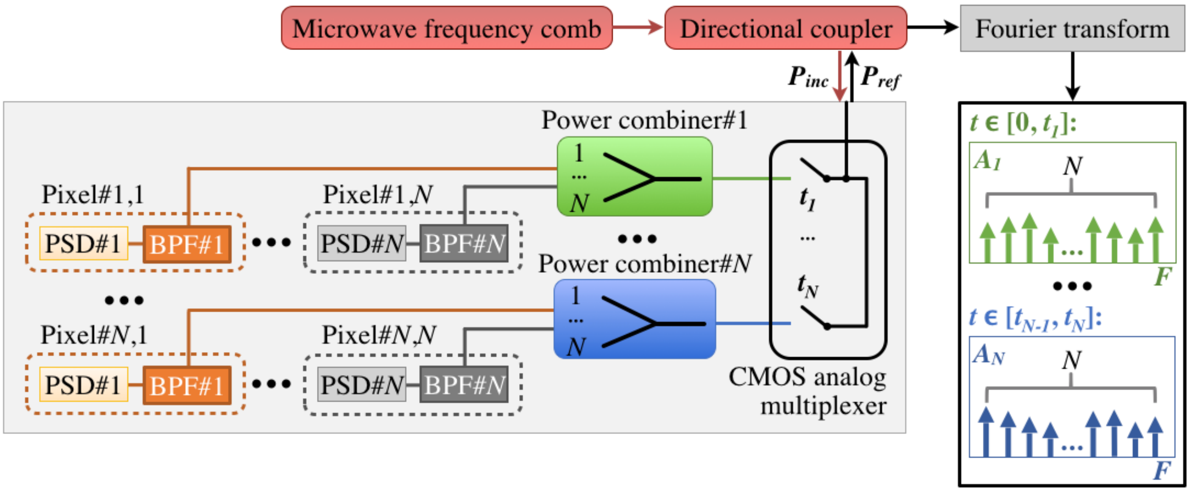

Figure 3. Layout of a terahertz camera and its readout scheme.

We believe that our findings inspire further implementation of a terahertz Schottky diode camera comprising the readout scheme making use of microwave reflectometry and CMOS analog multiplexing [5]. Figure 3 provides a schematic diagram of such a $N\times N$ pixels THz camera. A microwave reflectometer is used to readout each row of the camera, and the row switching is maintained by an analog multiplexer. The diodes within a row are equipped with filters to distribute the probing microwave signal properly. The injected microwave power (P_{inc}) is chosen to achieve decent performance of each pixel, and it can vary for pixels of identical columns and different rows. The change of reflected power (P_{ref}) is caused by the PSD impedance variation in accordance with the power of incident THz signal. Fourier transform algorithm is employed to process the camera response, and array of N amplitudes is acquired for N pixels of each row. N arrays of amplitudes ($A_1 \ldots A_N$) are acquired within N consequent time slots corresponding to the multiplexer switching sequence. The layout proposed enables to reduce the camera response time by a factor of N. It is also worth mentioning that the frequency of a probing signal incident onto the diode on the upper side is only limited by the output line RF losses. Thus, the requirement for a Q-factor of the filters is relaxed for a 32×32 pixels camera interesting from a practical point of view. Given the compactness required, one can rely on a miniaturized dual-mode resonator filter, which can be implemented on a high permittivity substrate and provides fractional bandwidth of 2.5 % at microwaves [6]. The feasibility of a suitable PSD array with high homogeneity of elements is insured by our lately enhanced fabrication technology, which enables the fabrication of diodes with better crucial parameters and yield of ~97 %.

4. Conclusion

Microwave reflectometer was employed to readout the response of a terahertz planar Schottky diode to incident AM radiation produced by a 150 GHz CW source. We observed an increase of PSD's optical *NEP* by a factor of 2 compared to that measured within a conventional readout scheme: 320 and 160 $\mathrm{pW \cdot Hz^{-0.5}}$ were obtained. Our findings inspire further implementation of a THz PSD camera. Microwave reflectometer is to be used to readout each row of the camera, and the row switching is to be maintained by a CMOS analog multiplexer. The diodes within a row have to be equipped with filters to distribute the probing microwave signal properly. The simultaneous use of analog multiplexing and microwave reflectometry enables to reduce the camera response time by a factor of its number of columns which is beneficial for the implementation of a real-time imaging system.

Acknowledgments

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