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60 GHz current gain cut-off frequency graphene nanoribbon FET

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We report investigations on the fabrication and characterization of graphene nanoribbon (GNR) field-effect transistors. Graphene layers are obtained from the thermal decomposition of a Si-face 4H-SiC substrate. To achieve high dynamic performance, a structure with an array of GNR connected in parallel was fabricated by e-beam lithography. The best intrinsic current gain cut-off frequency of 60 GHz and maximum oscillation frequency of 28 GHz were achieved. This study demonstrates the exciting potential of GNR in high-frequency electronics.

Keywords: Graphene FET, Ribbon, HF characterization, GNR

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I. INTRODUCTION

Since the stability of graphene was demonstrated under an ambient condition in 2004 [1], the research community has been attracted by its potential high carrier mobility even at room temperature [1–3]. Actually, graphene appears as a promising candidate for the fabrication of the future generation of high-frequency electronic devices, in particular, for field-effect transistors (FET) [1, 4–12]. One of the main advantages of graphene for this kind of application comes from its planar structure, which allows the use of well-matured planar processes in the semiconductor industry. Several research results focused on the static characterization of graphene-based transistors are available in the literature [7–12]. However, studies in the high-frequency domain are still lacking [4–6]. We present a study dedicated to the fabrication and characterization of graphene-based field-effect transistor for high-frequency applications.

II. GRAPHENE SYNTHESIS AND CHARACTERIZATION

There are different ways to synthesize graphene [1, 13–17]. In this work, thermal decomposition on axis SiC-4H {0001} substrate is considered [14, 15]. In order to achieve graphene layer of high quality, an exposure of SiC substrate to a silicon flux during 1 h at 1100°C is used to obtain a high-quality SiC surface [18]. Based on the parameters of graphitization (6 min at 1400°C), the multilayer of graphene is realized. The layer number is deduced from Atomic Force Microscopy (AFM) measurements of the active layer's total thickness (1.66 nm) (Fig. 1(a)) after selective etching of graphene versus the SiC substrate: the oxygen plasma etching is used. By assuming that the inter-distance between two layers is 0.335 nm, the estimated number of graphene layers is 5. The total thickness is measured on the same atomic step (Fig. 1(a)) in order to improve the result accuracy. Transport properties of the active layer are determined from the Hall effect measurement. Mobility of 427 cm^2/V s and carriers density (electrons) of -7.5×10^{13} are obtained.

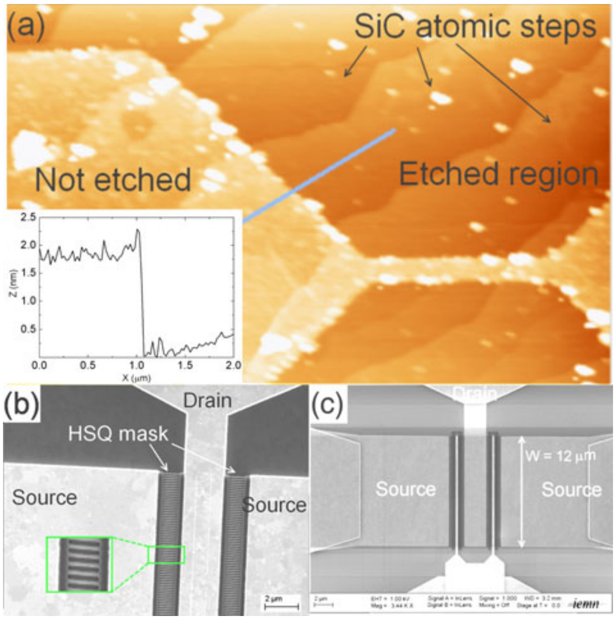

Fig. 1. (a) Measurement of grapheme-layer thickness by AFM. On the same SiC atomic step, the height measured is 1.66 nm, which results about five monolayers of graphene. (b) Scanning electron microscopy (SEM) images of e-beam mask showing arrays of ribbons (50 nm width, and 50 nm spaced). (c) SEM image of final device.

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III. DEVICE FABRICATION AND CHARACTERIZATION

A) Device fabrication

Graphene nanoribbon field-effect transistors (GNRFET) considered in this work is a dual gate device, in a coplanar access structure. GNR arrays are defined by e-beam lithography with a ribbon width of 50 nm, 50 nm spaced (Fig. 1(b)). The Al_2O_3 gate oxide on GNR is obtained by two steps of oxidation of thin aluminum films deposited by e-beam evaporation. To this end, about 2 nm of aluminum is evaporated before exposure in air during 4 h. This process, repeated twice, leads to a final Al_2O_3 thickness of 5 nm. The top gate (Ni/Au 50 nm/300 nm) is finally deposited by lift-off process. The gate length is $L_g = 150$ nm, and the gate width is $W = 12$ µm (Fig. 1(c)). Therefore, there are 120 GNRs per gate channel.

B) Device characterization

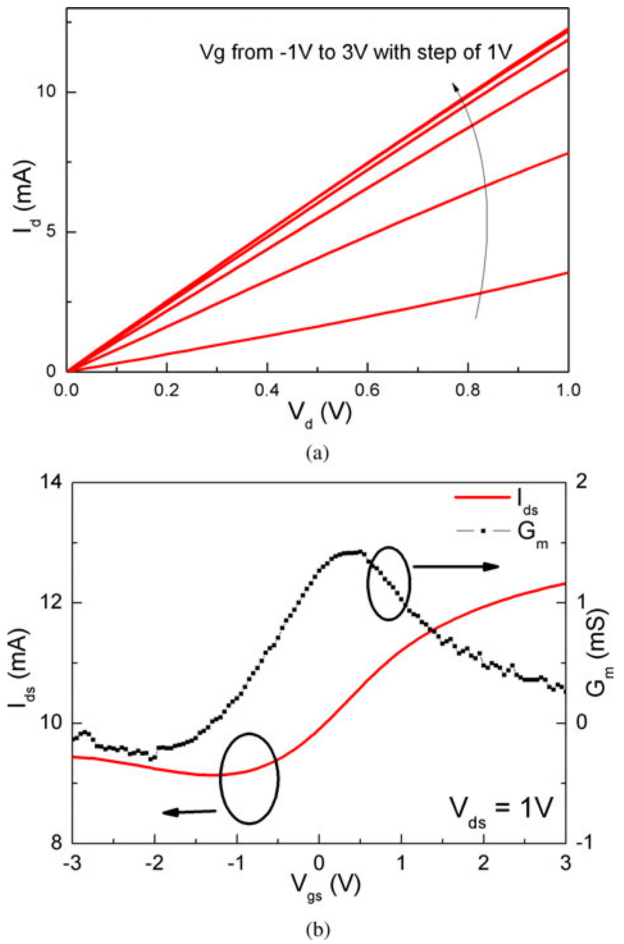
DC and HF characterization of our GNRFET are performed using an Agilent E8361A network analyzer (VNA). In the DC regime, at $V_{ds} = 1$ V, a drive current (I_{ds}) of 12.5 mA, and G_m of 1.47 mS are obtained (Fig. 2). Asymmetrical ambipolar effect is observed (Fig. 2(b)) because of the presence of high electron density in the multilayer of graphene.

HF characterization is performed from 10 MHz to 20 GHz. A common Line-reflect-match calibration procedure is used. In order to investigate the intrinsic HF characteristics of our GNRFET, a special “open” structure is fabricated on wafer by means of the same process used for the active device. This “open” structure is exactly the same as our GNRFET except there is no graphene between the source and the drain region. The de-embedded procedure is similar to the one described in [19]. The intrinsic current gain cut-off frequency (f_T) of 30 GHz and maximum oscillation frequency (f_{max}) of 17 GHz (Fig. 3(a)) were obtained at $V_{ds} = 1$ V and $V_{gs} = -0.8$ V.

We have also investigated the impact of V_{ds} on the HF performance of our GNRFET. For the same device, better f_T (60 GHz) and f_{max} (28 GHz) (Fig. 3(b)) were obtained when increasing V_{ds} from 1 to 3 V. This can be partially explained by the rise of G_m from 1.47 to 4.05 mS, knowing that f_T can be approximately estimated by the expression $G_m/(2\pi Cgs)$.

IV. CONCLUSION

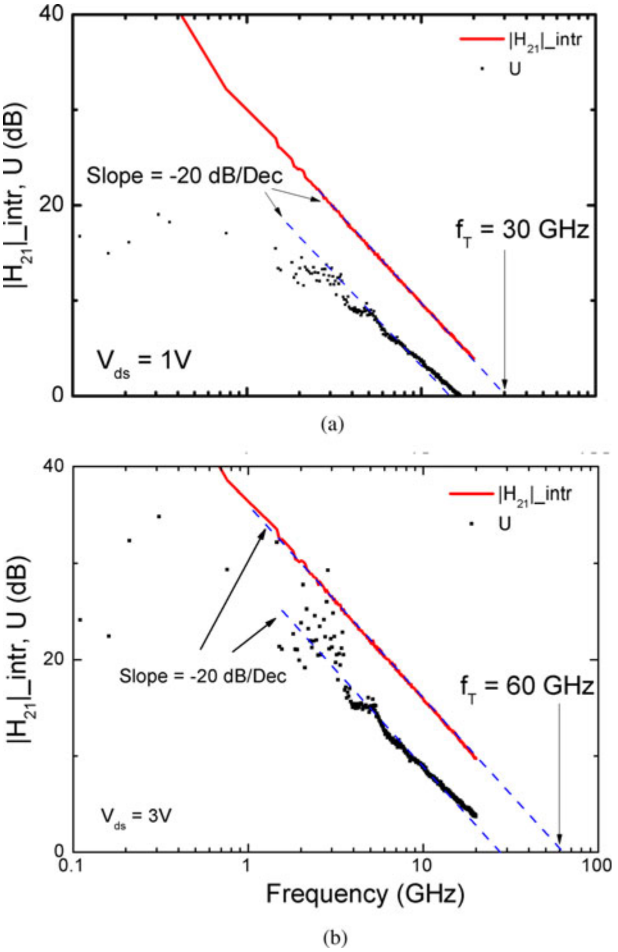
In conclusion, multilayered graphene on SiC is used to fabricate field-effect transistors. The active layer shows high carrier



(a)

(b)

Fig. 2. (a) DC output characteristics (device drain current I_{ds} versus drain voltage V_{ds} at different gate voltage V_{gs}). (b) Transfer characteristics (I_{ds} versus V_{gs}) of the device, Dirac point is at $V_{gs} = -0.8$ V; and transconductance G_m as a function of V_{gs}, at $V_{gs} = 0.8$ V, $G_{m\_max} = 1.45$ mS is obtained.



(a)

(b)

Fig. 3. (a) Intrinsic current gain ($|H_{21}|$_*intr*) and unilateral gain (U) under bias of $V_{ds} = 1$ V. The best intrinsic f_T of 30 GHz and f_{max} *of* 17 GHz are obtained. (b) Under the bias of $V_{ds} = 3$ V, $f_T = 60$ GHz, and $f_{max} = 28$ GHz have been measured.

density and low mobility. The use of array of nanoribbons helps to improve the gap of graphene layers and to achieve a high DC current. Analysis of high-frequency performance shows that despite the relatively low on/off current ratio, the intrinsic current gain cut-off frequency of 60 GHz, associated to a maximum frequency of oscillation of 28 GHz are obtained. Most importantly, this work shows that using GNR is another way to improve high-frequency performance of graphene multilayered devices.

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