Extremely Broadband Characterization of a Schottky Diode Based THz Detector

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***Abstract*— A Schottky diode based module for direct detection of THz power provides fast measurement capabilities at room temperature. This paper presents the broadband spectral characterization of a Schottky diode in comparison to a Golay cell in the frequency range from 0.1 THz up to 2 THz.**

I. Introduction

Rectification by a Schottky diode is an advantageous technique for the direct detection of THz radiation. This kind of detector combines a high responsivity with very short response time and compact dimensions. The output signal is proportional to the incoming power over a wide range of power. Unlike some other detectors such as bolometers it operates at room temperature.

The short circuit current responisivity η for low frequencies can be estimated using the theory of [1]:

$$\eta = \frac{I_{\text{det}}}{P_{THz}} = \frac{1}{2}\frac{d^2I/dV^2}{dI/dV}$$

The equation shows that the responsivity can be extracted from the curvature of the current-voltage (I-V) behaviour at the working point. At room temperature, the theoretical maximum achievable value for the responsivity is 19.7 A/W for an ideal diode. At high frequencies, the responsivity is reduced by the parasitic shunt capacitance of the diode.

To receive radiation from free space the diode is connected to a suitable antenna. For detection over a broad frequency range, an antenna with small variation of impedance and beamform is preferred. An inherent property of such an frequency independent antenna on a high impedance substrate such as silicon is a low impedance of ~75 Ω [2]. The typical impedance of the detector diode is more than a magnitude higher than that of the antenna. This mismatch is a typical problem of this kind of detector, and leads to a large power loss. Resonant antennas can obtain a better coupling efficiency at the expense of bandwidth.

In addition to its responsivity the performance of the detector is also determined by its noise level. In recent years the development of detector diodes with an optimum working point at zeros bias has been pushed forward in order to avoid noise caused by a bias current. The noise level of a zero bias diode is mainly defined by the thermal noise generated at the junction.

There are a few reports on zero bias Schottky diodes for direct detection of THz radiation. In [3] a zero bias diode has been fabricated. Mounted in waveguide it has been characterized up to 800 GHz. The authors of [4] have measured an ErAs:InAlGaAs based diode placed on square spiral antenna up to 639 GHz. In [5] a diode based delta-doped layer is presented together with measurements up to 94 GHz.

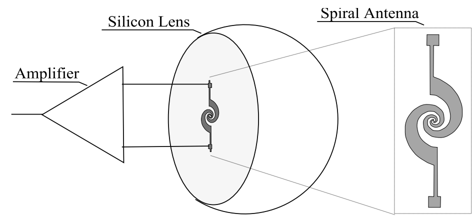

Figure 1. The diode is mounted in the centre of a self-complementary logarithmic spiral antenna which is placed on a silicon lens. A pre-amplifier with DC stabilization is included in the detector module.

In this paper the spectral capabilities of a Schottky diode based detector is presented in the greatly extended range up to 2 THz.

II. Device

The developed Schottky detector module is based on an planar InGaAs diode working at zero bias. It provides a low noise level which is almost equal to the thermal noise of the differential resistance of the diode. From DC measurements a differential resistance of 4.7 kΩ and a current responsivity of 13.0 A/W have been extracted.

As shown in Fig. 1, the diode is mounted on a planar logarithmic spiral antenna [6]. The shape is self-complementary. The small impedance variation over a broad frequency range makes this antenna type ideal for spectroscopic applications. The outer dimensions of the antenna are designed to work down to 50 GHz. From FDTD simulations its circular polarization in main lobe direction has been extracted. Furthermore the real part of the impedance has been calculated as illustrated in Fig. 2 increases from 70 to 150 Ω in the range up to 2 THz. The antenna is placed on a hyperhemispherical lens for free space coupling. The lens has a diameter of 10 mm and the complete extension of the antenna from the centre of the lens is 1.55 mm.

The diode is working in current detection mode. Low noise amplifier with DC stabilization is integrated in the detector module. Without taking into account the roll-off of the diode at high frequencies the optical responsivity of the module has calculated to be 17 kV/W with a noise equivalent power (NEP) of 30 pW/$\sqrt{Hz}$. It has to be stated that the exact calculation of NEP at THz frequencies is challenging, because the estimation of the incoming power at the diode is error prone.

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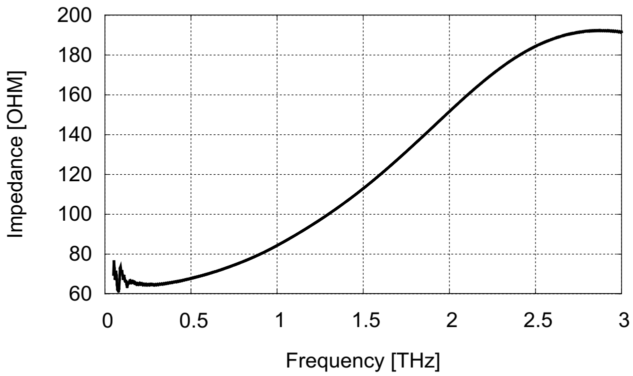

Figure 2. Calculated real part of impedance of the planar spiral antenna on silicon halfspace using the FDTD solver from CST.

III. Measurement Setup

The device has been characterized using a Michelson Interferometer with a thermal broadband source. In order to compare the results of the Schottky diode based detector, a Golay cell with black polyethylene window has been employed as a reference detector. It exhibits a typical responsivity of 100 kV/W with a NEP of 140 pW/$\sqrt{Hz}$ [7].

The interferometer has a classical Michelson configuration. The radiation source is a Globar, a blackbody radiator made out of silicon carbide, which is modulated by a mechanical chopper. Since such a thermal source working at a temperature of ~1300 K has a weak output signal in the far infrared, different thicknesses of Mylar foils (125 µm, 70 µm, 23 µm) are used as beam splitter in order to obtain a good signal to noise ratio over the complete frequency range. Due to internal reflections inside the beam splitter, each thickness covers only a limited range of the spectrum.

IV. Characterization

The spectral response of both detectors using the 125 µm beamsplitter is shown in Fig. 3 (bottom part). The values have been normalized to unity at 0.3 THz for both detectors. The response of the Schottky is visible up to 2 THz. Both signals show clearly the influence of the beamsplitter. The spectral behaviour of the optical path in the interferometer and the source can be eliminated by calculating the ratio between the signal of the Schottky and the Golay as shown in the top part of Fig. 3. At the lower end of the frequency range the performance of the spectrometer drops due to the low output power of the source and the low reflectivity of the mylar beamsplitter. This leads to a fluctuating signal at the lower end of the spectrum. The ratio seems to be nearly constant below 0.3 THz, above this frequency it starts to drop. The main reason for this roll off is the RC time constant of the diode in combination with the antenna.

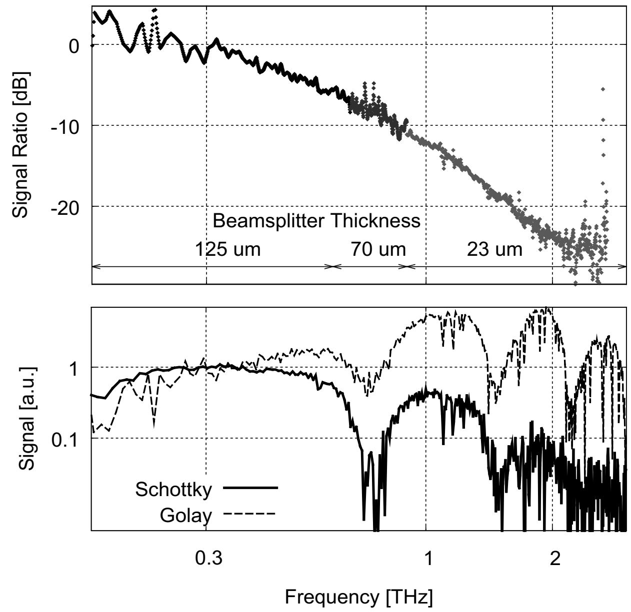

Figure 3. Bottom: Output signal of Schottky detector and Golay detector (beam splitter thickness 125 µm). Top: Ratio between output signal Schottky and Golay. Both signals are normalized to unity at 0.3 THz.

V. Conclusion

The extremely broadband spectral characterization of a Schottky diode based detector has been presented. The advantages of this detector are a very short response time, small dimensions and room temperature operation. It can be manufactured in arrays for imaging applications. The detector shows excellent performance in the sub-mm range where it is comparable to the Golay cell.

VI. Acknowledgment

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