Monte Carlo Analysis of Plasma Enhanced Terahertz Detection in InGaAs HEMTs

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INTRODUCTION

In the last years, the possibility of exploiting plasma resonances in semiconductor devices in order to fabricate compact room temperature THz sources and detectors has attracted increasing attention. THz detection as a result of plasma wave resonances has been demonstrated by recent experiments made with classic HEMTs based on different material systems (GaAs, InGaAs and GaN) and Si MOSFETs [1]. Also, some evidence of plasma related THz emission has been found. Up to now, only ideally simple 1D theoretical models, not considering the complex geometry and electron dynamics of HEMTs, have been used for predicting the different plasma modes present in the transistor [2]. In this work we analyze the mechanisms of plasma-resonant THz detection in InGaAs HEMTs at a microscopic level by means of a 2D Monte Carlo (MC) simulator self-consistently coupled with a Poisson solver [3].

MONTE CARLO MODEL AND STUDIED DEVICES

The semiclassical MC transport description is based on a 3-valley model (Γ-L-X nonparabolic spherical valleys for both InGaAs and AlInAs) and includes ionized impurity, alloy, polar and non-polar optical phonon, acoustic phonon and intervalley scattering [3]. The simulated 80 nm T-gate InGaAs HEMTs is shown in Fig. 1, with a recessed topology similar to that commonly used in fabricated devices. Different values of the lengths of the source, recess and drain regions (Ls, Lr and Ld, respectively) will be considered to identify their influence on the plasma effects. Simulations are performed at T=300 K.

In order to model THz detection (AC to DC conversion), a sinusoidal signal of varying frequency is superimposed to the DC gate bias V_{gs} and the average drain current I_d is recorded. The detection of the AC signal is therefore performed in terms of the increment in the drain current ΔI_d. Noise in the currents has also been calculated and compared to rectification results.

RESULTS

Fig. 2 shows the variation of the drain current with respect to its static value ΔI_d as a function of the frequency of the signal (of amplitude 0.1 V) superimposed to different DC values of V_{gs} in a HEMT with Ls=200 nm, Lr=100 nm and Ld=500 nm. As observed, ΔI_d shows a resonant peak (mainly for V_{gs} near pinch off) for a frequency around 2.5 THz, in good agreement with similar experimental measurements [1].

For having a deeper insight into the origin of the plasma-resonant detection we have performed simulations of HEMTs with different geometries for V_{gs}=-0.3 V, gate bias providing the optimum AC to DC response. As observed in Fig. 3(a), the frequency of the resonant peak does not depend on the gate length Lg nor on the recess-drain region Ld. On the contrary, it strongly depends on the lengths of the recess-source region Ls [Fig. 3(b)] and of the source side of the recess Lr [Fig. 3(c)]. A similar behaviour is found in the corresponding noise spectra. These results clearly indicate that the source-gate region (including the recess) acts as the plasma-wave cavity that produces the resonant detection of THz radiation in HEMTs. Indeed, the dependence of the frequency of the resonant peak on Ls and Lr can be explained by the appropriate combination of the different possible (gated and ungated) plasma modes that, due to the complex geometry of the simulated HEMT, appear in the source-gate region, sketched in Fig. 4. This will be illustrated at the conference.

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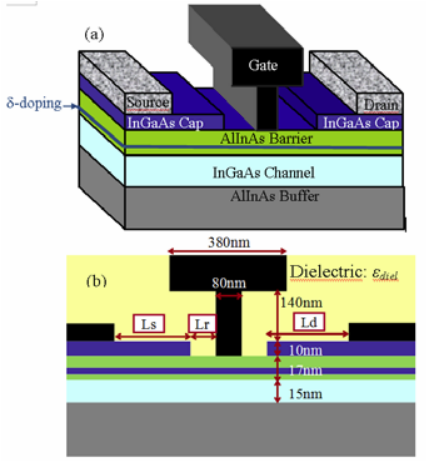

Fig. 1. (a) Layer structure and geometry of the simulated HEMTs based on InGaAs channels. (b) 2D simulation domain and main dimensions.

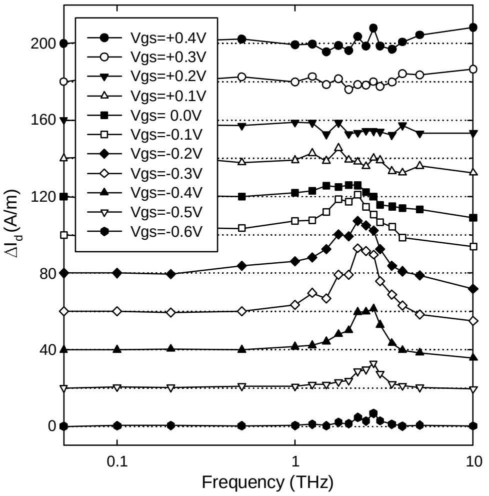

Fig. 2. Average drain current variation ΔI_d originated by the superposition of a sinusoidal signal of 0.1 V of amplitude and varying frequency to the DC gate potential (V_{gs}) of a HEMT with *Ls*=200 nm, *Lr*=100 nm and *Ld*=500 nm. The different curves have been shifted by 20 A/m each for the sake of clarity. V_{ds}=1.0 V.

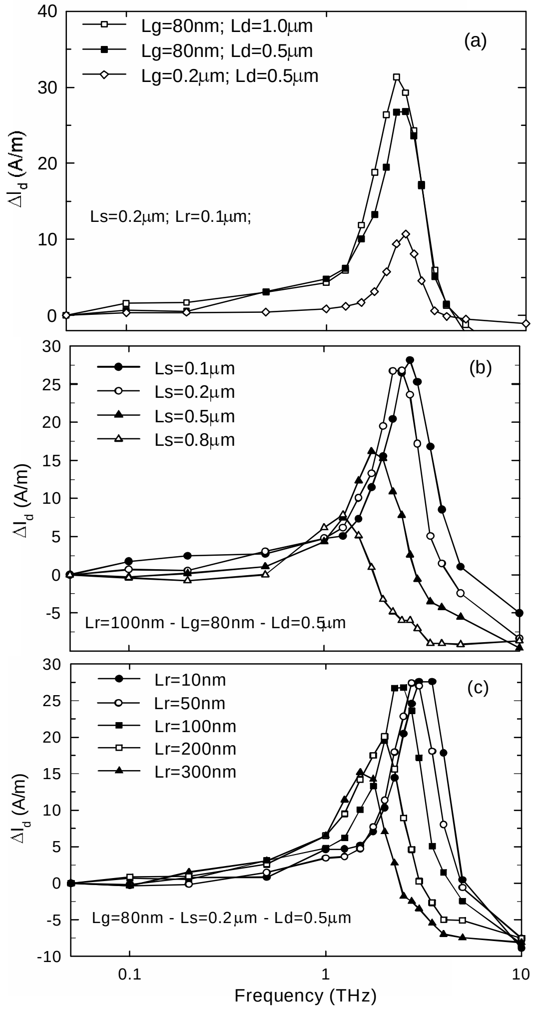

Fig. 3. ΔI_d vs. frequency for V_{gs}=-0.3 V and V_{ds}=1.0 V for HEMTs with different (a) *Ld* and *Lg*, (b) *Ls* and (c) *Lr*.

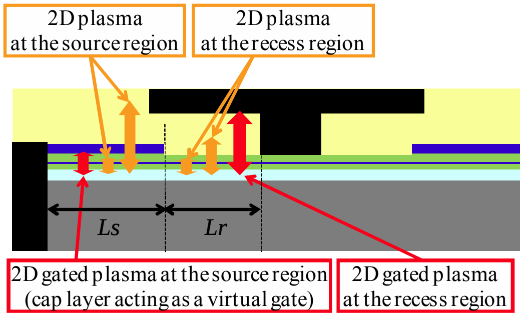

Fig. 4. Representation of the different possible 2D plasma modes in the source-gate region of the recessed T-gate HEMT. Ungated 2D plasma modes are shown in yellow, while the gated ones are shown in red. The source and recess regions are indicated.