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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  $\mu\text{m}$  down to 0.2  $\mu\text{m}$  applying a model of the quasi-ballistic charge carrier transport. The analysis indicates that, in particular, at the gate length of 0.2  $\mu\text{m}$  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. 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  $\mu\text{m}$  down to 0.2  $\mu\text{m}$  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  $L=0.2 \mu\text{m}$  and 2  $\mu\text{m}$ . 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]

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

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  $\mu$  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  $\mu$  decreases with decreasing  $L$ . We applied the model of the ballistic transport phenomenologically proposing that [3]

$$\frac{1}{\mu} = \frac{1}{\mu_0} + \frac{1}{\mu_B}, \quad (2)$$

where  $\mu_0$  is the mobility associated with the diffusive charge carrier transport and the  $\mu_B$  is an  $L$  dependent quantity called the ballistic mobility. It can be shown that

$$\frac{1}{\mu} = \frac{1}{\mu_0} + \frac{1}{\mu_0} \frac{\lambda_B}{L}, \quad (3)$$

Where  $\lambda_B$  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]

$$T = \lambda_B / (L + \lambda_B) \quad (4)$$

Fig. 5 shows the transmission coefficient versus gate length calculated using  $\lambda_B$  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  $L=0.2 \mu\text{m}$  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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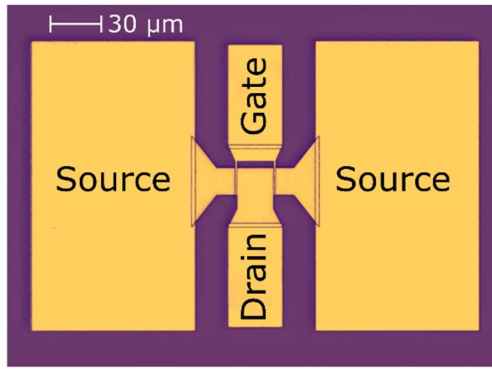


Fig. 1. Optical microscope image of a fabricated dual-gate GFET.

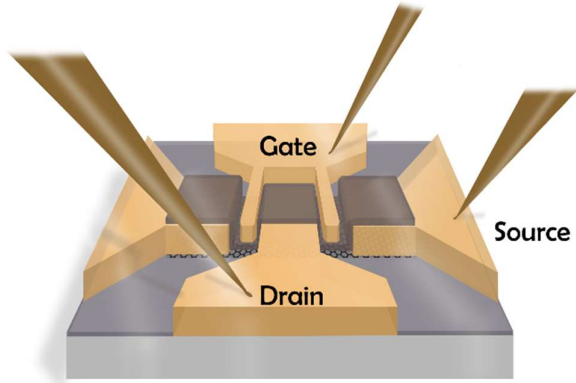


Fig. 2. A 3D-schematic of a GFET with shown microprobes used for characterization.

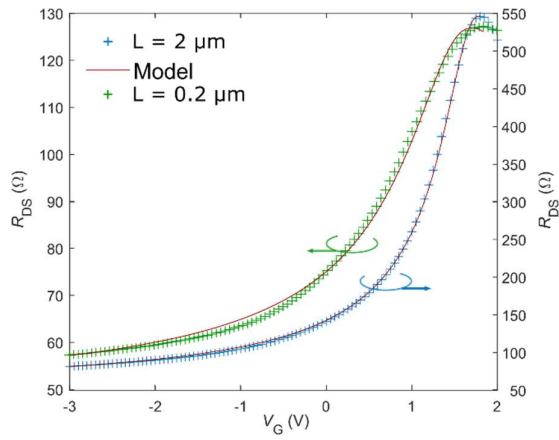


Fig. 3. Dependences of the drain resistance ( $R_{DS}$ ) on the gate voltage ( $V_G$ ) of the GFETs with  $L=0.2 \mu m$  and  $2 \mu m$ .

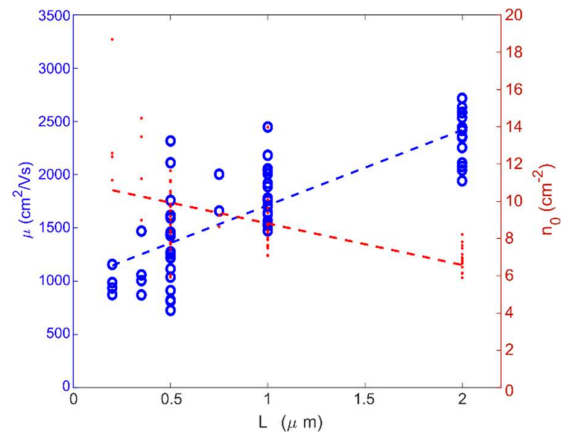


Fig. 4. Mobility ( $\mu$ ) (blue symbols and left axis) and residual concentration of charge carriers ( $n_0$ ) (red symbols and right axis) found using Eq. 3 in GFETs with different gate length. The dashed lines serve only as guides for the eyes.

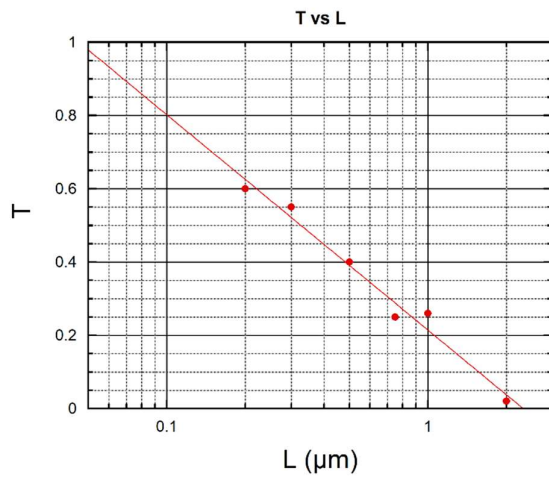


Fig. 5. Transmission coefficient ( $T$ ) versus gate length calculated using  $\lambda_B$  found from Eq. 3 by linear fitting of  $1/\mu$  on  $1/L$  dependence and mobility of GFETs shown in Fig. 4. The solid line is a linear fit.