Extended Abstracts of the 2006 International Conference on Solid State Devices and Materials, Yokohama, 2006, pp. 30-31

A-2-6

Resonant Terahertz Detection Based on High-electron-mobility Transistor with Schottky Source/Drain Contact

Akira Satou[1], Victor Ryzhii[1], Taiichi Otsuji[2] and Michael S. Shur[3]

[1]Computer Solid State Physics Laboratory, University of Aizu,
Aizu-Wakamatsu 965-8580, Japan
Phone: +81-242-37-2563, E-mail: d8071201@u-aizu.ac.jp
[2]Research Institute of Electrical Communication, Tohoku University,
Sendai 980-8577, Japan
[3]Department of Electrical, Computer, and Systems Engineering,
Rensselaer Polytechnic Institute, Troy, NY 12180, USA

1. Introduction

Two-dimension electron gas (2DEG) systems in gated channels with sufficiently high mobility of electrons confined in the lateral directions can serve as resonant cavities for electron plasma waves in different devices. As proposed [1,2], the resonant plasma effects in gated 2DEG systems similar to high-electron mobility transistors (HEMTs) can be used for detection, frequency multiplication and generation of terahertz (THz) radiation. The devices with lateral Schottky junctions (LSJs) have been proposed and studied for more than decade [3,4], primarily for applications as varactors for frequency multiplication in the THz range. However, since the 2DEG channels with high electron mobility can exhibit pronounced resonant response at the plasma frequencies, the high-frequency characteristics of detectors and frequency multipliers can be substantially different from those of more conventional devices with Schottky junctions and provide very high responsivity at the signal frequencies coinciding with the resonant plasma frequencies.

In this paper, we consider a detector of THz radiation with the structure of a high-electron mobility transistor (HEMT) with a gated 2DEG channel supplied by the Ohmic source and Schottky drain contacts. The gated 2DEG channel serves as a resonant cavity, while the LSJ formed at the Schottky contact to 2DEG provides nonlinearity used for the rectification (and frequency multiplication). We shall refer to this device as a LSJ-HEMT resonant detector. The operation of the resonant detector in question with an LSJ at the drain is associated with a nonlinearity of the thermionic current (or current due to thermo-asisted tunneling) from the channel to the drain contact.

We also consider the LSJ-HEMT resonant detector with Schottky source and Ohmic drain contacts. In contrast to a detector with Schottky drain contact, the nonlinearity in this case is provided by the tunneling of electrons from the contact to the channel.

The LSJ-HEMT resonant detectors (and frequency multipliers) in question can be fabricated using heterostructures based on different III-V materials or nitrides.

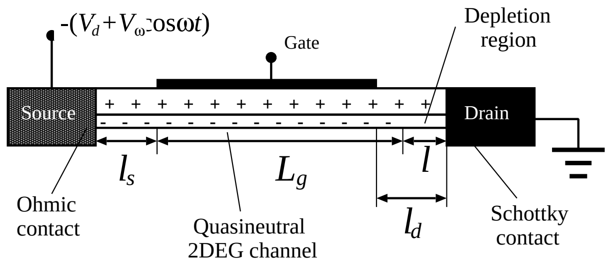

Figure 1: Schematic view of LSJ-HEMT with with Schottky drain contact.

2. Device model

The structure of LSJ-HEMT with Schottky drain contact is schematically shown in Fig. 1. We assume that the drain-source voltage is $V = V_d + V_\omega \cos\omega t$, where $V_d > 0$ corresponds to the forward bias (and reverse bias in the case of Schottky source contact) and $V_\omega \cos\omega t$ is induced by incoming THz radiation. Due to the high conductivity of 2DEG channel, and at not too high drain-source voltage ($V_{bi} - V_d > kT$, where V_{bi} is built-in voltage determined by the Schottky barrier height, T is the temperature, and k is the Boltzmann constant), almost all fraction of V_d drops at the LSJ. The device model of LSJ-HEMT detector is based on the hydrodynamic electron transport model coupled with the 2D Poisson equation for the gated section of 2DEG channel [1, 5, 6] and on the thermionic emission model for the LSJ depletion region (or tunneling model in case of the Schottky source). Assuming that the conductivity of the 2DEG channel significantly exceeds the conductivity of LSJ, as is the case when $V_{bi} - V_d > kT$, the net drain current can be expressed as

$$J = J_s \left\{ \exp\left[\frac{e(V_d + \delta V^{LSJ})}{kT} \right] - 1 \right\}, \qquad (1)$$

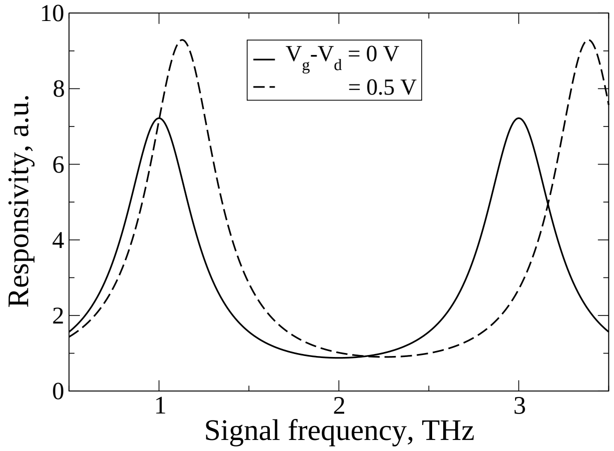

Figure 2: Normalized current responsivity of LSJ-HEMT detector with Schottky drain contact at room temperature for different gate voltages.

where J_s is saturation current and δV^{LSJ} is the drop of the ac potential across the LSJ. Nonlinearity of the LSJ current-voltage characteristics results in the rectification ofthe net current. Using the model under consideration, for the LSJ-HEMT resonant detector current responsivity (defined as the ratio of the rectified part of the dc current to the THz power, $P_\omega \propto V_\omega^2$, recieved by the detector's antenna) we obtain

$$R_\omega \simeq \frac{J_{00}}{P_\omega}\frac{(eV_\omega/2kT)^2}{[\sinh^2(\pi\nu/4\Omega_g)+\cos^2(\pi\omega/2\Omega_g)]}. \quad (2)$$

Here, $J_{00} = J|_{V_\omega=0}$ is the dark current, ν is the electron collision frequency (with impurities and phonons), $\Omega_g = \sqrt{\pi^3 e^2\Sigma_0 W/m æ L_g^2}$ is the fundamental plasma frequency, e is the absolute value of electron charge, $\Sigma_0 = \Sigma_d + æ(V_g - V_d)/4\pi eW$ is the electron concentration in the gated section of the channel, Σ_d is the concentration of donors in (or somewhat above) the channel, æ is the dielectric constant, W is the distance between the gate and channel, and L_g is the length of the gated section of the channel. Equation (2) can be presented in the form

$$R_\omega \simeq \frac{R_0}{\sinh^2(\pi\nu/4\Omega_g)+\cos^2(\pi\omega/2\Omega_g)}, \quad (3)$$

where $R_0 = (J_{00}/P_\omega)(eV_\omega/2kT)^2$ is the responsivity of a similar detector with the LSJ but without the plasma oscillation excitation.

3. Results

Figure 2 shows the frequency dependences of the normalized responsivity R_ω/R_0 of LSJ-HEMT detector with Schottky drain contact at the room temperature calculated for different gate voltage. We assumed the AlGaAs/GaAs device with following parameters: $\Sigma_d = 10^{12}$ cm^{-2}, $W =$ 0.125 μm, $L_g = 0.5 - 0.6$ μm, and the electron mobility $\mu = 9000$ cm^2/Vs ($\mu \propto \nu^{-1}$). These parameters correspond to $\Omega_g(V_g = 0)/2\pi = 1$ THz. One can see from Fig. 2 that the responsivity exhibits the resonant maxima at the frequencies coinciding with the plasma frequency and its harmonics, pronouncedly exceeding the value R_0. In the LSJ-HEMT structure with higher electron mobility in the channel, the height of resonant peaks can markedly exceed the height of the peaks shown in Fig. 2. The resonant frequencies can be tuned by the gate and drain voltages.

One can show that the responsivity of the LSJ-HEMT detector with LSJ at the source is also given by Eq. (3). However, in this case, the quantity R_0 is determined primarily by the tunneling characteristics of the LSJ.

The LSJ-HEMT resonant detectors can also operate in the photovoltaic mode.

4. Conclusions

In conclusion, we developed a device model for a novel THz detector based on a HEMT with an LSJ at the drain (or at the source). We demonstrated that the LSJ-HEMT resonant detector can exhibit significantly higher responsivity than other THz detectors based on Schottky junctions ($R_\omega \gg R_0$ at the plasma resonances).

References

[1] M. Dyakonov and M. Shur: IEEE Trans. Electron Devices **43** (1996) 1640.

[2] M. S. Shur and V. Ryzhii: Int. J. High Speed Electronics and Systems **13** (2003) 575.

[3] W. C. B. Peatman, T. W. Crowe and M. Shur: IEEE Electron Device Lett. **13** (1992) 11.

[4] P. J. Koch, W. C. B. Peatman and T. W. Crowe: IEEE Microwave and Guided Wave Lett. **5** (1995) 73.

[5] A. Satou, I. Khmyrova, V. Ryzhii and M. S. Shur: Semicond. Sci. Technol. **18** (2003) 460.

[6] M. Dyakonov and M. Shur: Phys. Rev. Lett. **71** (1993) 2465.