Multiphysical Models of Electron-Plasma Electronics for Terahertz Sources and Detectors

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Terahertz nano- and micro- fabricated semiconductor devices are essential to developing compact room-temperature sources and detector. Among terahertz devices, plasma-wave high electron mobility transistors (HEMTs) have demonstrated applications such as terahertz detectors, mixers and emitters. But, to extend the applications of the plasma-waves to terahertz devices and systems, it is important to understand their physics using accurate modeling. In this paper, we propose and develop rigorous numerical multiphysics toolsets to model plasma-wave HEMT devices at terahertz frequencies. Notably, proposed algorithms are also applicable to 2D materials, including graphene layers and MoS_2.

The developed computation algorithm models two interdependent phenomena within the HEMT device: 1) electron transport within the 2DEG channel and 2) electromagnetic fields in the semiconductor media. Transport in the channel is modeled via hydrodynamic equations while the field propagation is modeled using Maxwell's equations. A numerical finite difference time domain (FDTD) algorithm is used to achieve a multiphysics solution. Specifically, the influence of channel AC-currents on EM fields and vice-versa are self-consistently modeled. The developed algorithm is then validated by comparing the plasma-wave resonances observed in the measured transmission spectra of a grating-gated HEMT device.

The developed algorithm is also used to examine a class of HEMT devices and model plasma-wave oscillations for terahertz sources and detectors. First, terahertz instability is demonstrated in a short channel HEMT. It is estimated that several tens of nano-watts of power is possible from InGaAs HEMTs. We also consider RTD-gated HEMTs and demonstrate a new method of plasma-wave amplification and terahertz emissions. As is well known, RTDs exhibit negative differential resistance and the transport equations are modeled in novel manner to account for this properties.

As third example, we examine plasma-wave modes existing in a double channel HEMTs (bilayer). Our simulations revealed new plasma-modes in such bilayer systems. As such, bilayer HEMTs can be used as multimode systems for a new class of applications.