Device applications of graphene prepared by chemical vapor deposition

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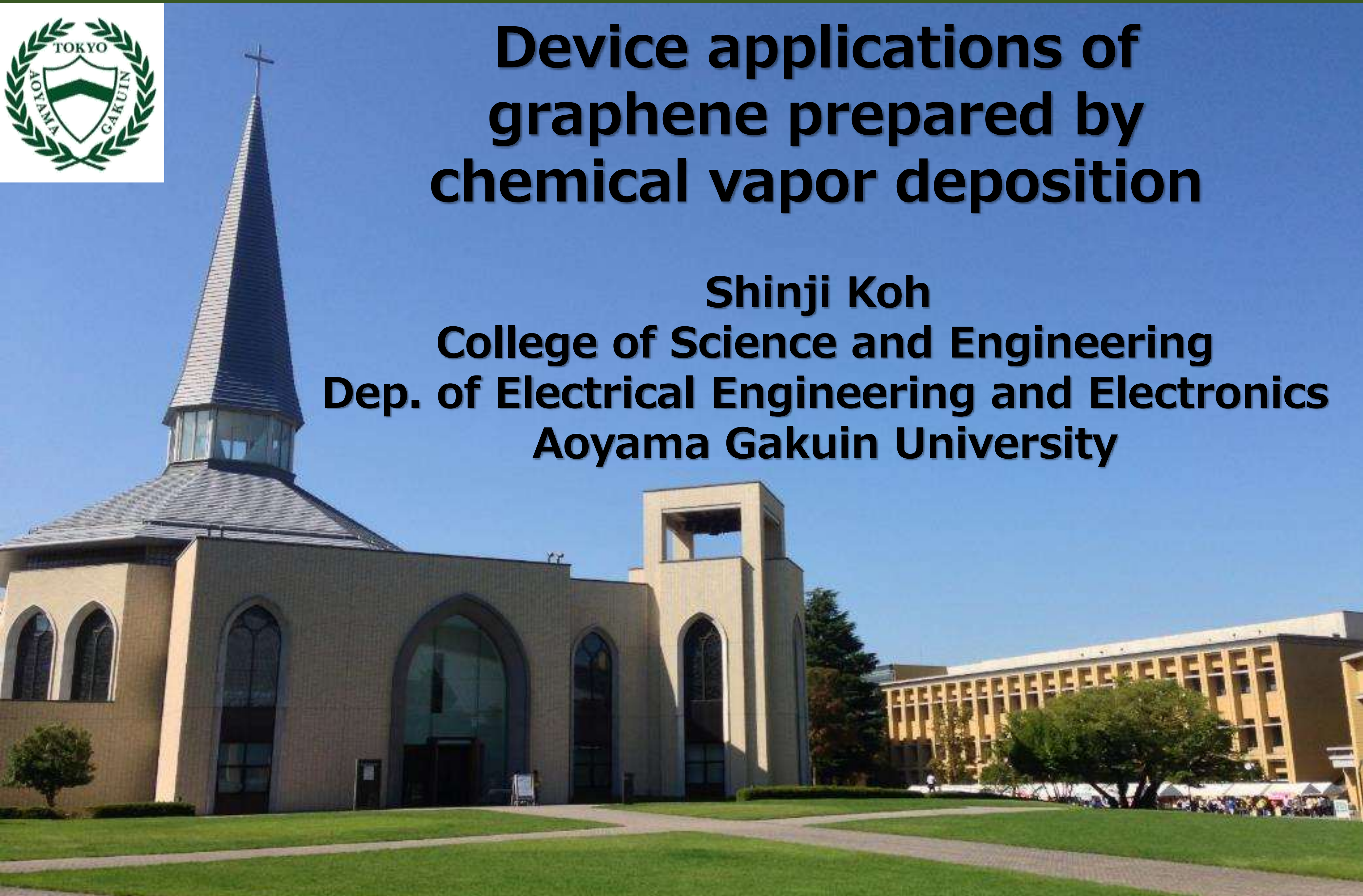
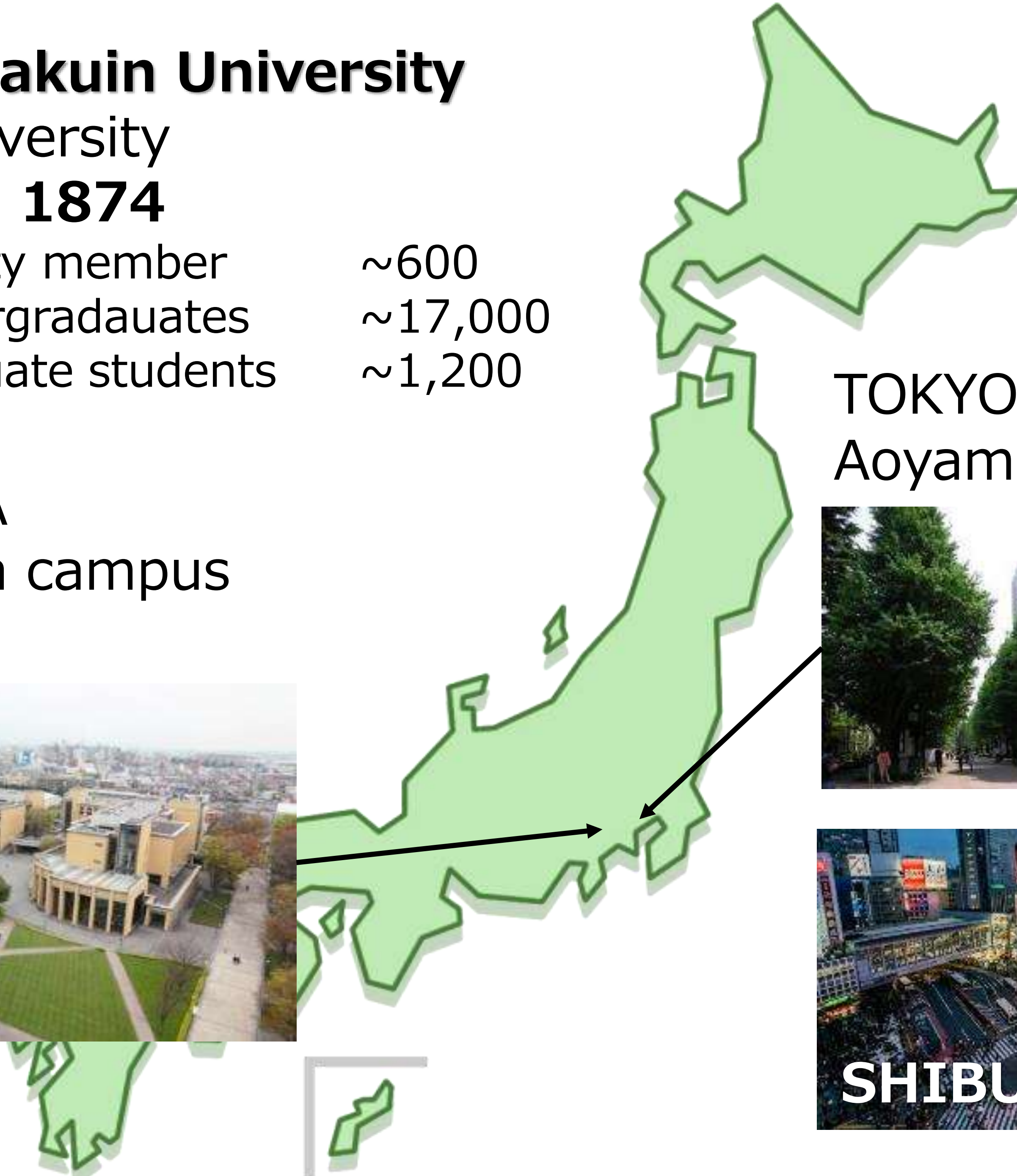


Aoyama Gakuin University

Private University

Founded in **1874**

Faculty member	~600
Undergradauates	~17,000
Graduate students	~1,200



KANAGAWA

Sagamihara campus

I work here!

TOKYO

Aoyama campus

nature INDEX

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Home / Supplements / Nature Index 2018 Japan / Top academic institutions by normalized WFC

Top academic institutions by normalized WFC

The tables show Japan's leading institutions ranked by normalized weighted fractional count (WFC), an in
proportion of total output in the natural sciences (NS) from 2012 to 2017. This is derived by dividing an ins
total number of natural sciences articles in Scopus (Scopus NS articles 2012–2017). Also listed are an ins
2012–2017) and the percentage of its total articles in Scopus that are in the natural sciences (NS articles

Rank	Institution	Normalized WFC 2012–2017
1	Gakushuin University	0.0938
2	The University of Tokyo (UTokyo)	0.0680
3	Konan University	0.0611
4	Kyoto University	0.0577
5	Aoyama Gakuin University	0.0575
6	Osaka University	0.0574
7	Nara Institute of Science and Technology (NAIST)	0.0563
8	Okinawa Institute of Science and Technology Graduate University (OIST)	0.0561
9	Tokyo Institute of Technology (Tokyo Tech)	0.0547
10	Nagoya Institute of Technology (NITech)	0.0491
11	Nagoya University	0.0478

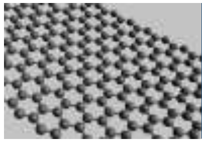
Nature Index 2018

5th position

Japanese academic institution

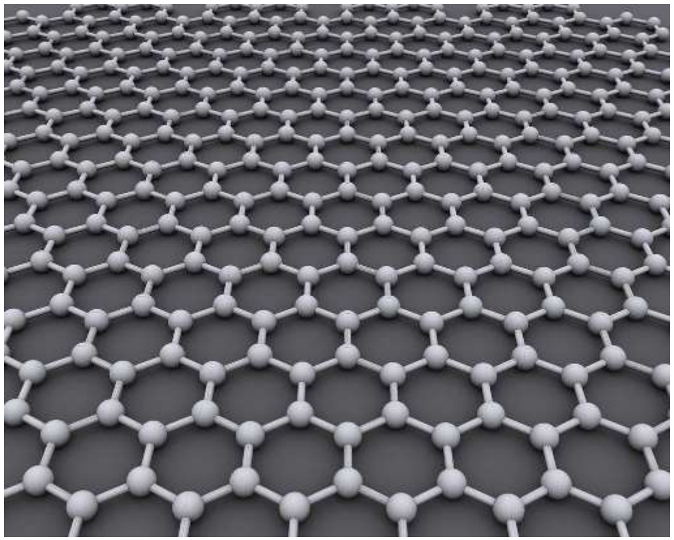
OUTLINE

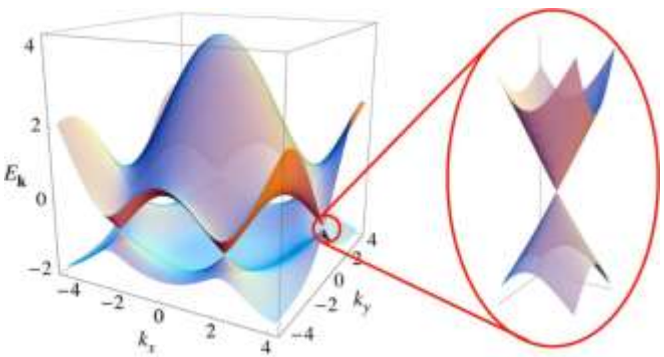
1. CVD growth of graphene on Ir(111)/sapphire
2. Device applications of CVD graphene grown on Cu
   a. Optically transparent antennas
   b. Free chlorine sensors



GRAPHENE

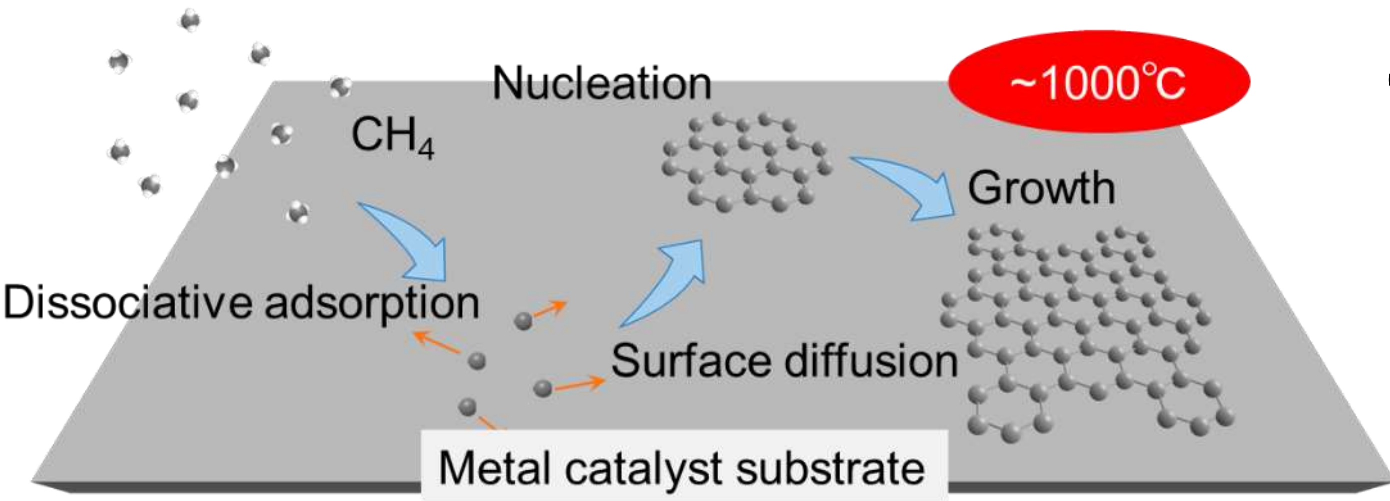
2-D honeycomb lattice of carbon atoms



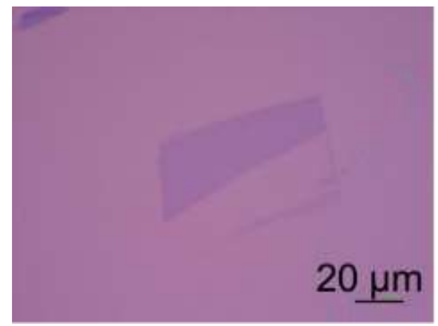


- **Ultrathin ~0.3 nm**
- **High Conductivity of Electricity and Heat**
- **High Mechanical Strength**
- **High Optical Transparency (97.7%)**

CVD Growth of Graphene



Graphene prepared by scotch tape method

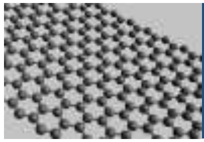


Chemical vapor deposition (CVD)

Large-area and high-quality graphene sheet

Scalable technology

Suitable for industrial applications



CVD Growth on Cu substrate

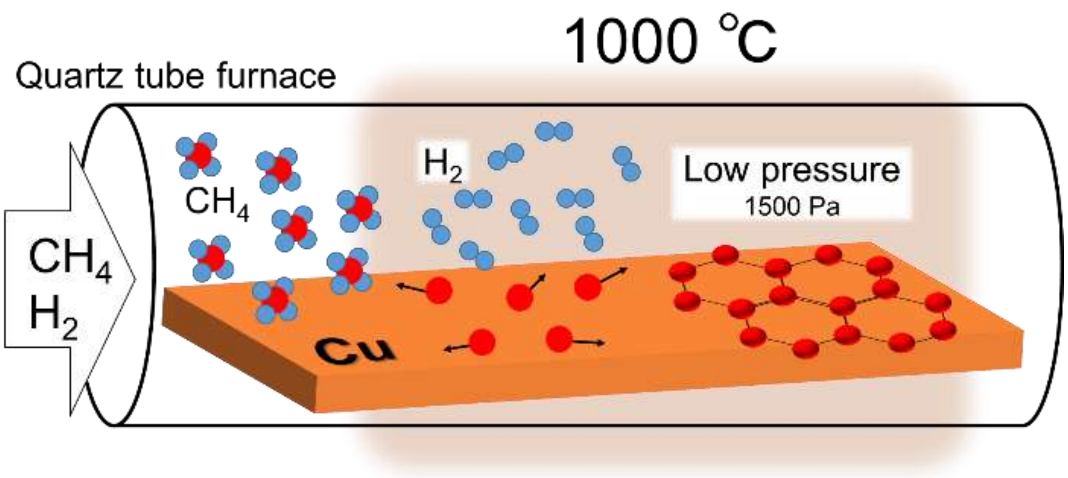
Cu metal catalyst substrate (~0.035 mm)

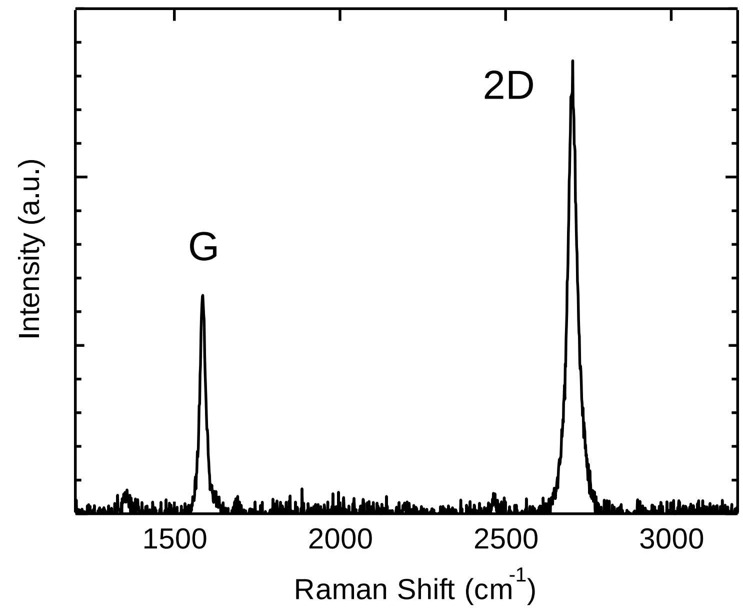
Low cost

Low carbon solubility

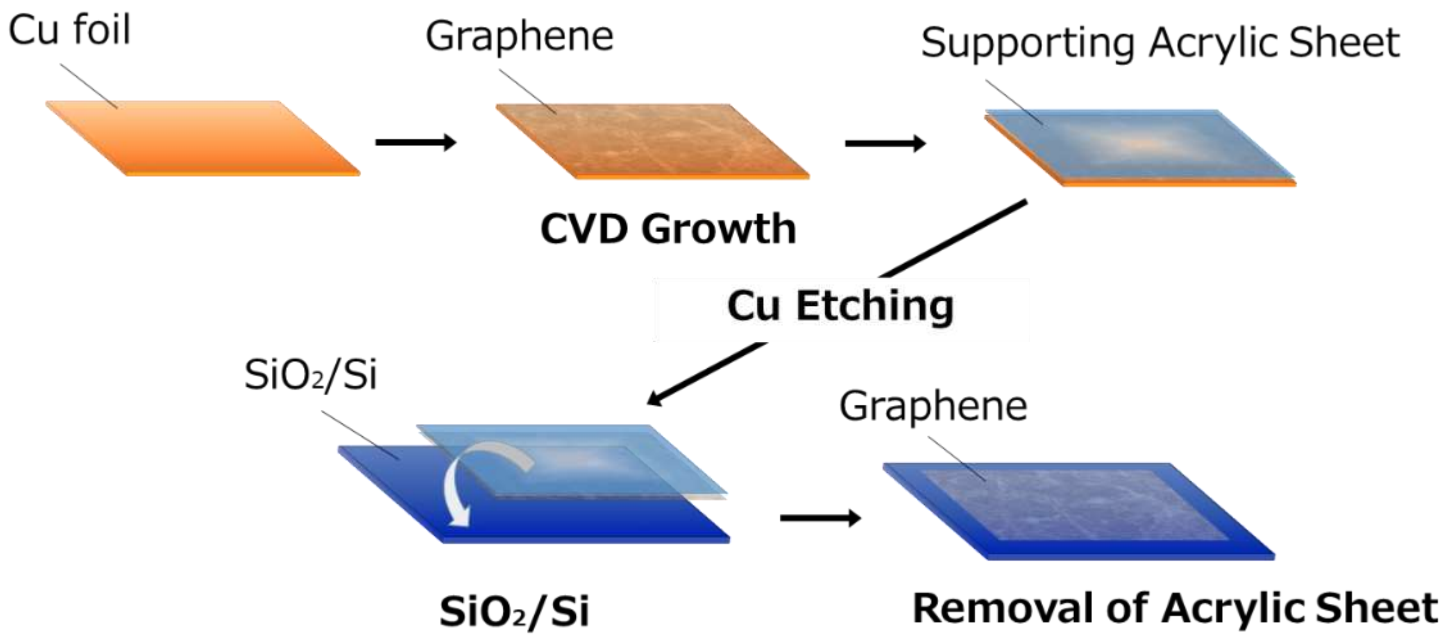
Self-limiting growth of

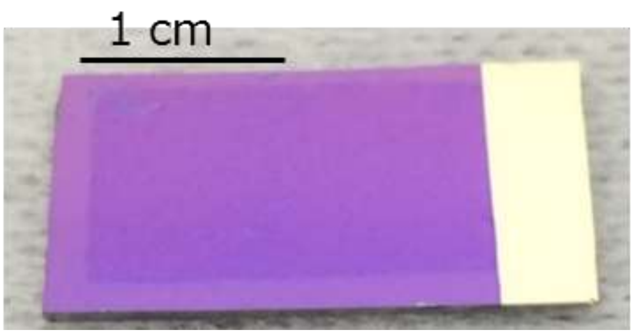
monolayer graphene





Transfer of Graphene





One-atom-thick graphene
transferred onto SiO_2/Si

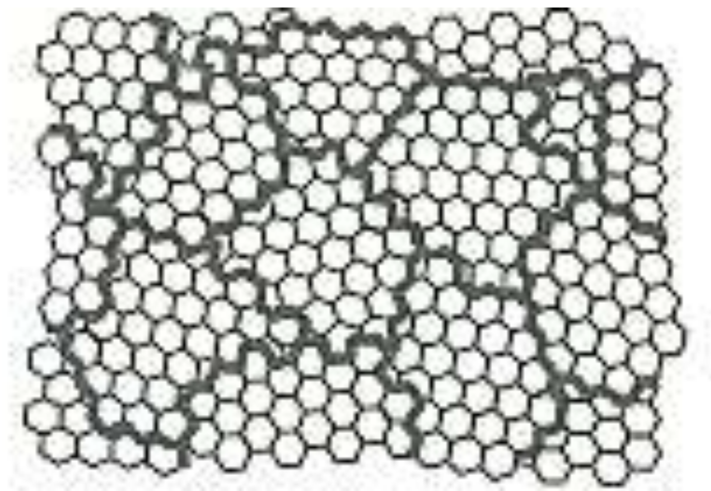
We can transfer graphene onto
Various types of substrates.

Quarts glass, PET, PEN, etc.

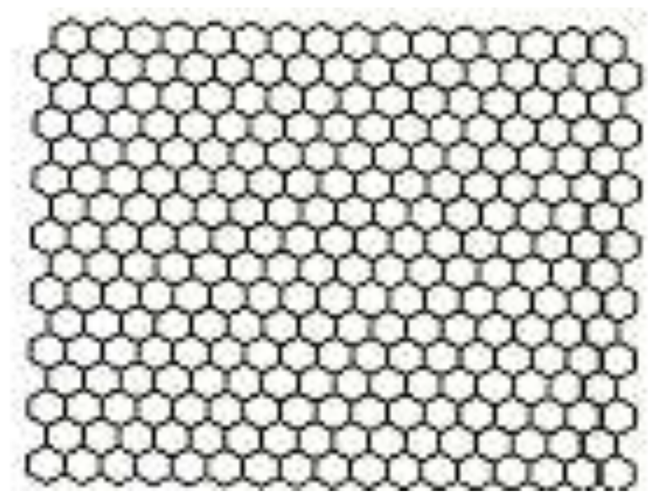
→ **Device Applications**

Single Crystalline CVD Graphene

Poly-crystalline graphene on Poly-crystalline Cu



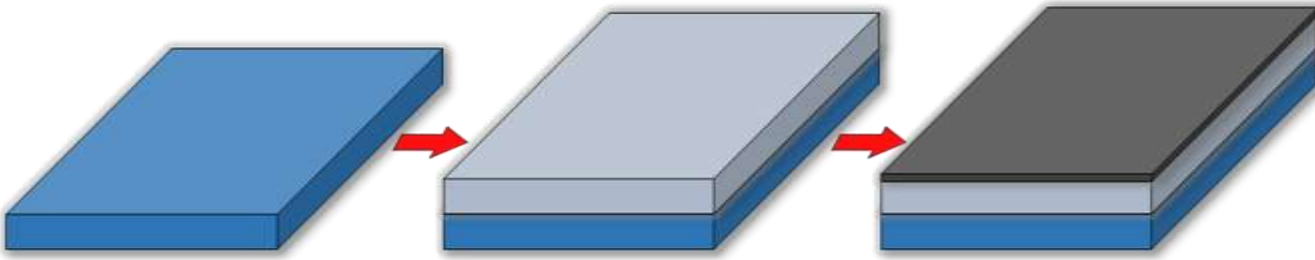
single crystalline graphene



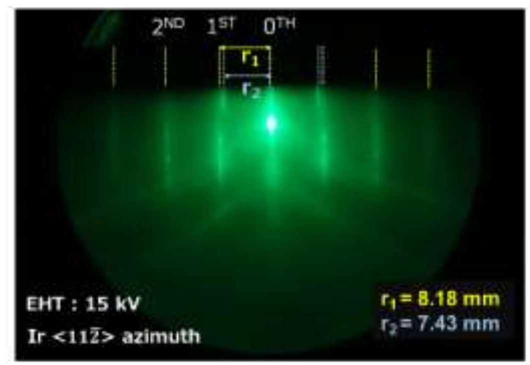
Single crystalline CVD graphene is favorable to utilize 100% of graphene's properties.

CVD Growth on Iridium

Single crystal sapphire → **Epitaxial layer Ir(111)** → **Single Crystalline Graphene**



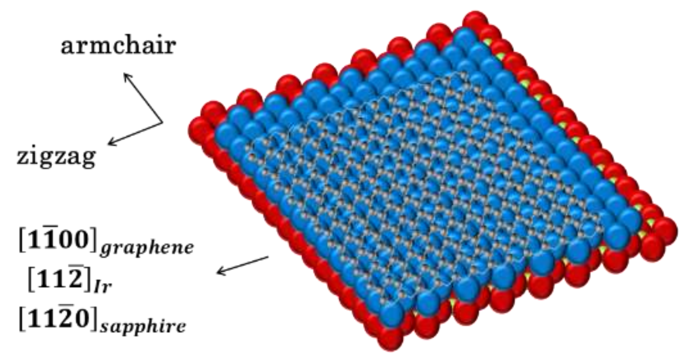
RHEED Pattern for Graphene/Ir(111)



Iridium

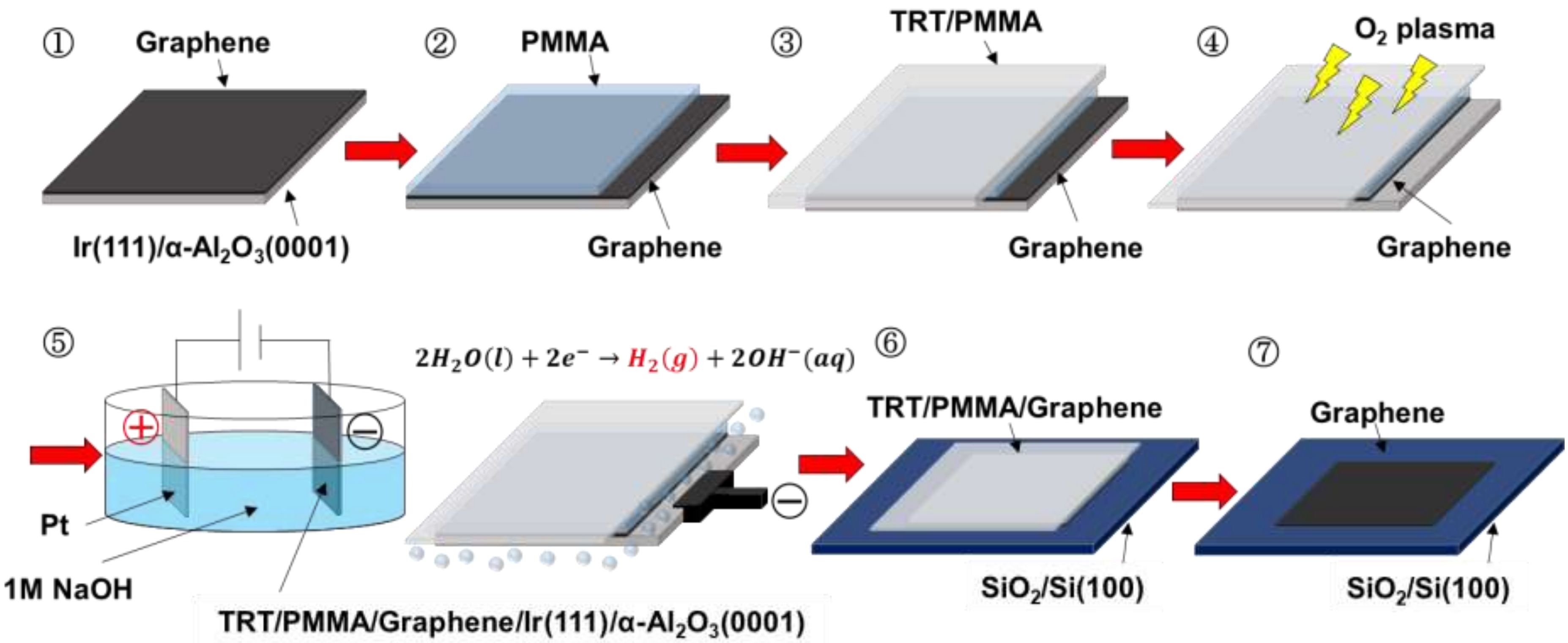
- High melting temperature (~2400℃)
- Chemical stability
- Low carbon solubility (0.041 at.%)

We demonstrated CVD growth of **single-crystalline monolayer graphene on Iridium metal catalyst substrate**



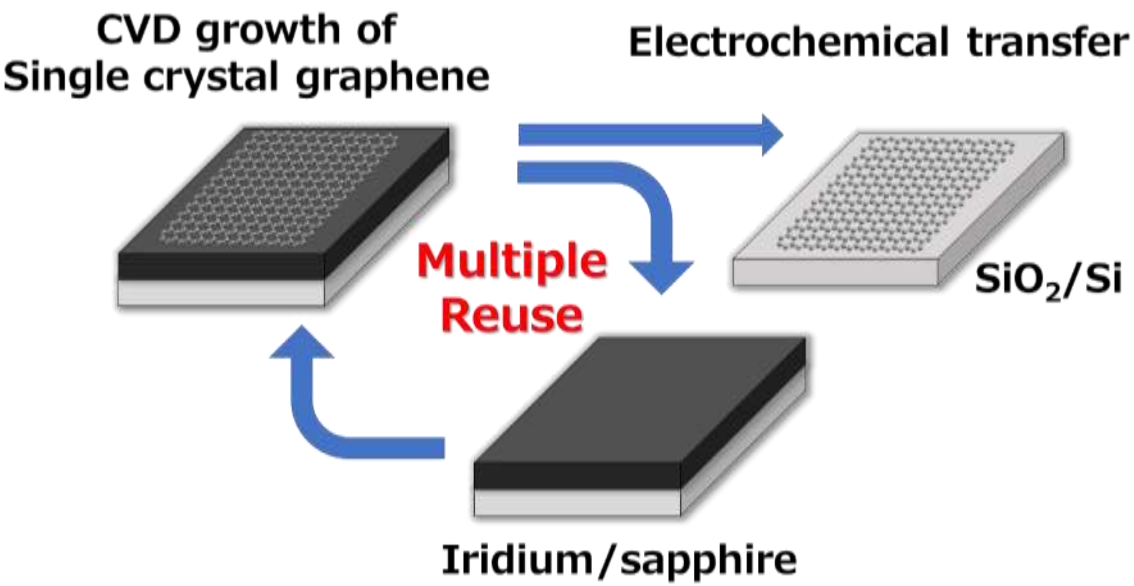
S. Koh, Y. Saito, H. Kodama, and A. Sawabe,
Appl. Phys. Lett., **109,** 023105 (2016).

Electrochemical Transfer

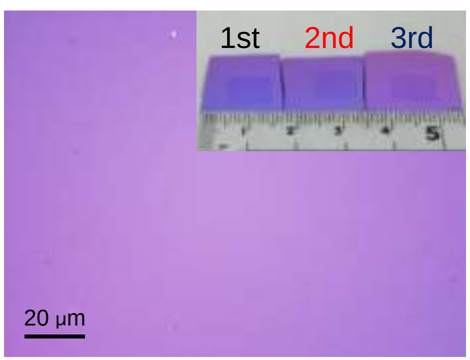


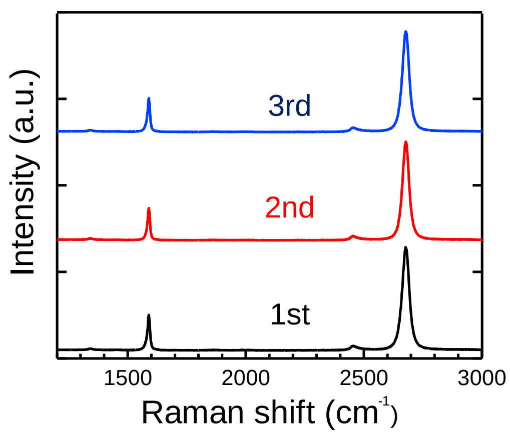
Electrochemical peeling of graphene using H_2 gas bubble generation

Reusability of Ir(111)/Sapphire



Reusability of Ir/sapphire in multiple cycles of CVD and transfer processes was demonstrated.





S. Koh, Y. Saito, H. Kodama, and A. Sawabe, Appl. Phys. Lett., **109**, 023105 (2016).

A. Sakurai, M. Niki, T. Watanabe, A. Sawabe and S. Koh, To be appeared in JJAP (2020)

OUTLINE

1. **CVD growth of graphene on Ir(111)/sapphire**

2. **Device applications of CVD graphene grown on Cu**

   a. **Optically transparent antennas**

   b. **Free chlorine sensors**

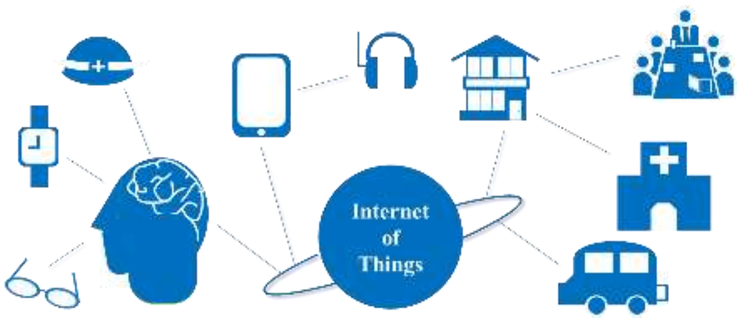
   c. **Luminescent graphene**

Doctor course student
Mr. Shohei Kosuga

JSPS's DC2 Research Fellowship for Young Scientists

Backgrounds: Transparent Antennas

Internet of Things



Various things are connected each other in the network.

5G system

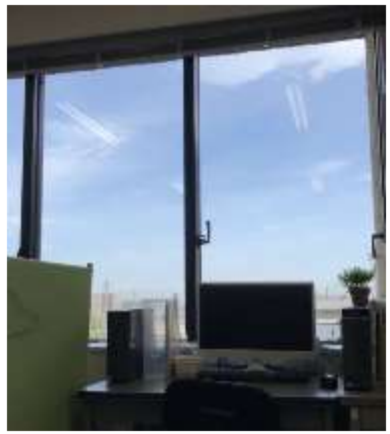
High frequency ~27 GHz

Propagation loss
becomes higher.
Propagation distance
becomes shorter.

We need many ANTENNAS!
ANTENNA, ANTENNA, ANTENNA!
Everywhere!

Optically Transparent Antennas

Optically transparent antennas
maintain transparency of objects
do not change the landscape.



Metal(Ag) mesh antennas
ITO transparent antennas

CVD Graphene for Antennas

High optical transparency (~97.7 %)

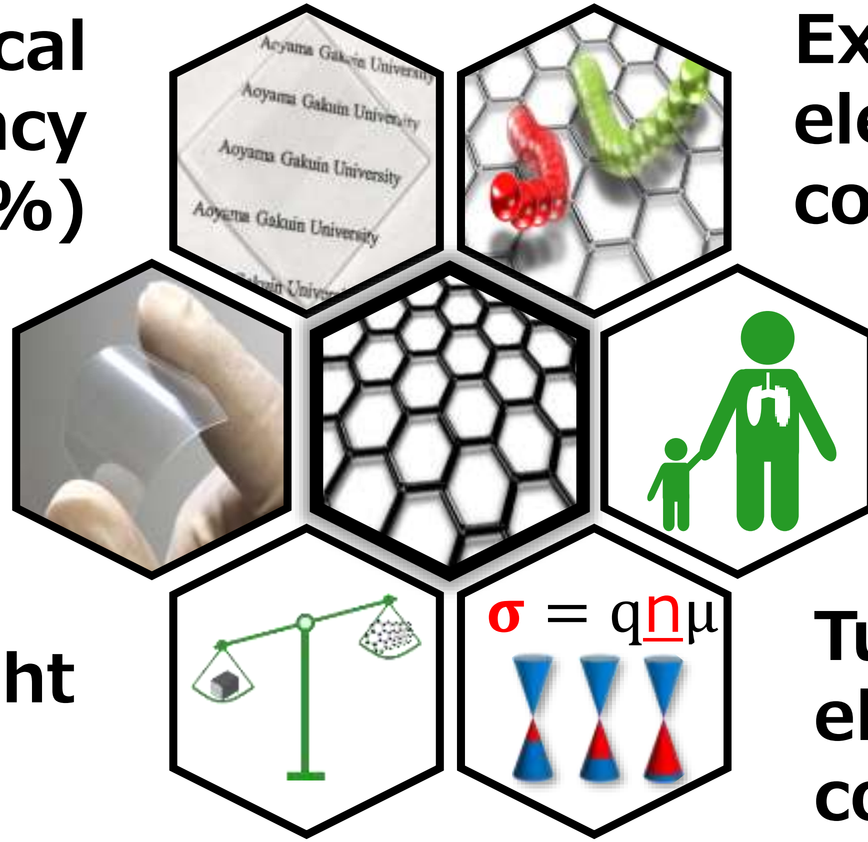
Excellent electrical conductivity

Flexibility

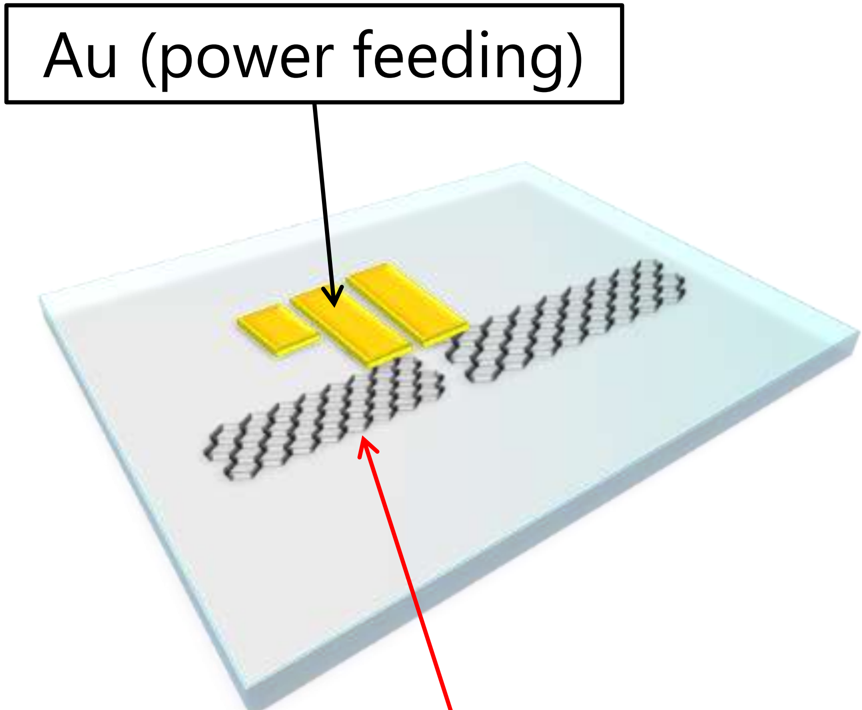
Metal free material

Ultralight

Tunable electrical conductivity

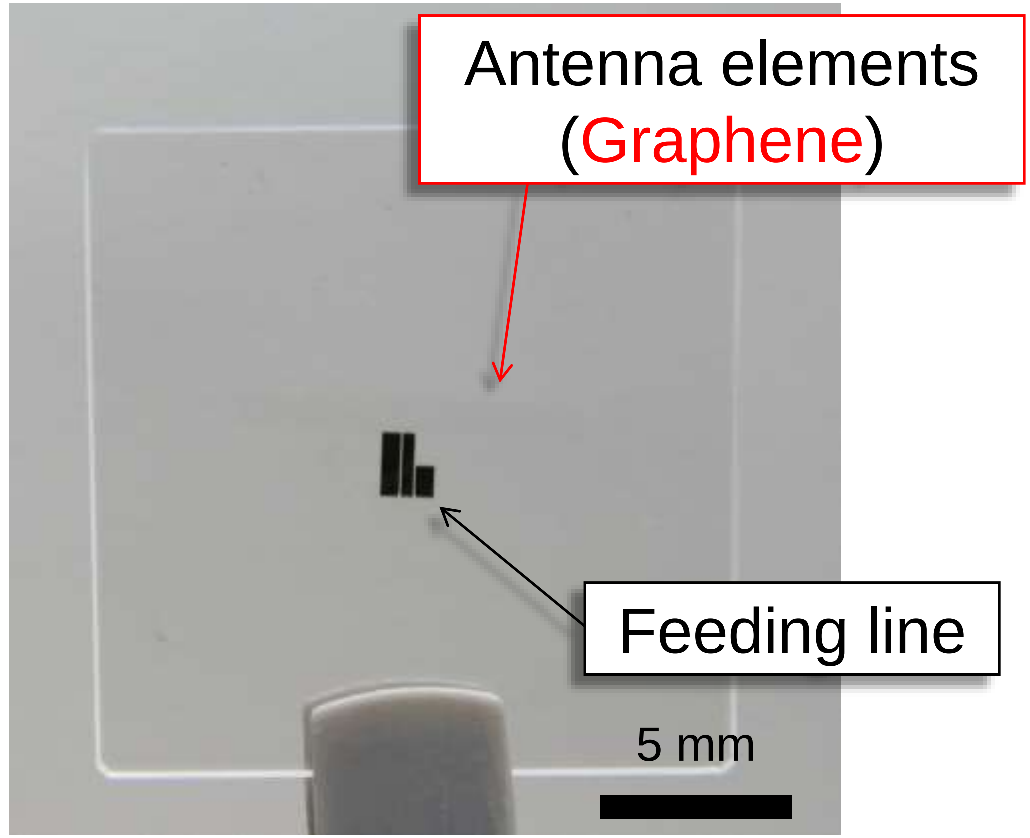


Graphene Transparent Antennas



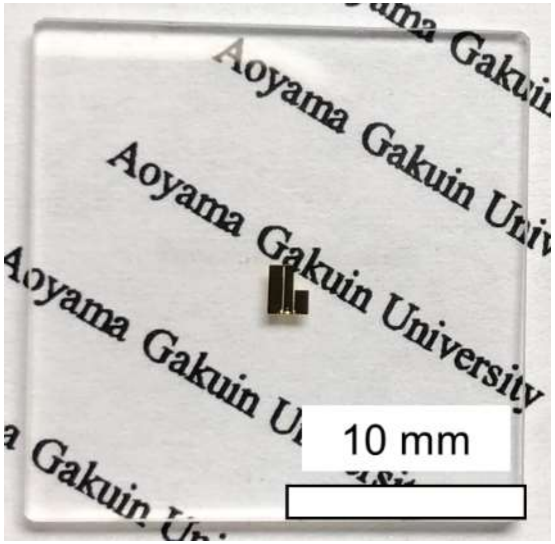
Graphene antenna elements

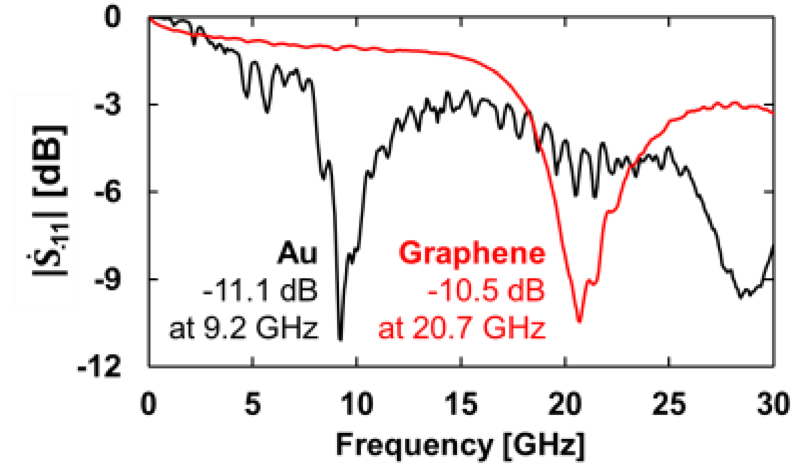
- Transparency (～97 %)
- High conductivity
- Flexibility
- Metal Free



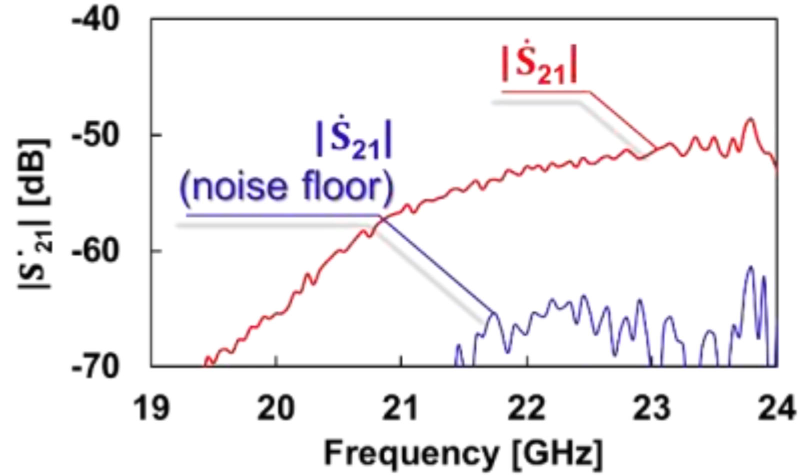
S. Kosuga et al., Appl. Phys. Lett. **110**, 233102 (2017).
S. Kosuga et al., PIERS, Singapore (2017).

Graphene Transparent Antennas





We demonstrated
microwave radiation at ~20 GHz
from monolayer graphene antenna.



Dielectric behavior of monolayer graphene
High Sheet resistance Rs ~ 700 Ω/sq

S. Kosuga et al., Microwave. Opt. Technol. Lett. **60,** 2992-2998 (2018).
S. Kosuga et al., 30th Asia-Pacific Microwave Conference, Kyoto, Japan, 7 Nov. (2018)

Stacking & Doping

Monolayer

3 layers

Chemical p-doping

Sheet resistivity

700 Ω/sq. ⟶ 80 Ω/sq.

Optical transparency at 550 nm

97.0% ⟶ 90.6%

Fabrication of transparent antennas is now underway.

OUTLINE

1. **CVD growth of graphene on Ir(111)/sapphire**

2. **Device applications of CVD graphene grown on Cu**

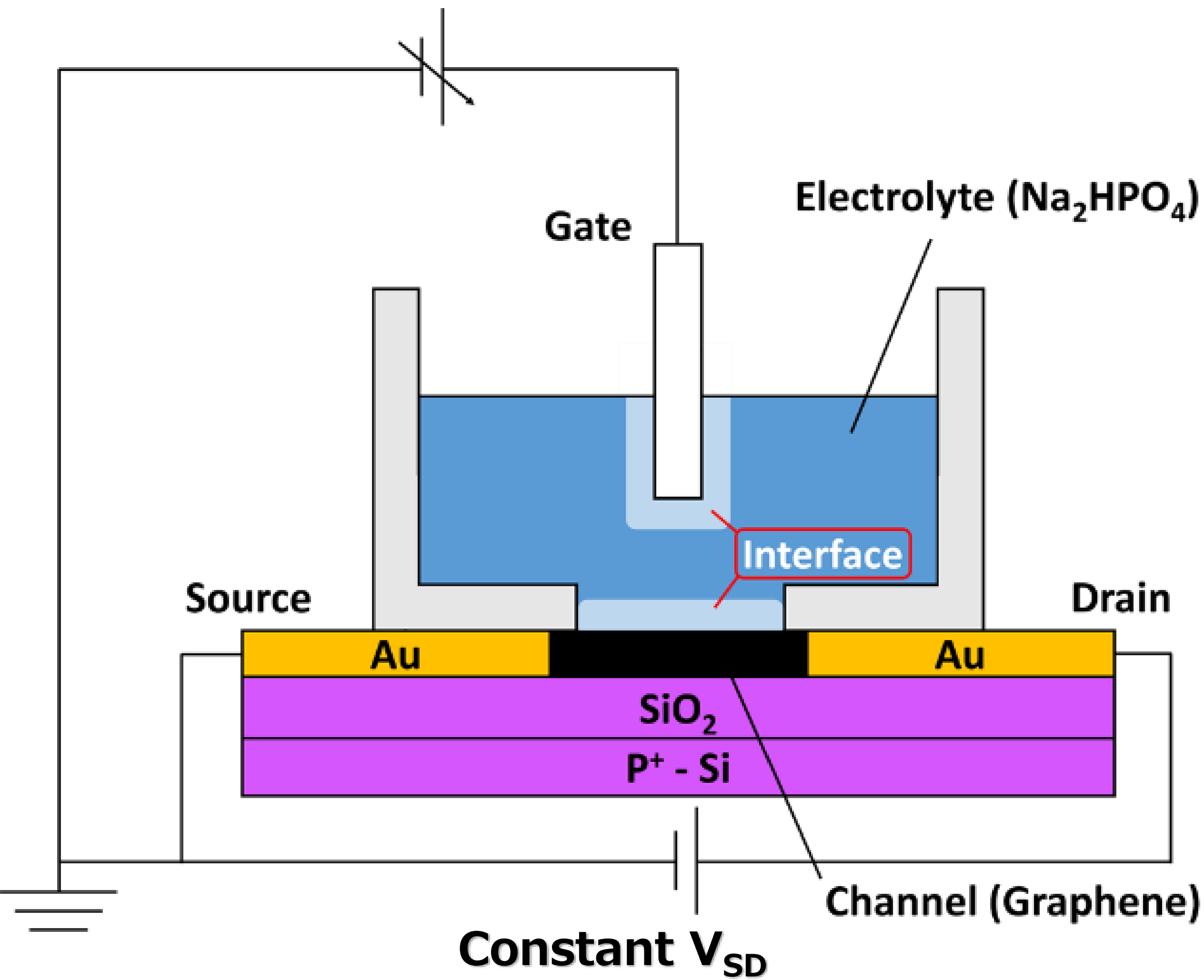
   a. Optically transparent antennas

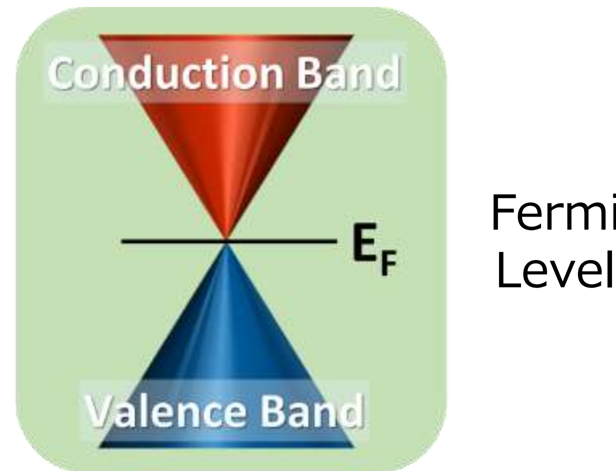
   b. **Free chlorine sensors**

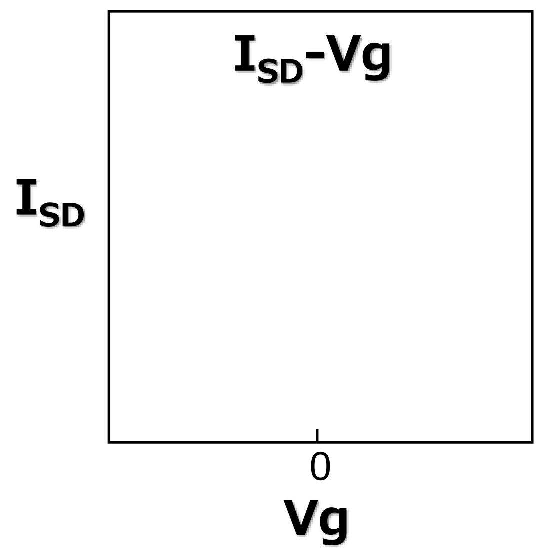
Assistant Professor
Dr. Takeshi Watanabe

Solution Top-Gated GFET

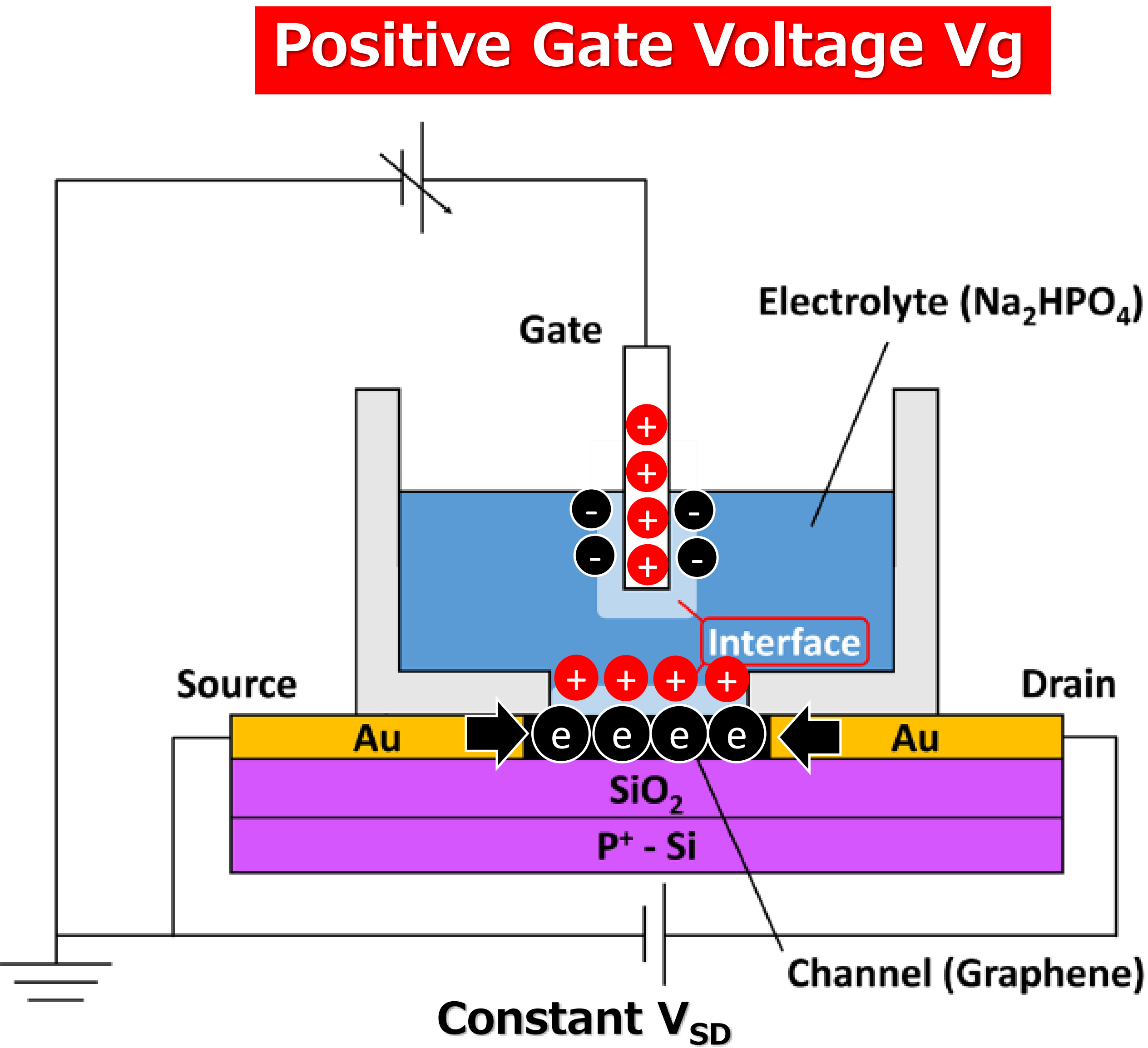
Conductivity modulation by top-gating



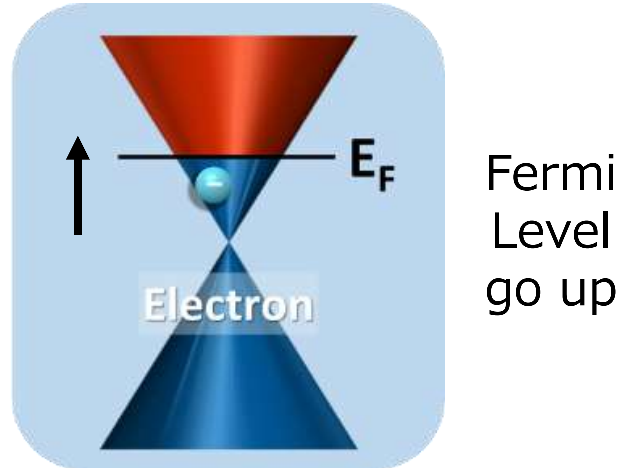


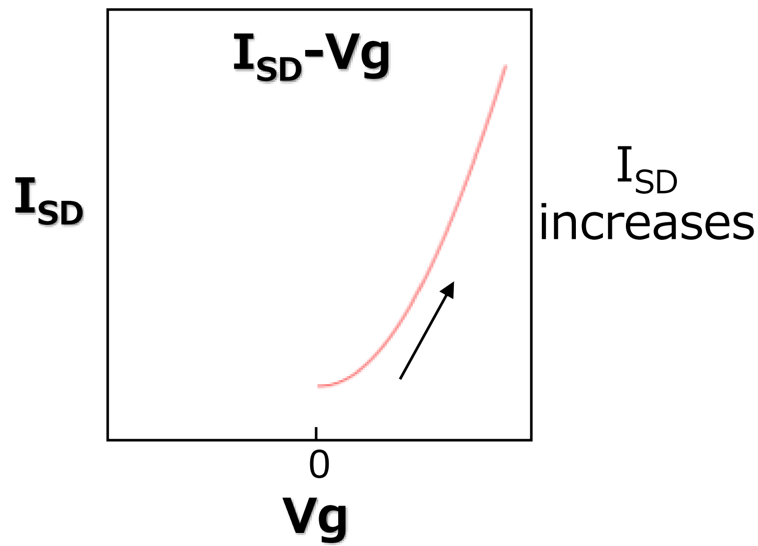


Top-gated GFET in Electrolyte



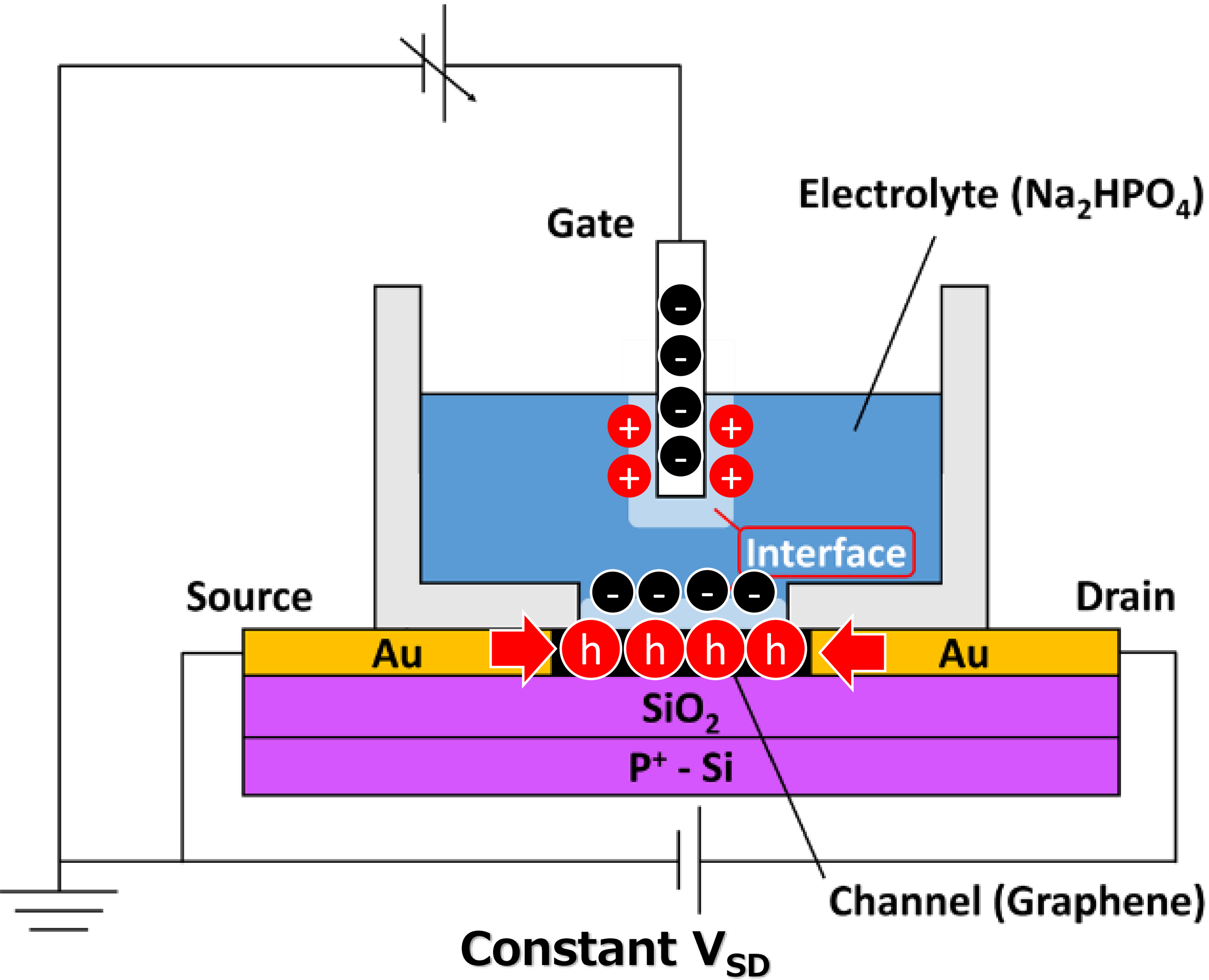
Electron increases (n-type).



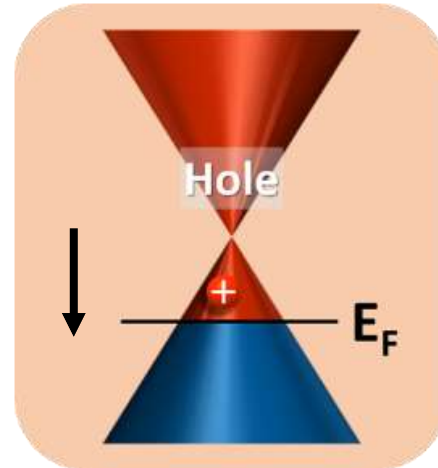


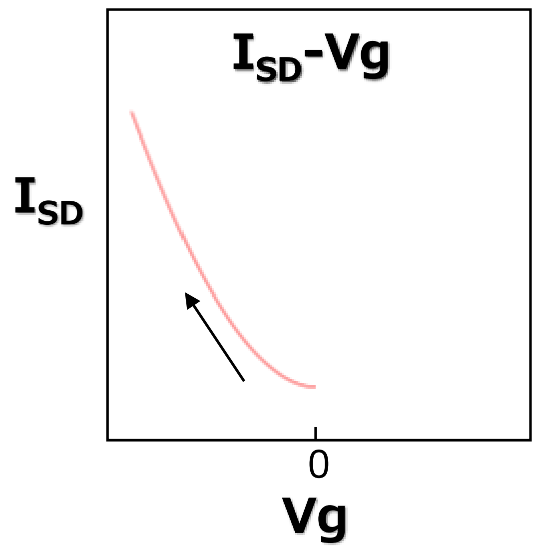
Top-gated GFET in Electrolyte

Negative Gate Voltage Vg

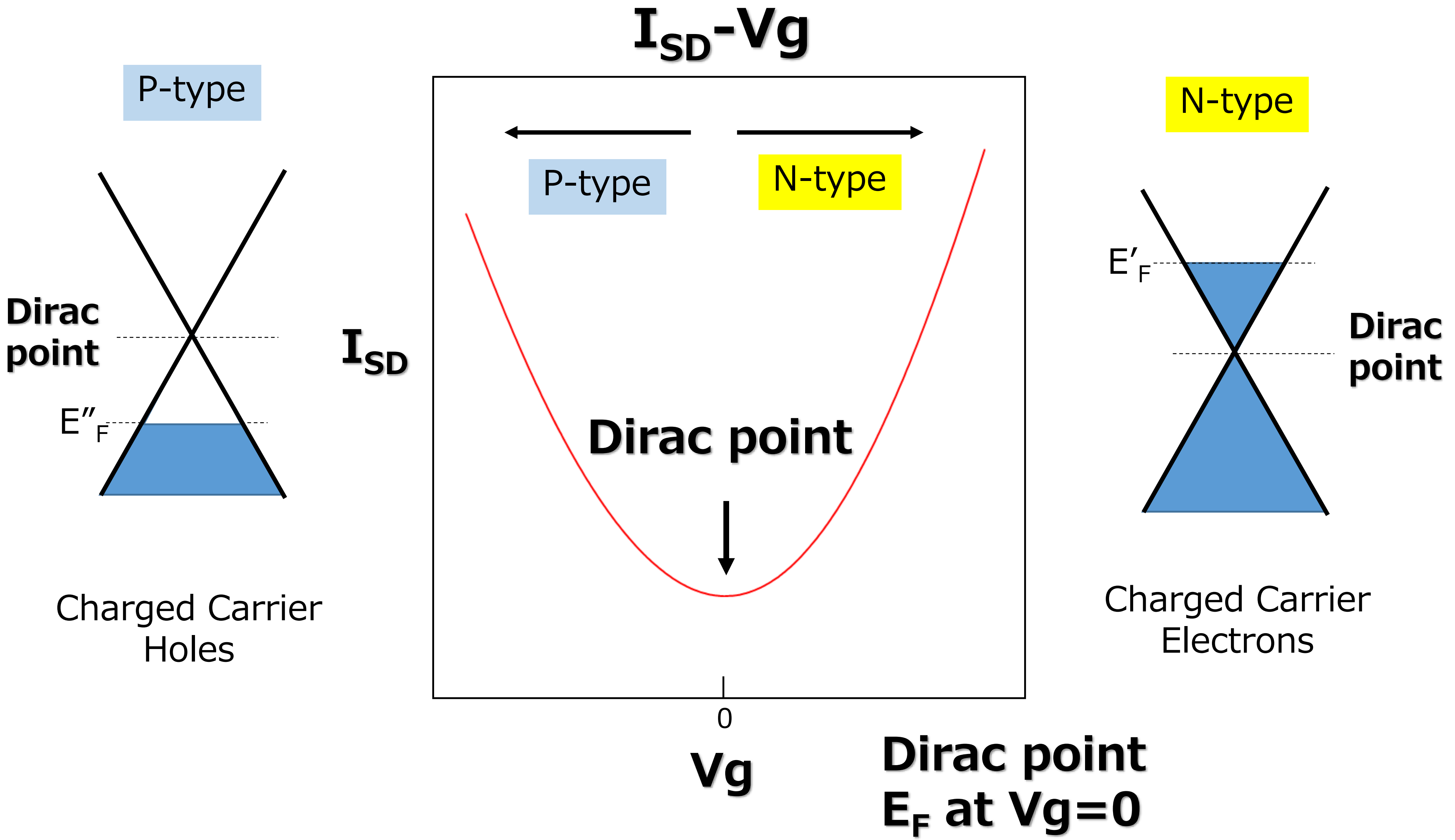


Hole increases (p-type).

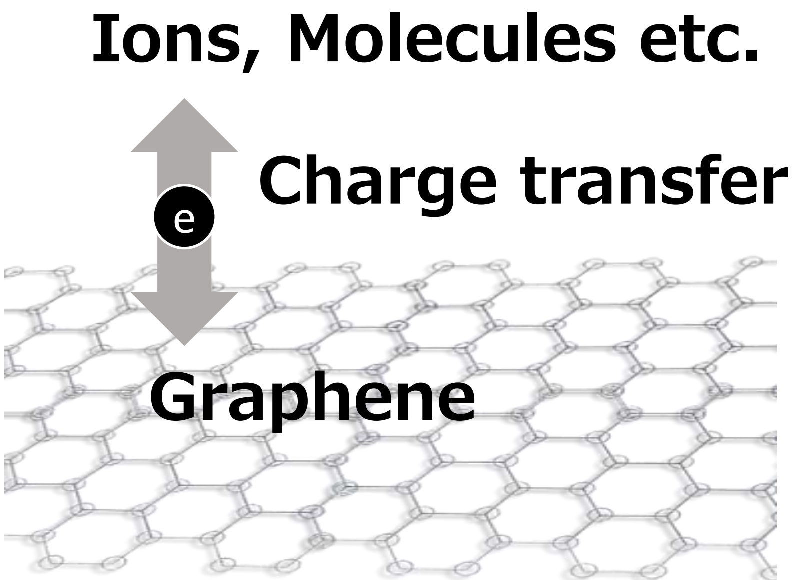




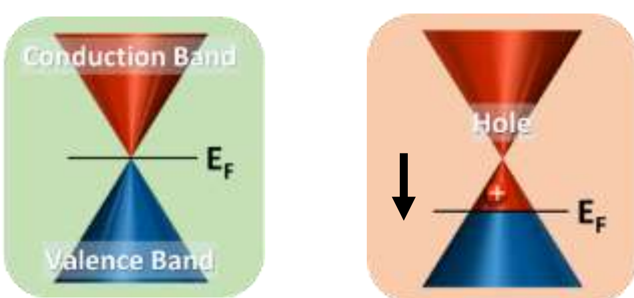
Ambipolar Characteristics of GFET

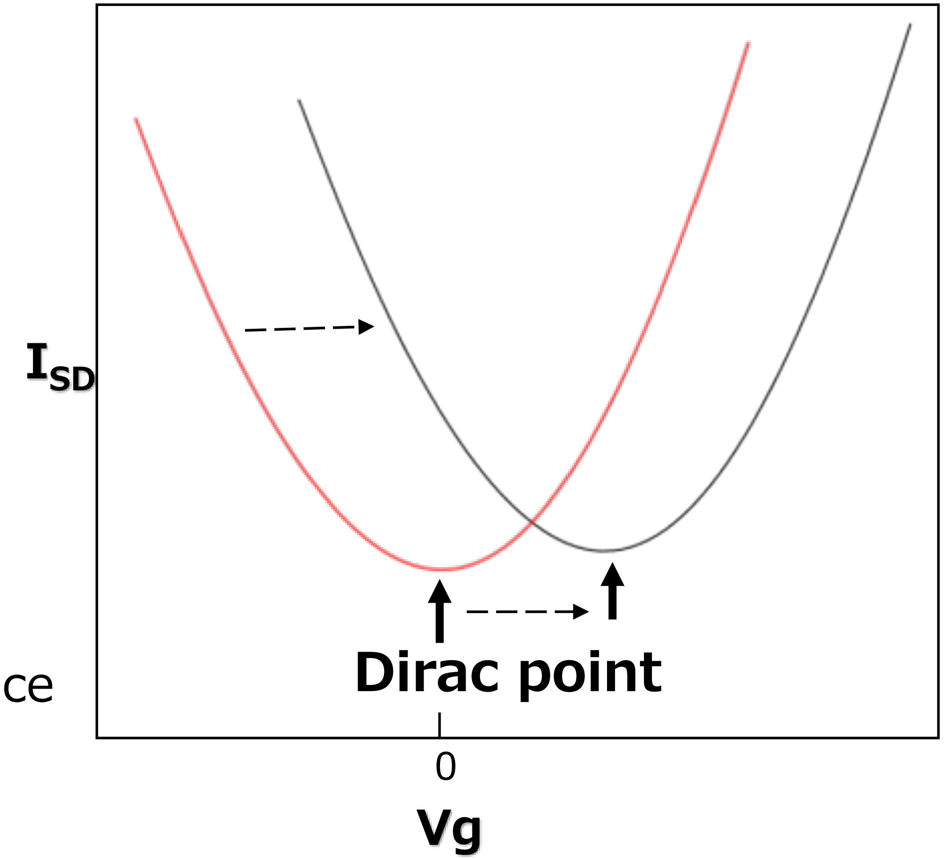


GFET-Based Sensors



Charge transfer at the graphene surface causes **carrier doping**, resulting in **Shift of Fermi Level**.

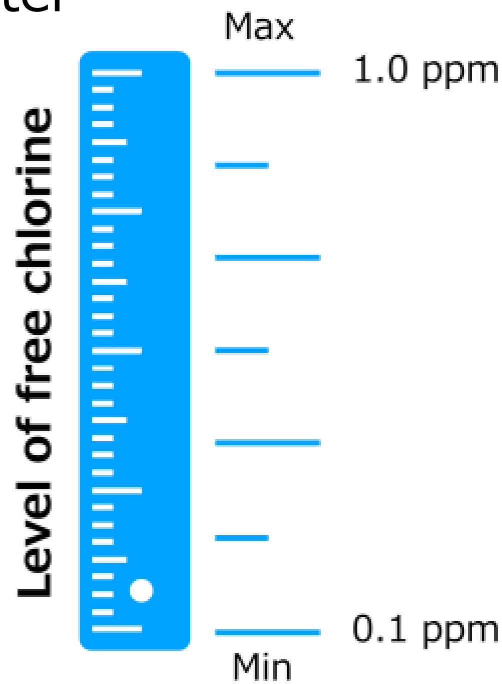




Charge transfer intaraction is observed as the shift of I_{SD}-V_g curves.

GFET Free Chlorine Sensors

Chlorine for disinfection of water



Too High
Harmful for human

Too Low
Not effective at killing bacteria and viruses

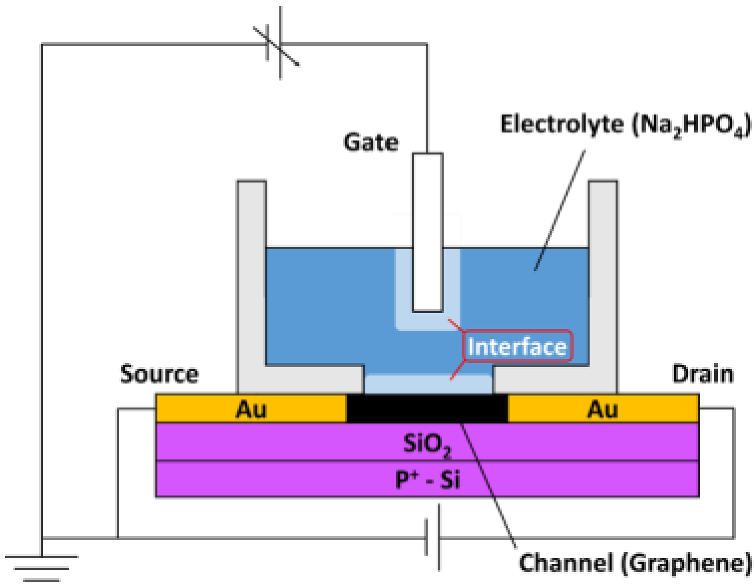
Free chlorine: hypochlorous acid (HOCl) and hypochlorite (OCl-) ion

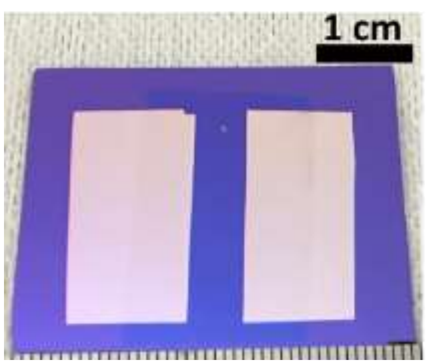
Conventional methods

Colorimeteric method: Not applicable to continuous measurements

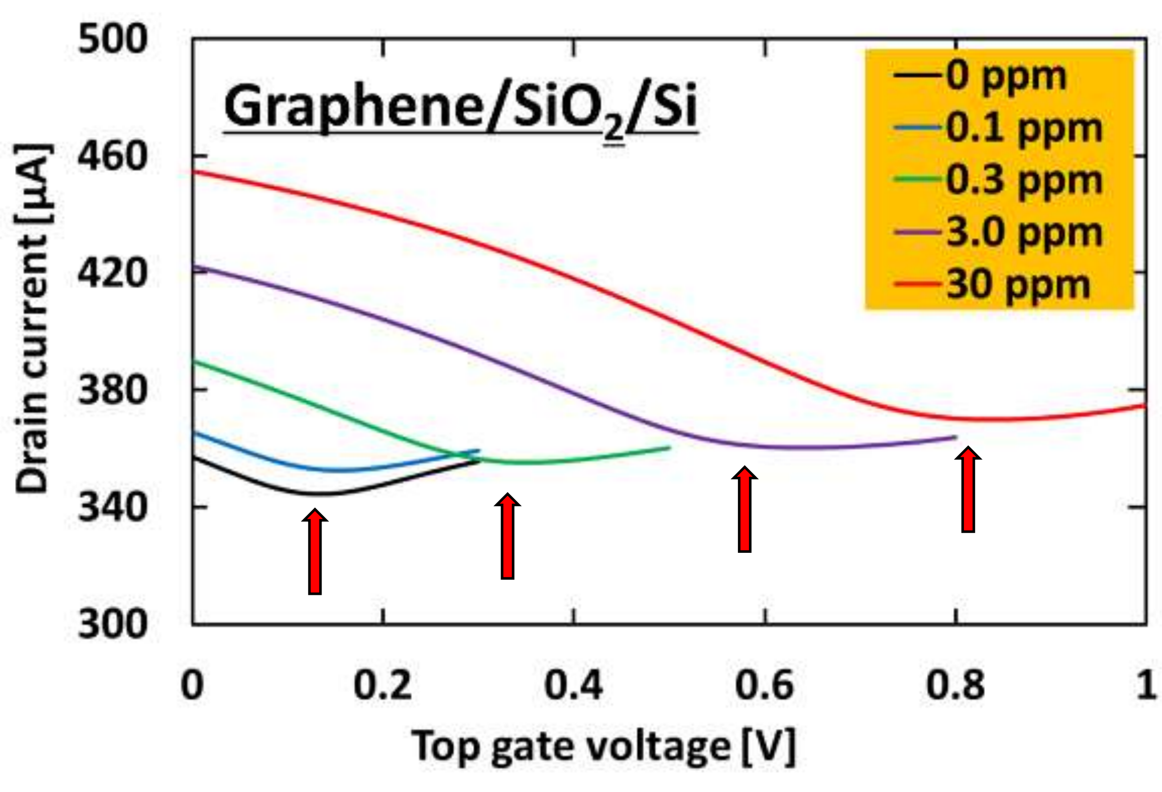
Electrochemical method using Pt: High cost, Oxidation of Pt surface

GFET Free Chlorine Sensors



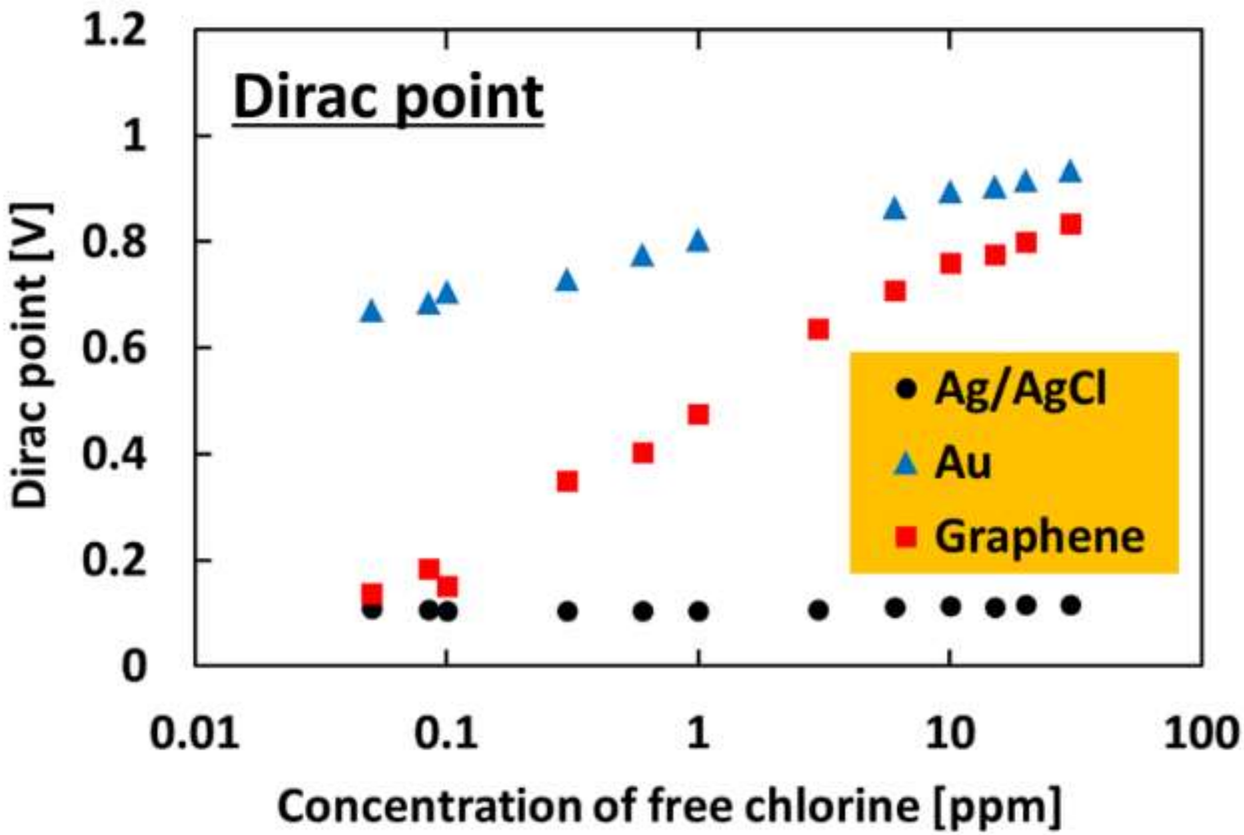


Graphene channel



Dirac point shifts to positive voltage as free chlorine concentration increases.

GFET Free Chlorine Sensors



Detection of
Free Chlorine Conc.
0.08 ~ 40 ppm

High sensitivity
was obtained with

Graphene channel
Graphene top gate

Chlorine sensor.

JSAP Autumn meeting 2019, 21a-PB1-44, Hokkaido Univ. 21th Sep. (2019).

Summary

1. CVD growth of graphene on Ir(111)/sapphire

CVD growth of single-crystalline monolayer graphene

Reusability of Ir(111) substrates

2. Device applications of CVD-grown graphene

Optically transparent antennas

Free chlorine sensors

TOKYO AOYAMA GAKUIN

科研費 KAKENHI

Nippon Sheet Glass Foundation for
Materials Science and Engineering