Student Paper

Ultrahigh Sensitive Plasmonic Terahertz Detector Based on an Asymmetric Dual-Grating Gate HEMT Structure

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We report on ultrahigh sensitive, broadband terahertz (THz) detectors based on asymmetric double-grating-gate (A-DGG) HEMTs demonstrating a record responsivity of 2.2 kV/W at 1 THz. Hydrodynamic nonlinearities of two-dimensional (2D) plasmons in high-electron-mobility transistors (HEMTs) are promising for fast and sensitive rectification/detection of THz radiation [1], which can be applied to real-time THz imaging/spectroscopic analysis and future THz wireless communications [2]. Recently, InP- and GaN-based HEMTs as well as Si-MOSFETs have demonstrated improved responsivities [3,4], approaching 1 kV/W at 1 THz by introducing narrow-band dipole antenna structure merged with the gate electrode [3].

We propose an A-DGG structure shown in Fig. 1 which can greatly enhance the asymmetry of the cavity boundaries by applying different gate voltages V_{g1} and V_{g2} to the two different sub-gratings of the A-DGG. Terahertz electric field distribution and resultant photovoltaic response were numerically simulated using a self-consistent electromagnetic approach combined with the perturbation theory for the hydrodynamic equations for 2D plasmons in HEMTs [5]. Strong build-in asymmetry in the unit cell of the structure can be created by introducing the A-DGG structure. The THz photoresponse dramatically increases if the parts of 2D channel under the fingers of one of the two sub-gratings are depleted. Strong THz photocurrent is generated by the nonlinearity of the plasmon mode resonantly excited in undepleted portions of the 2D electron channel under the unbiased sub-grating of the A-DGG while depleting the channel under the other (biased) sub-grating greatly enhances the channel resistance. Hence, enormous enhancement of the photovoltage is induced between the source and drain contacts of the entire A-DGG-HEMT structure. Figure 2 shows giant enhancement (by four orders of magnitude) of the responsivity in respect to that for a symmetric DGG HEMT.

A-DGG HEMTs have been designed and fabricated using InAlAs/InGaAs/InP material systems (see Fig. 1). Two grating gates G1 and G2 were formed with 65-nm thick Ti/Au/Ti. The geometrical parameters of the A-DGG HEMTs are summarized in Table I. Asymmetric factor, the ratio of the inter-finger spaces, $d1/d2$, was fixed to be 0.5. Moreover a chirped grating structure for the G1 finger L_{g1} was introduced, which can compensate the electron density chirp along the channel under a specific drain-source bias V_{ds} condition so as to uniform the plasmon frequencies [6].

We conducted room temperature THz photovoltaic measurements with the fabricated detectors using a ring-cavity THz parametric oscillator source delivering tunable monochromatic THz pulsed waves with frequencies from 1 to 3 THz (see Fig. 3) [7]. The responsivity was estimated as $R\text{v} = \Delta U * S_t / (P_t * S_d)$ where ΔU is the THz-radiation induced dc drain voltage, P_t is the total power of the source on the detector plane, S_t is the radiation beam spot area, and S_d is the active area of the detector. Figure 4 shows the measured responsivity of detector #2-4 at 1 THz under zero V_{ds} condition as a function of gate voltage swing ($V_{g1,2} - V_{th}$); dc voltage of G1: V_{g1} (G2: V_{g2}) is swept while V_{g2} (V_{g1}) is floated (biased at 0 V). The best result with Rv = 2.2 kV/W was obtained when sweeping V_{g1} to the thleshold V_{th}. It is worth to stress that even at higher frequencies relatively high responsivities are obtained with detectors #2-3 having shorter L_{g1}. As seen in the inset of Fig. 4, the responsivities monotonically decrease from 1.7 kV/W at 1 THz to 0.52 kV/W at 2 THz. All these values are, to the authors' knowledge, the best ever reported at these frequencies. Figure 5 demonstrates excellent noise equivalent power (NEP) for detectors (a) #2-4 and (b) #2-3 as a function of $V_{g1,2}$. The detector #2-3 exhibits extremely low NEP with the minimal value 15 pW/Hz$^{0.5}$ at 1 THz. These values are lower than those of commercial room temperature THz detectors such as Golay cells (200–400 pW/Hz$^{0.5}$) or SBDs (100 pW/Hz$^{0.5}$) [4].

In conclusion, InP-based A-DGG HEMTs demonstrate a record responsivity of 2.2 kV/W at 1 THz with a superior low NEP of 15 pW/Hz$^{0.5}$. These results give a major breakthrough towards the achievement of ultrahigh sensitive THz detectors for room temperature operation.

References

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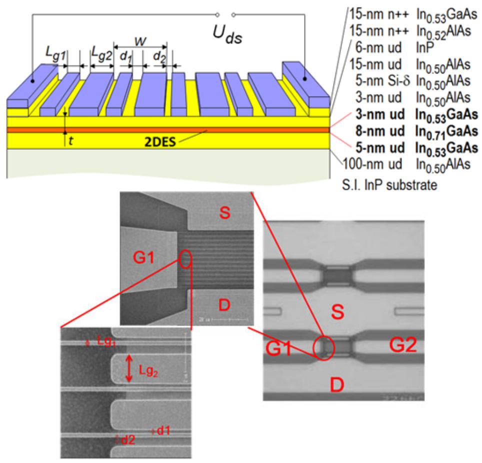

Fig. 1. Schematic view and SEM images of an asymmetric double-grating-gate (A-DGG) HEMT THz detector. L_{g1} = 200 nm, L_{g2} = 400 nm, d_1 = 200 nm, d_2 = 400 nm.

Table I. Design parameters.

Sample #	2-3	2-4
L_{g1} (nm)	215～430	400～705
d_1/ d_2 (nm)	200/400	400/800
L_{g2} (nm)	1600	1600
# of fingers: G1/G2	8/9	6/7
Active area (μm^2)	20 x 20	20 x 20

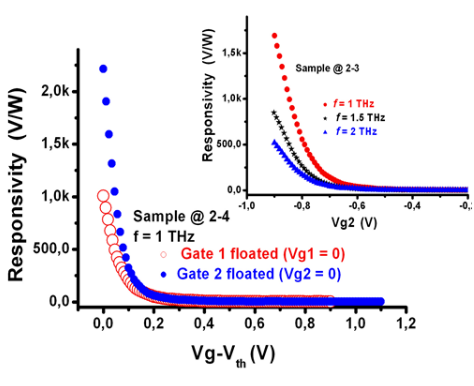

Fig. 4. Responsivity of detector #2-4 as a function of gate voltage swing (V_{g1}-V_{th} or V_{g2}-V_{th}) at 1 THz. The inset: responsivities of detector #2-3 at 1, 1.5, and 2 THz as functions of V_{g2} when G1 is floated.

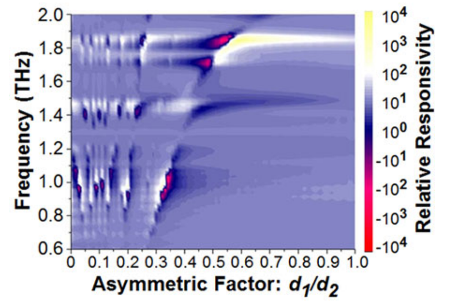

Fig. 3. Simulated relative responsivity for an A-DGG HEMT. L_{g1} = 400 nm, L_{g2} = 2.4 μm, $d_1 + d_2$ = 800 nm, W = 3.6 μm. Electron density under the gate G1 and G2 are 2.5x10^{12} and 2.5x10^{12} cm^{-2}, respectively.

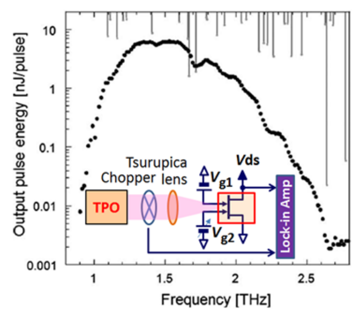

Fig. 4. Experimental setup and output profile of the tunable THz parametric oscillator (TPO) used as the light source.

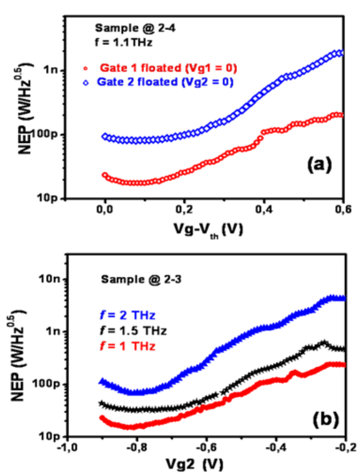

Fig. 5. Measured noise equivalent power for (a) sample #2-4 at 1 THz as functions of the gate voltage swings V_{g1}–V_{th} and V_{g2}–V_{th} and (b) sample #2-3 at 1, 1.5, and 2 THz as a function of the gate voltage swing V_{g2}–V_{th}.