Plasma Wave Terahertz Electronics

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***Abstract*—The frequencies of plasma waves (i.e. waves of electron density) in short channel field effect transistors (FETs) lie in terahertz (THz) range. Excitation, instability, and rectification of plasma waves enable a new generation of THz electronics promising to bridge the famous terahertz gap.**

I. Introduction And Background

As device feature sizes scale down to the nanometer range, the electron mean free path becomes comparable to the device feature size, and physics of electron transport becomes completely different from that for longer channel devices. The electron transport becomes ballistic or quasi-ballistic.[1] Even main stream silicon CMOS technology is now close to the ballistic limit (see Figure 1).

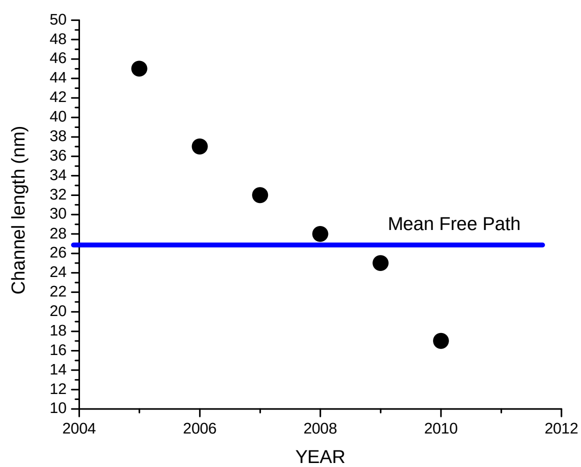

Figure 1. Effective channel length projections and mean free path in silicon at room temperature (from[2]).

Under such conditions, the conventional notion of the electron mobility determined by electron scattering with impurities or lattice vibrations is no longer valid. Instead, the current becomes contact dominated, even for the ideal n^+-n contacts. The effective field effect mobility becomes proportional to channel length [3,4] and the electron velocity in high electric field might greatly exceed the peak and saturation velocity in long channel devices. At high frequencies, electron inertia starts playing a dominant role, and the propagation of the waves of electron density in the device channel – plasma waves – determines the device response at THz frequencies. As seen from Figure 2, the plasma wave frequencies are much higher that the inverse transit times of electrons across the device channel).

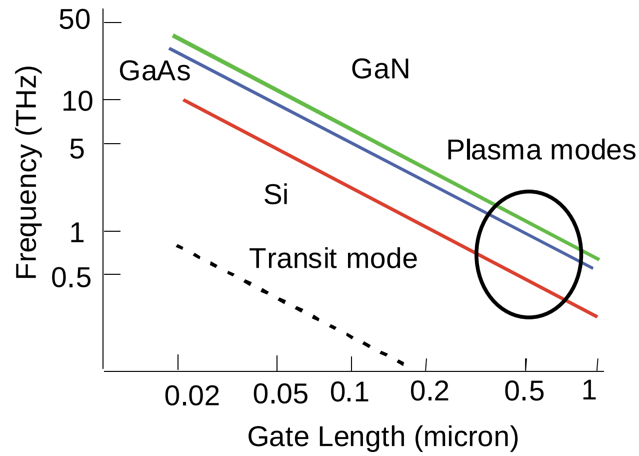

Figure 2 Plasma wave frequency in FET channels versus gate length for AlGaN/GaN HEMTs, AlGaAs/InGaAs HEMTs, and for Si n-MOSFETs (from [5] ©IEEE 2003).

II. Results

A THz beam impinging on a FET excites plasma waves in the gated and ungated sections of the device channel. The frequency of the ungated plasma waves is much higher and they are coupled more efficiently to the THz radiation. The frequency of the plasma waves can be tuned by the gate bias. The gated and ungated plasma waves can interact resulting in a complicated excitation pattern. Ideally, the channel plays a role of a resonant cavity for the plasma waves. In reality, these waves are often overdamped. The rectification of the resonant or overdamped plasma waves leads to an additional induced drain bias that can be used to detect the THz radiation. [6]

The device bias strongly affects the plasma wave frequency and amplitude, and biasing the device close to the drain current saturation regime greatly enhances the plasma wave THz detector responsivity (see Figure 3).

In a ballistic channel, the drain current causes the plasma wave instability[7] that can lead to the THz emission. [8,9] Figure 4 shows emission spectra from a nanometer size AlGaN/GaN and InAlAs/InGaAs FETs at helium and room temperatures (these results obtained by Dr. Knap's group at the University of Montpellier). The generated power is from a single nanometer scale FET is quite small but orders of magnitude improvements have been predicted for the FET arrays (see Figures 5). [10,11] A much better coupling to THz radiation compared to a single channel device should also result in a much more sensitive THz detection (see Figure 6).

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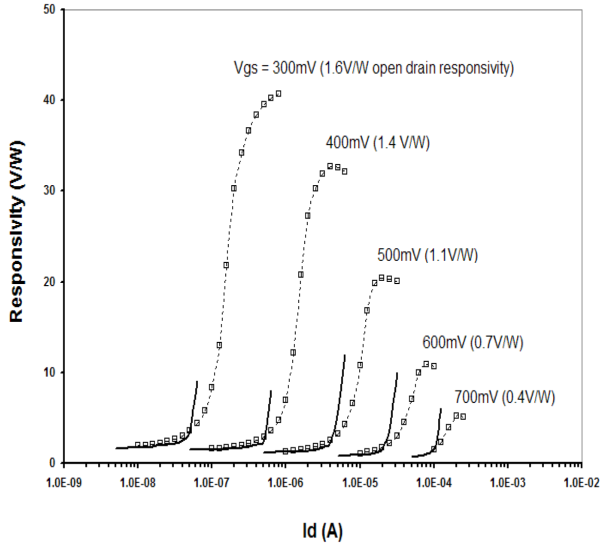

Figure 3. Drain current enhanced 0.2 THz responsivity (left). Heavy lines illustrate the onset of enhancement predicted after Veksler, et al. Physical Review B vol. 73, pp. 125328-1, 2006.

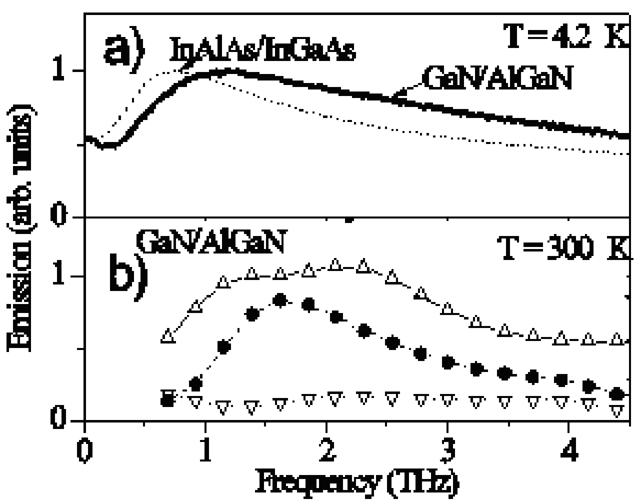

Figure 4. THz emission spectra from a nanometer size AlGaN/GaN and InAlAs/InGaAs FETs at helium and room temperatures.[12]

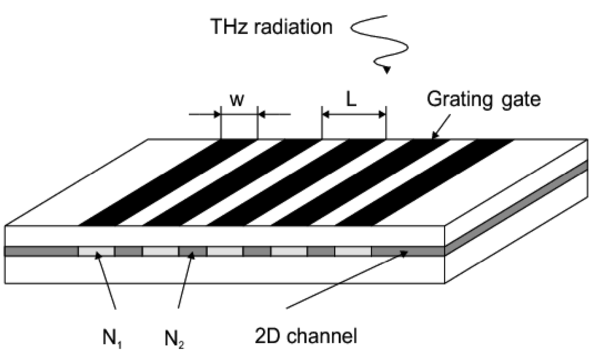

Figure 5. Schematic diagram of field effect transistor array for enhanced THz detection.[13]

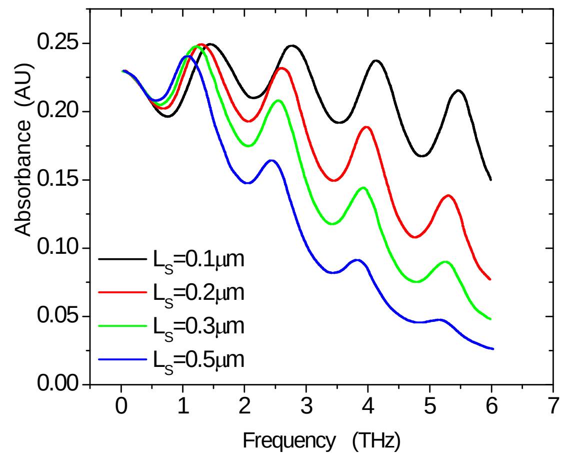

Figure 6. Plasmon absorption in a slit-grating gate device is 10^3 times stronger than in array of non-interacting FET units.[13]

Moving the device with respect to the focused THz beam and recording the induced drain voltage generates the FET THz image that is sensitive to the electric field distribution in the devices channel (see Figure 7).[14],[15] Such subwavelength images can be used for in-situ testing of nanometer scale devices under bias.

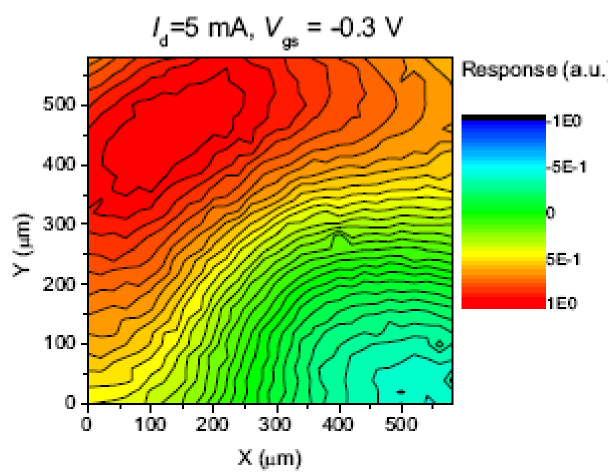

Figure 7. THz images of AlGaAs/GaAs HEMT recorded as the dependence of the transistor response versus its displacement. [14] ©IEEE 2007

In conclusion, plasma wave electronics holds promise of developing tunable sources and tunable sensitive detectors of sub-THz and THz radiation using nanoscale FETs. The implementation of such devices will require better understanding of coupling of THz radiation and plasma waves and will rely on using arrays of nanoscale FETs.

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