Evidence of quasi-ballistic transport limiting f_T in graphene field-effect transistors

Isabel Harrysson Rodrigues[1], Andrei Vorobiev[1]

[1]*Terahertz and Millimetre Wave Laboratory, Department of Microtechnology and Nanoscience, Chalmers University of Technology, SE-41296 Gothenburg, Sweden*

The realization of high-frequency graphene field-effect transistors (GFETs) has moved slowly, despite large research efforts to improve limiting factors i.e., extrinsic scattering of charge carriers and high contact resistance [1]. However, in this work, we report on another reason for the limited high-frequency performance of GFETs. We show a correlation between quasi-ballistic transport and the high-frequency performance of GFETs. The dependencies of the extrinsic frequency f_{T-ext} and maximum frequency f_{max} on gate length have previously indicated that GFETs are very promising for scaling down, particularly for developing amplifiers operating in the mm-wave frequency range. Though, little attention has been brought to the fact that scaling down will eventually force us to enter the quasi-ballistic transport regime. Evaluating a large number of transistors, scaling down the gate lengths has shown to reduce mobility [2], hence affecting the velocity saturation. Fig. 1 a) shows the mobility of devices with gate lengths from 2 µm down to 0.2 µm, where the reduction in mobility is evident. Furthermore, the data in Fig.1 a) have been used to calculate f_{T-ext} as in Ref. [3]. Plotting the obtained f_{T-ext} as a function of gate length, presented in Fig. 1 (b), shows a clear saturation of f_{T-ext} for the smaller gate lengths. For comparison, experimental data and the fitting from Ref. [4] have been implemented in Fig. 1 b), which shows to be in good agreement with our data from Fig.1 a). The mobility in the GFETs cannot reach higher than approximately 60 GHz in f_{T-ext} due to the contribution of ballistic transport in devices with smaller gate lengths, hence limiting the high-frequency performance and setting an upper physical limit.
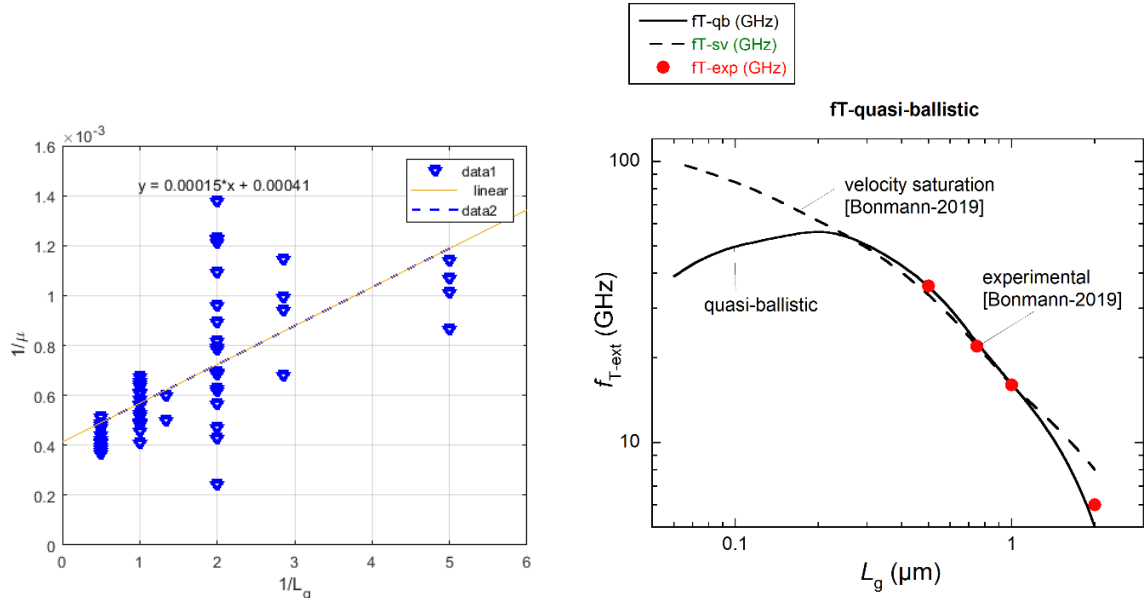

Fig. 1. (a) The reciprocal of mobility as a function of one over gate length for 67 GFETs, with a linear fit. (b) Calculated f_{T-ext} as a function of gate length (solid line), with an additional fit (dashed line) and data points (red solid circles) from Ref. [4].

[1] M. Bonmann, et al., Appl. Phys. Lett. 111, 233505 (2017).
[2] I. Meric et al. Nano Lett., 11, 3, 1093–1097 (2011)
[3] S. Rakheja, et al., IEEE Trans. 13, 1005-1013 (2014)
[4] M. Bonmann et al., IEEE Electron Device Lett., vol. 40, no. 1, pp. 131-134, (2019)