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Wideband high frequency response graphene-FET on flexible substrate

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Abstract

The transparent RF device is fabricated on PET substrate by graphene unique properties.

1. Introduction

Graphene is a perfect two-dimensional semimetal, in which each carbon atom is covalently bonded by three sp^2 orbital and one half-filled p_z orbital is used for electron transport. The electrons near the Dirac points behave like massless Dirac Fermions, so it has high electron mobility at room temperature. Due to the property of gapless semiconductor, graphene device “off” current is too large to be a perfect switch, but graphene is suitable for radio frequency applications because it always operate in “on” current. However, the properties of graphene high frequency response still cannot be compared with Ⅲ-Ⅴ based RF device. The reasons responsible for suppressing graphene high frequency response are the impurities and surface phonon scattering from substrate [1, 2].

In order to reduce the substrate effects, there is one method reported by separating graphene from substrate [3] and in another report, they have used epitaxial graphene on high surface phonon energy substrate [4], SiC. Indeed, both of them get high electrical performance, but the former is worthless on device production, where as the latter is too expensive because of the SiC substrate and less development on flexible electronics. Therefore, according to these points of view, we use Poly (ethylene terephthalate) (PET) as a graphene RF device substrate.

2. Experiments procedure

We transfer the high quality CVD graphene from copper foil to PET substrate by HCl etching. Then, the isolation area was defined the by e-beam lithography and Reactive-ion etching (RIE). Following the isolation, patterning the 200 nm length T-shaped gate was made by coating different sensitive e-beam resist PMMA 996K/MMA/ PMMA120K as shown in Fig. 1(a). Then aluminum (360 nm) was evaporated on graphene without additional dielectric material between graphene and aluminum, and put inside high purity O_2 chamber for more than 12 hrs. to form a thin AlO_x (5 nm)[5] around the surface (Fig. 1b). After self-oxidation, self-aligned deposit Cr (0.5 nm)/ Au (30 nm) to cover all of graphene, and it is automatically separated by thick Al/ AlO_x top gate as shown in Fig. 1c & 1d. Finally, we define and evaporate source/drain pads by Cr (0.5 nm)/ Au (35 nm)/ Cr (0.5 nm)/ Cu (200 nm)/ Cr (0.5 nm)/ Au (45 nm) (Fig. 1e).

2. Results and discussion

In device controllability aspects, gate quality is one of the most important issues in device fabrication. Owing to graphene and aluminum interface has small van der Waals distance that makes H_2O and O_2 easily drill into the interface and oxidize the aluminum surface. To avoid hydrogen-induced defect level [5], we use dry oxidation in O_2 chamber rather than wet oxidation in atmosphere. Through this method, we can get high breakdown voltage gate capacitor (-6.37V~7.3V), and it will be self-healing after put inside the O_2 chamber for 12 hrs as illustrated in Fig. 2.To check the gating ability, we measure the capacitor ratio between AlO_x top gate and 300nm SiO_2 back gate, by changing the different back gate voltage and it corresponds to different top gate charge neutral point (CNP). We estimate that our gate capacitor is large enough (950~1100 nF/cm^2) to modulate graphene well (Fig. 3). In order to get wideband current gain and maximum available power gain (f_t,f_{max}),we should bias device in maximum transconductance (g_m) .From our device I_D-V_G curve shown in Fig. 4, we find the maximum transconductance (-0.51 mS/μm), which is near close to zero gate bias that corresponds to f_t=8.58 GHz and f_{max}=10.5 GHz (Fig. 5). Because of the thicker gate electrode evaporation and using the self-aligned metal deposition to reduce access resistance, our device f_{max} is larger than f_t.

3. Conclusions

We use high quality CVD graphene to make RF device on PET substrate, and get high breakdown voltage and high gating ability by using the dry aluminum self-oxidation in pure O_2 chamber. Using thick T-shaped gate electrode, we can deposit thicker self-aligned metal, which can reduce the access resistance and get high transconductance, and wideband current gain and maximum available power gain (f_t=8.58 GHz, f_{max}=10.5 GHz).

References

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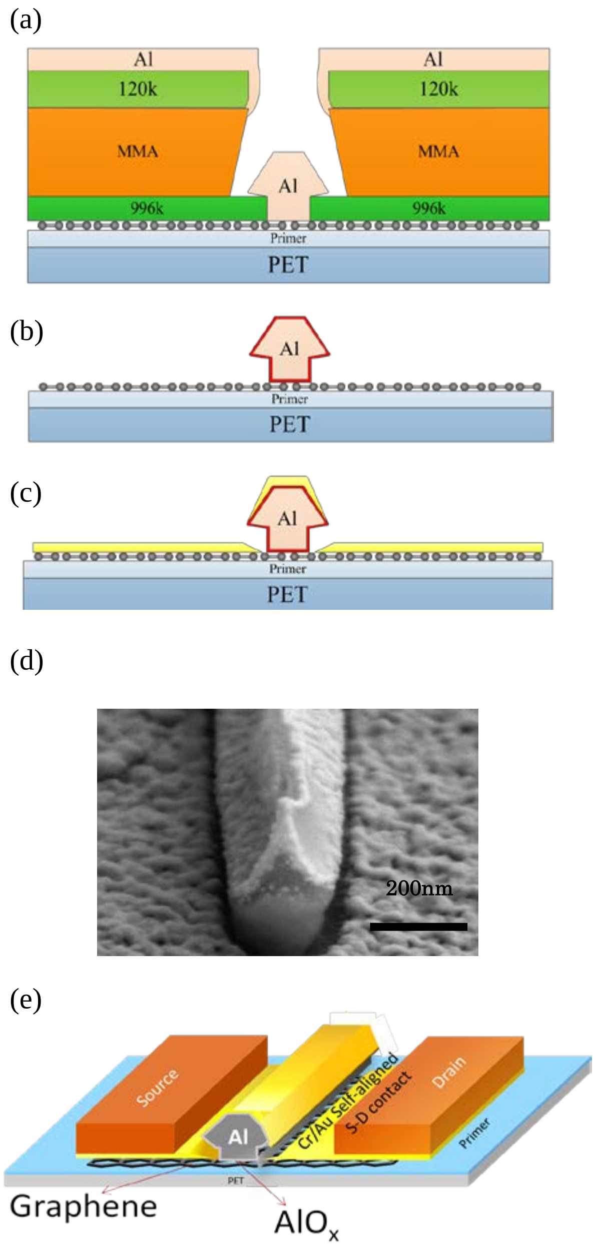

Fig. 1 (a) E-beam lithography and Al evaporation (b) Self-oxidation around Al surface (c) Self-aligned deposit metal (d) SEM image of a T-shaped gate (e) Device structure.

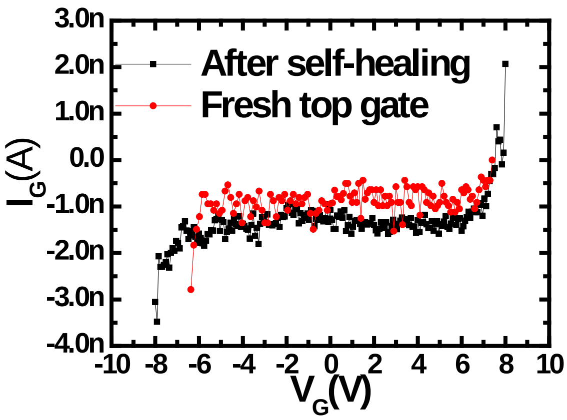

Fig. 2 Top gate breakdown voltage

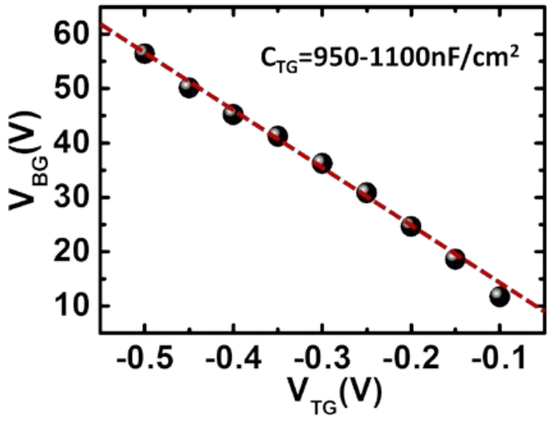

Fig. 3 Back gate (300nm SiO_2) and top gate (AlO_x) capacitor ratio.

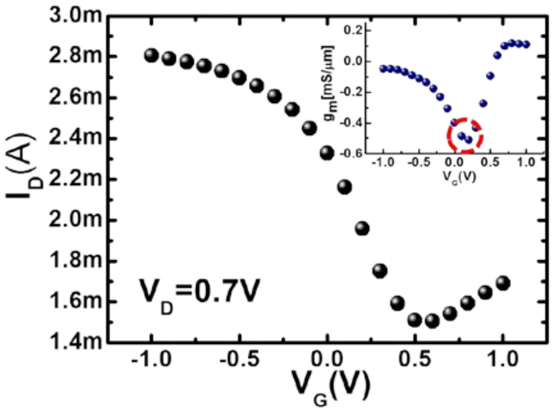

Fig. 4 Graphene RF device I_D-V_G curve and gm curve (inset).

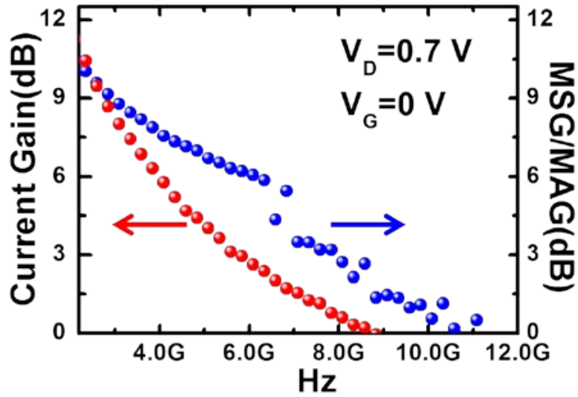

Fig. 5 Graphene RF device current gain (red) and maximum available power gain (blue) frequency response.