Ultimate response speed of plasmonic THz detectors

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Field effect transistors detect electromagnetic radiation at frequencies much higher than their cutoff frequency and maximum frequency of operation. The detection mechanism is the rectification of the resonant or overdamped plasma oscillations in the device channel. High responsivity and low noise equivalent power (NEP) make these devices superior for applications ranging from high-bandwidth communication and femtosecond pulse detection to imaging and sensing.

We now report on the analysis of the temporal response to short pulses and modulated signals based on the numerical and analytical solutions of the hydrodynamic equations. The hydrodynamic model includes the effects of viscosity, temperature gradients and pressure that we show to be a dominant factor in the subthreshold regime.

In relatively low-mobility transistors (such as typical III-V and III-N HEMTs and Si MOSFETs at room temperature) and in the above-threshold regime, the plasmonic FET response to a short femtosecond pulse is a decaying exponential function with a characteristic decay time of the order of $L^2/(\mu V_0)$, where L is the gate length, μ is the field effect mobility, and V_0 is the gate voltage swing. This result is in agreement with the analytical drift model reported in [1]. A new and important feature predicted by the hydrodynamic model (even for the low mobility transistors) is a delay time between the application of the pulse and the start of the transient response [2]. This delay time is on the order of L/s, where s is the plasma velocity.

In high-mobility samples (such as typical III-V and III-N HEMTs at cryogenic temperatures), the response is a periodic decaying function, with the period determined by the inverse plasma wave frequency. As a consequence, the maximum modulation frequency as a function of the field effect mobility has a sharp maximum reaching approximately 1 THz (for the 100 nm III-V HEMTs at room temperature).

These results confirm that plasmonic FET detectors hold promise for THz communications, establish a model for the device design and parameter extraction, and reveal a new interesting physical mechanism responsible for the plasmonic delay time, even in the devices with highly overdamped plasmonic modes.

The work at RPI (M. S. Shur) was supported in part by the U.S. Army Research Laboratory through the Collaborative Research Alliance (CRA) for Multi-Scale Modeling of Electronic Materials (MSME).

1. V. Yu. Kachorovskii and M. S. Shur, *Solid State Electronics* **52**, 182 (2008).
2. S. Rudin, G. Rupper, and M. S. Shur, "Ultimate response time of high electron mobility transistors", to appear in *J. Appl. Phys.* (2015).