Graphene Ferroelectric Heterostructures

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Introduction

Graphene

- Wonder material with excellent electronic properties
  - Highest mobilities of charge carriers
  - Zero band-gap and linear dispersion cone
  - Highest mobilities of charge carriers
  - Unique electronic properties like ambivalent action between metal surfaces and similar shapes of the curves, as that on top of graphene show similar values of coercive fields and loop shapes indicate that the switching is dominated by the bulk. This is due to the intrinsic drawback of the long polymer chain structure which prevents a perfectly smooth crystallization.

PVDF (-TrFE)

- It is a ferroelectric copolymer between Vinylidene Di-Fluoride and Tri-Fluoro Ethylene
- Allows low temperature processing (~130°C)
- Thickness of our films is around 200–250 nm
- Relatively high spontaneous polarization of 6~7 μC/cm²

Results: Charge carrier density in the memory device

Asymmetrical resistance hysteresis loops obtained for our devices with doped-graphene as expected, [11]. We get two distinct resistance states of the memory device, which are marked R_L and R_H.

Mobility of charge carriers in our graphene-FET can be calculated from the p-V curve (below):

\[ \mu = \frac{\Delta \nu}{\Delta V} \]

Thus, in our samples, \( \mu = 10,000 \text{ cm}^2/\text{Vs} \)

Mobility of charge carriers in the graphene-ferroelectric FET ~ 500 cm²/\text{V.s}

Amount of doping \( = 1.51 \times 10^{13} \text{ cm}^{-2} \)

This is approx. 40% of the ideal polarization of PVDF (-TrFE)

Retention Measurements

Low Resistance (left) and high resistance (right) retention curves for device 1

Low Resistance State - The resistance gradually increases and saturates over a period of time. This is probably due to charge injection and trapping into the dead layer of amorphous polymer adjacent to the graphene channel.

High Resistance State - There is a sudden surge in the resistance of the device when left at this state (depicted as X in the above figure). This is probably due to the ferroelectric which undergoes charge compensation and thus causes a reduction in the polarization. Thus we interpret that the device effectively climbs the curve from X to Y.

Working Principle

Resistance in the graphene channel is controlled by the density of charge carriers. When the ferroelectric is poled in either direction, it dopes the graphene channel with either electrons or holes and increases charge carrier density and reduces resistance (Points A-B, D-E). When the ferroelectric is switching at the coercive field, the polarization is zero and doping is least, causing an increase in the resistance (Points C, F). In perfectly non-doped graphene samples, we get symmetrical loops with only one zero-field resistance state.

Graphene on top of 300nm SiO2 - converted to graphene FETs

Flakes were prepared by mechanical exfoliation - Zero band-gap and linear dispersion cone - Highest mobilities of charge carriers

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Conclusion

- Successfully demonstrated the working of graphene ferroelectric FET memory devices, with resistance hysteresis curves at coercive fields confirming resistance increase to the switching of the ferroelectric
- Retention characteristics, hitherto unreported, were studied for the two memory states. Gradual increase in the low resistance state is attributed to time-dependent charge injection into the ferroelectric dead layer. Surge in high-resistance state is attributed to charge compensation and polarization reduction in the ferroelectric
- Switching characteristics of PVDF (-TrFE) on top of graphene, hitherto unreported, were studied. Similar values of coercive fields and loop shapes indicate that the switching is dominated by the bulk. This is due to the intrinsic drawback of the long polymer chain structure which prevents a perfectly smooth crystallization at the interface.

PFM Measurements

- The hysteresis loops obtained (below) for PVDF (-TrFE) on top of graphene show similar values of coercive fields and similar shapes of the curves, as that on metal surfaces
- This indicates that the switching is mostly due to interaction between the lamellae and different domains inside the polymer and is not dominated by nucleation at the interface

References


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