Broadband Characteristics of Ultrahigh Responsivity of Asymmetric Dual-Grating-Gate Plasmonic Terahertz Detectors

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***Abstract*—We report on the intrinsic responsivity of an asymmetric dual-grating-gate plasmonic detector over 100 kV/W at 200 GHz and 50 kV/W at 300 GHz measured at room temperature with zero source-drain bias. We demonstrate that broadband characteristics of the responsivity depend much on the geometrical parameters of the detectors.**

I. INTRODUCTION

REALIZING sensitive, high-speed terahertz (THz) detectors operating at room temperature is one of the most challenging problems in THz wireless communications. Recently, detectors based on plasmons in two-dimensional (2D) electron channels, which were proposed by Dyakonov and Shur [1], have made remarkable progress. We reported on ultrahigh intrinsic responsivities of the so-called asymmetric dual- grating-gate (A-DGG) plasmonic detectors based on InP high- electron-mobility transistors, shown in Fig. 1(a), at room temperature with zero source-drain bias [2,3].

The ultrahigh responsivities originate from (1) strong hydrodynamic nonlinearities of 2D plasmons, (2) efficient coupling of incoming THz wave to the plasmons via the grating gates, (3) creation of plasmonic cavities with high electron concentration and voltage-readout regions with low electron concentration in the 2D channel by two types of gates, and (4) asymmetric placement of the gates which induces huge unidirectional photocurrent [4]. The fourth factor enables detection without source-to-drain bias and thus, with very low noise. Conversely, the responsivity can be dramatically improved by applying the source-to-drain bias [5,6].

In this work, we measure the intrinsic responsivity of an A-DGG plasmonic detector at room temperature with geometrical parameters different from those measured previously [2,3], and we report on the responsivity over 100 kV/W at 200 GHz and 50 kV/W at 300 GHz. By comparison with the previous results, we demonstrate that broadband characteristics of the responsivity depend much on the geometrical parameters.

II. EXPERIMENTAL

Samples of A-DGG plasmonic detectors were fabricated using InAlAs/InGaAs/InP material system. Two types of A-DGGs, G1 and G2, were formed with 156-nm thick Ti/Au. The 2D electron channel is formed in a 16-nm-thick, undoped InGaAs layer sandwiched between undoped InAlAs barrier layers; the upper barrier layer contains remote-doping layer inside. The electron concentration in the channel is 2.5×10^{12} cm^{-2} with the electron mobility = 11,000 cm^2/Vs at room temperature. Geometrical parameters of samples are listed in Fig. 1(b).

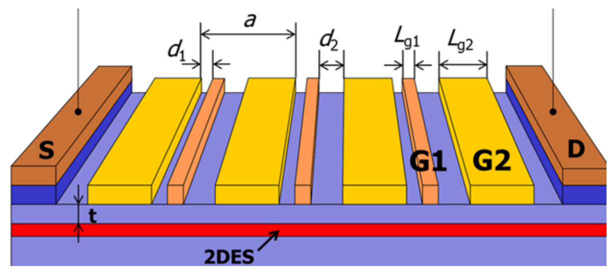

Fig. 1. Schematic view of an A-DGG plasmonic detector.

We measured the photovoltage of the A-DGG HEMT samples upon input THz waves at normal incidence, with polarization parallel to the source-to-drain direction, and under room-temperature and zero source-to-drain bias conditions. The detection system for 200 GHz has a CW THz source with power 2.8 mW and a spot size 2 mm in diameter. The THz wave was focused onto the top surface of the samples by TPX lenses (see [7] for details). The 292-GHz detection measurement was conducted using the similar experimental system shown in [2]. A THz source with power 2 mW and a spot size 4 mm in diameter was focused onto the top surface of the sample by parabolic mirrors. In both systems, the THz sources consist of microwave signal-generator and multipliers. On the other hand, the detection measurement for 1 to 2 THz was performed using a ring-cavity THz parametric oscillator source [8] that generates a monochromatic THz pulse with repetition rate 500 Hz and average power 4 μW at 1.5 THz, with focusing by a Tsurupica™ lens.

Table 1. Geometrical parameters in this work (sample #1) and in Refs. [2,3] (sample #2) (all length in μm).

Sample #	L_{g1}	L_{g2}	d_1	d_2	Active area
1	0.4	1.6	0.4	0.8	20×20
2	0.2	1.6	0.2	0.4	20×20

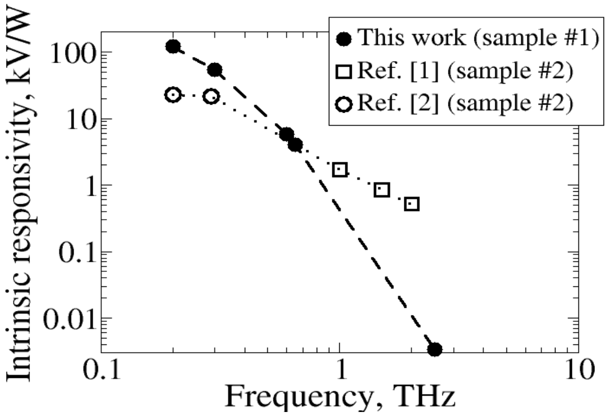

Fig. 2. Responsivity of samples #1 and #2 vs frequency.

III. Result And Discussion

Figure 2 shows the measured broadband characteristics of responsivity of samples #1 and #2. The responsivity of sample #1 is over 100 and 50 kV/W at 200 and 300 GHz, respectively. Fig. 2 illustrates significant difference between the broadband characteristics of samples #1 and #2; in 200-300 GHz the responsivity of the former is much larger, whereas at higher frequencies it decreases steeper than the latter.

This can be attributed to a difference in diffraction patterns of the incident THz wave by the different grating-gate geometries. The difference in the diffraction pattern in one grating-gate geometry leads to, say, an increase in the amplitude of travelling plasmon in one direction (and decrease in another) excited by the diffracted THz wave in the former case. According to [4], the plasmonic drag photocurrent, which is dominant in the lower frequency region ($\omega\tau < 1$), should be enhanced by the amplitude difference. On the other hand, the plasmonic ratchet photocurrent, which is dominant in the higher frequency region ($\omega\tau > 1$), should be reduced in such a case. In total, it results in the enhancement of responsivity in the lower frequency region and its reduction in the higher frequency region.

IV. Summary

We have demonstrated the ultrahigh intrinsic responsivity of an A-DGG plasmonic detector over 100 kV/W at 200 GHz and 50 kV/W at 300 GHz and have shown dependences of the responsivity on the geometrical parameters. Those results suggest that the responsivity as well as its broadband characteristics can be controlled/optimized by the appropriate choice of geometrical parameters.

Acknowledgments

This work has been supported in part by SCOPE (No. 145002001), Japan, and by the JST/ANR "WITH," a Japan-France strategic collaborative research project. Y.M.M. acknowledges the financial support from the MINECO through the Project No. TEC2012-32777. V.V.P. acknowledges the support by RFBR through Grant Nos. 12-02-00813 and 14-02-92102.

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