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Photo-induced current in n-AlGaAs/GaAs heterojunction field-effect transistor driven by local illumination at edge regions of Schottky metal gate

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Abstract

We investigated photo-responses of the Schottky gate region of an n-AlGaAs/GaAs field-effect transistor (FET) by a local illumination with a near-infrared (IR) laser beam. We examined (1) the Schottky photocurrent J_{SG} from the source to the metal gate and (2) the lateral photocurrent J_{SD} from the source to the drain in the open gate condition. We found that the magnitudes of J_{SG} and J_{SD} rapidly increases as the laser spot approaches the edges of the metal gate; the IR photo-responses are enhanced in the regions near the gate edges. Experimental findings are well explained by a simple model considering the IR photo-responses with the gate edge effect.

1. Introduction

For a few decades, the infrared (IR) photo-responses of Schottky-barrier diodes have been intensively studied because of their importance as IR detectors. Since the detectable photon energy is limited by the Schottky-barrier height, not by the band-gap energy of the semiconductor, the IR photo-sensing in the energy range of 0.2 ~ 0.6 eV is potentially achieved by choosing an appropriate combination of a metal and a semiconductor. Various attempts have been made for improving the quantum efficiency of Schottky-barrier photodetectors, such as back illuminations, very thin metal gates, two Schottky-barriers, and optical cavities.

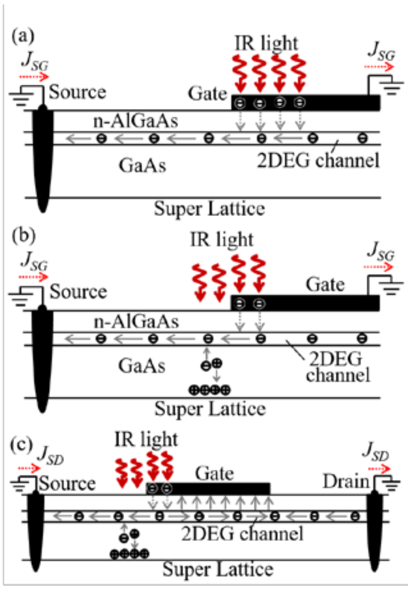

Fig. 1 Schematic drawings of the FET cross section views.

In this work, we study the photocurrents in a selectively doped n-AlGaAs/GaAs field effect transistor (FET) by locally irradiating the Schottky metal gate with a near-IR laser beam. The IR light illumination excites photo-electrons, and they transfer from the gate to the two-dimensional electron gas (2DEG) channel (gray dotted arrows in Fig. 1). When the Schottky metal gate and the source are connected to an external circuit, a photocurrent J_{SG} from the source to the gate is generated (Fig. 1(a)). This work demonstrates that J_{SG} increases as the laser spot approaches the gate edges (Fig. 1(b)). We also examine a lateral photocurrent J_{SD} from the source to the drain in the open gate condition (Fig. 1(c)), where the magnitude of J_{SD} exhibits the maximum values for the beam centered at the gate edges. The experimental data are compared with a simple theoretical model.

2. Experimental methods

The heterojunction studied here was prepared on a semi-insulating GaAs (100) substrate by molecular beam epitaxy. We grew at the substrate temperature 580 °C a 450-nm-thick GaAs buffer layer, a superlattice buffer (20 periods of 10 nm AlGaAs/3 nm GaAs), a 820-nm-thick GaAs layer, a 10-nm-thick non-doped AlGaAs spacer, a 80-nm-thick Si-doped AlGaAs layer, and a 15-nm-thick GaAs capping layer. The heterojunction wafer was processed to form a Hall bar device with five electrode pads (S, D, X, Y, and C) and an Al gate (G) as schematically sketched in the left insets of Figs. 2 and 3. The contacts between the electrode pads and the 2DEG (hatched circles) were made by alloying InSn at 400 °C. Then, the Schottky metal gate was formed by vacuum evaporation of Al. The width W and length L of the gate region are about 50 and 550 μm, and the distance L_c between the X and C terminals is 200 μm, respectively.

For the illumination of the sample, we used a 808-nm laser beam focused by a microscope objective lens, where the laser power and spot radius are about P = 300 μW and a = 20 μm, respectively.

3. Results and discussion

3.1 Schottky photocurrent

The Schottky photocurrent J_{SG} from the source contact to the metal gate was measured in the setup schematically sketched in the left inset of Fig. 2. Solid circles in Fig. 2

show J_{SG} as a function of the laser spot position x_l. Here, the laser spot is scanned from left to right in the Schottky gate. The origin of the x_l-axis represents the left edge of the gate area. When the ungate region of the sample is irradiated with the IR light (x_l < -20 μm), the photocurrent does not arise (J_{SG} ~ 0). In contrast, J_{SG} flows from the source to the gate and is about 0.76 μA for the IR illumination of the inside region of the Schottky gate (x_l > 20 μm). Note that J_{SG} rapidly increases as the laser spot approaches the edge region of the Schottky gate (-20 < x_l < 20 μm), the current reaching its maximum for the beam centered at the edge. The maximum J_{SG} is 2.0 μA and is about 2.6 times larger than that for the illumination of the inside region. In the right inset of Fig. 2, we also plot J_{SG} in the wide x_l range (x_l = -200 ~ 750 μm), showing both the photocurrent peaks at the left and right edges of the gate area. J_{SG} for the right edge illumination is 2.7 μA and is about 3.5 times larger than that for the illumination of the inside region.

When the laser beam is centered at the edge of the Schottky metal gate (Fig. 1(b)), the half of the laser beam excites the photo-electrons at the Schottky metal-semiconductor interface, and the other half generates electrons and holes in GaAs. The holes generated in GaAs move toward the substrate and accumulate at the superlattice interface, while the electrons are attracted toward the n-AlGaAs/GaAs heterointerface and instantaneously redistribute themselves uniformly over the FET due to the large conductivity of the 2DEG channel. The positive charge of holes under the gate induces electric fields. Such electric fields may promote the transfer of the IR-excited electrons from the metal gate to the 2DEG channel, resulting in the increase of the IR photocurrent J_{SG}.

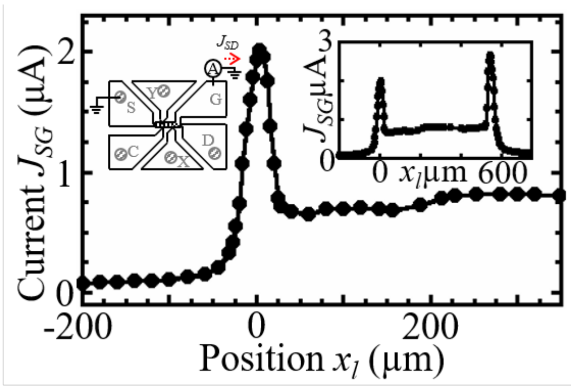

Fig. 2 Photocurrent J_{SG} as a function of laser spot position x_l.

3.2 Lateral photocurrent

When the metal gate is illuminated by an IR light with the energy above the Schottky barrier, the photo-excited electrons transfer from the gate to the 2DEG channel. If the Schottky gate is open (Fig. 1 (c)), the electron transfer raises the gate voltage, leading to a leakage current from the metal gate to the 2DEG. When an asymmetric position of the Schottky metal gate is illuminated, the electron transfer and the leakage current cause an asymmetric electron flow in the 2DEG channel under the metal gate, leading to a lateral current J_{SD} through the sample.[1)]

Solid circles in Fig. 3 show J_{SD} as a function of the laser spot position x_l. The left inset represents the measurement setup. In the right inset, we also plot J_{SD} in the wide x_l range (x_l = -200 ~ 750 μm). When the left side of the Schottky gate (x_l < 275 μm) is illuminated with the laser, J_{SD} is positive, i.e. the lateral current flows from the source to the drain. In contrast, the lateral current from the drain to the source occurs (J_{SD} < 0) for the irradiation on the right side of the gate (x_l > 275 μm). Note that the J_{SD} exhibits its maximum (minimum), when the left (right) edge of the Schottky gate is irradiated. These peak structures of J_{SD} originate from the enhancement of the IR photo-responses in the regions near the gate edges discussed in Sec. 3.1. J_{SD} for the illuminations of the left and right gate edges are about 0.46 and -0.64 μA, respectively.

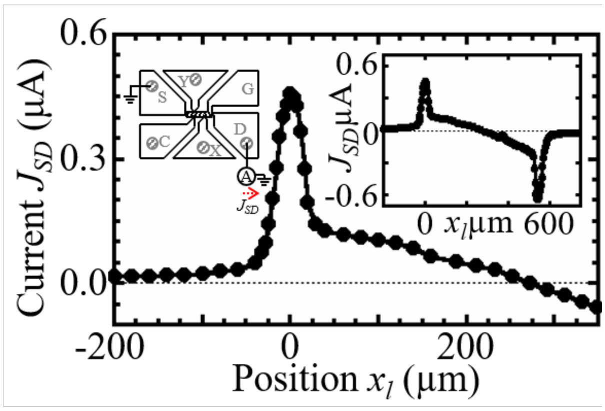

Fig. 3 Photocurrent J_{SD} as a function of laser spot position x_l.

3.3 Theoretical analysis

We also analyze the experimental data by using a theoretical model. The experimental results are well explained by a simple model considering the IR photo-responses with the gate edge effect.

4. Summary

We investigated photo-responses in an n-AlGaAs/GaAs FET for the local illumination of the Schottky metal gate with a near-IR laser beam. We measured the Schottky photocurrent J_{SG} from the source to the metal gate and found that J_{SG} rapidly increases as the laser spot approaches the gate edges. We also examined the lateral photocurrent J_{SD} in the 2DEG channel induced by the metal gate illumination in the open gate condition. We found that the magnitude of J_{SD} exhibits the maximum values, when the laser beam is centered at the gate edges. The experimental results were compared with a simple model considering the IR photo-responses with the gate edge effect.

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References

[1] Appl. Phys. Lett. **106**, 022103, (2015).