Ballistic Transport and Shallow Water/Deep Water Effects in HEMTs

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Ballistic effects in short-channel high electron mobility transistors (HEMTs) might greatly reduce the field effect mobility compared to that in long gate structures. This reduction is related to a finite electron acceleration time in the channel under the device gate. As an example, the field effect mobility at room temperature in 0.15 μm gate AlGaAs/GaAs HEMTs cannot exceed 3,000 $cm^2/V \cdot s$. These predictions are consistent with the values of the field effect mobility extracted from the measured AlGaAs/GaAs HEMT current-voltage characteristics.[1] The effect of the effective mobility reduction affects the predicted "shallow water waves" instability that the electron momentum relaxation time should be much larger that the electron transit time. The resonant terahertz detection by plasma waves only requires that the electron momentum relaxation time should be much larger than the period of the plasma oscillations. This condition is much easier to meet, and recent observations of resonant terahertz detection in short channel GaAs and GaN-based HEMTs[2,3,4] confirmed the effect of the rectification of surface plasma waves excited by terahertz radiation.

The plasma waves in field effect transistors (FETs) are described by the same equations as shallow water waves with the frequency being inversely proportional to the wavelength.[5] A similar analogy applies to the plasma waves propagating in ungated regions of a FET structure. These waves correspond to deep water waves that have a much higher frequency, which is inversely proportional to the square root of the wavelength. The entire gated and ungated channel has therefore a smaller fundamental frequency. This prediction is in agreement with our experimental data.

To achieve the terahertz emission caused by plasma waves, we proposed the ways to enhance the instability increment using electron transit time effects across the gate barrier layer or across the high field region at the drain side of the channel in the saturation regime. We will present preliminary results on achieving such emission in GaN-based HEMTs.

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