Imaging of a THz beam with Si-MOSFET detectors

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Abstract—Silicon metal-oxide-semiconductor field-effect transistors with four different types of planar antennas were used to scan the cross section of radiation beams of 0.1 THz and 0.336 THz. Transistors were mounted on a support and bonded with Au wires. We show that the map of the power distribution in the beam cross-section depends on details of mounting of a transistor (in particular, on a configuration of bonding wires) as well as on the orientation of the antenna with respect to the direction of the radiation polarization.

I. INTRODUCTION

IMAGING is one of the most important applications of THz radiation. There are many examples of imaging systems which are based on cw [1] or pulsed sources [2]. Since THz multipixel cameras are only at the first stage of development, imaging is typically carried out with a single pixel detector. Usually, in the case of an object imaging, a source and a detector are kept in a fixed configuration and the object is moved. On the other hand, if one wants to characterize the radiation beam, a detector must be moved while the beam position is fixed. Our experiments concern the latter case with silicon metal-oxide-semiconductor field-effect transistors (Si-MOSFETs) used as single pixel detectors. The idea of application of FETs as detectors of the electromagnetic radiation originates from a theoretical prediction by Dyakonov and Shur [3] who showed that a source-to-drain photovoltage was generated in a FET under an incident radiation. This theoretical proposal was confirmed in many experiments (for a review, see, e.g., [4]). Si-MOSFETs gained a particular position after it had been shown that they could be detectors of THz radiation [5] and they exhibited a very low signal-to-noise ratio at room temperature [6]. Recently, a multi-pixel camera based on Si-MOSFETs was demonstrated [7]. The idea of testing single Si-MOSFETs in a detection set-up comes from the fact that they can be better optimized for particular applications, e.g., by coupling with antennas designed for a given frequency band [7].

II. RESULTS

The experimental system consisted of THz sources and optical elements (lenses and mirrors) which allowed to form a parallel beam of a diameter of about 3 cm. The sources used were a Gunn diode operating at 100 GHz and a frequency-multiplier-based source (by Virginia Diodes, Inc.) operating at 336 GHz. A detector was placed on a x-y-z scanner and the signal was registered with a lock-in technique to give a map of a THz power distribution in a cross-section of the beam. The shape of the beams was first determined with a pyroelectric detector. In the case of both sources, the beam was found to be of a Gaussian shape.

NMOS transistors with monolithically coupled antennas were fabricated within the device layer of a SOI substrate. Each transistor resides on a separate chip of about 3 mm x 3 mm. The chip was glued to a metallic plate of a home-made DIL support and bonded to the bond pads. An example of a bonded transistor is shown in Fig. 1.

![Fig. 1. An example of a transistor bonded to a support with three gold wires connecting the source, drain and gate electrodes to the bonding pads on a support.](image)

We investigated four types of antennas which are described in detail in [8]. For each type of antenna we tested three nominally identical MOSFETs; each of them was, however, mounted in a different way. We changed the orientation of the chip with respect to the support (turning the chip visible in Fig. 1 by 90 degrees) and changing the direction of the bonding wires.

Let us note that there are two factors which break the symmetry of the experimental set-up. First, all antennas investigated were designed to be polarization-sensitive which means that a transistor response to the radiation depends on the angle between the the source-drain line and the direction of polarization of the beam. Second, both sources used in the experiment generated a linearly polarized beam. It is thus obvious that the amplitude of the signal must depend on the orientation of the transistor with respect to the beam polarization, the letter being kept constant in the experiment.

However, an unexpected result of the experiment was that the observed distribution of the power in the beam cross-section was different for different transistor bonding schemes. An example of this observation for one type of an antenna is given in Fig. 2. In these cases, the direction of the beam polarization coincided with the direction of the high sensitivity of the antenna but the bonding wires were positioned in a different way for the three scans.
We interpret these results as a convolution of two factors. The first one is that the bonding wires and the chip itself must be considered as forming a part of an antenna. The second one is that the response of the MOSFET is strongly dependent on details of a distribution of the electromagnetic excitation of the electron plasma in the channel. We think that modelling the experimental situation requires a detailed numerical analysis, particularly in the case when typical dimensions of the detector are comparable with the THz wavelength.

III. SUMMARY

In conclusion, we carried out a detailed investigation to get cross-scans of THz beams with single Si-MOSFET detectors with different lithographically designed antennas and different bonding schemes. We observed a strong dependence of the obtained images on details of mounting of the transistors. Also, polarization sensitivity was in some cases strongly influenced by the mounting geometry.

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REFERENCES


Fig. 2. An example of the scan of a 100 GHz linearly polarized beam with nominally identical transistors, differently bonded for each scan. The vertical and horizontal scale are in mm. The colour scale (in Volts) gives the signal amplitude read by the lock-in.

Practically in all cases we observed deviations from a Gaussian shape registered by a pyroelectric detector. Also, in some cases, a sensitivity of the detectors to the direction of the THz radiation polarization was much smaller than expected.