Electrostatically-Reversible Polarity of Dual-Gated Graphene Transistors

Shu Nakaharai

Green Nanoelectronics Center (GNC),

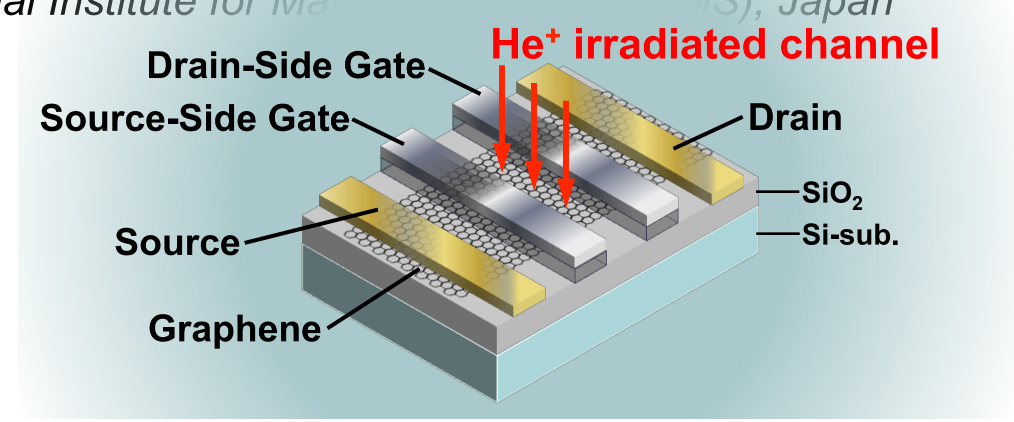
National Institute of Advanced Industrial Science and Technology (AIST), Japan

Collaborators

T. Iijima*, S. Ogawa†, K. Tsukagoshi¶, S. Sato, N. Yokoyama

**ICAN, †NeRI, National Institute of Advanced Industrial Science and Technology (AIST), Japan*

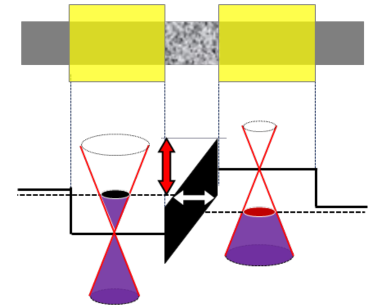
¶WPI-MANA, National Institute for Materials Science (NIMS), Japan



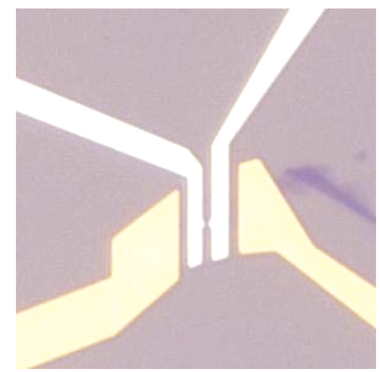
Outline

0. Introduction

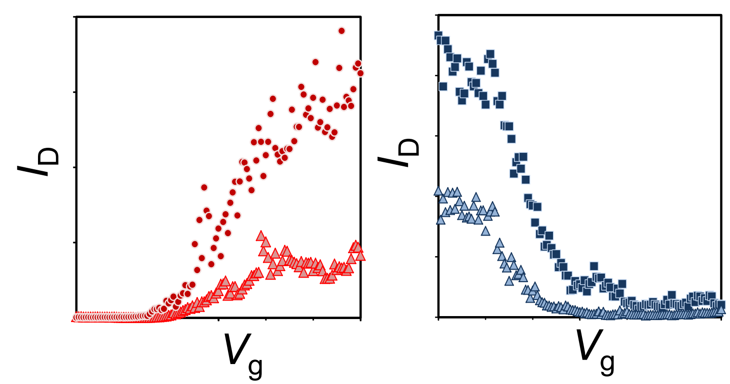
1. Device <u>Concept</u>



2. Device <u>Fabrication</u>



3. Device <u>Operation</u>

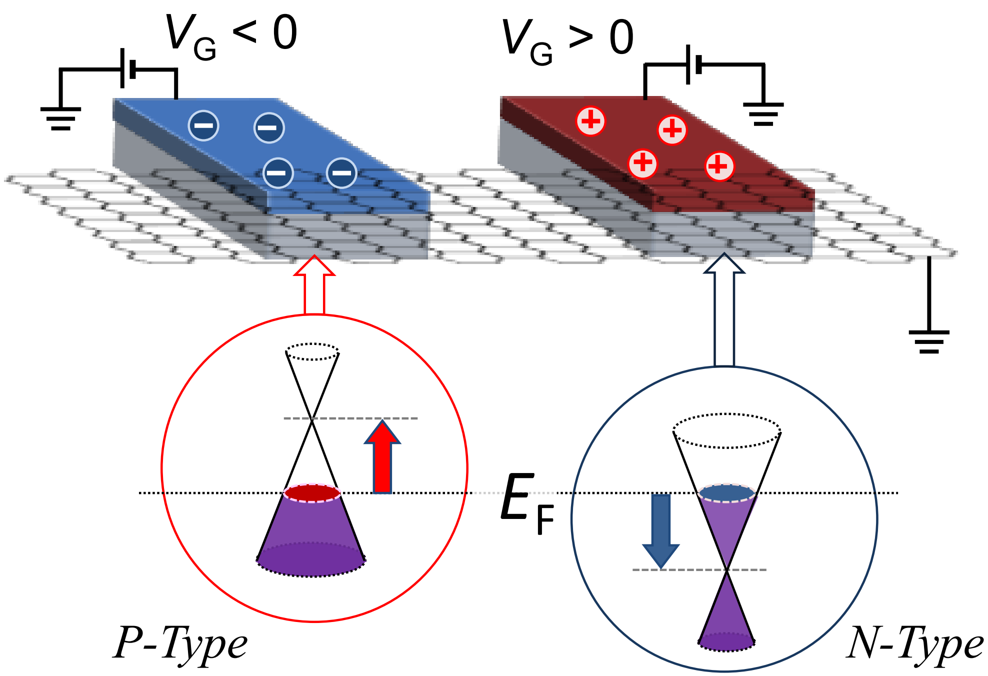


4. Summary

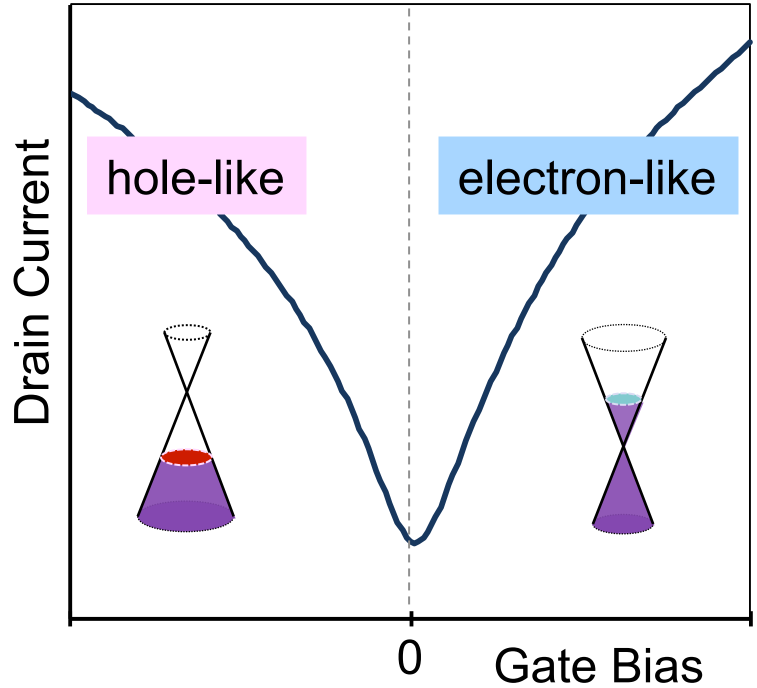
Background — Why Graphene?

Advantages for **polarity-reversible** devices:

Electrostatically-Reversible Polarity of Carriers



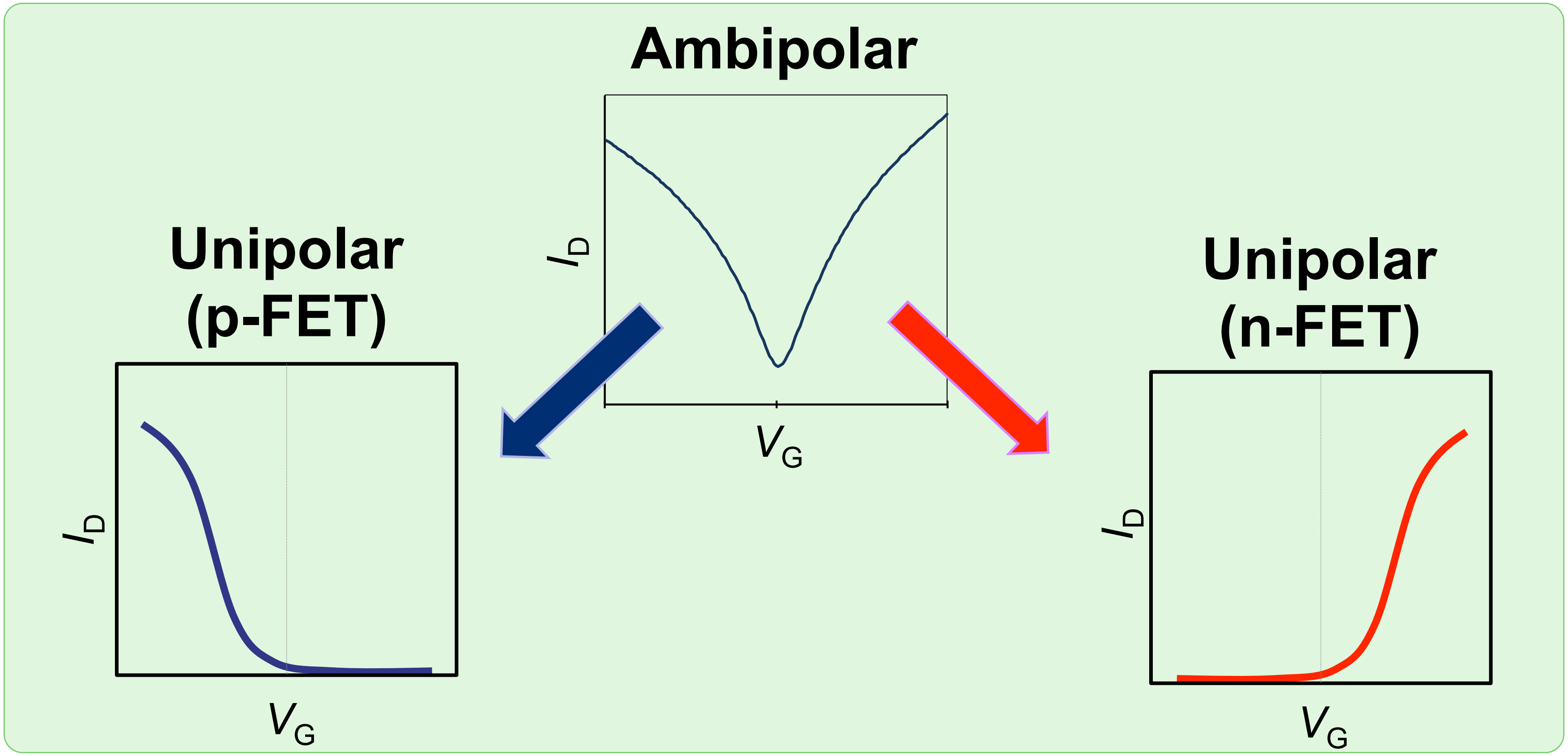
Symmetric Conduction of Electrons and Holes



Graphene is Ideal for Polarity-Reversible Transistors!

Issues

- Poor current on/off switching
- Ambipolar carrier conduction



Objectives

- Improve on/off switching of current
- Demonstrate unipolar transistor operations with electrostatically-reversible polarity

We propose a novel concept graphene transistor with…

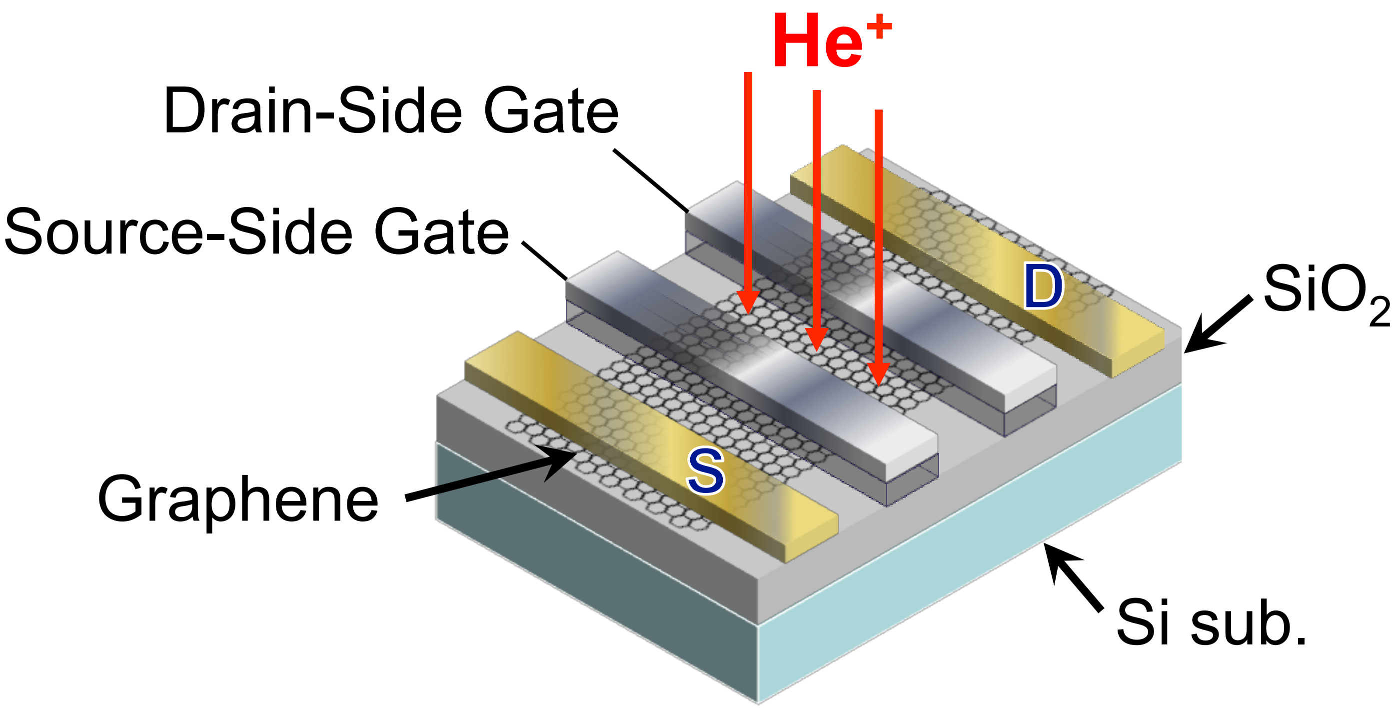
– Gate-controlled P-I-N junction device structure
  - S. Nakaharai *et al.*, APEX **5**, 015101 (2012)

– He ion irradiated graphene channel
  - S. Nakaharai, *et al.*, Ext. Abst. SSDM **2012**, p676

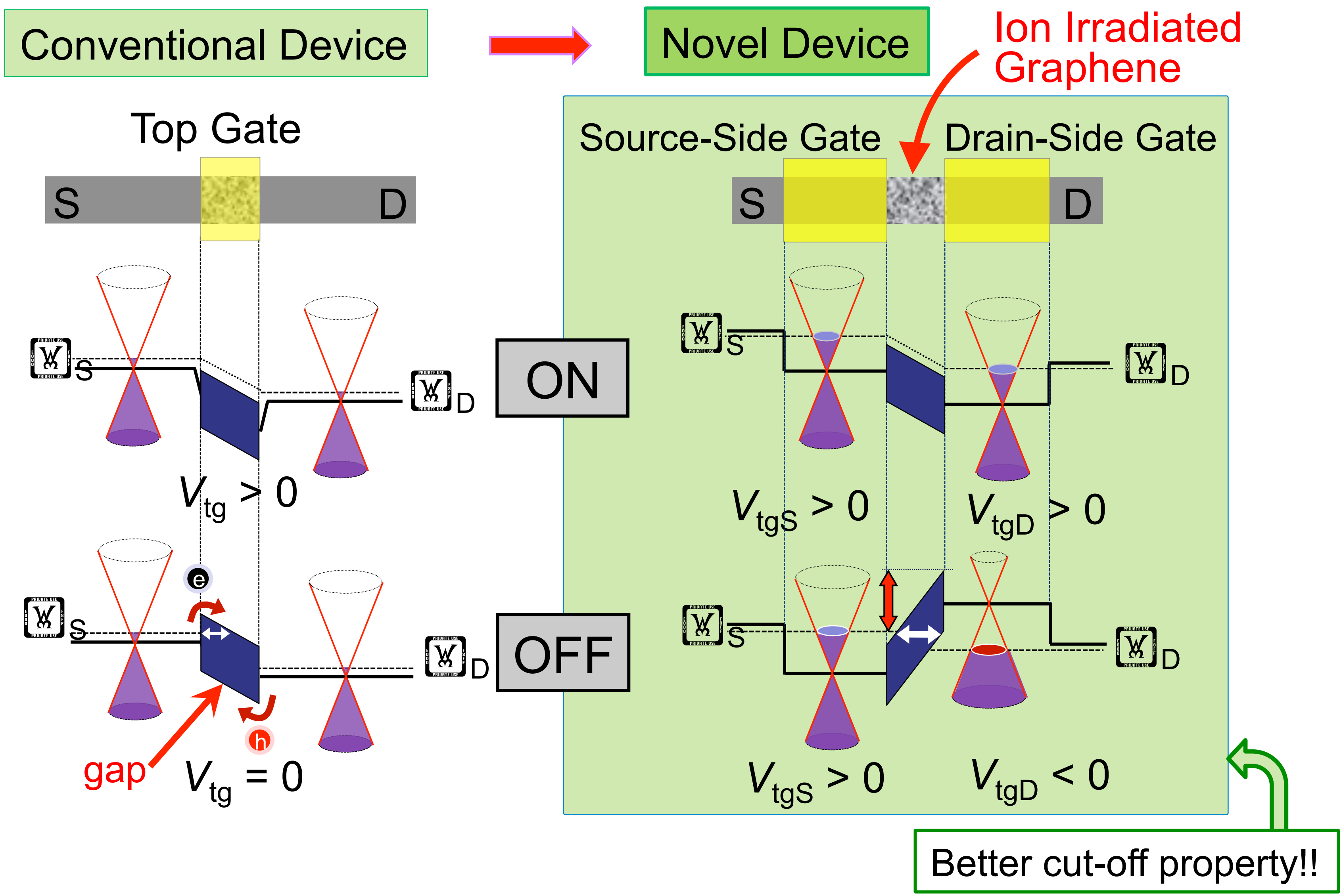
1. Device Concept

Novel Device Structure

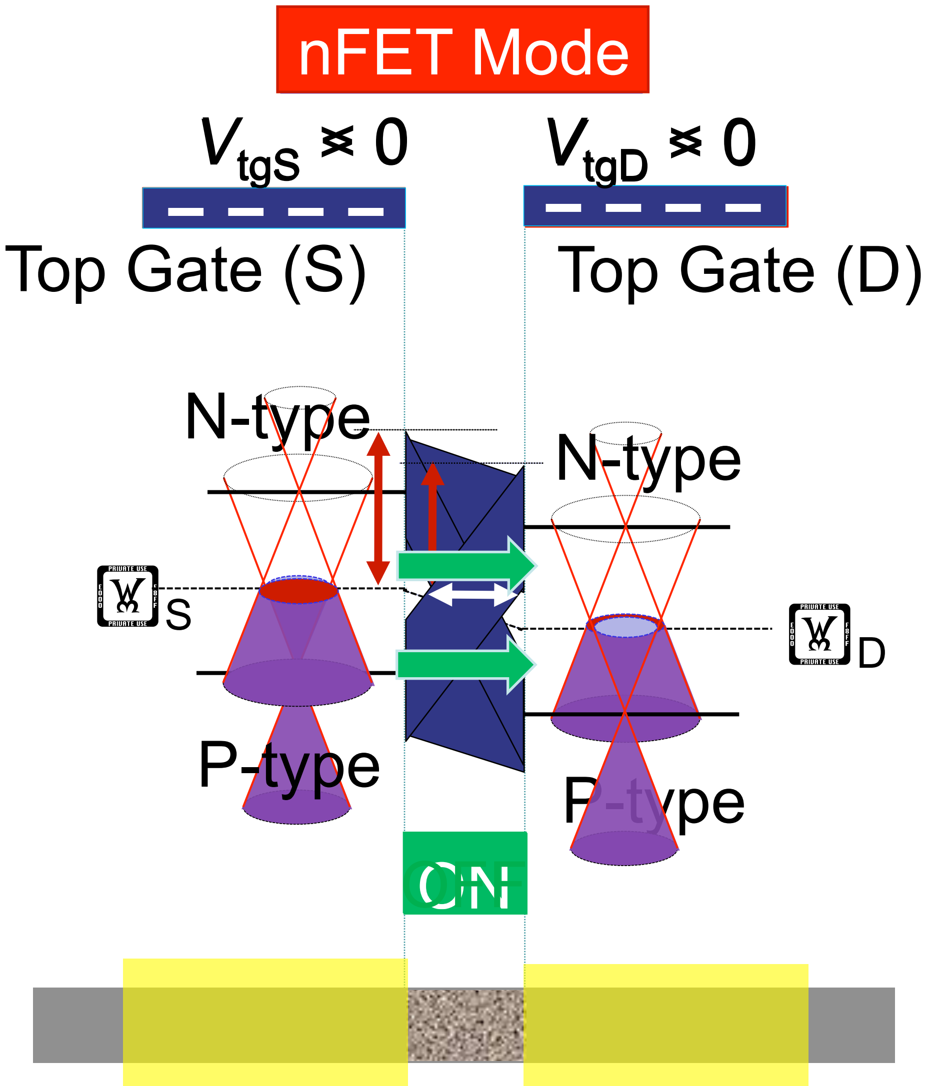
- ➢Two top gates — Independent biasing
- ➢Irradiation of He ion beam only between top gates
- ➢Defect-induced transport gap opens

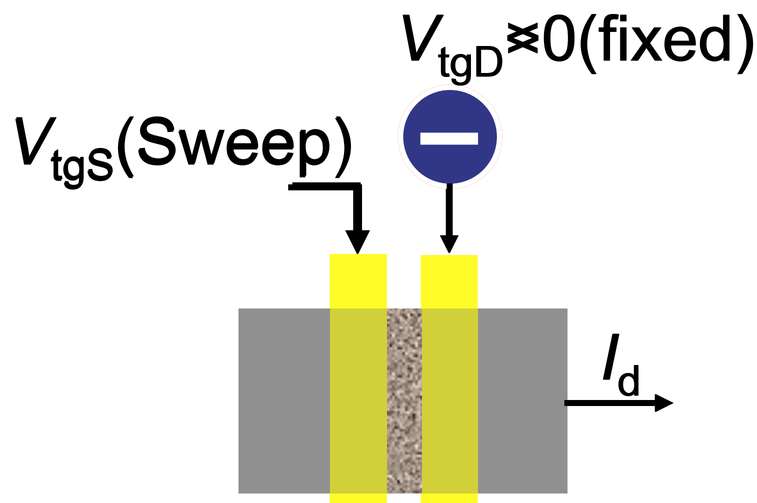


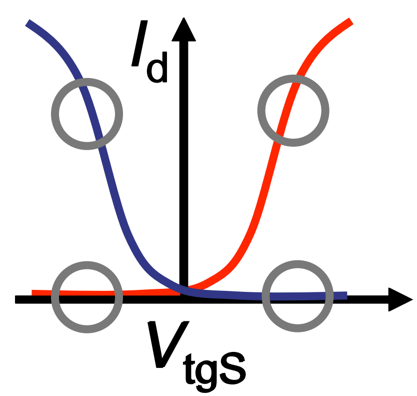
Current On-Off Operation



Polarity-Reversible Operation







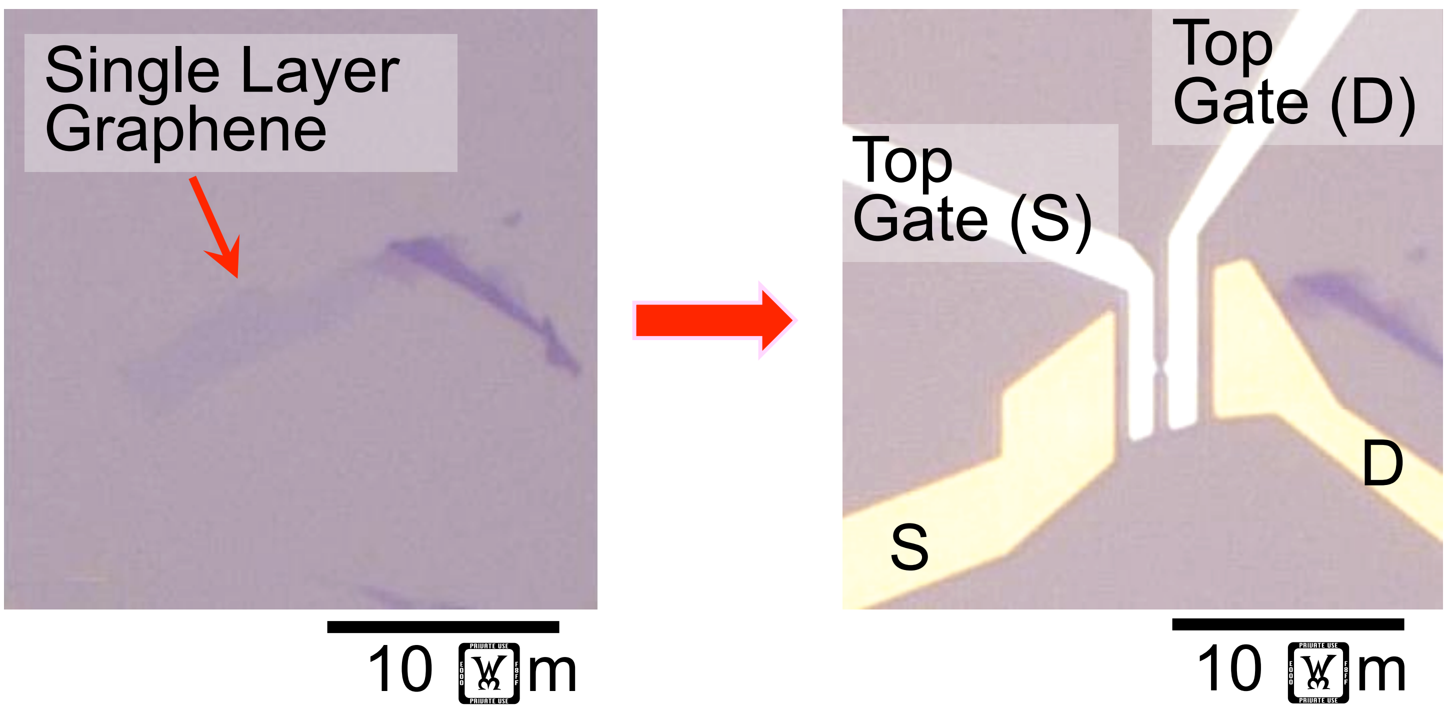
Advantages of Novel Concept Device

- **Better on/off switching**
- **Unipolar, and electrostatically-reversible**
- **No impurity doping is needed.**
  - Free from dopant-related problems
- **CMOS-compatible fabrication process**
  - Only with "top-down" process

2. Device Fabrication

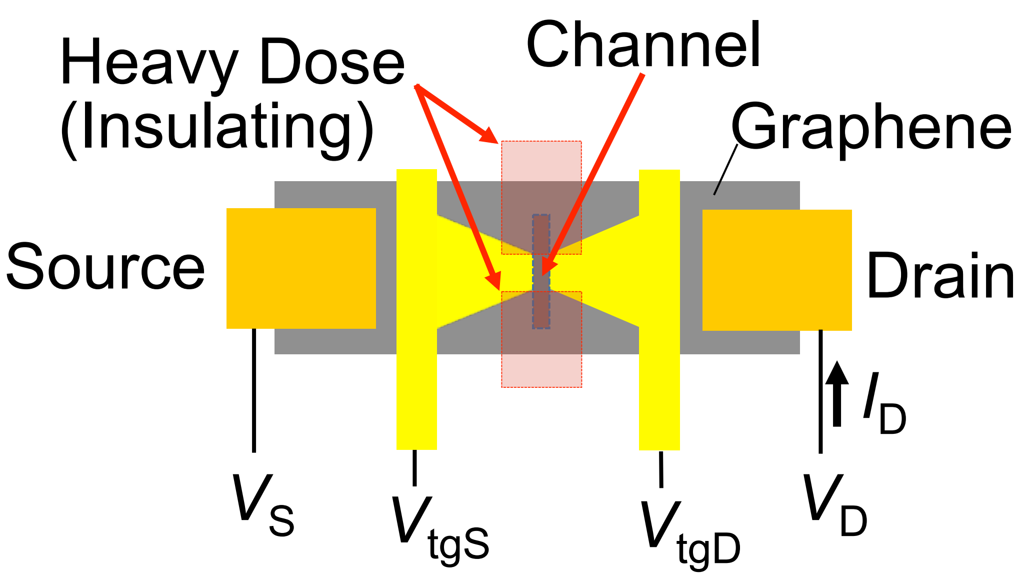
Device Fabrication

- Mechanically-exfoliated single layer graphene was deposited on a 285-nm-thick SiO_2 layer.
- Lift-off of contacts and top gates
  - Contact: Ti/Au; Top Gate: SiO_2/Al

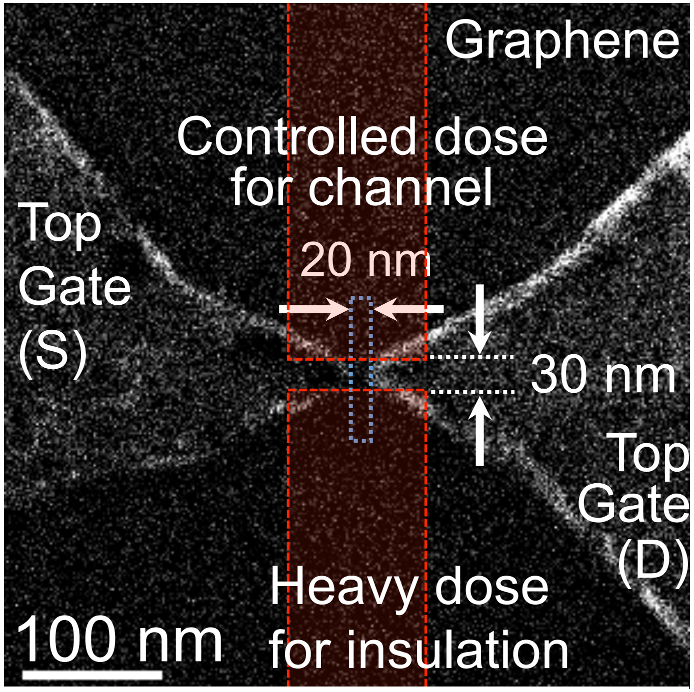


Channel Fabrication

- He ion irradiation for “channel” at an ion dose of 6.9×10^{15} ions/cm^2.
- Heavy dose makes graphene insulating.
- Channel size: L = 20 nm, W = 30 nm.



Device structure

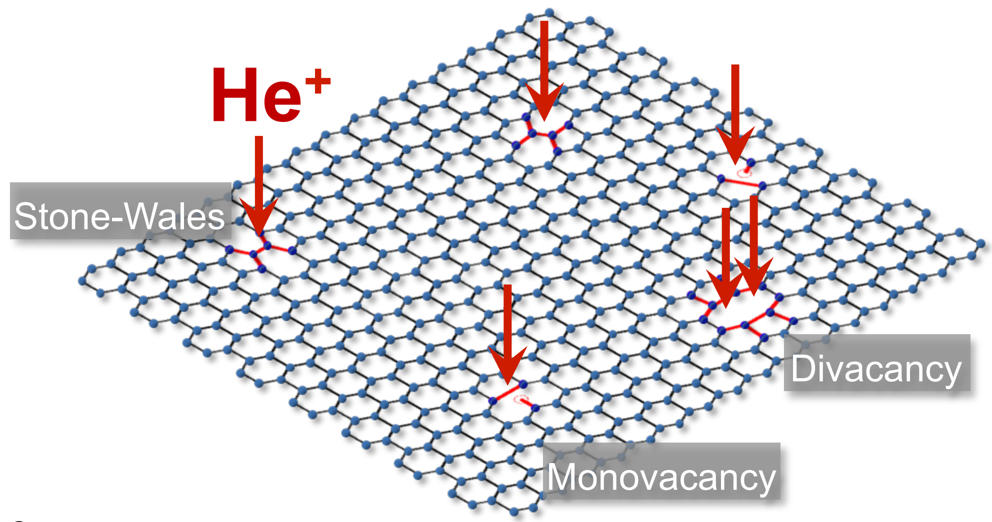


He Ion Irradiated Graphene Channel

- Impact of He ions to graphene generates randomly distributed **point defects**.
- Defect-induced strong **localization** of carriers.
- **Transport gap** ([illegible]380 meV) enables conduction control in graphene by gate biasing.

Helium Ion Microscope (Carl Zeiss)

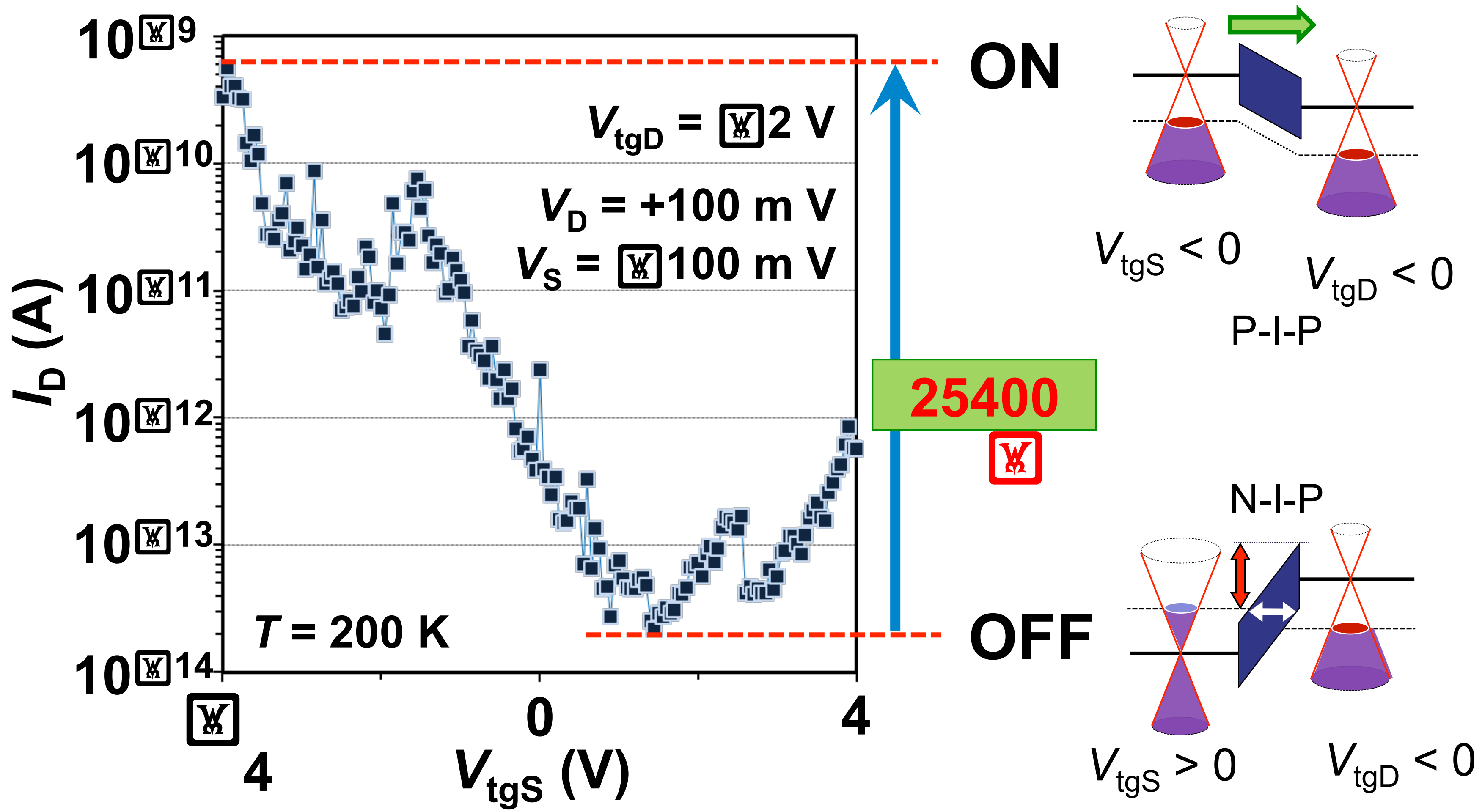
- V_{acc} = 30 kV
- Ion dose: 1[illegible]10^{15} [illegible] 10^{16} ions/cm^2
- Defect density : **0.1 % [illegible] 1 %**



Graphene with 1% point defects

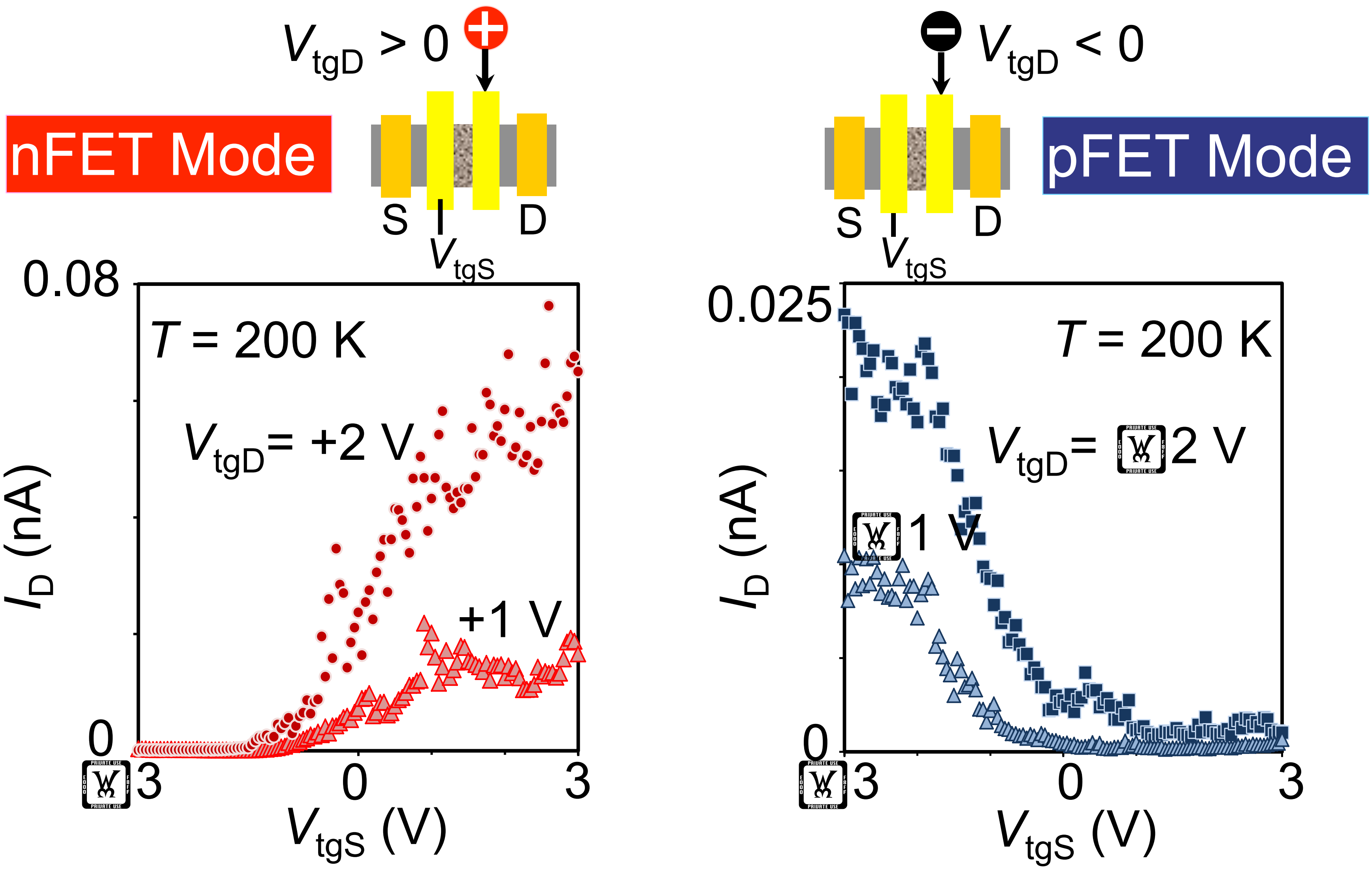
3. Device Operation

On-Off Operation of Current



On-Off ratio of <u>25400</u> was achieved at 200 K.

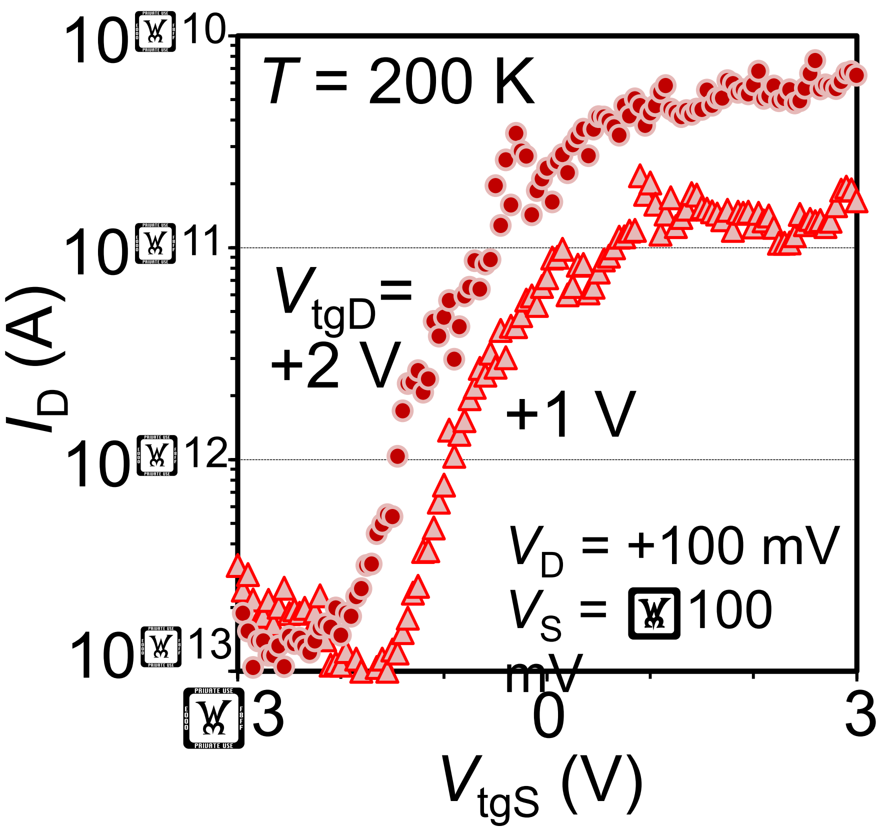
Transistor Operations



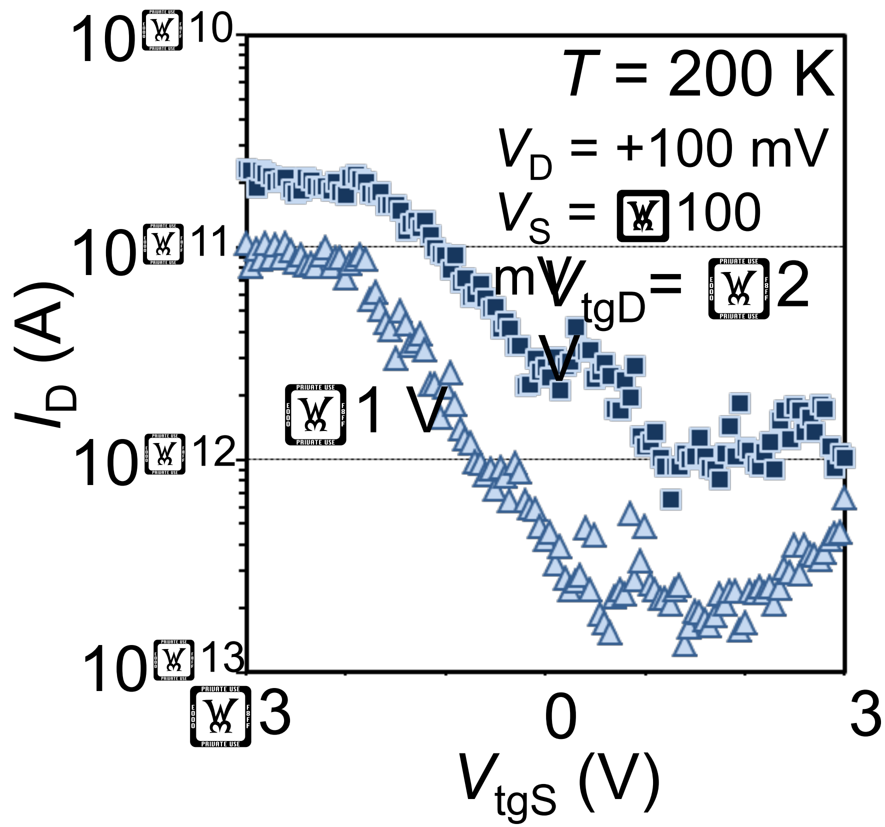
Transistor polarity is reversible by a gate bias.

Transistor Operations (Logarithmic Scale)

nFET Mode



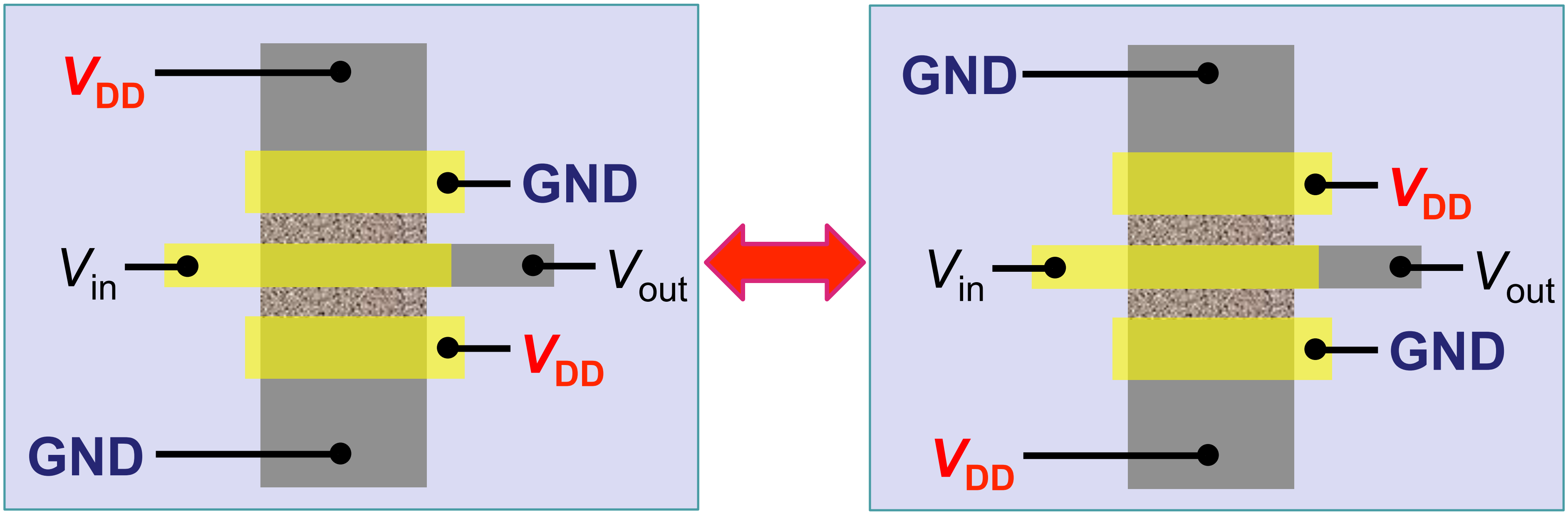
pFET Mode



Transistor polarity is REVERSIBLE!

Electrostatically-Reconfigurable Circuit?

Reversible Inverter



Dynamic reconfiguration of circuit structure from the transistor level during computation is possible.

Summary

- **Novel concept graphene transistor with dual gates was proposed.**
- **Electrostatically-reversible transistor polarity was demonstrated.**
- **Dynamically-reconfigurable circuit is expected.**

For details: S. Nakaharai, *et al*., Tech. Digest of IEDM **2012**, p.72

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This research is granted by JSPS through FIRST Program initiated by CSTP.

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