Nanoscale Transistors for On-Chip Sourcing of Terahertz Plasmons

B. Barut[1,2], X. Cantos-Roman[3], J. Crabb[3], C.-P. Kwan[1,2], R. Dixit[1], N. Arabchigavkani[1,2], S. Yin[1], J. Nathawat[1], K. He[1], M. D. Randle[1], F. Vandrevala[1], T. Sugaya[4], E. Einarsson[1,5], J. M. Jornet[3], J. P. Bird[1,†] & G. R. Aizin[6,‡]

[1] Department of Electrical Engineering, University at Buffalo, the State University of New York, Buffalo, NY 14260, USA, [2] Department of Physics, University at Buffalo, the State University of New York, Buffalo, NY 14260, USA, [3] Department of Electrical and Computer Engineering, Northeastern University, Boston, MA 02115, USA, [4] Global Zero Emission Research Center, National Institute of Advanced Industrial Science and Technology (AIST), Tsukuba, Ibaraki 305-8568 Japan, [5] Department of Materials Design and Innovation, University at Buffalo, the State University of New York, Buffalo, NY 14260, USA, [6] Kingsborough College, The City University of New York, NY 11235, USA

E-mail: [†]jbird@buffalo.edu, [‡]Gregory.Aizin@kbcc.cuny.edu

1. Introduction

Plasma oscillations in semiconductors occur at terahertz (THz) frequencies, and represent a potential path to implement ultra-fast electronic devices and circuits. Here, we present an approach to generating on-chip THz signals that relies on the stabilization of plasma waves in nanoscale transistors, designed with very specific structural asymmetry. A hydrodynamic treatment of the electron fluid in the transistors shows how their asymmetry supports the amplification of plasma waves, giving rise to pronounced negative differential conductance (NDC) once this THz plasma mode is stabilized. A proof-of-concept demonstration of this effect is provided in high-mobility $In_{0.8}Ga_{0.2}As$ transistors, which exhibit NDC in accordance with their structural asymmetry. The NDC onsets once the drift velocity in the channel reaches a threshold value, triggering the initial plasma instability. It can also persist beyond room temperature (to at least 75 ºC) when the gating is configured to maximize the instability conditions. Our findings therefore represent a significant step forward for efforts to develop active components for THz electronics.

2. Results

The possibility of realizing sustained plasma oscillations in asymmetric transistors was first suggested by Dyakonov and Shur [1], who formulated a hydrodynamic model of this effect in a two-dimensional electron gas (2DEG). For transistors in which the ac impedance between the source and gate is zero while that between the gate and drain is infinite, they predicted that plasma waves generated under static drain bias should grow exponentially as they travel back and forth below the gate, generating instability in the 2D plasmonic system. Subsequent numerical simulations have shown that these unstable motions can stabilize as a sustained, periodic plasma mode (see [2] for example).

While many experiments have sought to demonstrate the Dyakonov-Shur (DS) instability, efforts to implement the asymmetric boundary conditions called for by Dyakonov and Shur were only made in ad hoc fashion. The experiments then focused on detecting the weak electromagnetic radiation emitted by the plasma mode; the broadband radiation reported in these studies did not show the resonant THz features expected for this phenomenon, however. Consequently, there remain questions as to whether the predicted plasma mode can indeed be realized.

In this work we have taken a novel approach to this problem, demonstrating how the DS instability is manifested in the static (dc) characteristics of transistors designed with intentional structural asymmetry. In our proof-of-concept demonstration [3], we realize plasmonic cavities with asymmetric coupling by fabricating transistors with a narrow gate in an InGaAs/InAlAs 2DEG. Asymmetric coupling of the cavity is achieved by closely aligning the gate with an etched boundary in the heterostructure. Evidence for the DS mechanism is then provided by the observation of NDC with a strong dependence on bias direction, consistent with the engineered asymmetry of our devices. This asymmetry is essential to sustaining the plasma modes predicted in the DS theory. The approach that we have developed may provide the basis for implementing local on-chip THz oscillators, which may be used to source high-frequency signals for future communication systems [4].

3. Conclusions

A strategy to engineer the structural symmetry of nanoscale transistors has been demonstrated that can allow their application as on-chip THz plasmonic sources.

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