Terahertz-Frequency Plasmonic-Crystal Instability in Field-Effect Transistors with Asymmetric Gate Arrays

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The design of efficient and tunable on-chip sources of terahertz (THz) electromagnetic (EM) radiation remains a challenging technological problem, with these sources being one of the key required elements of nanoscale wireless communications systems [1]. Plasmonic THz field-effect transistors (TeraFETs) offer the potential of sourcing signals at frequencies up to 10 THz [1]. These devices use the instability of collective plasma oscillations in the two-dimensional electron channel of a transistor to generate EM radiation. The channel functions as a plasmonic cavity, reflecting plasma waves at its opposite ends. As first predicted by Dyakonov and Shur [2], when the reflection conditions differ substantially, a constant (dc) drive current may induce plasma instability. Recently, we have implemented transistors with specially engineered structural asymmetry, resulting in features characteristic of the DS instability in their transistor characteristics, at temperatures as high as 350 K [3]. In spite of this, the radiated EM power measured in previous experiments has been too small (~nW) to enable practical applications. To improve the emitted power of such radiation transistors can be combined into arrays, but the lack of coherence among plasma oscillations, generated in the individual devices, impedes any significant power increase.

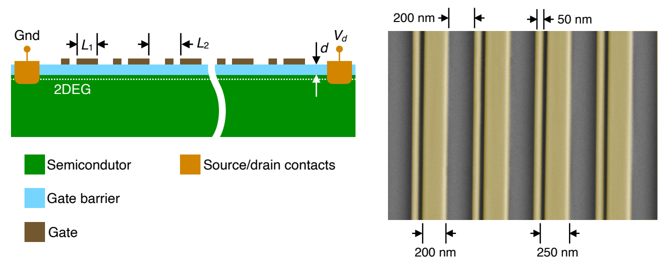

Fig.1. At left is a cross sectional schematic of the structure of the suggested grating device. Shown right is an electron micrograph of a grating-gate fabricated on a GaAs substrate.

To address the problems described above, in this work we analyze a high-electron-mobility transistor with an asymmetric grating-gate array (see Fig. 1) that generates a periodically modulated (equilibrium) carrier density in its channel. When plasma oscillations are excited in the individual elementary cells defined by the grating gates, the coupling of these oscillations forms a plasmonic crystal, with the ungated sections providing coherent electromagnetic linkage between the gated plasmonic cavities. The asymmetric boundary conditions necessary for the plasma instability in individual cells are provided by placing a narrow metal finger near one edge of each gated cavity (dual grating gate, see the right panel of Fig. 1). This array structure is designed to achieve strong asymmetry within the elementary cells of the resulting plasmonic crystal, together with the coherence of plasma oscillations in individual cells. We present a quantitative theoretical study of plasma-wave generation in the channel of such a transistor and demonstrate that a dc bias current may cause the plasma band modes of this periodic system to become unstable within the *entire* Brillouin zone. In this way, we identify the conditions under which, with dc current biasing, the plasma-wave instability increment can exceed the damping rate of the plasma waves due to (phonon and impurity) scattering. In these circumstances, any spontaneous charge inhomogeneity that develops in the channel will grow exponentially with time as plasma waves are excited. This process should eventually lead to sustained plasma oscillations once the initial instability reaches its endpoint, allowing the transistor to serve as a controlled source of THz EM radiation.

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References

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