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

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***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.

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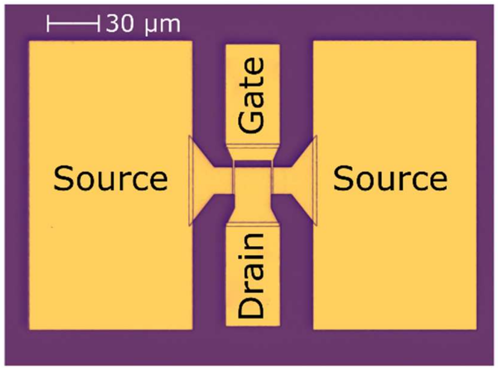

Fig. 1. Optical microscope image of a fabricated dual-gate GFET.

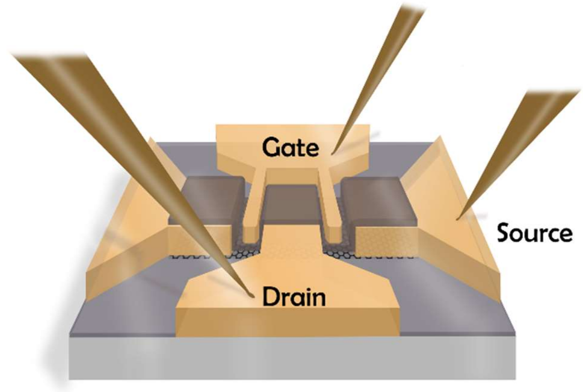

Fig. 2. A 3D-schematic of a GFET with shown microprobes used for characterization.

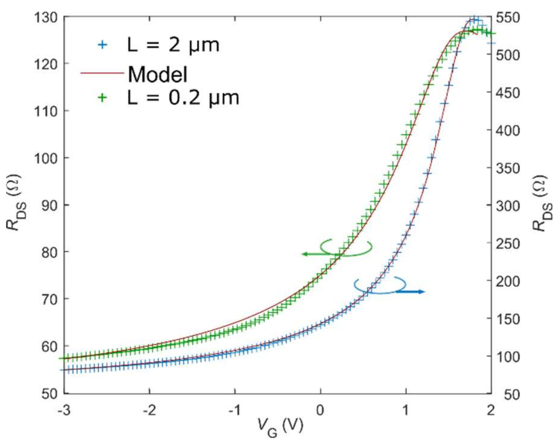

Fig. 3. Dependences of the drain resistance (R_{DS}) on the gate voltage (V_G) of the GFETs with L=0.2 μm and 2 μm.

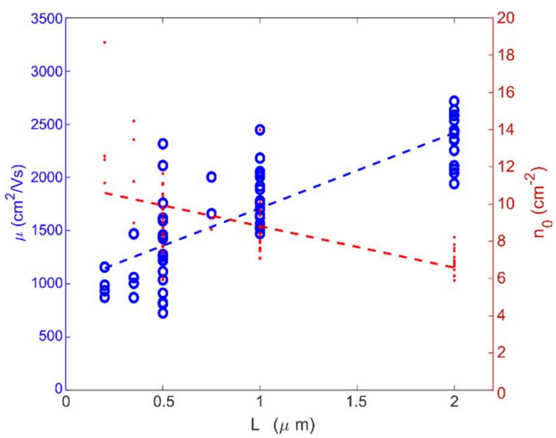

Fig. 4. Mobility (μ) (blue symbols and left axis) and residual concentration of charge carriers (n_0) (red symbols and right axis) found using Eq. 3 in GFETs with different gate length. The dashed lines serve only as guides for the eyes.

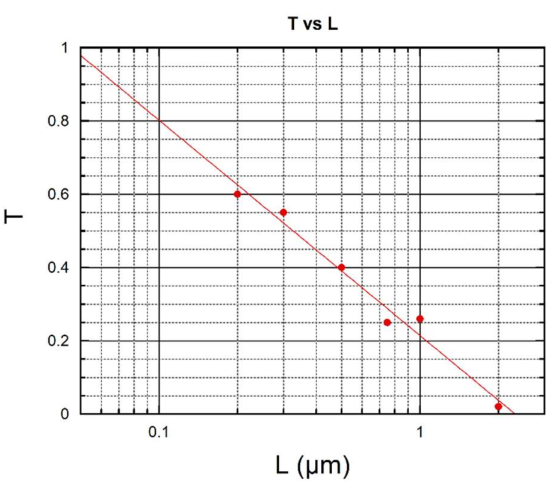

Fig. 5. Transmission coefficient (T) versus gate length calculated using λ_B found from Eq. 3 by linear fitting of $1/\mu$ on $1/L$ dependence and mobility of GFETs shown in Fig. 4. The solid line is a linear fit.