# Graphene/Silicon vertical field effect transistor

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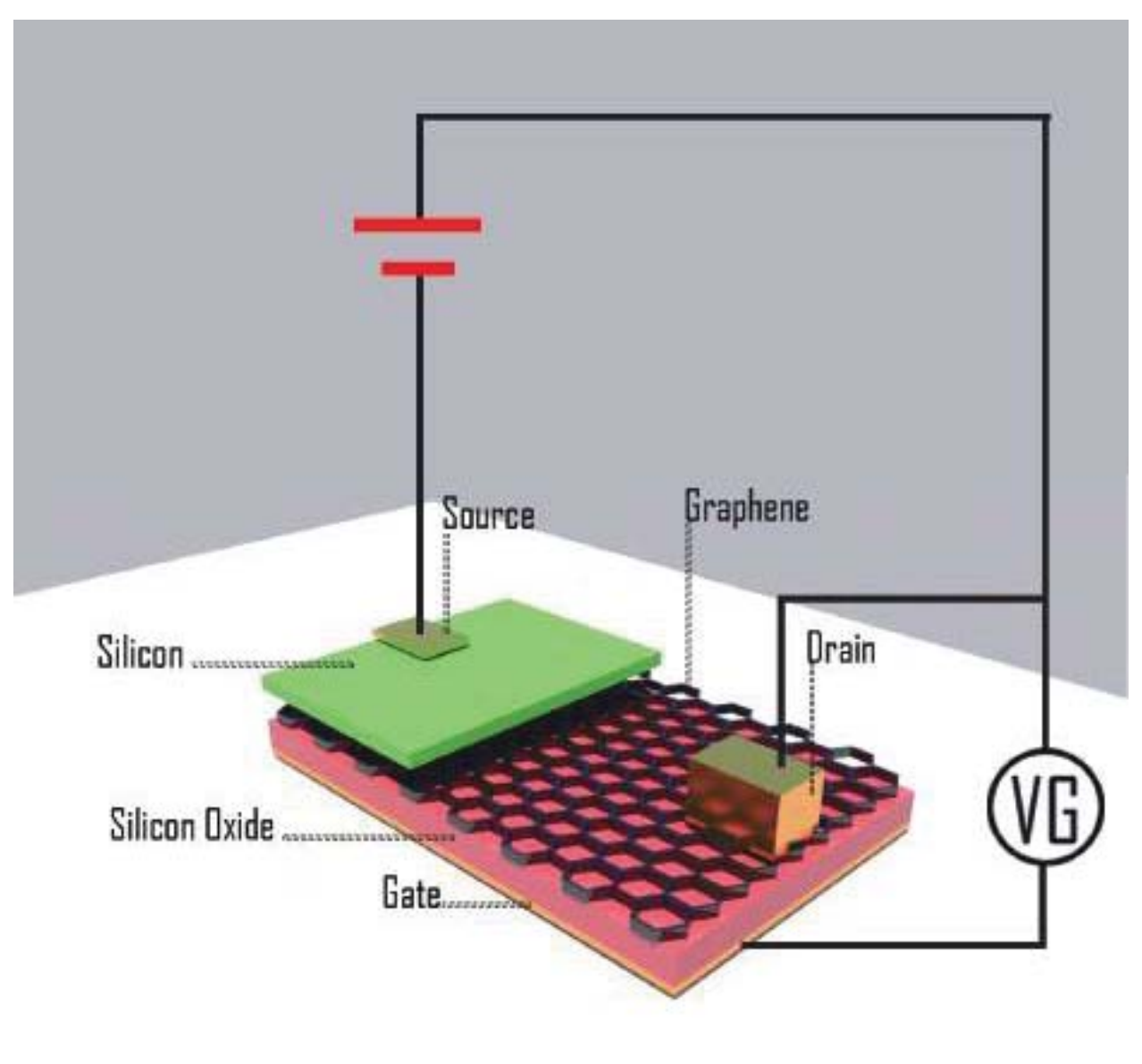
## Introduction

Graphene/ silicon vertical field effect transistor(FET) is a 3 terminal active device, which is the key function on interface between graphene and silicon. According to electrical properties of graphene such as high electron mobility characteristic, it is a great material to be electronic device. The device key function takes place at gated graphene/silicon interface where a tunable Schottky barrier controls charge transport across a vertically stacked structure [1], and then, we try to change the device structure in order to replace the heavy doping silicon as an insulator of gate(ion-gel). This ion gel gate material allows for lower voltages and higher currents to operate the transistor.

## Device structure and working principle

- Process of wafer involves photolithography and gold evaporation, which is a method to deposit the gold electrodes onto the wafer. Next, the process is transfer graphene and the following step is transfer the silicon on the graphene. Finally, electrodes are located on top of the graphene and silicon.



- The working principle takes place at the electrostatically gated graphene/silicon interface where a tunable Schottky barrier controls charge transport across a vertically stacked structure.[1]

fig.1 The structure of Graphene/ silicon vertical field effect transistor(FET)

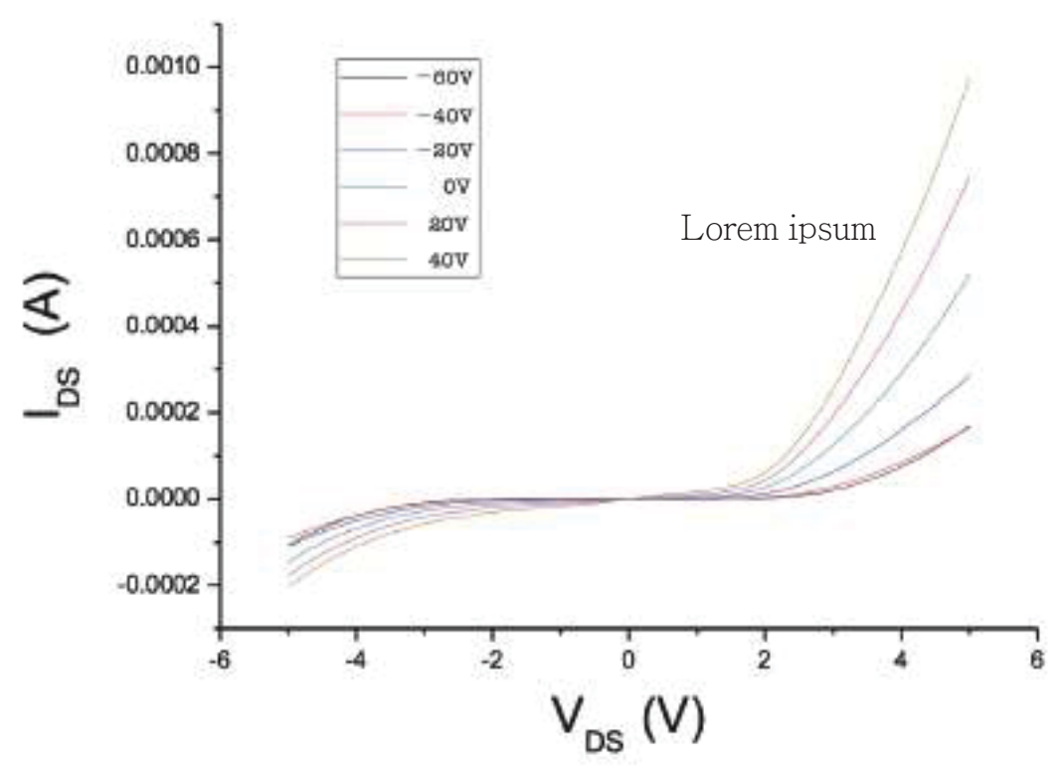


Fig 1.1 I-V characteristic of graphene and silicon

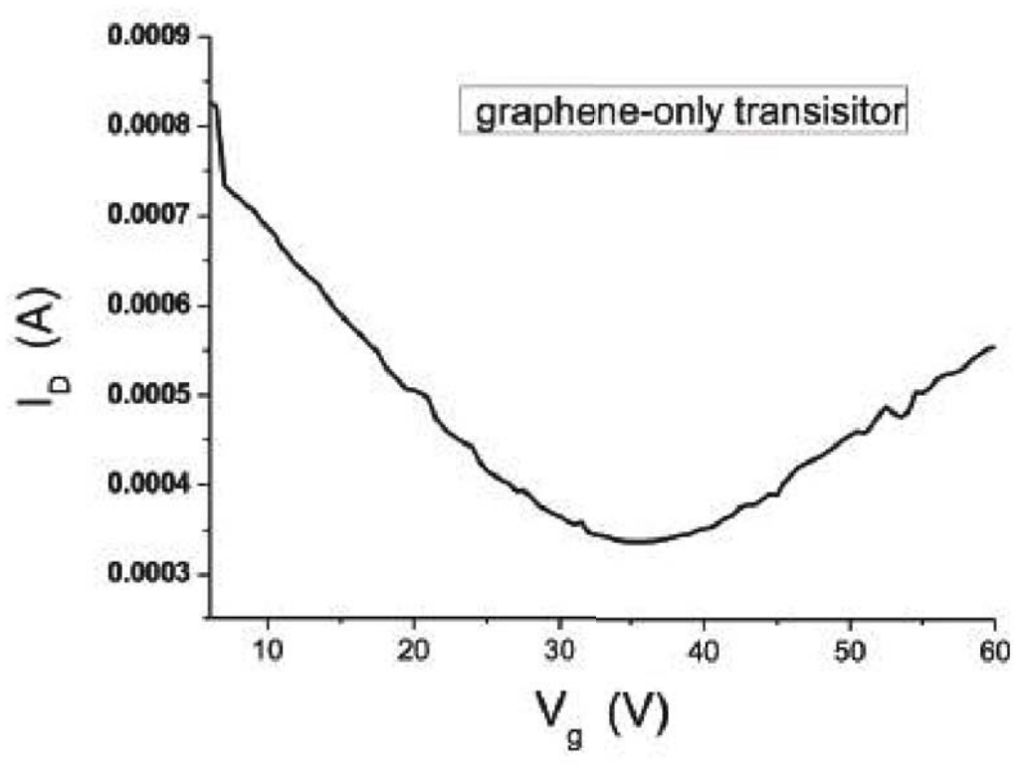


Fig 1.2 transfer curve of the graphene

**Result**

- Measuring the drain to source electrode can obtain the graphene and silicon I-V characteristic. Applying the positive gate voltage, then Schottky barrier height is smaller than the negative voltage. So the electronc is easy to overcome the barrier height.
- The transfer curve shows a typical graphene 'V' shape I-V characteristics. The Dirac point is found at the gate voltage of about 35V.

## Experiment

In order to extract the Schottky barrier height, we have investigated the various temperature experiment.

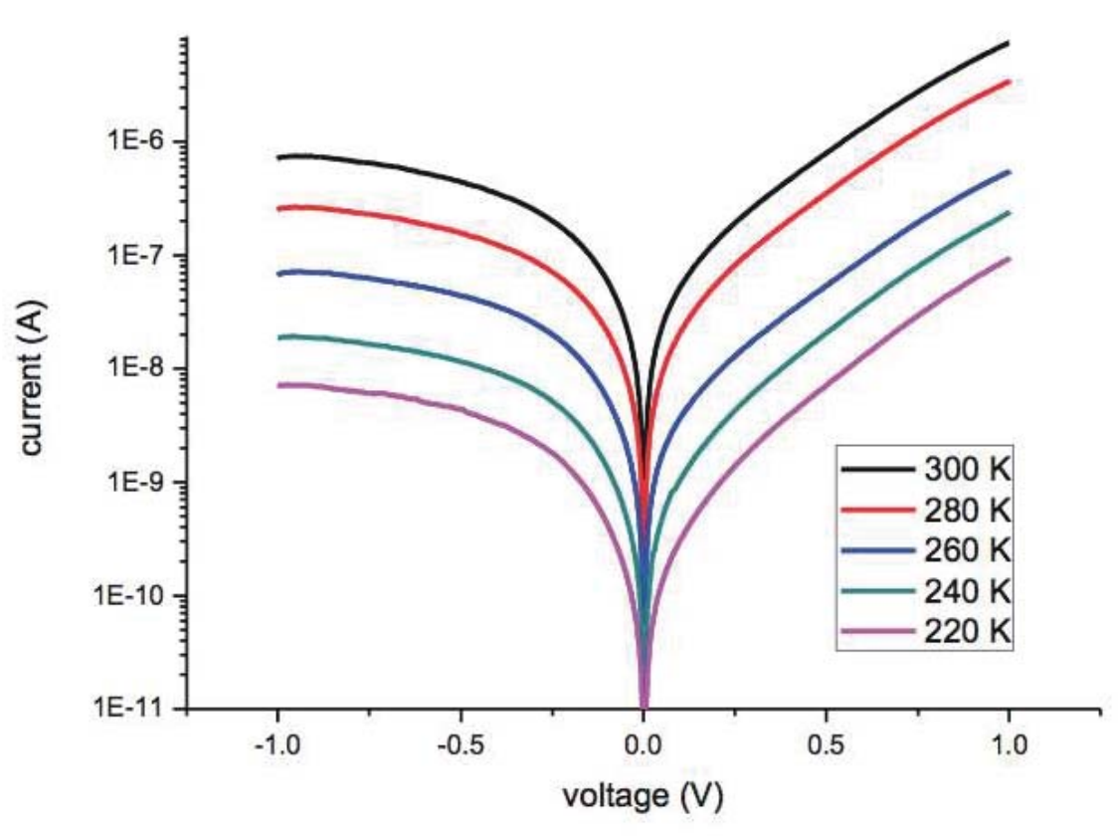


fig 2.1 Temperature-dependent I-V behavior of graphene - Si Schottky junction

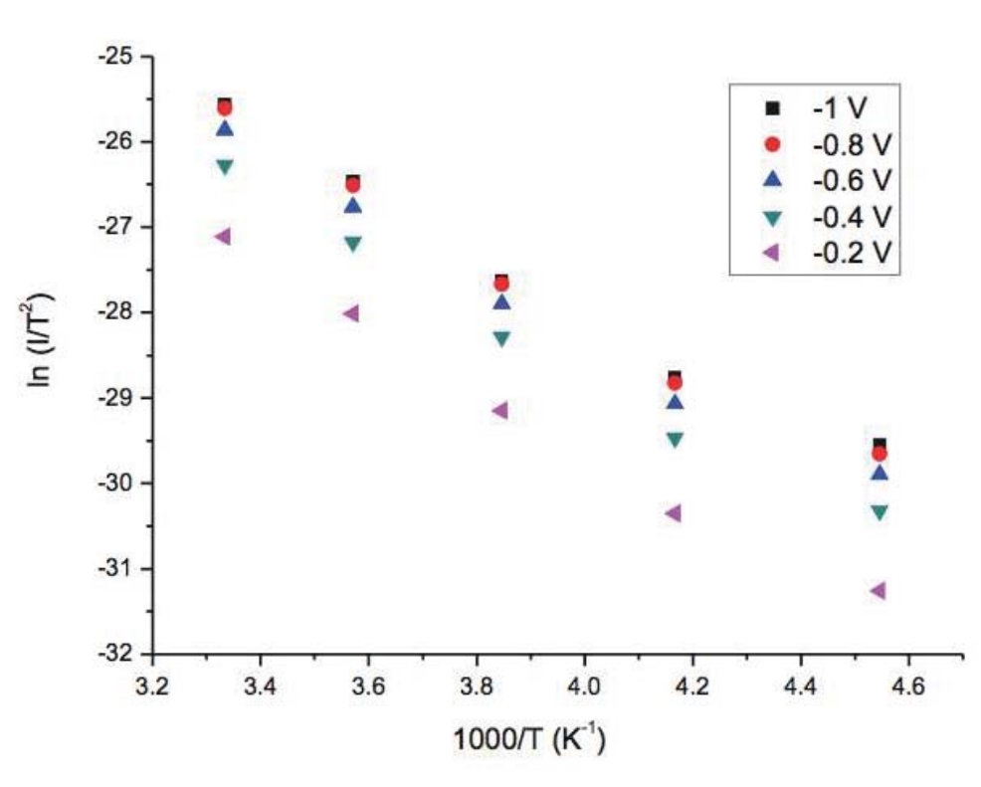


Fig. 2.2 The $(\ln(\frac{I_0}{T^2}) \sim \frac{1000}{T})$ of reverse saturation current graph

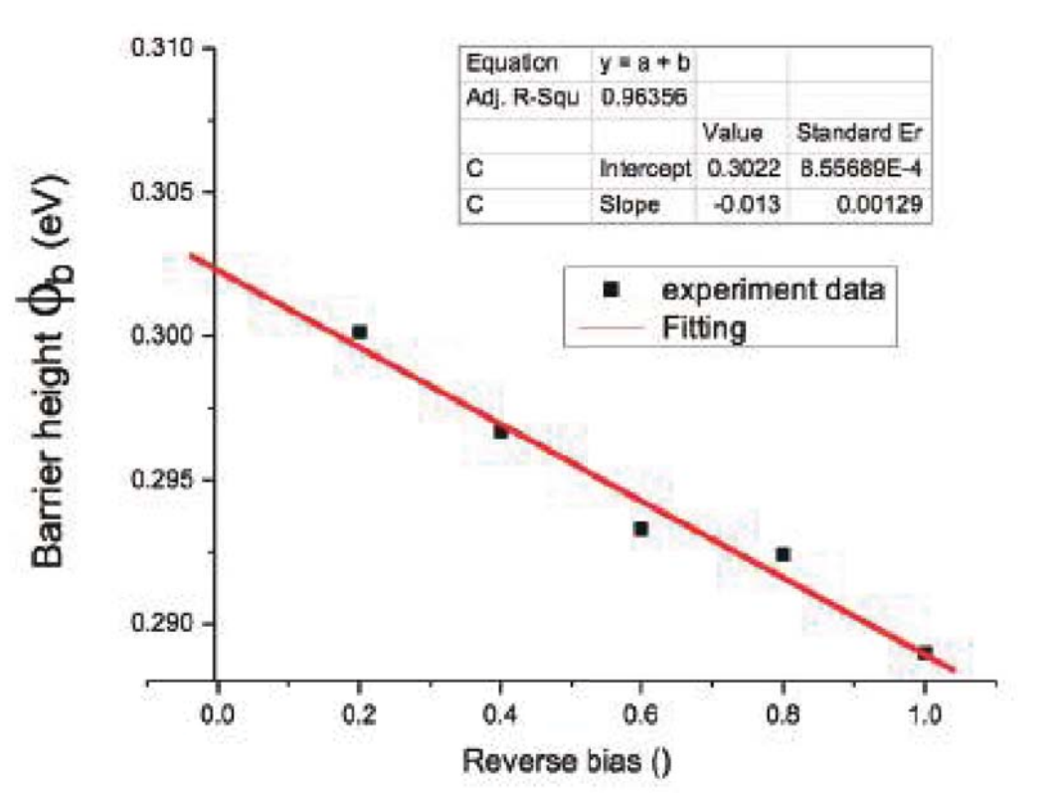


Fig.2.3 The barrier height at the various reverse voltage of Graphene/ silicon Si Schottky junction

- When the carrier transport governed by thermionic emission, the current through the barrier of a Schottky contact (from the semiconductor into the metal) is given by $I = I_0 \exp(\frac{-q\,\phi_b}{k_B\,T})\left[\exp\left(\frac{q\,V_{bias}}{\eta_{id}\,k_B\,T}\right) - 1\right]$ [2] the barrier height can be determined by $\ln(I_0) = \ln(AA^*) - q\,\phi_b\,\frac{1}{k_B\,T}$ [2]
- The barrier height for zero bias is obtained by extracting the intercept. The fitting curve for the barrier height extracted at various reverse bias values. So the Schottky barrier height equal to 0.3022 eV at zero bias.

## Flexible vertical field effect transistor based on graphene with ion-gel gate

**New device structure and Fabrication**

- The schematic diagram of the VGFET is shown in Figure. To fabricate the device, (100) silicon membrane was etched off from SOI wafer and transferred to PET substrate. The nanoscale thickness of silicon allows the device to be bended and make the device flexible [3].

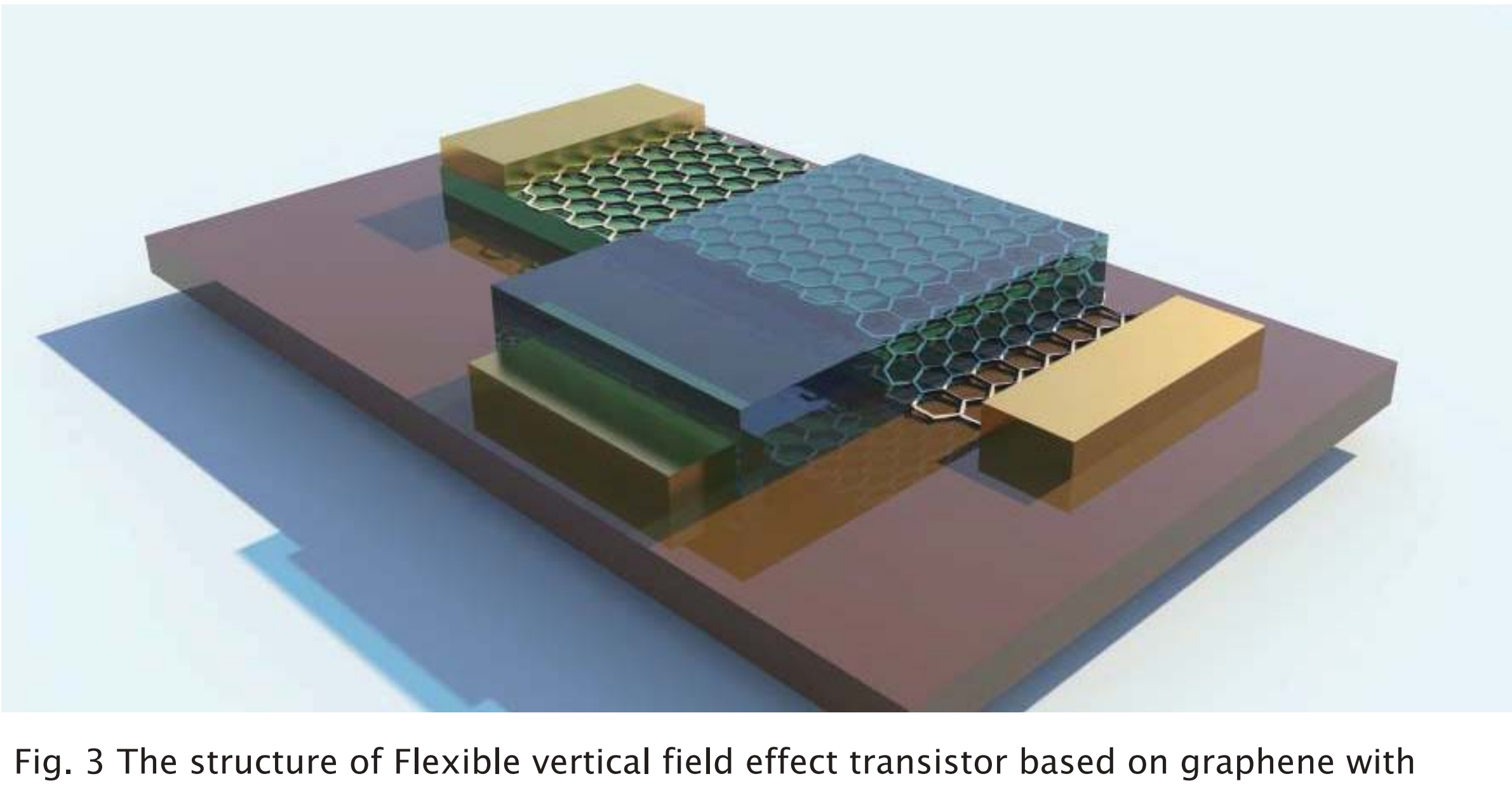


Fig. 3 The structure of Flexible vertical field effect transistor based on graphene with ion-gel gate

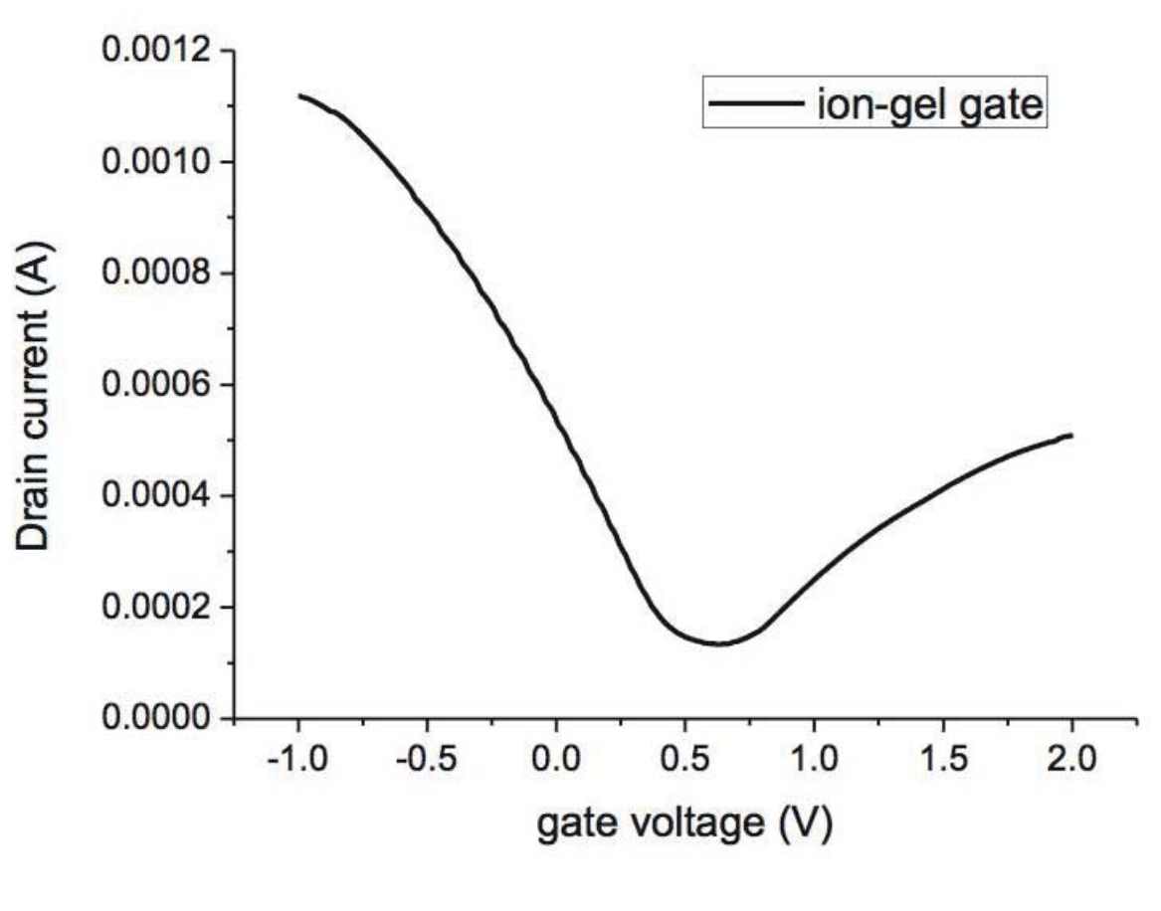


fig. 3.1 Transfer curve of the graphene with ion-gel gate

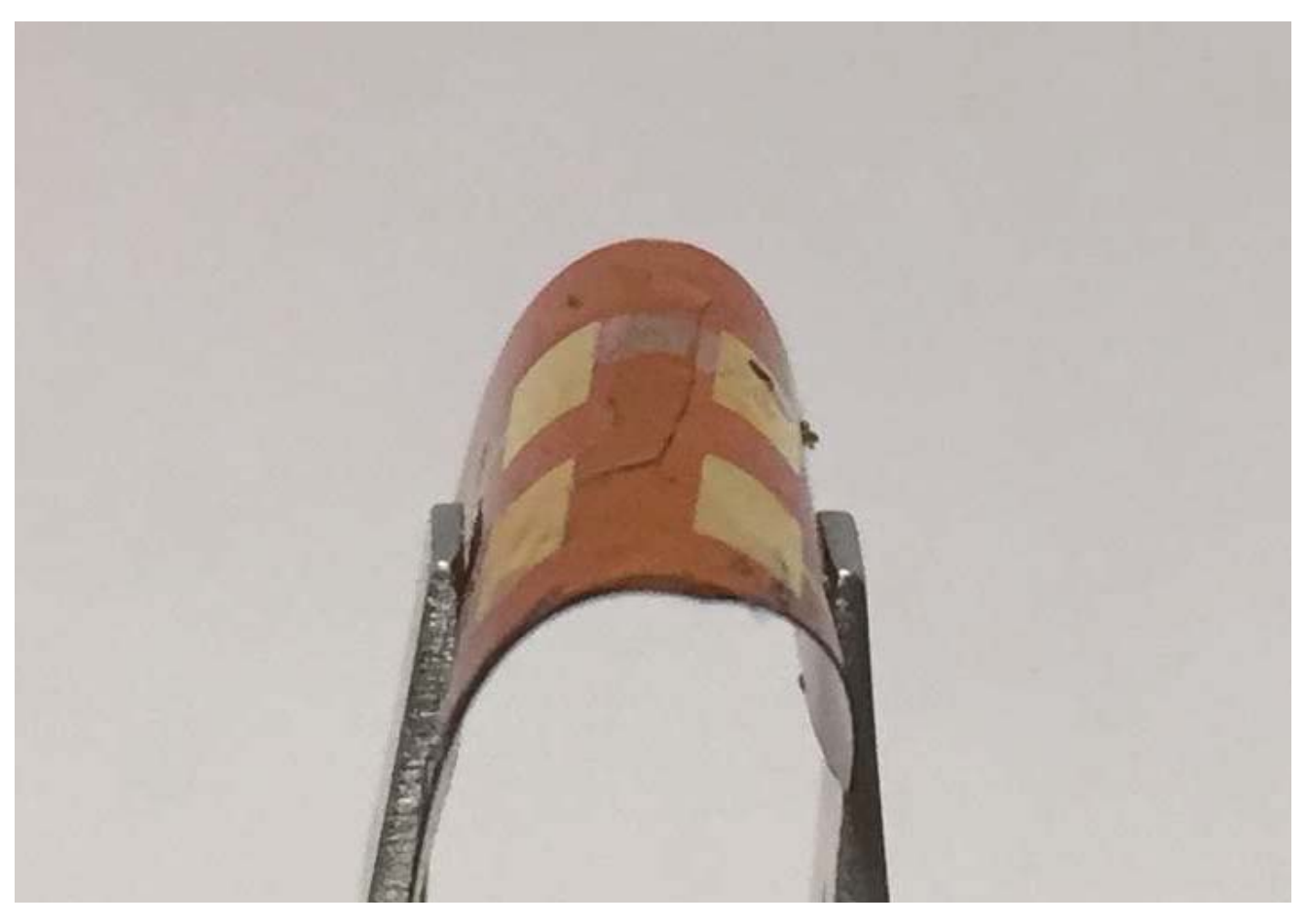


Fig. 3.2 Flexible feature of the transistor

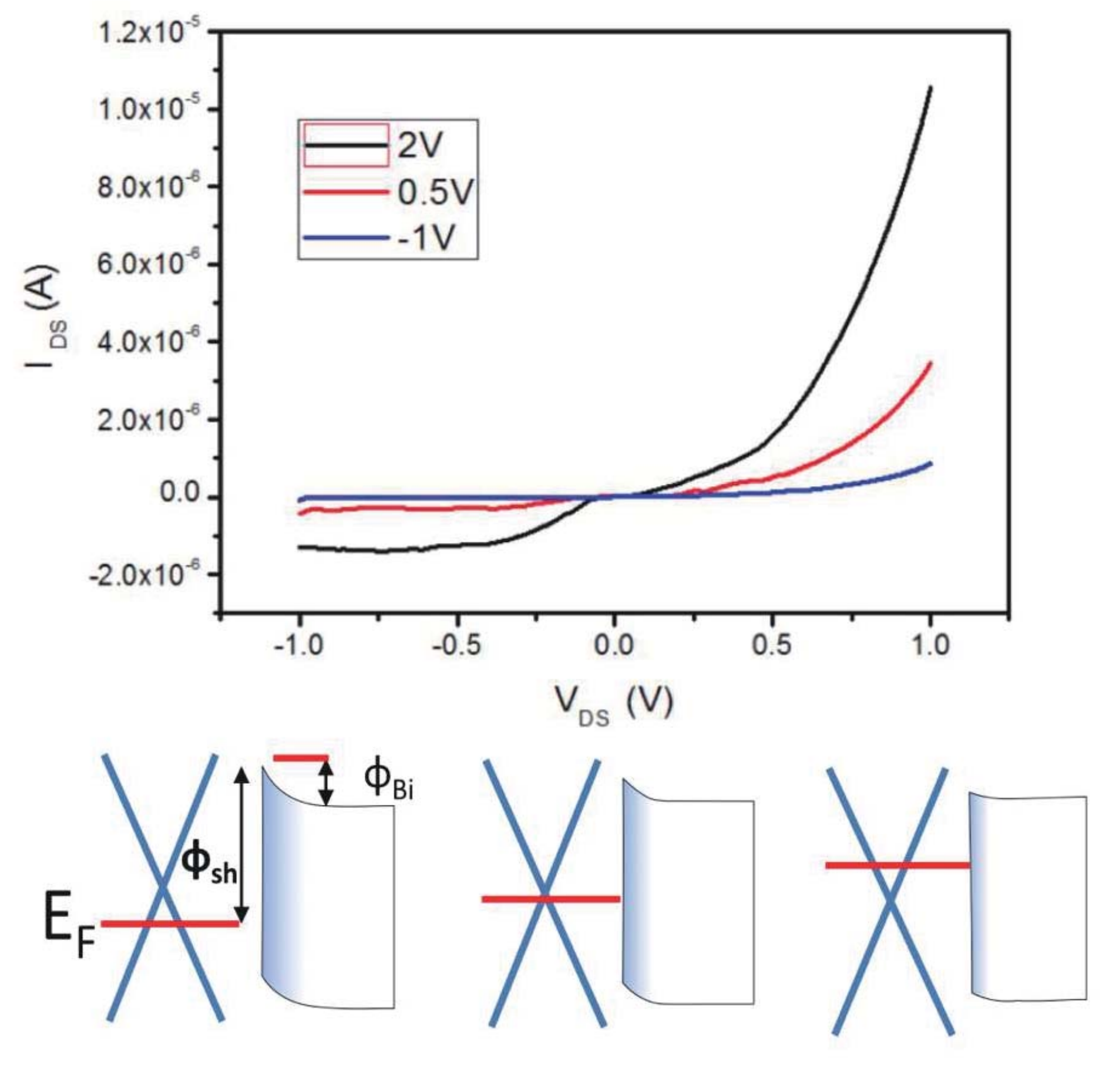


Fig. 3.3 I-V characteristic of the flexible device and the energy band diagram at gate voltage from -1V, 0.5V and 2V

**Result**

- The transfer curve shows a typical graphene 'V' I-V characteristics. The neutral point is found at the gate voltage of about 0.5V.
- The fig.3.3 I-V characteristic clearly shows a rectifying behavior, with the source-drain current increasing in the positive bias region. It indicates the Schottky barrier characteristic. The fig. 3.3 energy band diagram shows the different Fermi level when the gate voltage at -1V, 0.5V and 2V.

## Conclusion

In conclusion, the flexible vertical field effect transistor based on graphene with ion-gel gate not only has a high on/off ratio, but It also has a well performance in schottky current curve. Most importantly, that is a flexible transistor which has great potential in human wearing.

## Reference

[1] [7] H. Yang, J. Heo, S. Park, H. J. Song, D. H. Seo, K. E. Byun, P. Kim, I. Yoo, H. J. Chung, K. Kim, "a Triode Device with a Gate-Controlled Schottky Barrier", Graphene Barristor, the American Association for the Advancement of Science, Washington, 2012

[2]2017. [Online]. Available: http://Temperature Dependency of Schottky Barrier Parameters of Ti Schottky Contacts to Si-on-Insulator.

[3] ] Rogers, J. A., et al, Materials and mechanics for stretchable electronics, Science 327, 1603–1607 (2010).