Investigation of Parasitic Coupling of THz Radiation to a Large Area Field-Effect Transistor

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***Abstract* — THz radiation can couple in various undesired ways to THz detectors, e.g. through wires or contact pads, aggravating calculation of sensible values for the device responsivity. We therefore investigate coupling of THz radiation to antenna-less large area field-effect transistors with dimensions in the range of the THz spot size proving that only a very small fraction of power is coupled through the pads.**

I. Introduction

There are several examples of THz detectors in the literature with dimensions much smaller than the THz spot size, often without antenna, where it is difficult to estimate the amount of power coupled to the device [1,2]. In some cases, the authors claim extreme values of responsivity by assuming that the device receives only that amount of power impinging on its active area but neglect that the device is embedded into circuitry consisting of wirings and contact pads that may as well act as receiving elements. The power coupled to the device is thus severely underestimated, leading to overestimates of the responsivity.

In this paper, we investigate coupling of THz power to large area field effect transistors [3] that consist of arrays of transistors that are all connected in parallel, acting as one large active area which is larger than the THz spot size used in this experiment. These detectors have proven in the past to be excellently suited for detecting short THz pulses (<20 ps), are able to measure NIR and THz pulses with their respective intensity and temporal delay simultaneously [3,4], and can be used for autocorrelation measurements, even allowing for the measurement of the temporal pulse shape of the THz pulse [5]. Since field effect transistors only rectify signals polarized along the source-drain direction and since the LA-FET size is larger than the THz spot, we can discriminate whether a detected signal originates from the active area or from hitting a contact pad or wiring.

II. Experimental Setup

The measurements were carried out at 3.9 THz at the free electron laser FELBE at the Helmhotz-Zentrum Dresden-Rossendorf. The rectified signal of the LA-FET is measured using a transimpedance amplifier and a lock-in amplifier. A mechanical chopper in the THz path modulates the THz signal for lock-in detection. The setup is illustrated in Fig. 1 and in the inset of Fig. 2. The LA-FET covers an active area of 0.3 x 0.3 mm². The source (right pad) and drain (left pad) contacts are approximately 0.35 x 0.25 mm² in size, the gate pad (bottom) has dimensions of 0.13 x 0.5 mm². The device is mounted on a hyperhemispheric silicon lens of radius 5 mm and a total hyperhemispheric offset of 1.5 mm. The THz radiation is coupled to the device through the silicon lens. The spot size of the FEL pulse at 3.9 THz is estimated to 0.2 mm in the substrate at the device. The silicon lens integrated device is mounted on a 2D stage for scanning beam patterns. The silicon lens magnifies the dimensions of the device by about a factor of a:b=12 according to the schematic shown in Fig. 1. This factor is calculated by refracting the optical axis of a THz beam on the silicon lens surface. The beam pattern scans have therefore to cover an area in the range of >4 mm in each direction.

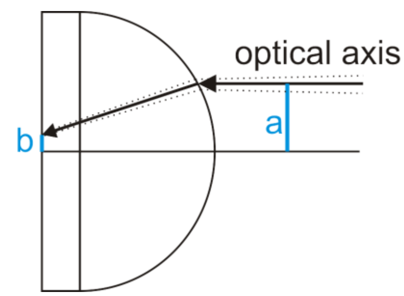

Fig. 1 Imaging of the THz beam by the silicon lens on the active area of the transistor.

III. Results

Fig. 2 shows the rectified signal of a 2D sweep in 0.25 mm steps with the THz polarization aligned parallel to the channels of the single FETs (z direction). The LA-FET is operated at the optimum gate bias of -0.2 V. The beam pattern shows a pronounced detection maximum close to the device center with a small shift towards the left. This shift is most likely attributed to slight misalignment of the device with respect to the silicon lens center. The device responds to THz radiation within a window of about 4.8 mm along the z-direction and about 4.5 mm along the x-direction. Taking the magnifying factor of the silicon lens into account, the imaged area on the device is about 0.38 x 0.4 mm² which corresponds well to the convolution of the THz spot size (0.2 mm) and the dimension of the active area (0.3 mm).

In the next step, the THz polarization is turned by 90° as shown in Fig. 3 which should yield no response if only the active area of the device is excited. Indeed, the device detects a faint signal with about a factor of 7 smaller amplitude than that shown in Fig. 2 and features the opposite sign. Interestingly, the response shows two pronounced elongated maxima that resemble the shape of the source and drain pads.

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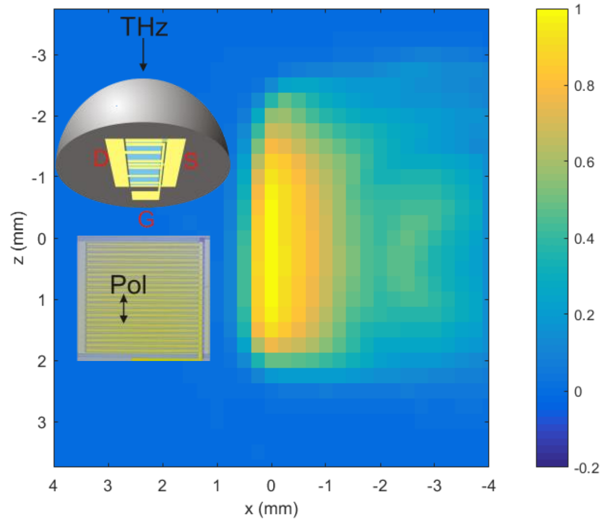

Fig. 2 Lateral scan of the Terahertz beam with a LA-FET at 3.9 THz. The rectified signal is normalized. The polarization is along the channels of the FETs in direction of the z axis. Inset: Schematic drawing of the LA-FET on the silicon lens and microscope image of the used LA-FET. The beam is incident from the backside though the silicon lens along the y-direction. It is scanned in x and z direction with respect to the transistor.

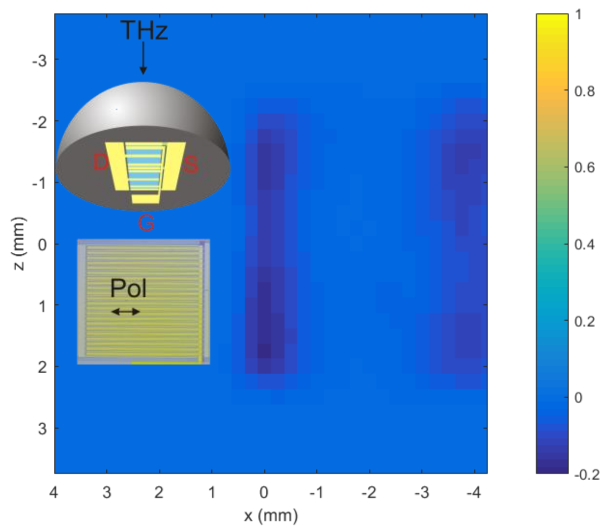

Fig. 3 Lateral measurement of the Terahertz beam with a LA-FET at 3.9 THz for the polarization perpendicular to the channels of the single FETs in direction of the x axis. The rectified signal is normalized the same way as Fig. 2. Inset: Schematic drawing of the LA-FET on the silicon lens and microscope image of the used LA-FET.

Taking the magnifying effect of the silicon lens into account, their distance on the detector surface is about 0.33 mm, i.e. approximately the dimension of the active area. The source and drain pads seem to act as antennas when excited very close to the active area. However, the signal amplitude is much smaller than that shown in Fig. 2 since the received signal has to travel from the pads to the rectifying FETs in the active area. For the LA-FET, this distance may be several wavelengths at the investigated frequency, being prone to radiative and metallic conduction losses, leading to the suppression by a factor of 7 in terms of detected power. The gate pad does not seem to show any response at all. This is reasonable, as the wiring from the gate pad to the gates of the active area is fairly long, of the order of 100 µm. The wiring is expected to have a high radiative loss at 3.9 THz. We also do not notice any off-axis elongated features and therefore can exclude coupling of THz radiation to wires connecting the pads. We note, however, for devices of the order of or smaller than the investigated THz wavelength and for spot sizes much larger than the active device area coupling to pads and wiring may be the dominant receiving mechanism as outlined in references [1,2].

IV. Conclusions

We conclude that for the LA-FET the majority of the detected signal originates indeed from the rectifying effect of the LA-FET excited by the polarization along the FET channels with very little contributions from wiring and pads. Unwanted contributions are a factor of 7 lower than the ordinarily detected signal. This strong suppression is attributed to the LA-FET being larger than the THz spot.

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