Hydrodynamic Modeling and Experimental Study of the Plasmonic Terahertz Detector.

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In the Dyakonov-Shur terahertz (THz) detector, nonlinearities in the plasma wave propagation in the gated channel of a Field Effect Transistor (FET) lead to a constant source-to-drain voltage providing the detector output, ΔU [1]. For a small signal, the perturbation theory treatment shows that the response is proportional to the intensity of the radiation. The proportionality factor can have a resonant or a broad dependence on the signal frequency for low and high plasma wave damping, respectively. The frequency of the plasma waves in the gated channel of a FET is much higher than the cut-off frequency. A resonant response to electromagnetic radiation at the plasma oscillation frequency can be used for detection, mixing, and frequency multiplication in the terahertz range. For submicron High Electron Mobility Transistors (HEMTs) the typical measured response falls within the range of 0.1 to 4.5 THz.

The hydrodynamic model analysis shows that for small signal the response is proportional to the square of the THz voltage amplitude U_a, induced between the source and the gate:

$$\frac{\Delta U}{U_0} = \left(\frac{U_a}{U_0}\right)^2 F(\omega)\cdot \tag{1}$$

Here $U_o = U_g - U_T$ is the gate voltage swing, U_g being the gate-to-source voltage and U_T being the threshold voltage. In a high mobility channel the function F(ω) has a resonant structure while in a low mobility channel the response is broadband, as shown in Fig. 1 where F is plotted as function of frequency f.

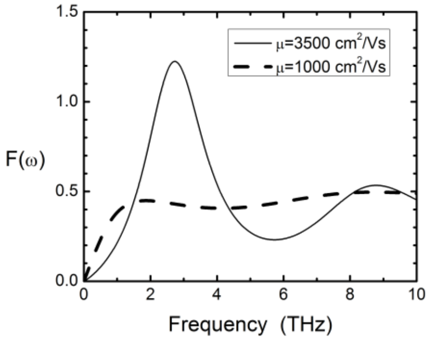

Fig. 1. The response function for InGaAs channel of length 130 nm and gate voltage $U_0 = 0.4$ V for different values of mobility μ.

The deviations from the relation in Eq. (1) have been studied and reported in the approximation of the local Ohm's law and transmission line model for the non-resonant response [2]. Here we present the results obtained with the hydrodynamic model using the electron plasma Navier-Stokes equation, thus fully accounting for the hydrodynamic non-linearity, the electron fluid viscosity [3], and pressure gradients in the detector response [4]. The model is applicable to both resonant and broadband operations of the HEMT based plasmonic detectors. The relation between the electron channel density and gate voltage was modeled by the unified charge control model applicable both above and below the threshold voltage [5]. In the detector mode, the THz harmonic amplitude U_a is proportional to the square root of the intensity of the THz radiation impinging on the FET. Using U_a as a parameter of the external signal strength, we show the response, ΔU, at the external signal of frequency f = 1.63 THz, for three different values of mobility in Fig. 2. The gate voltage was set at 0.09V and the kinematic viscosity was evaluated at room temperature [3].

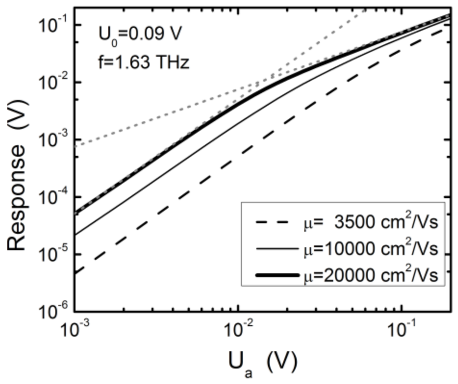

Fig. 2. Response of an InGaAs HEMT as a function of the amplitude of applied time-harmonic signal, with gate voltage swing U_0 = 0.09 V, for three values of electron mobility. The dotted lines (two slopes) indicate transition from the small signal regime to different response dependence $\Delta U(U_a)$ for large signals.

The theoretical results are compared with the response measured in the short channel InGaAs HEMT. The THz source was operating at 1.63 THz and the response was measured at varying signal intensities, Fig. 3. The theoretical and experimental results are in good agreement. This model can be used for the design optimization of plasmonic detectors operating in wide temperature and dynamic ranges.

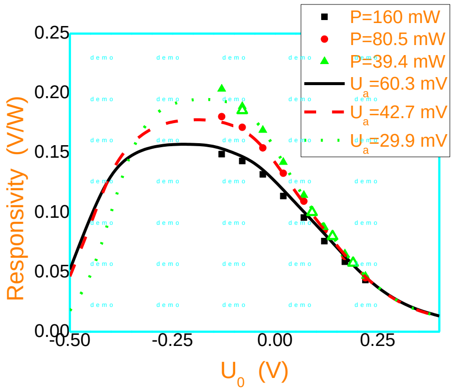

Fig. 3. Detector response as a function of the gate voltage, for different signal strengths. The calculated response curves are compared to the measured results.

References

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