PS-9-12

Extended Abstracts of the 2013 International Conference on Solid State Devices and Materials, Fukuoka, 2013, pp318-319

Photoresponse Enhancement of Plasmonic Terahertz Wave Detector Based on Asymmetric Silicon MOSFETs with Antenna Integration

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1. Introduction

Since terahertz (THz) wave detection mechanism by using oscillations of channel plasma waves based on a field-effect transistor (FET) structure was proposed by Dyakonov and Shur [1], many research works for plasmonic THz detectors have been performed with FET structure where the photoresponse Δu appears in the form of dc voltage (V) between source and drain, which is proportional to the radiation power P (W) [2]. Therefore, responsivity R_V, which can be defined by the ratio Δu /P (V/W), is the important performance metric of the plasmonic THz detectors and thus, researches for the enhanced responsivity have a lot of attention recently. In order to induce such a dc voltage of photoresponse from a given radiation power, some asymmetry between the source and drain is needed such as the difference in the source and drain boundary conditions by using some internal [3] or external capacitances [4], and the asymmetry in feeding the incoming radiation with a special antenna [5].

In this work, we demonstrate the experimental results for the enhanced responsivity R_V in silicon (Si) metal-oxide-semiconductor (MOS) FET-based plasmonic THz detector with asymmetric source and drain structure having monolithically integrated antenna for sub-THz frequency detection regime.

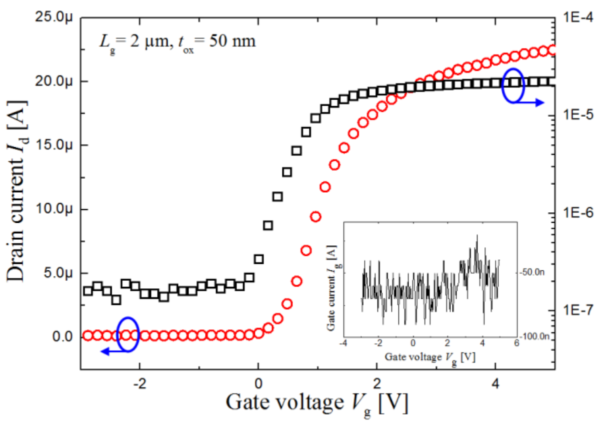

Fig. 1 I_d-V_g curves of the fabricated Si-FETs. The threshold voltage V_{th} extracted from these DC curves at V_d= 1 V. Inset shows the negligible gate current for all gate voltages.

2. Fabrication and Experiments

The devices with L_g= 2 μm, and t_{ox}= 50 nm were fabricated on the 1 × 10^{15} cm^{-3} p-doped <100> Si wafer. The threshold voltage (V_{th}) extracted from the transfer characteristics at low drain bias was within the range of V_{th}= 0.4~0.6 V for all devices (see Fig. 1).

Figure 2 shows the image of the fabricated FET-based THz detectors monolithically integrated with bow-tie antenna. The architecture of the bow-tie antenna has been designed for a single FET operating condition with a connection between gate and source terminal as THz wave detecting element. It can be noted that the wide-band detection is the advantage of bow-tie antenna structure for non-resonant plasmonic THz detection regime. The micrograph image shows the fabricated Si FET with asymmetric source and drain structure. Asymmetric structure condition is determined by split of the source width W_S as 2 μm, 4 μm, 10 μm, and 20 μm with the fixed drain width W_D= 20 μm. The corresponding asymmetry ratio η_a (= W_D/W_S.) would be 10, 5, 2, and 1 respectively.

3. Results and Discussion

The sub-THz radiation with frequency f= 0.2 THz was generated by a gyrotron source in higher order mode resonator, which enables real-time detection with the continuous-wave (CW) method since it is stable in sub-THz frequency regime [6].

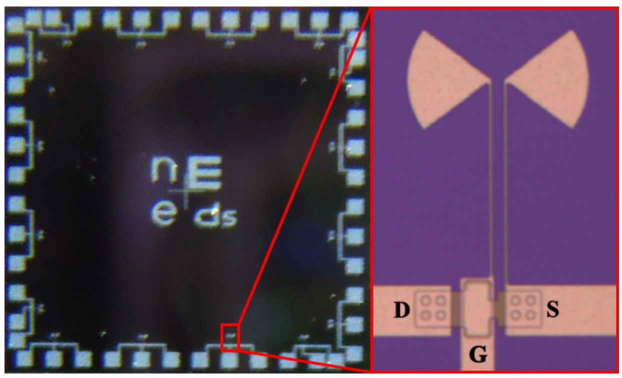

Fig. 2 Photo image of the detector sample. Inset shows Micrograph (top view) of the fabricated Si FET with asymmetric source and drain. The bow-tie antenna has been integrated on electrode metal of gate and source.

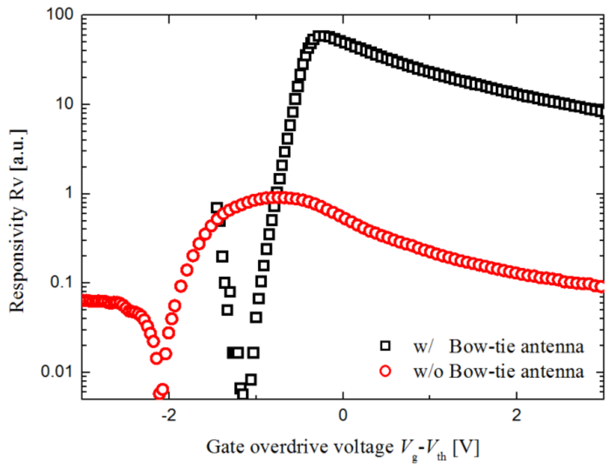

Fig. 3 Experimental results of the Si FET response signal to 0.2 THz radiation. The responsivity has been normalized by maximum value w/o antenna (red circle) with arbitrary unit in order to confirm the relative responsivity results for the effect of antenna.

As shown in Fig. 3, the non-resonant plasmonic response signals to 0.2 THz radiation from gyrotron source have been successfully observed in the subthreshold region (V_g-V_{th} < 0) of the fabricated Si FET detectors with or without (w/o) antenna structure. The responsivity has been normalized by maximum value of the w/o antenna (red circle) with arbitrary unit in order to confirm the relative responsivity enhancement effect of the antenna. In comparison with the symmetrical source and drain structure (asymmetry ratio η_a=W_D/W_S=1, where W_D and W_S are gate-overlapped drain and source width, respectively) as reference, the photoresponse of the w/ antenna structure (asymmetry ratio η_a= W_D/W_S= 10) has been enhanced about 60 times.

Figure 4 shows the normalized experimental data R_V versus polarization and indicates that the peak R_V occurs at the different rotation angle by considering the polarized THz radiation effects with the bow-tie antenna on the photoresponse. From this result, it should be noted

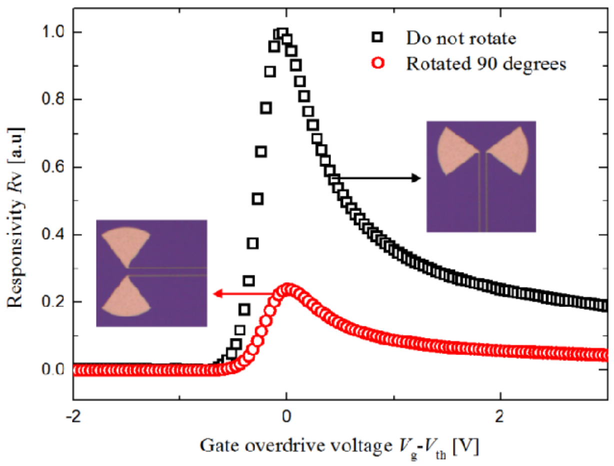

Fig. 4 Responsivity R_V as a function of V_g-V_{th} for the polarized THz radiation effects with bow-tie antenna.

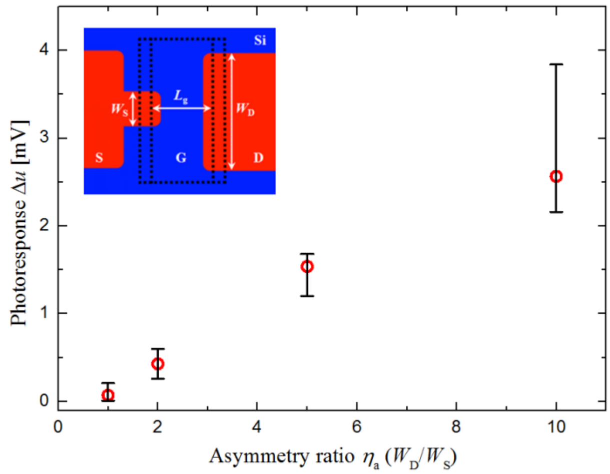

Fig. 5 Experimental results of the photoresponse Δu (mV) for the different asymmetry ratio (Error bars show the sample ranges with standard deviation). Drain width W_D= 20 μm and source width W_S = 2, 4, 10, and 20 μm with corresponding asymmetry ratio η_a = W_D /W_S is 10 , 5 , 2 and 1 (symmetric), respectively.

that the integrated bow-tie antenna works well for the polarized THz radiation from gyrotron source.

Figure 5 shows the measured peak voltages of the photoresponse Δu (mV) for the different asymmetry ratio. Based on the same antenna effect on the performance, we clearly demonstrate that the enhancement of the photoresponse can be achieved by increasing asymmetry ratio between source and drain width experimentally.

4. Conclusions

We have experimentally demonstrated that the non-resonant plasmonic THz detector based on Si FETs with asymmetric source and drain structures with antenna can enhance the responsivity at room temperature. These results can provide the possibility of the performance enhancement focusing on the asymmetric design of source and drain structure under the gate in field-effect devices integrated with antenna for sub-THz regime.

Acknowledgements

This work was supported by the Joint Research Project of the Korea Research Council for Industrial Science and Technology (ISTK), Republic of Korea.

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