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COMPARATIVE STUDY OF BROADBAND ROOM TEMPERATURE THz DETECTORS FOR HIGH AND INTERMEDIATE FREQUENCY RESPONSE*

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Abstract

Room temperature terahertz (THz) detectors based on Field effect transistors (FETs) and Zero-bias Schottky diodes (SD) are prominent members for the temporal-spatial characterization of pulses down to the picosecond scale generated at particle accelerators. Comparative study of in house developed THz detectors both at higher and intermediate frequency (IF) is carried out using table top THz systems and commercially available sources. In this paper, we present high frequency and intermediate frequency (IF) response of Gallium Arsenide (GaAs) FET and Zero-bias Schottky diode THz detectors. The IF results obtained are helpful for understanding and designing of optimized IF circuit with broader bandwidth.

INTRODUCTION

The generation of THz radiation in particle accelerators allows for prospective applications in the THz domain [1]. Coherently generated picosecond scale THz pulses can be used for various applications such as spectroscopy, imaging [2]. In order to explore the inter and intra molecular moments of molecules, highly sensitive, accurate, stable and fast detectors are the key elements. The Gallium Arsenide (GaAs) based high electron mobility transistors, commonly known as field effect transistors (FETs) and Zero-bias Schottky diode based THz detectors are prominent members as the heterodyne detectors [3–5]. In order to optimize the detectors, it is required to understand the active channel characteristics of FETs [6] and designing the optimal readout IF circuitry for packaging.

In this paper, the IF and THz characteristics of these in house developed THz detectors is presented. The IF characterization is done from 0 - 30 GHz and the THz characterization from 50 GHz to 1.2 THz. The technical and incremental results shown in this paper are essentials for optimizing the detectors to best of their level.

EXPERIMENTAL SETUP

The THz and IF experiments were performed in order to understand the frequency response of the detectors. The detailed experiment setup is explained below.

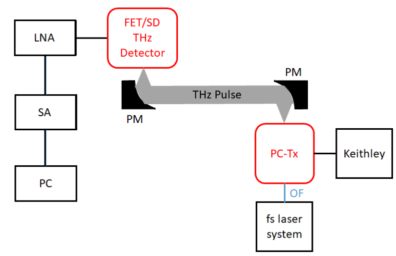

Figure 1: Experimental setup for IF frequency response measurements.

Intermediate frequency measurements

The experimental setup used for IF characterisation is shown in Fig. 1. A THz pulsed laser system from Menlo Systems GmbH was used along with in housed developed photomixer transmitter [7] as a source (PC-Tx). A keithley is used to bias the photomixer. The optical fiber (OF) was used to connect the photomixer to the laser source. Low noise amplifier (LNA) working between 50 kHz - 17 GHz was used after the detector followed by a handheld spectrum analyzer (SA) from Anritsu, as shown in Fig. 1.

High frequency measurements

The THz characterization experimental setup is shown in Fig. 2. A Continuous Wave (CW) laser system from TOPTICA Photonics AG was used. The P-I-N diode continuous wave emitter (CW-Tx) from TOPTICA Photonics AG / Fraunhofer Heinrich Hertz institute was used as a source. On the detector side, the Trans-Impedance Amplifier (TIA) followed by the lock-in is used in order to measured the detected signal.

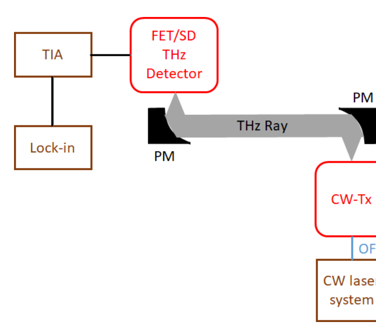

Figure 2: Experimental setup for THz frequency response measurements.

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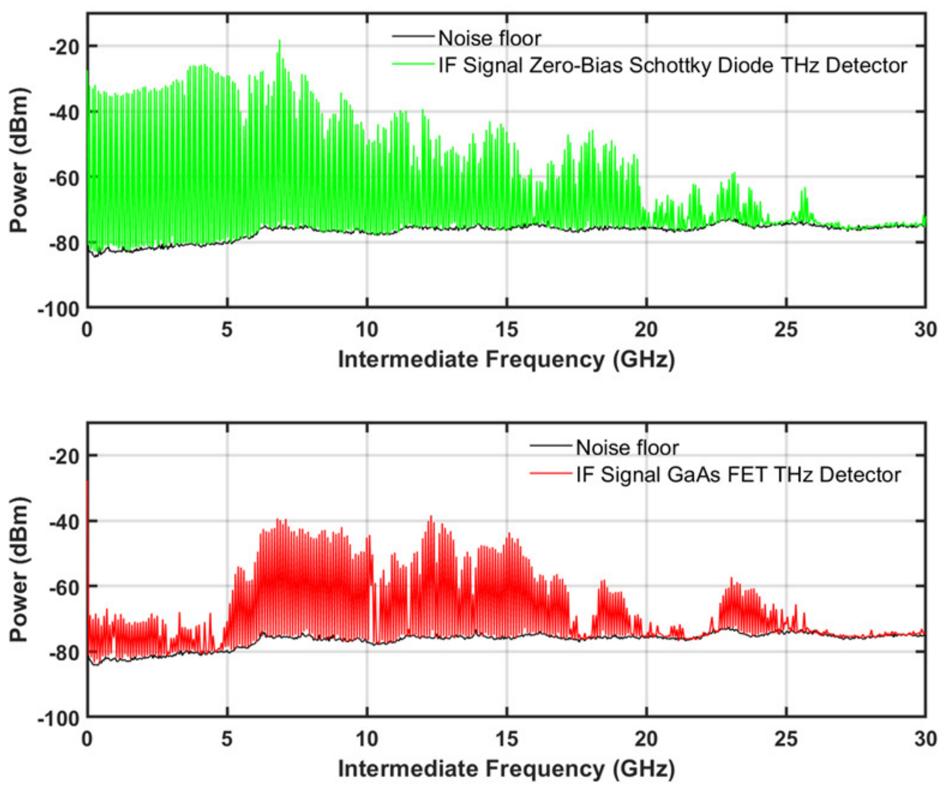

Figure 3: Top: The IF frequency response of Zero-bias Schottky diode THz detector, Bottom: The IF frequency response of GaAs FET THz detector

RESULTS AND DISCUSSION

The frequency response comparative study results are shown and discussed in this section.

Intermediate Frequency Results (IF)

The IF frequency results using the setup depicted in Fig. 1 for Zero-bias Schottky diode and GaAs FET based THz detectors are shown in Fig. 3. The modal structure with a mode spacing of 100 MHz, equalling the repetition rate of the pulsed laser, is clearly visible. The IF measurements are limited by both, the LNA performances as well as the RF cables used in the post detection part. Observing Fig. 3, for Schottky THz detector the rectified power is higher and gradullay decreases towards higher frequency, while for GaAs FET based THz detectors in frequency less than 5 GHz, the power observed is very low. This can be due to the rectification mechanism of GaAs FET is different than Schottky diodes and also can be due to design of the GaAs FET. However, for both detectors we observed the signal until 26 GHz, which indicates that it's not the limitation of active device, but rather the post detection electronics. In general, the Schottky detector is more sensitivity compared to GaAs FET detector used in this study for lower THz power levels.

High Frequency Results(THz)

For studying the detectors THz responses, we used a commercial P-I-N diode emitter from TOPTICA Photonics AG / Fraunhofer Heinrich Hertz institute. We estimate the power of the P-I-N diode source to a few 100 μW around 100 GHz which gradually decreases to about 1 μW at 1 THz. The THz frequency results using the setup depicted in Fig. 2 for Zero-bias Schottky diode and GaAs FET based THz detectors are shown in Fig. 4. The frequency response trend of both the detector is different due to principle of operation, sensitivity, fabrication tolerances (due to different ways of fabrication process used for them) and substrate characteristics. At 0.1 THz, with time constant of 500 ms, GaAs FET THz detector features a dynamic range (DR) of 110 dB, while SD THz detector features 113 dB of DR. A low frequencies, performance of both the detectors is comparable. At 0.6 THz, the GaAs FET have 40 dB of DR, while SD have 58 dB of DR, which is higher than GaAs FET because of different rectification mechanism, sheet charge concentration and mobility of electron in both technologies. At 1.2 THz, GaAs FET have 20 dB of DR while compared to 30 dB DR with SD. The results obtained at IF and THz frequency responses are prospective with respect to the future development of these detectors. We can conclude that the post detection electronics is the bottleneck in terms of the IF frequency, while for THz frequency the sensitivity can be improved by impedance matching between the active area and the antenna. The implementation of the amplifier on chip inside the package will be to reduce additional losses being induced due to cables, connectors and other electrical components.

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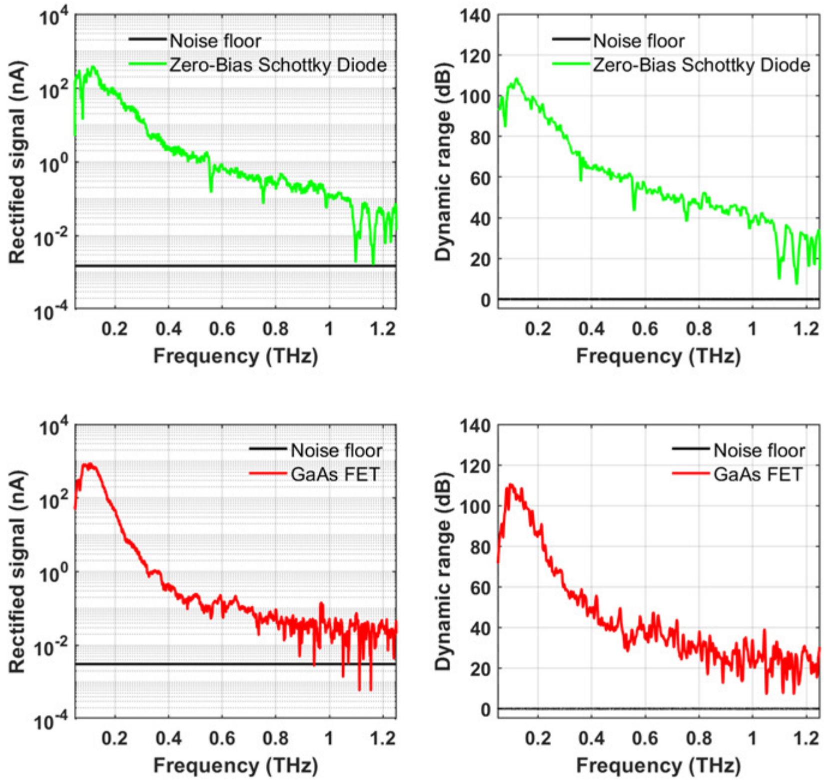

Figure 4: Top right: Rectified signal of Zero-bias Schottky diode, Top left: Dynamic range (DR) of Zero-bias Schottky diode, Bottom right: Rectified signal of GaAs FET, Bottom left: Dynamic range (DR) of GaAs FET

CONCLUSION

The study shown in this paper gives an insight view of THz as well as IF response of both types of detectors. The goal is the development of a highly sensitive, fast and stable THz detector, initially for particle accelerators, which can be used in another applications such as communications (higher IF provides higher video bandwidth). Also, this study redirects towards resonant GaAs FET THz detectors for higher sensitivity compared to their broadband counterparts. In future optimizing the IF circuitry can be useful to these detectors for communication applications, while the higher THz sensitivity will be useful to explore the THz band more extensively.

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