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Threshold Behavior of Photoresponse of Plasma Waves by New Photomixer Devices

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1. Introduction

Two dimensional (2D) plasma-wave instabilities in submicron transistors have attracted much attention in the last decade due to their properties to emit and/or detect terahertz radiation [1-5]. Plasma waves are the spacio-temporal oscillations of electronic polarization. The resonant frequency is determined by the gate length (L) and plasmon velocity (s): $f \sim s/L$. The plasma wave velocity itself is proportional to square root of electron density which is controlled by the gate bias giving rise to the tunability of the resonant frequency.

Here, we show an experimental investigation of photoresponse observed by our new device with doubly interdigitated grating gates. We observe a threshold property of detection as a function of the drain-source bias at different values of the gate bias. The result is interpreted as a signature of plasma wave instability.

2. Grating bicoupled plasmon resonant photomixer

The device of our original [4] was fabricated with InGaP/InGaAs/GaAs material systems as shown in Fig. 1. The 2D plasmon layer is formed with a quantum well in the InGaAs channel layer. The grating gate was formed with 65-nm thick Ti/Au/Ti by a standard lift-off process. The grating geometry was designed in a 70-nm (350-nm) length for a Gate 1: L_{G1} (Gate 2: L_{G2}) finger with a 100-nm space.

When an appropriate 2D electronic charge (10^{11} ~10^{12}cm^{-2}) is induced in the plasmon cavities under Gate 1 (G1) while the regions under Gate 2 (G2) are far lightly charged, a strong electric field (1~10 kV/cm) arises at the plasmon cavity boundaries. When the device is photoexcited by laser irradiation, photoelectrons are dominantly generated in the regions under G2 and then are injected to the plasmon cavities under G1. If a specific drain-to-source bias is applied to promote a uniform slope along the source-to-drain direction on the energy band in the regions under G2, photoelectrons under G2 are unidirectionally injected to one side of the adjacent plasmon cavity. This may extensively accelerate the plasmon instability, leading to terahertz oscillation even at room temperature. The grating gates also act as terahertz antenna that converts non-radiative plasmon modes to radiative electromagnetic modes. Furthermore, a vertical cavity is formed in between the 2D-plasmon plane and the ITO mirror at the backside, which can effectively enhance the conversion gain and radiation power [4].

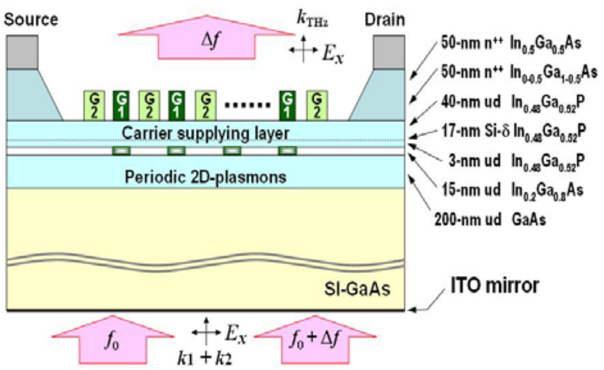

Fig. 1 Device structure used in our experiment with L_{G1} = 70 nm and L_{G2} = 350 nm.

3. Results and discussion

Inset of Fig. 2 shows typical photoresponse observed by our photomixer at room temperature as a function of the drain bias: V_{ds} at a fixed G1 bias: V_{g1} = 0V. The measurement was done for different values of the G2 bias: V_{g2} (from 0 to -3V) by using lock-in technique. We observed threshold properties of photoresponse under relatively high V_{g2} conditions at critical V_{ds} points. The photoresponse, on the other hand, shows saturation under low V_{g2} conditions, which is due to the saturation of the drain-source current already been observed by Lü et al [6].

In case of $V_{g1} = V_{g2}$ = 0V, the sample is assimilated to a very long-channel HEMT with $L_G \approx 60$ μm and the signal reflects the classical photoconductivity for standard "*calm*" HEMT's excluding plasma waves due to the long gate channel. For more clarity, the relative photoresponse with respect to the *calm* one is focused on:

$$\Delta U = U_{ds}(V_{g1}, V_{g2}) - U_{ds}\Big|_{V_{g1}=V_{g2}=0V} .$$

Figure 2 shows the relative photoresponse versus V_{ds} at V_{g1} = 0V for different V_{g2} values. When V_{g2} = –0.5V, ΔU exhibits one peak at V_{ds} = 2.5V. This peak is shifted to the lower V_{ds} region with decreasing V_{g2}. When $V_{g2} < V_{g1}$, the electron density of 2D plasmon region under G2 is lower than that under G1 and the band diagram can be described as Fig. 3 a). The photoelectrons are predominantly generated in the region under G2 and injected to the region under G1, resulting in plasma-wave excitation in the cavity under

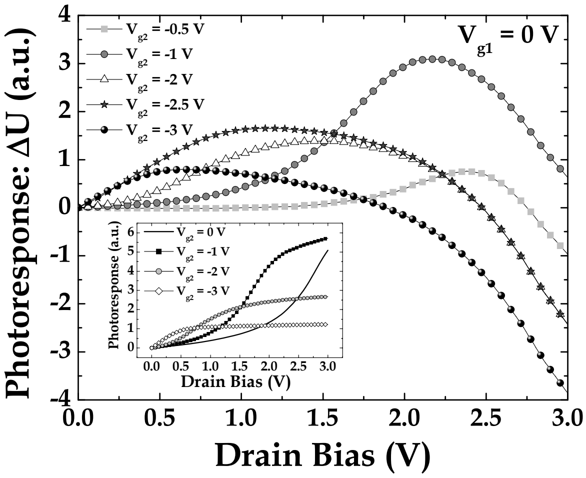

Fig. 2: Relative photoresponse vs. V_{ds} at V_{g1} = 0V for different V_{g2} values. Inset shows the photoresponse at V_{g1}=0V and V_{g2}=–3~0 V.

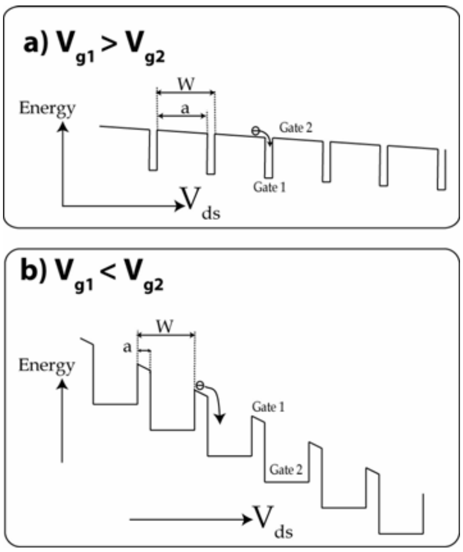

Fig. 3: Band diagrams for the case when: a) $V_{g1} > V_{g2}$ and b) $V_{g1} < V_{g2}$.

G1. When V_{g2} = –1.0V, the drift velocity of injected electrons becomes maximum, which is due to the velocity overshoot. This makes a good condition to excite plasma waves inside the cavity [7]. The negative relative-photoresponse caused by saturation of photocurrent is due to the accumulation of photocarriers.

The inset of Fig. 4 shows the photoresponse of the device at V_{g2} = 0V for different V_{g1} ($\leq V_{g2}$) values. In this case, the photoresponse exhibited threshold properties for all the V_{g1} conditions. Corresponding band diagram is shown in Fig. 3 b).

Figure 4 shows the relative photoresponse at V_{g2} = 0V for different V_{g1} ($\leq V_{g2}$) values. In this case, all peaks are observed in a focused area around V_{ds} = 2.5V. New interesting aspects are: 1) the peak point shifting upward with increasing V_{g1} and 2) the width of the peak becoming narrower with increasing V_{g1} (from -3 to -2 V). Such behaviors prove that the plasma waves are excited in the region under G1, directly reflecting the V_{g1}-dependences of the plasma-resonant frequency and the resonant quality factor. The quality factor is given by $s\tau/L_g$, where s and τ are respectively the plasma velocity and relaxation time. With decreasing V_{g1}, the electron density becomes low in the plasmon region under G1. The drift velocity of photoelectrons is high due to the electric field in the region under G1. The quality factor becomes higher, which deduces the width of the normalized photoresponse.

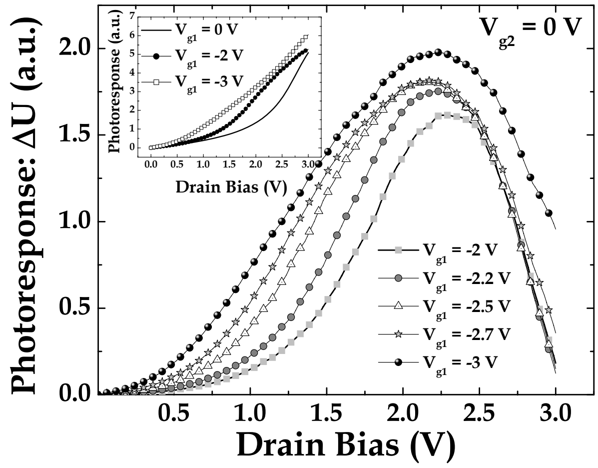

Fig. 4: Relative photoresponse vs. V_{ds} at V_{g2} =0V for different V_{g1} values. Inset shows the photoresponse at V_{g2} =0V and V_{g1}=-3~0 V.

3. Conclusions

We have experimentally investigated detection of terahertz radiation by our new grating bicoupled plasmon resonant photomixer. The experiment was done for different bias conditions at room temperature. First we observed that the relative-photoresponse peak shifts to the low V_{ds} region when V_{g2} decreases. Second, the peak becomes narrow when V_{g1} is decreased. This is a clear signature of the enhancement of plasma-wave excitation.

Acknowledgements

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