Charge carrier transport in graphene field-effect transistor scaled down to submicron gate lengths

Citation for the original published paper (version of record):

Harrysson Rodrigues, I., Vorobiev, A. (2022). Charge carrier transport in graphene field-effect transistor scaled down to submicron gate lengths. Compound Semiconductor Week 2022. http://dx.doi.org/10.1109/CSW55288.2022.9930439

Charge carrier transport in graphene field-effect transistor scaled down to submicron gate lengths

Isabel Harrysson Rodrigues[1], Andrei Vorobiev[1]
[1]Department of Microtechnology and Nanoscience
Chalmers University of Technology
Gothenburg, Sweden
isabelr@chalmers.se

Abstract— **We present a preliminary study of charge carrier transport in graphene field-effect transistor with gate lengths ranging from 2 µm down to 0.2 µm applying a model of the quasi-ballistic charge carrier transport. The analysis indicates that, in particular, at the gate length of 0.2 µm the fraction of the ballistic carriers can be up to 60 %. Our finding can be used as a guidance for further development of the graphene field-effect transistors with submicron gate length for variety of the advanced and emerging applications.**

Keywords—graphene; field-effect transistor; quasi-ballistic transport; charge carrier mobility

I. I. INTRODUCTION

Future progress in modern electronics relies on development of novel two-dimensional materials with cutting-edge performance, among which graphene is a promising candidate. The property of very high carrier mobility and velocity in graphene enables the possibility of much faster electronics than with traditional semiconductors [1]. However, a criterion for graphene to compete with existing technology is the possibility of scale down devices while maintaining high performance. In this work, we present a preliminary study of the graphene field-effect transistors (GFETs) with gate lengths (L) ranging from 2 µm down to 0.2 µm applying a model of the quasi-ballistic charge carrier transport.

II. RESULTS AND DISCUSSION

Fig. 1 and Fig. 2 show an optical microscopy image and a 3D schematic view of the dual-finger GFETs studied in this work. Fig. 3 shows typical dependences of the drain resistance (R_{DS}) on the gate voltage (V_G) of the GFETs with L=0.2 µm and 2 µm. We used the measured dependences of the R_{DS} on V_G to evaluate the mobility via fitting the dependences by the drain resistance model [2]

$$R_{ds} = R_s + \frac{L}{W}\frac{1}{\mu e}\frac{1}{\sqrt{n_0^2+\left(V_{go}\frac{C_g}{e}\right)^2}}, \tag{1}$$

where R_s is the series resistance, n_0 is the residual concentration of charge carriers, V_{go} is the gate voltage overdrive and C_g is the gate capacitance per unit area. Fig. 4 shows the mobility found as fitting parameters in (1) for a number of GFETs plotted versus L. The deviations of μ in GFETs with similar L are typical and caused by special inhomogeneity in graphene. It can be seen, from Fig. 4 that, in general, the μ decreases with decreasing L. We applied the model of the ballistic transport phenomenologically proposing that [3]

$$\frac{1}{\mu} = \frac{1}{\mu_0} + \frac{1}{\mu_B}, \tag{2}$$

where μ_0 is the mobility associated with the diffusive charge carrier transport and the μ_B is an L dependent quantity called the ballistic mobility. It can be shown that

$$\frac{1}{\mu} = \frac{1}{\mu_0} + \frac{1}{\mu_0}\frac{\lambda_B}{L}, \tag{3}$$

Where λ_B is characteristic length corresponding to the L on which the ballistic motion becomes important for the mobility reduction. The transmission coefficient showing the fraction of the ballistic carriers can be expressed as [3]

$$T = \lambda_B/(L + \lambda_B) \tag{4}$$

Fig. 5 shows the transmission coefficient versus gate length calculated using λ_B found from (3) by linear fitting of $1/\mu$ on $1/L$ dependence and mobility of GFETs shown in Fig. 4. It can be seen, that, in particular, at L=0.2 µm the fraction of the ballistic carriers can be up to 60 %. Our finding can be used as a guidance for further development of GFETs with submicron gate length for variety of the advanced and emerging applications.

This project was supported by the EU Horizon 2020 Programme, under Grant No 881603 (Graphene Core 3).

1. J.H. Chen et al., Nature Physics 4, 377-381 (2008)
2. S. Kim and J, Nah et al., Applies Physics Letters 94, 062107 (2009)
3. J. Łusakowski, W. Knap, et al., Solid-State Electronics, 50, 4, 632-636 (2006)

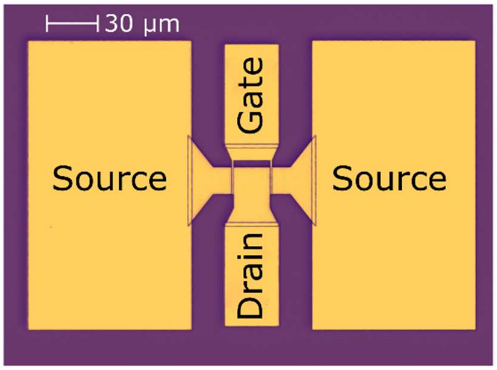

Fig. 1. Optical microscope image of a fabricated dual-gate GFET.

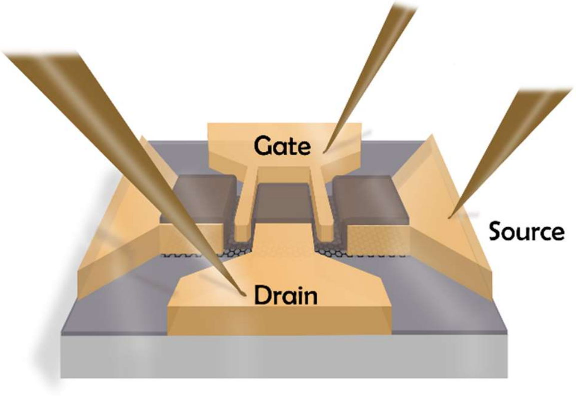

Fig. 2. A 3D-schematic of a GFET with shown microprobes used for characterization.

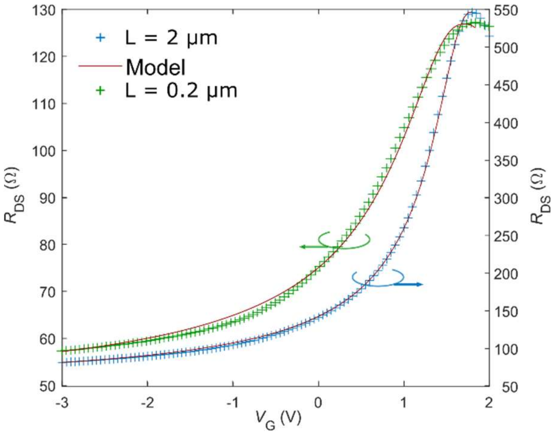

Fig. 3. Dependences of the drain resistance (R_{DS}) on the gate voltage (V_G) of the GFETs with L=0.2 µm and 2 µm.

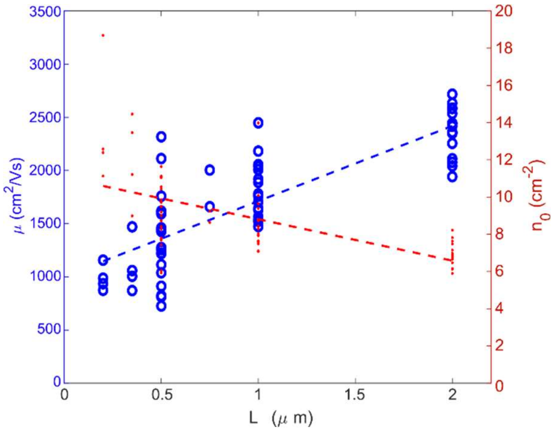

Fig. 4. Mobility (μ) (blue symbols and left axis) and residual concentration of charge carriers (n_0) (red symbols and right axis) found using Eq. 3 in GFETs with different gate length. The dashed lines serve only as guides for the eyes.

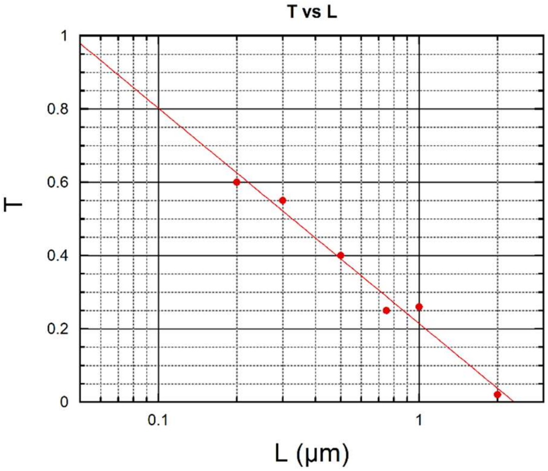

Fig. 5. Transmission coefficient (T) versus gate length calculated using λ_B found from Eq. 3 by linear fitting of $1/\mu$ on $1/L$ dependence and mobility of GFETs shown in Fig. 4. The solid line is a linear fit.