Session: Device Simulations

(Invited) Transport modeling for plasma waves in THz devices

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The plasma wave instability in a field effect transistor can be used to generate THz waves [1]. The analytical models which are used to investigate the behavior of the two dimensional electron gas in such devices are usually based on the first two moments of the semi-classical Boltzmann Transport Equation (BTE) which are the Euler and continuity equations [2] and we will call them the Semiconductor Equations (SE) [3]. The derivation of these equations requires many approximations and their accuracy compared to the BTE is limited. In this paper the accuracy of SE will be investigated by comparison with the results of the BTE.

The accuracy of the SE is assessed by comparing its small signal mobility with the one of the BTE. In this step no dispersion relation between the wave number and frequency is imposed by the Poisson Equation (PE) and therefore we can compare the transport models for arbitrary frequencies and wave numbers [3]. The stationary electric field is chosen such that both models yield the same stationary drift velocity.

In Fig. 1 the real and imaginary part of the small signal mobility is shown when the wave number is set to zero. The SE model fails even at low frequencies, because the analytical modeling does not contain velocity saturation. The absolute value of the small signal mobility for a constant frequency of 1THz is shown for positive and negative wave numbers in Fig. 2. For small wave numbers the product of frequency and relaxation time is much larger than one and the transport is ballistic. Therefore in this area the SE model and the BTE results agree well. In the case of larger wave numbers the SE model fails and the resonant behavior of the SE model is far too strong and two resonance peaks are found for negative wave numbers.

In order to obtain the plasma dispersion, the SE or BTE are solved together with the PE for the quasi-static potential as a general eigenvalue problem. Calculation of the plasma dispersion relation is exemplified for a simple double gate structure which is homogeneous in the transport direction and the thickness of the GaAs quantum well is assumed to be negligible compared to the oxide thickness. In Fig. 3 the Vlasov plasma modes for nonzero electric field are plotted for the SE and BTE. Again we can see that the SE fails in most cases.

We consider a device with a 60 nm long channel and asymmetric boundary conditions, to simulate the plasma instability by the Dyakonov and Shur approach [1]. Fig. 4 shows the growth rate (increment) of the oscillation versus drift velocity and its frequency. The drift velocity depends on the applied drain/source bias and for large voltages velocity saturation occurs leading to strong dissipation and damping of the plasma waves. Since velocity saturation is neglected in the SE, their results are far to optimistic.

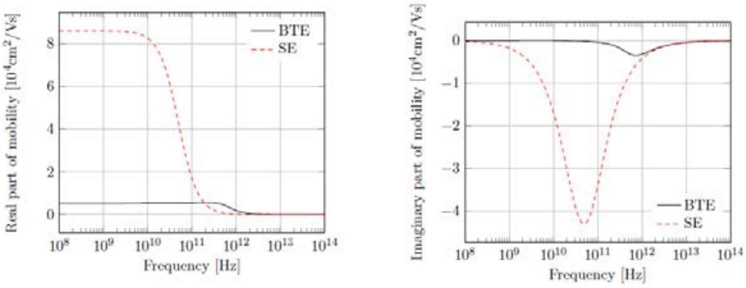

Figure 1: The real (left) and imaginary (right) parts of the small signal electron mobility for the GaAs quantum well at 77K and zero wave number for a drift velocity of $-2 \cdot 10^7$ cm/s

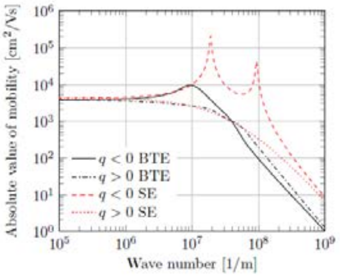

Figure 2: Absolute value of the small signal mobility for 1THz in the GaAs quantum well for a drift velocity of $-2 \cdot 10^7$ cm/s at 77K

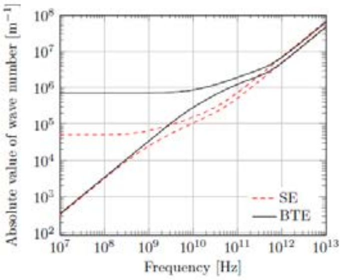

Figure 3: The two Vlasov plasma modes for a drift velocity of $-2 \cdot 10^7$ cm/s at 77K.

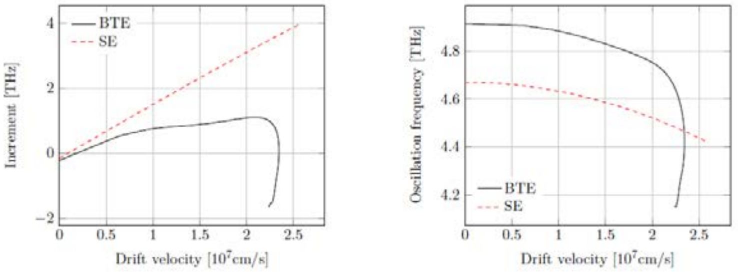

Figure 4: Increment (left) and oscillation frequency (right) of plasma waves versus drift velocity at 77K for a 60nm device.

[1] M. Dyakonov and M. Shur, *Phys. Rev. Lett.*, vol. 71, pp. 2465–2468, Oct 1993. [Online]. Available: http://link.aps.org/doi/10.1103/PhysRevLett.71.2465

[2] S.-M. Hong and J.-H. Jang, *Electron Devices, IEEE Transactions on*, vol. 62, pp. 4192– 4198, Dec 2015.

[3] Z. Kargar *et al.*, *IEEE Transactions on Electron Devices*, vol. 63, pp. 4402–4408, Nov 2016.