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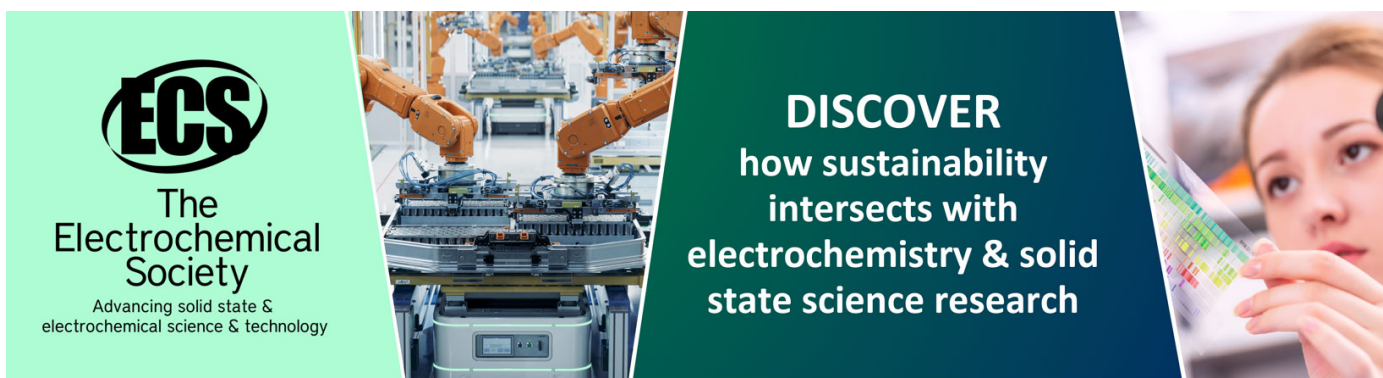
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Enhancement of terahertz radiation by CW infrared laser excitation in a doubly interdigitated grating gates transistors

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Abstract. We report on a broadband terahertz emission from a doubly interdigitated grating gates high electron mobility transistor. The observed emission was explained as due to the excitation of multi mode of plasmons: thermally excited incoherent modes and instability-driven coherent modes. The experiment was performed using Fourier spectrometer system coupled with high sensitive 4K Silicon bolometer under the vacuum. To enhance the efficiency, the device was subjected, from the backside, to a CW 1.5 μm laser beam. Dependence of the emission on the gate bias was observed and interpreted as due to the self-oscillation of the plasma waves.

1. Introduction

The oscillation of electrons density in a two dimensional system can become unstable against the generation of electromagnetic radiation within terahertz range [1-2]. This phenomenon is known as the instability of the plasma waves and can be used for tunable detection/generation, and photomixing of terahertz radiation. The oscillation frequency of the plasma waves depends on the sheet electron density (n_s) and the length of the transistor gate (L). Terahertz (THz) range can be reached for sufficiently high n_s and submicron size L . There are two types of excitation of the plasma waves: (i) incoherent type related to the thermal excitation of the plasmons by hot electrons and (ii) coherent excitation involving either the plasma wave instability mechanism such as Dyakonov-Shur [1] or the electron transit-time effect [3]. The first mechanism was studied earlier and emission of THz radiation was observed from selectively doped GaAs/GaAlAs heterostructure as well as Si metal-oxide semiconductor [4]. Room temperature terahertz emission interpreted in terms of coherent excitation was observed from GaInAs and GaN/AlGaIn transistors [5]. Emission of THz radiation has been measured recently by using doubly interdigitated grating gate high electron mobility transistors (HEMT's) [4] and related to incoherent excitation.

Here, we report on broadband terahertz emission from a doubly interdigitated grating gates HEMT. The observed emission was explained as due to the excitation of multi mode of plasmons: thermally excited incoherent modes and instability-driven coherent modes. The experiment was performed using Fourier spectrometer system coupled with high sensitive 4K Silicon bolometer under the vacuum. To enhance the efficiency, the device was subjected, from the backside, to a CW 1.5 μm laser beam. Dependence of the emission on the gate bias was observed and interpreted as due to the self-oscillation mechanism of the plasma waves.

2. Device structure

The device structure is based on a InGaP/InGaAs/GaAs material system and incorporates (i) dual interdigitated grating gates (G1 & G2) that periodically localize the 2D plasmon in sub-micron regions with 100 nm interval and (ii) a vertical cavity structure in between the 2D plasmon and a THz mirror at the backside. 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 (Fig. 1). Table 1 describes the geometrical parameters of the samples. The GaAs substrate was thinned down to a thickness of 43 μm , and 100 nm thick ITO (indium titanium oxide) transparent metal was sputtered on the optically polished back surface to form the vertical cavity, which make possible the irradiation from the backside. The reflectivity of the ITO mirror in the THz range (0.6 to 6 THz) is about 90% and the transmittance is 83% for 1.5 μm . More details can be found in [7, 8].

Table 1. Description of the geometrical parameters of the samples

	L_{G1} (nm)	L_{G2} (nm)	# fingers (L_{G1}/L_{G2})	d (nm)	L/W (μm)
Sample1	70	350	60/61	80	30/75
Sample2	100	1850	15/16	80	30/75

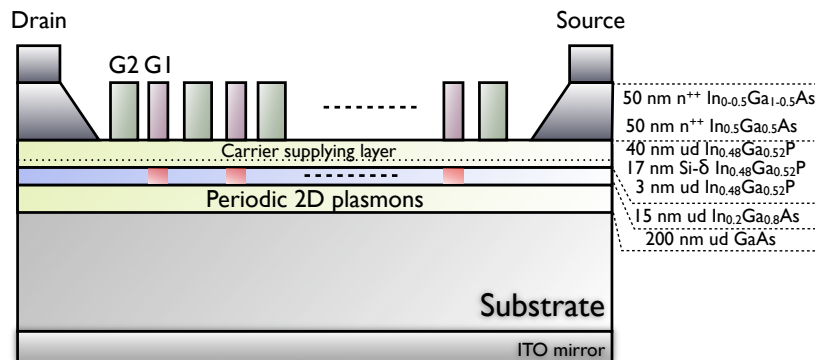


Figure 1. Device cross-section for typical GaAs-based heterostructure material system.

3. Results and discussions

3.1. Emission of terahertz rays.

The samples were placed in the source position of the vacuum cavity of the Fourier-transformed far-infrared spectrometer. The radiation intensity was measured using a high sensitive Silicon bolometer. The background spectrum was measured first (signal measured without any current flowing through the sample). It contains the information on the 300 K blackbody emission modified by the spectral functions of all the elements inside the spectrometer. Then we measured the spectrum with current flowing through the sample. The signal shown here is the ratio between both signals. Figure 2 shows the observed signal from both samples. A broadband signal with maximum at 2.5 THz for sample 1 and 3 THz for sample 2 is observed. For both samples the signal dies off abruptly around 6.5 THz,

which is believed to be related to the Reststrahlen band of optical phonon modes of the GaAs-based materials [4,9]. The detected signal was interpreted as due to the thermal excitation of the plasmons by means of injection of hot electron in the channel (incoherent excitation) [4]. However, dependence of the emission on drain-to-source voltage (V_{DS}) shows that some features of coherent excitation could be possible since a threshold property is observed (Fig.3) for $V_{g1}/V_{g2}=-1V/0V$. It's known that the coherent excitation by means of Plasmon instability could lead to threshold behaviour [1,3]. However, incoherent excitation gives a super-linear behaviour ($V_{g1}/V_{g2}=0/0V$ and $0V/-0.5V$).

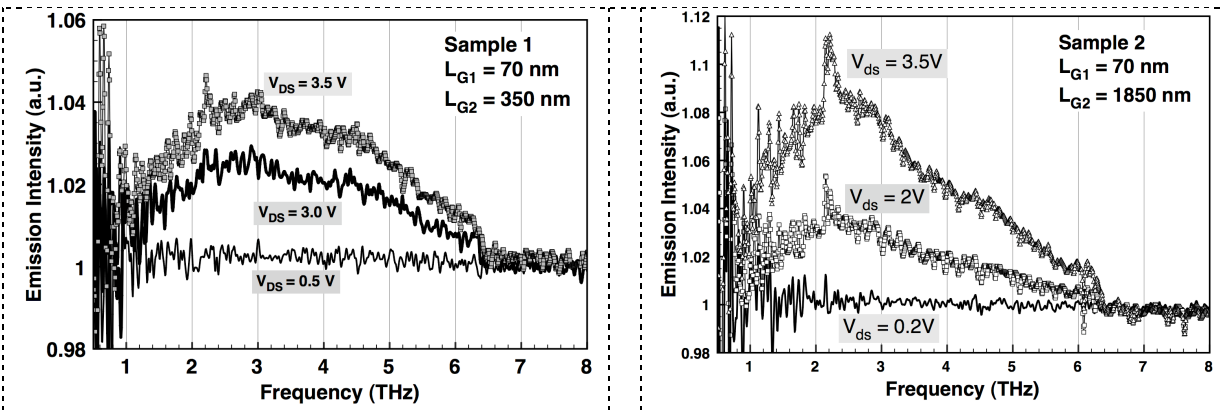


Figure 2. FTIR measured signal from the doubly interdigitated grating gates HEMT.

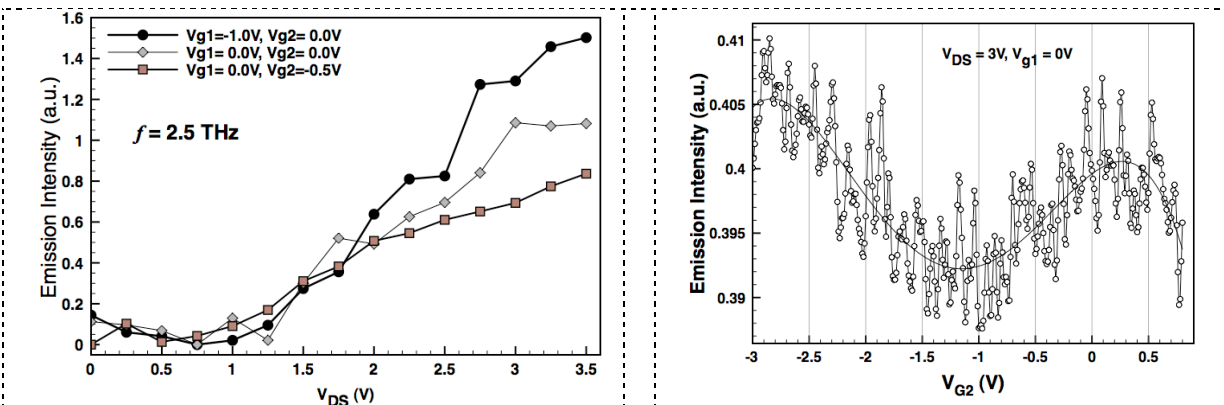


Figure 3. Emission intensity vs. drain-to-source bias at 2.5THz for sample 2.

Figure 4. Emission intensity vs. V_{g2} for sample 1 for fixed $V_{DS} = 3V$ and $V_{g1} = 0V$

3.2. Optical enhancement of terahertz radiations

The devices were subjected to 1500 nm CW laser from the back surface at room temperature. The beam was linearly polarized along the channel axis and the power was around 3 mW. A high sensitive 4K Silicon bolometer placed in the front of the sample was used to detect the THz radiation emitted from the device. A window of detection from 0.5 to 3 THz is possible by using a 100 cm^{-1} far-infrared cut-on type filter. The photon energy of the irradiated laser (0.8 eV) is much lower than all the band gap energies of this material system. However, the electrons are weakly photo-excited at the InGaAs/GaAs heterointerface via two-photon processes due to the existence of deep-level trap centers. From I-V characteristics with and without illuminations, the concentration of photoelectrons was estimated to be around $3 \times 10^{11}\text{ cm}^{-2}$. Figure 4 shows the detected signal as a function of gate 2 bias and for $V_{DS} = 3\text{ V}$ and $V_{g1} = 0V$. A maximum of signal is observed for V_{g2} around -2.8 V (close to threshold bias).

When the device is illuminated, the photoelectrons are generated under the depleted G2 gate due to the applied bias (close to threshold) and to more unoccupied states. If a specific drain-to-source bias is applied to promote a uniform slope along the source-to-drain direction on the energy band, photoelectrons under the depleted gate (G2) are unidirectionally injected to one side of the adjacent plasmon cavity under the other gate (G1). This may excite the plasmons under an asymmetric cavity boundary [2, 10]. The periodically localized 2D plasmon can be coupled with those in neighbour regions and make in-phase resonant oscillation so that the 2D-plasmon grating can convert the non-radiative plasma waves to radiative electromagnetic waves. It is noted that the laser irradiation may excite the plasmon not only in the regions under G1 but also in the regions under G2 if the cavity size and carrier density of the regions under G2 also satisfies the resonant conditions. The discrepancy between the gate biases of G1 and G2 can enhance the oscillations of the plasma waves via increasing the drift velocity of the photoelectrons injected in the plasmon cavities (self-oscillation mechanism) [11]. The second peak at V_{g2} around 0.25 V can also be interpreted as a self oscillation of the plasma waves: even the gate biases for G1 and G2 are similar, the sheet electron density in the cavities under both regions are different due to the difference of the threshold voltage. The self-oscillation of the plasma waves can also occur at this condition.

4. Conclusion

We report on a broadband emission from a doubly interdigitated grating gate high electron mobility transistor at room temperature. The emission was explained as due to coherent/incoherent excitation of the plasma waves. Enhancement of the terahertz radiation by optical stimulation has been also shown and related to self-oscillation mechanism.

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