3D Rectification Effect in InP-HEMT-Based Grating-Gate Plasmonic THz Detector

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For THz wireless communications, we have developed the so-called grating-gate (GG) plasmonic terahertz (THz) detectors based on InP-based high-electron-mobility transistors (HEMTs) [1, 2], which are highly sensitive, high-speed, room-temperature-operating, and monolithically integrable with HEMT-based amplifiers. The grating gates serve as a sub-wavelength grating coupler and thus enable broadband, direct coupling between incident THz waves and 2D plasmons in the channel, while the plasmonic hydrodynamic nonlinearities are responsible for the generation of DC photocurrent [2]. Recently, we have demonstrated that the scaling of the photovoltage with the active area size of a GG plasmonic detector and the impedance matching to a 50-Ω interconnection system can be realized by using one of the gate electrodes as a readout port of the photovoltage (gate readout), resulting in the one-order-of-magnitude higher responsivity than with the conventional drain readout [3]. Furthermore, with the gate readout, the utilization of the nonlinear rectification effect by the electron transport at the heterobarrier diode in the direction normal to the channel (formed between the InGaAs channel and the InAlAs spacer/carrier-supply/barrier layers) is expected together with the 2D plasmonic hydrodynamic nonlinearities, producing a 3D rectification effect.

In this work, we demonstrated that the nonlinear rectification at the heterobarrier diode is induced by the application of the positive gate bias voltage to a GG plasmonic THz detector and the output photovoltage is greatly enhanced. We designed and fabricated a GG plasmonic THz detector (Fig. 1(a)). We measured output photovoltage of the fabricated device from the gate 2 electrode using a digital storage oscilloscope upon pulsed-CW THz-wave irradiation centered at 0.95 THz generated by an injection-seeded THz-wave parametric generator. The drain voltage, V_{DS}, and the gate 1 voltage, V_{G1}, were set to zero, while we applied either negative or positive bias voltage to the gate 2, V_{G2}, corresponding to the usual detector operation of the GG plasmonic detector as in previous works [1, 3] or to the bias condition for the nonlinear rectification at the heterobarrier diode, respectively. The temporal waveforms of output photovoltage signals in Fig. 1(b) clearly demonstrate that the peak photovoltage corresponding to the peak input THz pulse is one-order-of-magnitude higher for the positive gate bias application. The dependence of the peak photovoltage on the gate 2 voltage depicted in Fig. 1(c) clearly demonstrates that the photovoltage significantly increases as the gate 2 voltage increases. The increase is almost exponential near the "photo-threshold" voltage, which agrees well with that of the diode-like photocurrent-gate 2 voltage characteristic shown in the inset of Fig. 1(c). The rectification process starts from the 2D plasmon excitation by the THz radiation incidence, originating harmonic 2D plasmonic photocurrents in the channel. The heterobarrier diode exponentially emphasizes the nonlinearity of the photocurrent to be multiplied by the diode nonlinearity, resulting in the enormously amplified 3D rectification. This work was financially supported by JSPS KAKENHI #18K04277, #18J21073, #18H053311, and #20K20349, Japan.

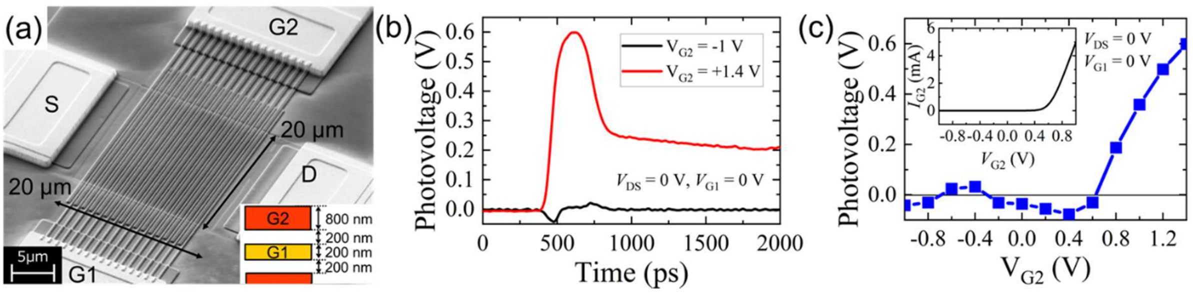

Figure 1. (a) A scanning-electron microscopic image of a GG plasmonic THz detector, (b) temporal waveforms of output photovoltage signals from the gate 2 electrode of the device with negative and positive bias voltages (-1 and +1.4 V), and (c) dependence of the peak photovoltage of the device on gate 2 voltage.

References

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