An Antenna-Coupled Dual-Gated Electron Channel as Direct Detector of 2 THz Radiation

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***Abstract*—An antenna-coupled dual-gated two-dimensional electron gas (2DEG) based on a GaAs-AlGaAs heterostructure shows a pronounced response to 2 THz radiation and is used as a direct detector. The novel detection mechanism yields a photoresponse of quantum-mechanical origin that is more than 10-fold stronger than predicted by the classical plasma-wave self-mixing and other mechanisms.**

I. INTRODUCTION

EFFICIENT detection of terahertz (THz) radiation is of paramount importance for the progress of terahertz science and technology. A number of detection mechanisms utilizing 2DEGs in semiconductor heterostructures have been proposed so far. Some of them exploit plasmonic rectification in field effect transistors due to the nonlinearity of hydrodynamic equations describing the electron motion and plasma oscillations in a uniform 2DEG [1,2], an effect that depending on the frequency is also referred to as distributed resistive self-mixing [3,4]. Other methods rely on THz photoconductance measurements of narrow gates made in the form of quantum point contacts [5,6]: the gate biasing makes the 2DEG non-uniform, and the THz response is achieved by exploiting electron heating [5] and/or photon-assisted tunneling [6] mechanisms. This was shown to successfully detect radiation at sub-THz frequencies (0.69 THz), yet not at higher frequencies (e.g. 1.63 THz in [6]).

II. SETUP AND MEASUREMENT

In this work, we fabricate a dual-gate field effect transistor based on a GaAs-AlGaAs heterojunction. The wafer structure, shown in Fig. 1, was grown by molecular beam epitaxy. The samples were then processed, using optical and electron beam lithography, into narrow (2 µm) channels.

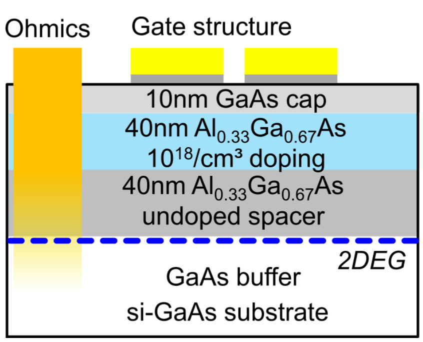

Fig. 1. Wafer heterostructure deposited by molecular beam epitaxy.

Source and drain Ohmic contacts were added, and the sample was covered by a TiAu gate structure integrated with a bow-tie antenna, to focus the THz radiation on the 2DEG channel. The gates and the 2DEG are separated by 90 nm.

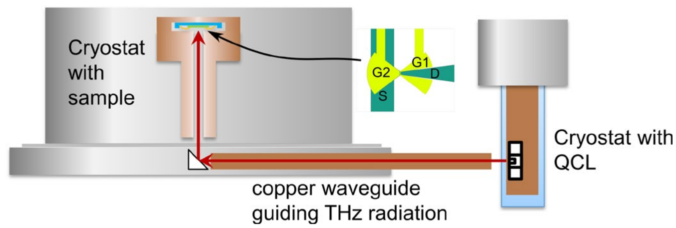

Fig. 2. Schematic setup with two liquid helium cryostats coupled by a copper waveguide delivering THz radiation to the sample.

For stable alignment and intensity quantification purposes, we built a setup consisting of two liquid helium continuous flow cryostats coupled together by a waveguide, Fig. 2. A single-plasmon quantum cascade laser is located in the right cryostat and cooled to a temperature of ~18 K. It irradiates the sample with square-wave modulated 2 THz radiation with a frequency of 772 Hz and a low duty cycle (2.14 %). In the left cryostat is the 2DEG sample cooled to 9 K. The transmission from the waveguide input to the sample space is 60 %. The absolute power density at the sample is measured using a Golay cell and a Thomas Keating absolute power meter. In our case, the maximum peak intensity is 0.29 mW/mm² during a QCL pulse (or 6.3 µW/mm² time-averaged).

III. RESULTS

The device shows a DC photovoltage and photocurrent response under zero source-drain bias, indicating successful direct detection of the radiation. The two gates allow simultaneously maximizing the THz response and tailoring the output impedance of the device. This facilitates impedance matching to external circuits. The same device can be switched between either low noise mode or high bandwidth mode by adjusting the operating point using the two gate voltages. A conservative estimation for the responsivities is >6.4 kV/W in photovoltage mode and >0.23 A/W in photocurrent mode.

The operation of the demonstrated direct THz detector in photovoltage mode is shown in Fig. 3: The output power of the QCL used is shown as a function of the voltage level of the current pulses driving it. Detection was carried out using a DC voltage measurement with the demonstrated detector (red line). It is compared to a separate lock-in measurement of the QCL output power with a Golay cell (black line). A great agreement is achieved up to a voltage of 6.2 V, above which the QCL becomes unstable and starts to switch to a different mode.

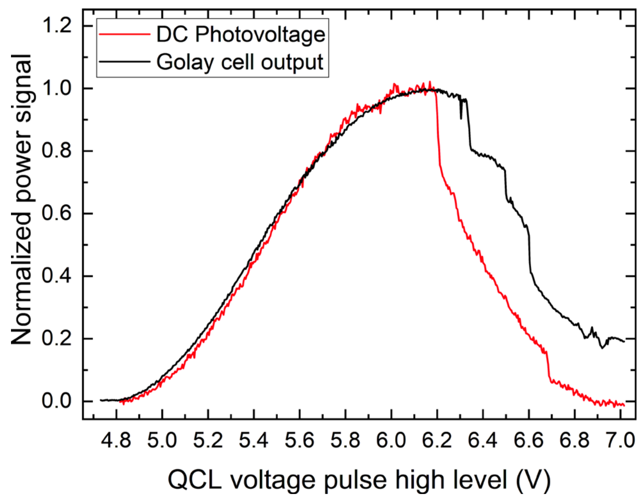

Fig. 3. Normalized QCL output power as a function of the high level of the voltage pulses driving the QCL. Black line: Golay cell response obtained by a lock-in measurement; red line: DC photovoltage of the detector device.

Careful analysis of the obtained results shows that the classical mechanisms [1-5] are unable to explain the observed effect. Estimations show that the magnitude of the photoresponse predicted by these mechanisms under the experimental conditions is at least an order of magnitude smaller than the experimentally observed photoresponse. A tunneling-related mechanism such as in [6] can be ruled out due the thickness of the barrier, >4 µm. Heating-related phenomena such as bolometric and thermoelectric effects can be excluded due to the large mean free path (18 µm) in the wafer material. The photoresponse is based on a purely quantum-mechanical phenomenon transferring electrons across a potential barrier under incident electromagnetic radiation, that has not been described so far. The demonstrated detection mechanism presents new opportunities for power measurements and timed event detection in applications of THz technology.

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