Optical Mixing in THz Schottky Diodes

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***Abstract*—This paper presents the effect of optical mixing in zero-bias InGaAs Schottky detectors at THz frequencies. The excitation of ultrafast carriers by illumination with two 1.5µm laser beams is verified. This proves the suitability of the diode for phase sensitive detection in CW THz systems.**

I. Introduction

OPTICAL mixing as a source of THz emission has its motivation in its wide frequency tuning range and its excellent frequency resolution. Particularly, it became a common technique in the last decade with regard to spectroscopic applications. A new generation of systems is based on 1.5µm optical wavelengths; they allow the use of all optical components developed for the telecommunication domain. This lowers the costs and enhances the reliability compared to the commonly used 0.8µm based systems.

At the moment, the 1.5µm region lacks coherent detectors which allow the measurement of amplitude and phase information. Recently, the operability of THz power detectors based on InGaAs Schottky diodes has been demonstrated by our group [1, 2].

In this paper we report about the applicability of our Schottky diode as mixing element for the 1.5µm optical beat signal and the RF signal for homodyne THz detection.

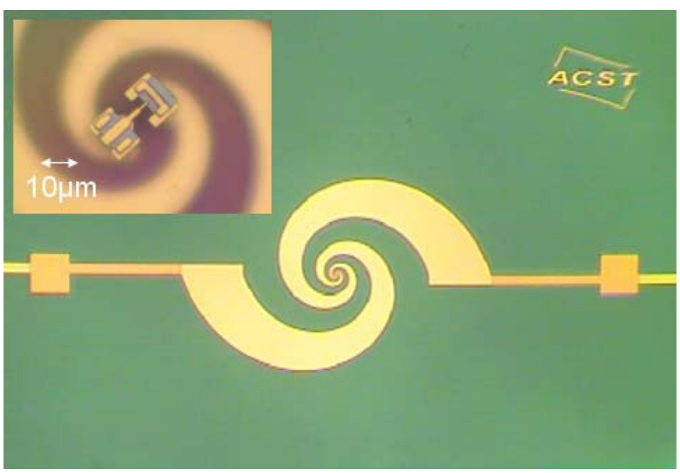

Figure 1: Photograph of the Schottky diode mounted on a spiral antenna. The inset shows the single diode in the center of the antenna.

II. Zero Biased Schottky Detector

The detector is fabricated by combining the planar InGaAs diode with a planar logarithmic spiral antenna. A photograph of the antenna with the diode is shown in figure 1. The low barrier of the material configuration of this diode provides the ability to operate the diode under zero bias condition, which dramatically reduces the noise of the detector. Small lateral pad dimensions make the diode capable for very high frequencies. Without optical mixing it can be used as a square law THz power detector. Measurable signals have been detected up to 1THz [2].

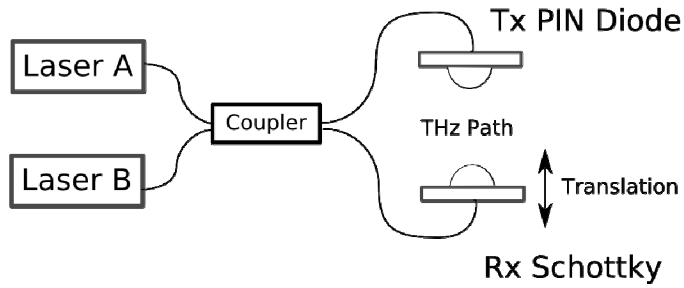

Figure 2: CW THz Measurement Setup. The optical part is single mode fiber based. Transmitter (Tx) and receiver (Rx) are mounted on Silicon lenses.

III. Measurement Setup

The optical signals are generated by two pigtailed DFB laser diodes working at 1.53µm. The signals are combined and split by a 3dB coupler, which results in an optical power modulated with the difference frequency of the lasers at the two fiber outputs of the optical part (Figure 2).

For homodyne mixing configuration a PIN photodiode based emitter is used [3]. It generates a THz radiation dependent on the difference frequency of the lasers.

The Schottky detector as receiver is mounted on a mechanical translation stage. By moving the receiver, the THz path length can be changed. The Schottky diode is illuminated with the second output of the optical system. The optical power is pumped into the active region by simply focusing the combined optical beam of both lasers on the Schottky diode using a lensed fiber. The smallest spot size of the fiber is 7µm, which is larger than the active area of the diode (~1µm^2). The detector current is measured by chopping the THz transmitter and using a lock-in amplifier at the receiver side.

Two different effects are combined at the detector. Firstly, the chopped THz radiation, collected by the antenna, results in an AC current in the device. Because of the nonlinearity of the Schottky contact this current can be measured as a DC signal at the detector. Secondly, when illuminating the active area of the diode with the second output of the optical coupler, photo carriers are excited, whereas the generation of the carriers is modulated by the difference frequency of laser beams. This results in a second AC current through the device. Both currents have the same frequency and are dependent on the beat signal of the optical system.

The measured signal is composed of the rectified THz radiation and the mixing of the incident THz radiation with the

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photocurrent. The mixed part is dependent on the phase relation between both currents. This phase relation can be affected by changing the length of the THz path. The DC signal at the diode is then modulated with $\cos(2\pi d/\lambda)$, where λ is the THz wavelength and d the THz path length.

IV. RESULTS

Figure 3 plots the IV characteristic of the diode under different level of illumination. The illumination has two different effects: It generates a negative photocurrent depending on the optical power and, furthermore, heats the device up changing the IV behavior. In the region above 50mV the increase of current due to the increase of temperature exceeds the generated photocurrent. In backward direction the thermal effects are smaller; the current is mostly affected by the photo generation of carriers. In this direction the generated photocurrent reaches up to 13µA at 4mW optical power.

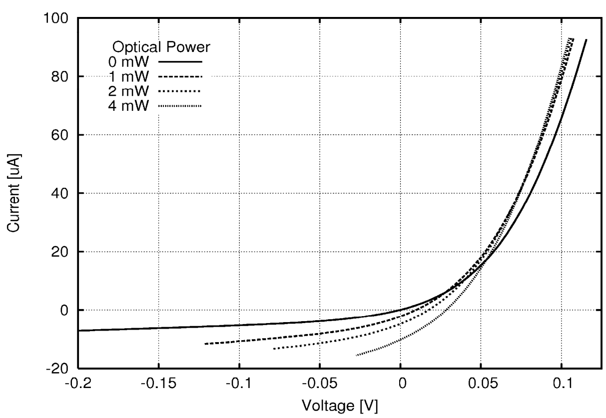

Figure 3: IV characteristic of the detector under different power of illumination. Abscissa denotes the total DC current through the device.

The continuous line in figure 4 shows variation of the dc current measured with the lock-in amplifier at the detector versus the relative THz path length at 300 GHz and zero bias operation. The current detected by the lock-in has a mean value of about 111.2nA due to the rectification and a modulation of ±20.8nA due to the mixing. Under these conditions the detector generates a DC current of 31µA. The bulk of this current is caused by the thermal gradient and the hole-diffusion process, because the optical beam was not optimally focused on the active diode area. Since these effects are too slow to follow the optical THz beat signal, they cannot contribute to the modulation current.

One drawback of the optical illumination is the increase of noise. Both, the increased temperature and DC current result together in a higher noise level compared to the zero bias power detection without illumination.

The suitability of the detector for phase measurements has been verified by identifying the refractive index of a silica glass. A 160µm thick glass plate has been placed in the THz beam in front of the detector. Figure 4 presents the dependency of the obtained signal versus the path length for a measurement with silica glass against the measurement without sample.

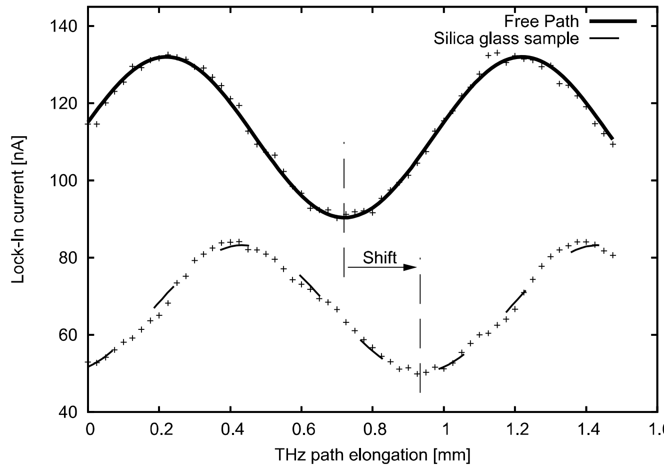

Figure 4: Chopped DC current versus relative THz path length at 300 GHz: First measurement with free THz path, second with silica glass sample placed between transmitter and receiver.

The insertion of the glass plate yields in a phase shift corresponding to a path difference of about 0.21mm, this means, that the refractive index of the glass plate is 2.31 times the refractive index of air. This result is in good agreement with reported values [4].

V. CONCLUSION

In conclusion, an InGaAs Schottky diode has been reported for the first time as mixing element for 1.5µm laser light and coherent THz power. It has been demonstrated, that this effect enables amplitude and phase sensitive measurements in CW THz systems based on the optical wavelength common in telecommunication systems.

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