Low-temperature THz magnetospectroscopy of silicon metal-oxide-semiconductor field-effect transistors

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Field effect transistors can be used as detectors of THz radiation. The detection signal - a photovoltage (PV) measured between the source and the drain - is generated due to a nonlinear high frequency conductivity of electrons in the transistor channel and an asymmetry between the drain and the source of the transistor. In theory, the detection signal is predicted to be a resonant or non-resonant (i.e., the transistor response is spectrally narrow or broad) depending on the electron relaxation time. In practice, only a non-resonant detection in silicon metal-oxide-semiconductor field-effect transistors (Si-MOSFETS) has been proved to be adequate for commercial applications.

We investigated a set of MOSFETs with the channel dimensions of 5 μm x 10 μm. They were supplied with planar antennas which allowed for a better coupling of the incident radiation with the electron plasma in the transistor channel. Transistors were tested both at the room and liquid helium temperatures. In the case of low-temperature measurements, which are of interest here, the THz radiation was guided to the sample through an oversized steel tube. We used single frequency THz sources covering the range 0.05 THz – 0.336 THz. To register the signal, a lock-in technique was used with the reference frequency equal to that of on/off THz beam modulation.

All transistors were characterized by magnetotransport measurements which allowed to determine a dependence of the electron concentration in the inversion layer on the gate polarization (V_G) by an analysis of Shubnikov - de Haas oscillations measured at different V_G. PV spectra were measured as a function of V_G and the magnetic field (B). A PV(V_G) dependence showed a maximum at V_G close to the threshold voltage, which is a typical, predicted by a theory, dependence observed in this type of experiments. In some of transistors, additional features were observed which position in B moved with the THz frequency as a cyclotron resonance of an electron in *bulk* Si (an effective mass equal to $0.95m_e$). Also, a B-independent splitting of this feature was observed in the range 3 T $< B <$ 12 T. These observations allow to interpret the observed features as resulting from a cyclotron resonance and impurity-shifted cyclotron resonance in heavily phosphorus-doped regions of the transistor source and drain.

In conclusion, THz spectroscopy allowed to characterize a low-temperature performance of Si-MOSFETs with planar antennas. The observed spectra show features which are related both to two-dimensional as well as three-dimensional parts of the transistor.

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