Introduction to Nanotechnology and Nanoscience – Class#27

Liwei Lin

Professor, Dept. of Mechanical Engineering
Co-Director, Berkeley Sensor and Actuator Center
The University of California, Berkeley, CA94720
e-mail: lwlin@me.berkeley.edu
http://www.me.berkeley.edu/~lwlin

Outline

- The rest of the semester
- One Final Presentation
- Graphene

Rest of the Semester

- Final Project Presentations – 4/23, 4/25, 4/29, 4/30
- These will be done via zoom – link to be sent by bcourse
- Final Project Report – 5/4 (Saturday midnight)

Final Project Presentation

- ☐ 10 mins – roughly 10 ppt slides
- ☐ Likely to include:
  - Title slide
  - Stats-of-Art, Other Works
  - Concept, Principle -what is your > 5% differences
  - Schematic Figure, Design & Fabrication Process
  - Analysis (some calculations?) & Discussions
  - Numerical Simulations – required for ME218N
  - Conclusion
  - References

Final Project Report

□ 4 Pages, double-column like a research paper

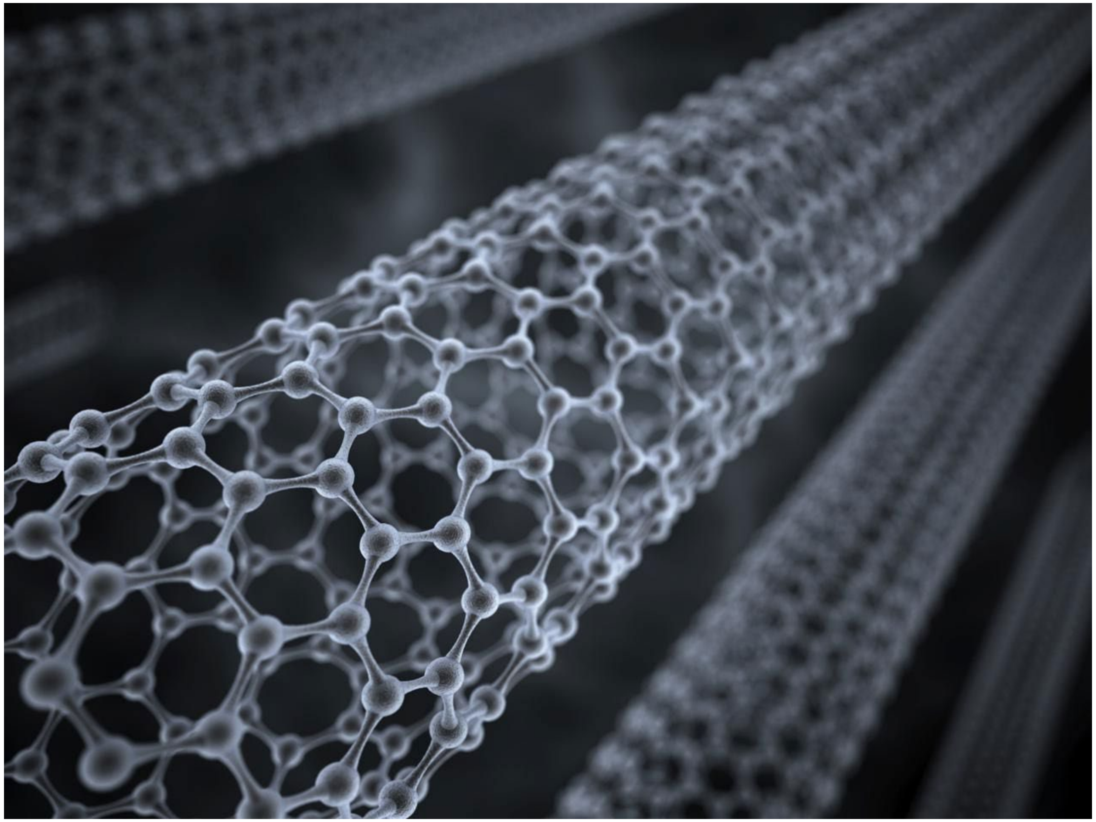
□ A complete report to tell your story!

□ Likely to include:

- Title (name, affiliation) & Abstract
- Introduction: Stats-of-Art, Other Works
- Concept, Principle -what is your > 5% differences
- Schematic Figure, Design & Fabrication Process
- Analysis (some calculations?) & Discussions
- Numerical Simulations – required for ME218N
- Conclusion

CNT-Infused Glass Panes

Matthew Amaro



Current Landscape of Smart Windows

- Asahi Glass, based in Japan has developed windows with electrochromic materials which change transparency by using electricity. This allows their glass to either block light or let it shine through with the flip of a switch.

- Suntuitive Glass, based in Michigan makes windows that incorporate thermochromic materials that automatically darken as the outside temperature rises.

Fig 1) A smart window going from being transparent to opaque [1].

Nanotube Innovation in Smart Windows

- Carbon Nanotubes embedded onto the graphene lattice of LIG windows can offer at least a 5% improvement in energy efficiency.

- Carbon Nanotubes are able to scatter and reflect infrared rays.
    - This unique trait of carbon nanotubes enhances thermal regulation, leading to less unwanted heat gain/loss through windows.

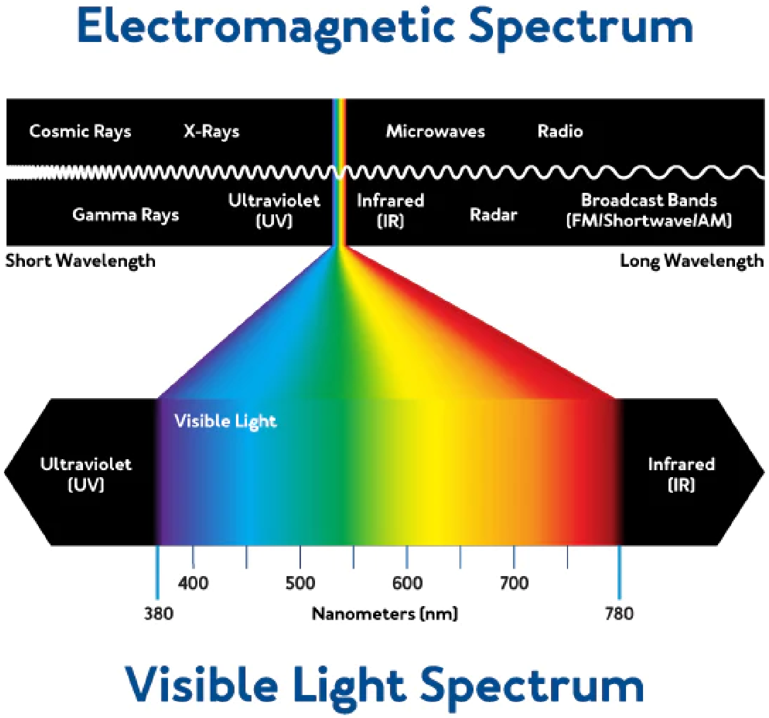
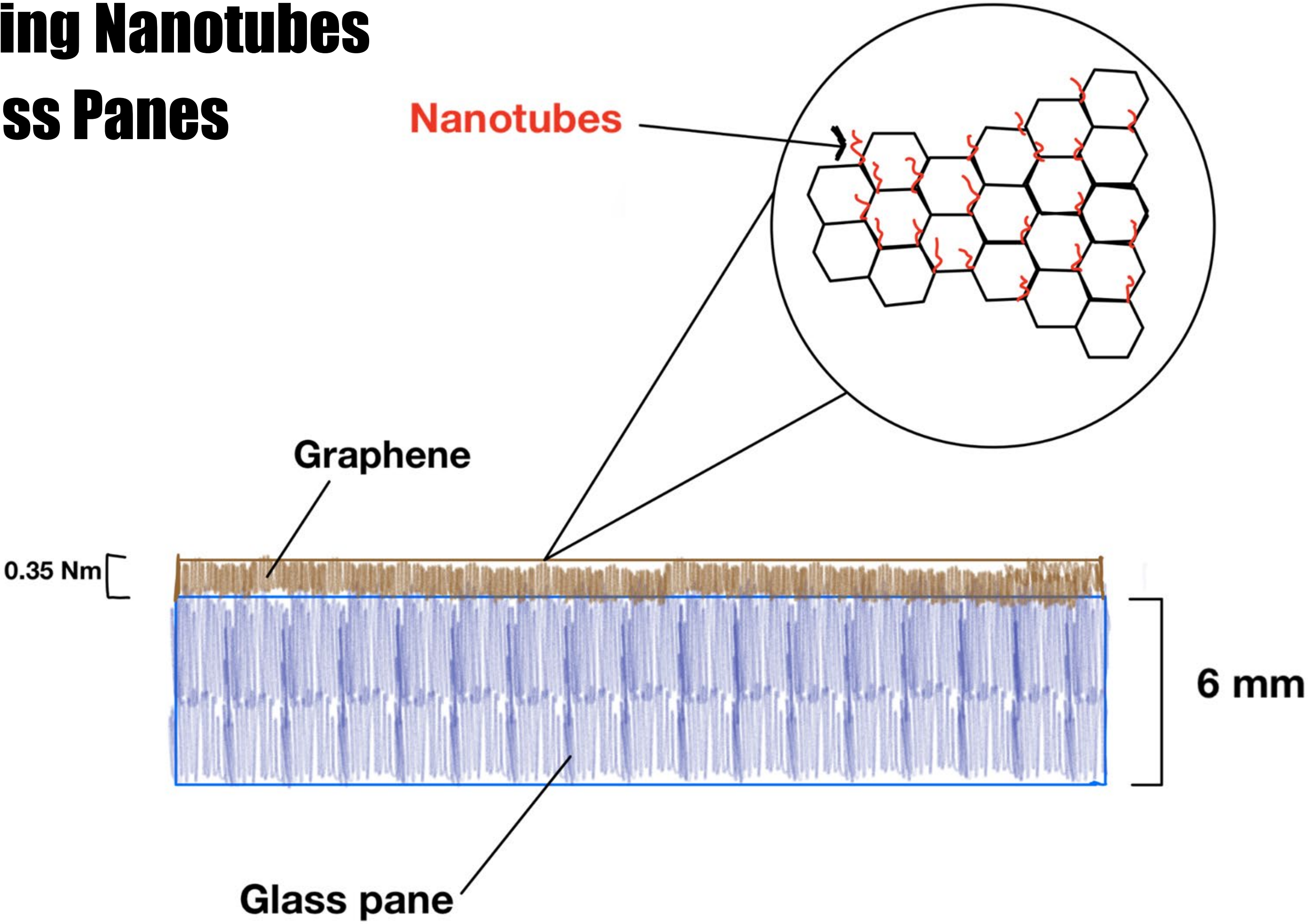


Fig 2) Light spectrum with corresponding wavelengths in nm [2].

Integrating Nanotubes onto Glass Panes



Relationship between Nanotubes and Conductivity

- At around a CNT weight percentage of 7% is where you see the most conductivity before it starts to flatten out.

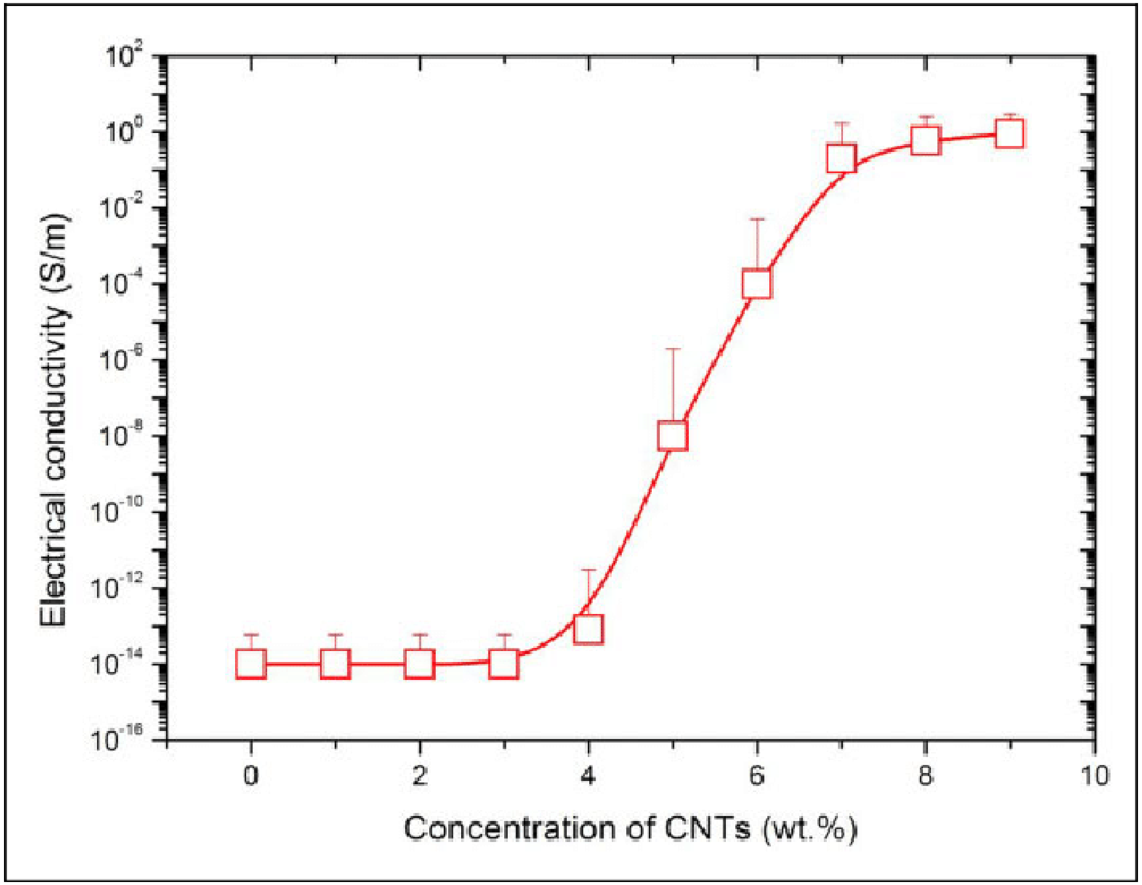


Figure 3) Relationship between CNT concentration and conductivity from a paper by Sung-Hwan Jang and Yong-Lae Park [3].

Carbon Nanotubes absorption of different wavelengths

- Carbon Nanotubes have their peak absorption at a wavelength of 253 nm.

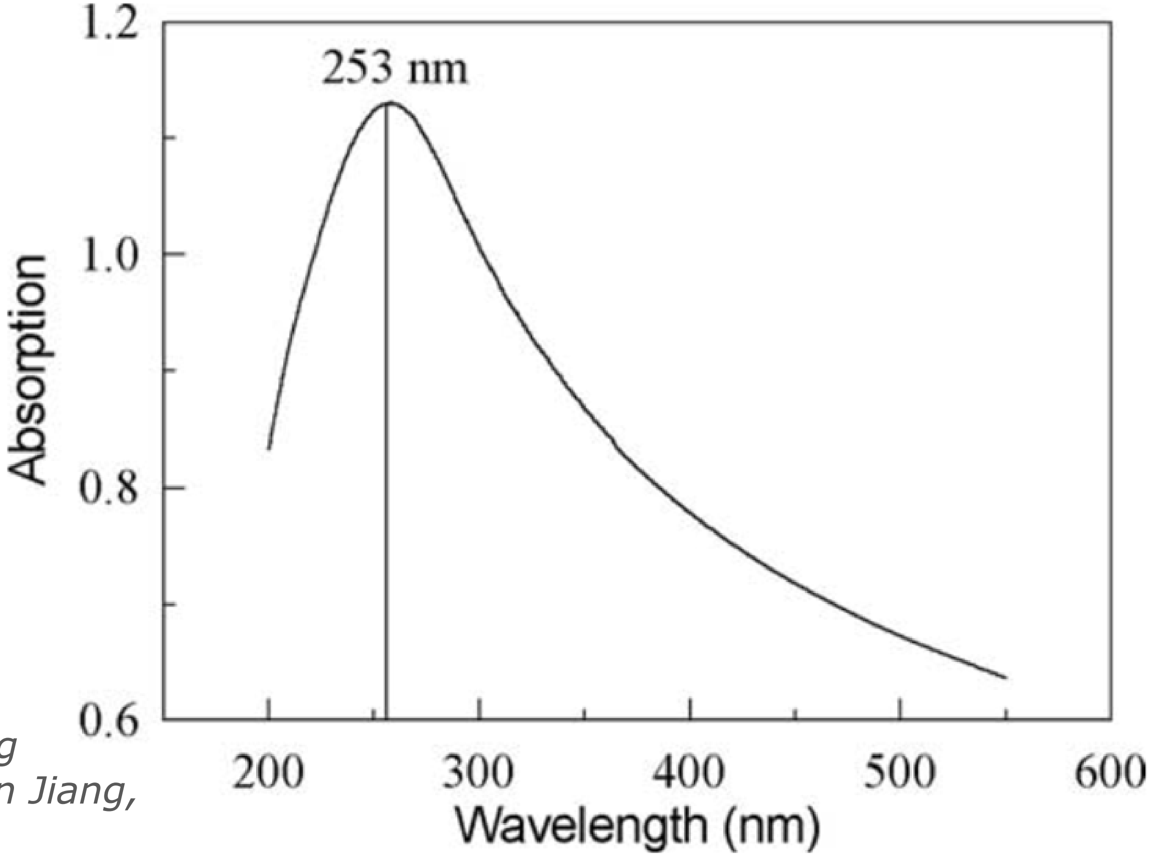


Figure 4) CNT Absorption of varying wavelengths from a paper by Linqin Jiang, Lian Gao, and Jing Sun [4].

Conclusions

- Carbon Nanotubes conductivity
    - Important to optimize the concentration of Carbon Nanotubes to maximize performance and manufacturing repeatability.

- Selective properties
    - Carbon Nanotubes absorb a 253 nm wavelength the most, subsequent wave lengths see a reduced absorption rate.

- Endless applications
    - This technology's potential extends beyond smart windows, with implications for energy savings and material innovation in many fields.

References

[1] Understanding the Light Spectrum and its Benefits– Carex

[2] Smart Glass Window: 5 Things You Should Know

[3] Jang, S.-H., & Park, Y.-L. (2018). Carbon nanotube-reinforced smart composites for sensing freezing temperature and deicing by self-heating. Nanomaterials and Nanotechnology, 8, 1-8.

[4] Jiang, L., Gao, L., & Sun, J. (2003). Production of aqueous colloidal dispersions of carbon nanotubes. Journal of Colloid and Interface Science, 260(1), 89-94

Outline

- Graphene synthesis by local CVD
    - Overview, synthesis methods, local CVD …
- Graphene synthesis by droplet CVD

→Flexible graphene FET gas sensor?

→New sensing insights due to graphene?

- Flexible gas sensors based on graphene FETs
    - Flexible substrate, graphene FETs, sensing characterizations …
- Graphene-on-Diamond Thin Film UV Detector
    - Concept, fabrication, sensor testing results …

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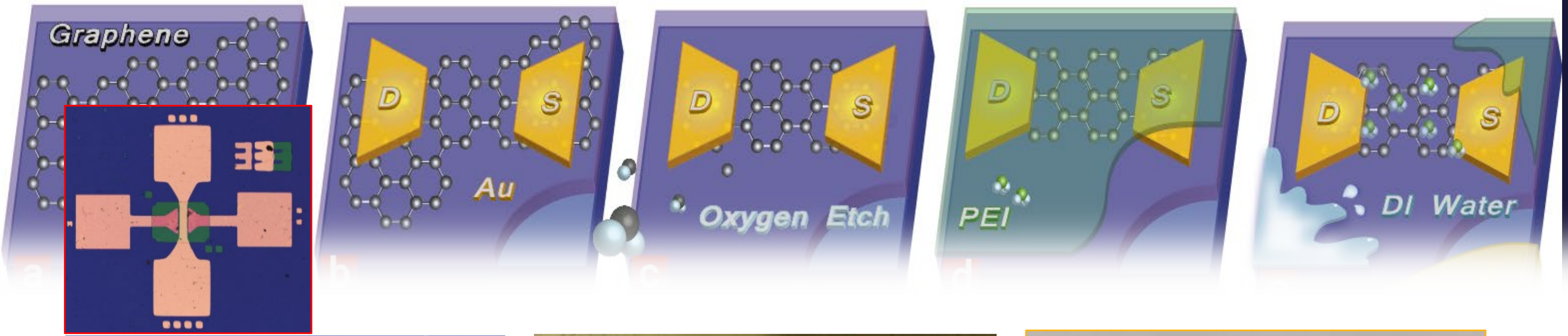
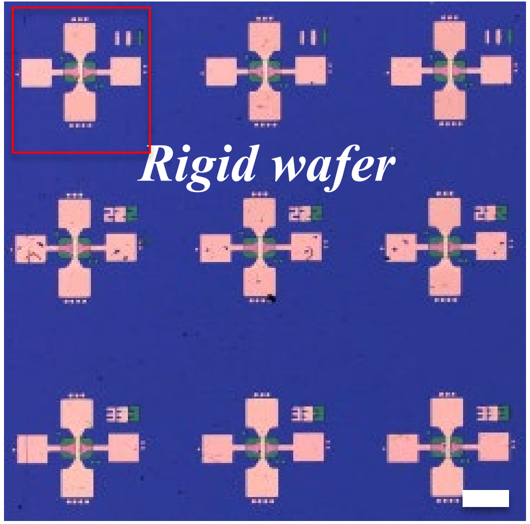
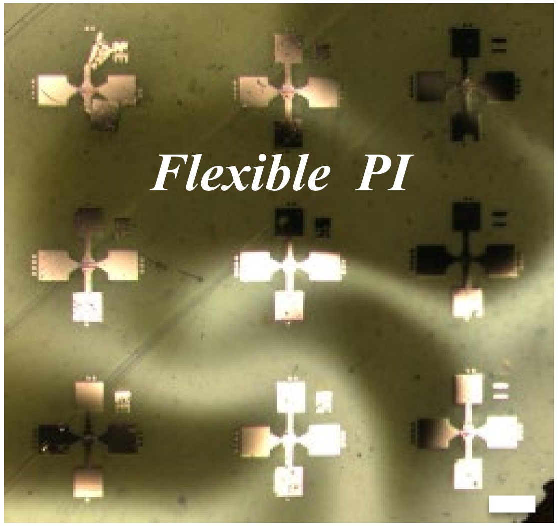
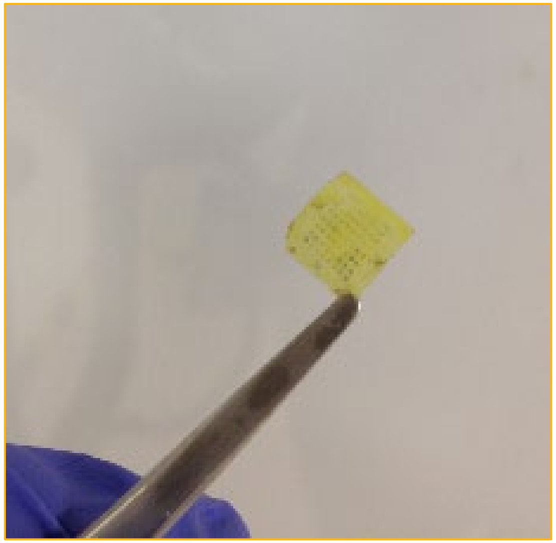
Fabrication Process

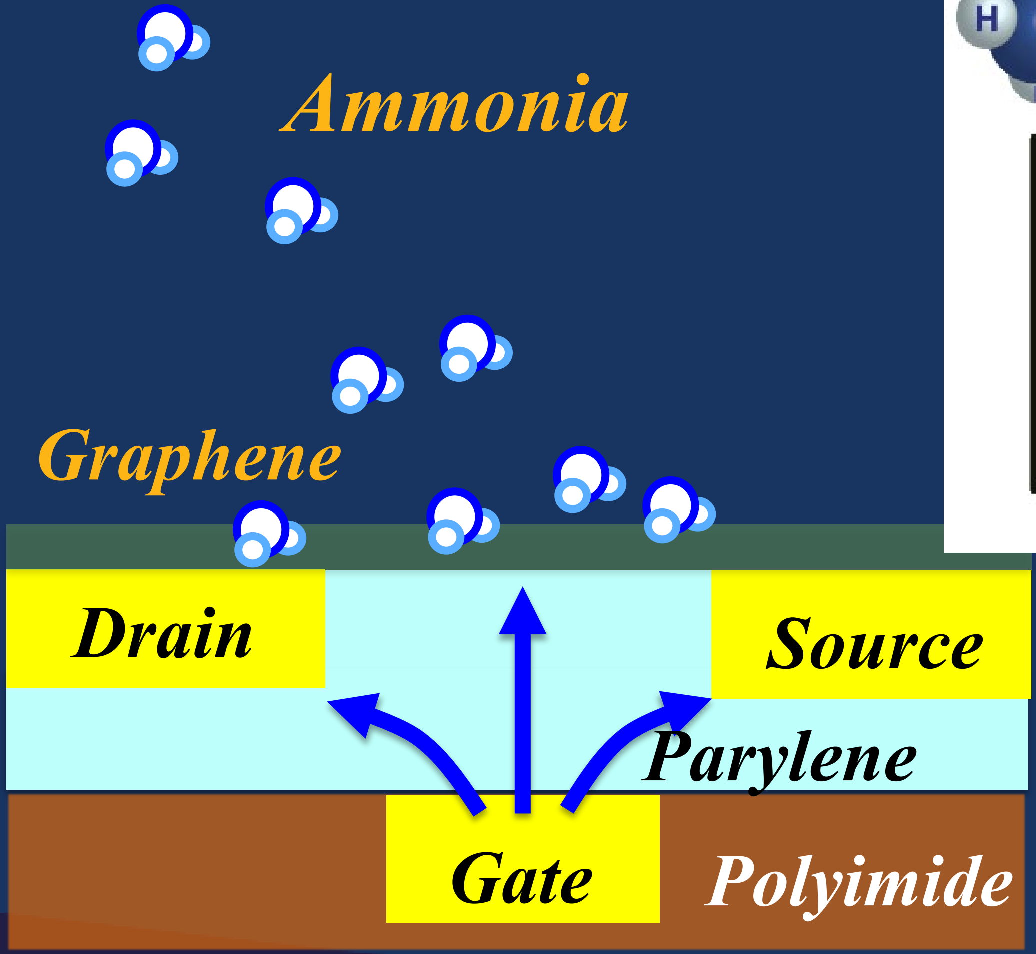


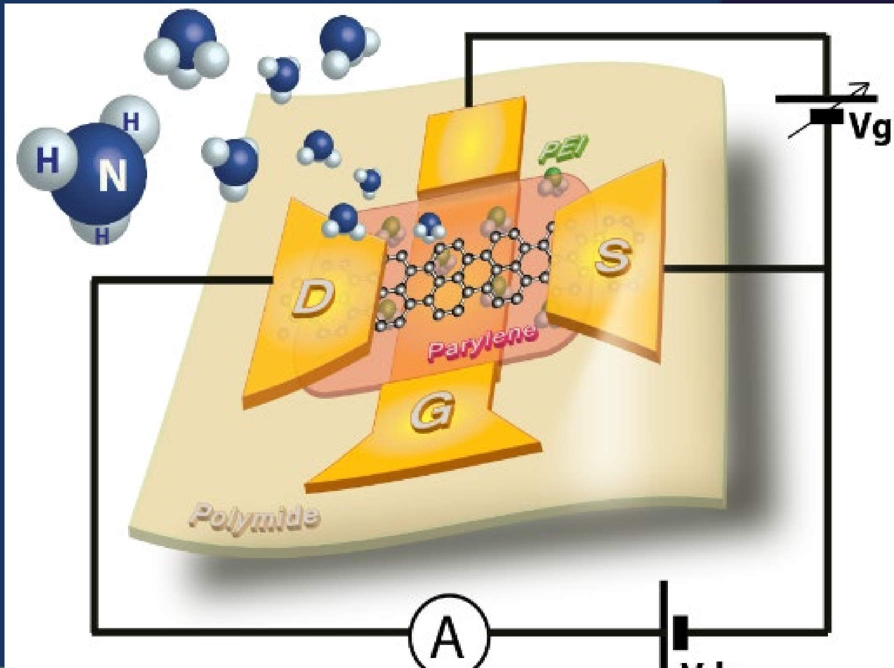






Gas Sensing


Ammonia
Graphene
Drain
Source
Parylene
Gate
Polyimide


H
N
H
H
PEI
D
S
G
Parylene
Polyimide
Vg
A
Vds

Sensing Mechanism

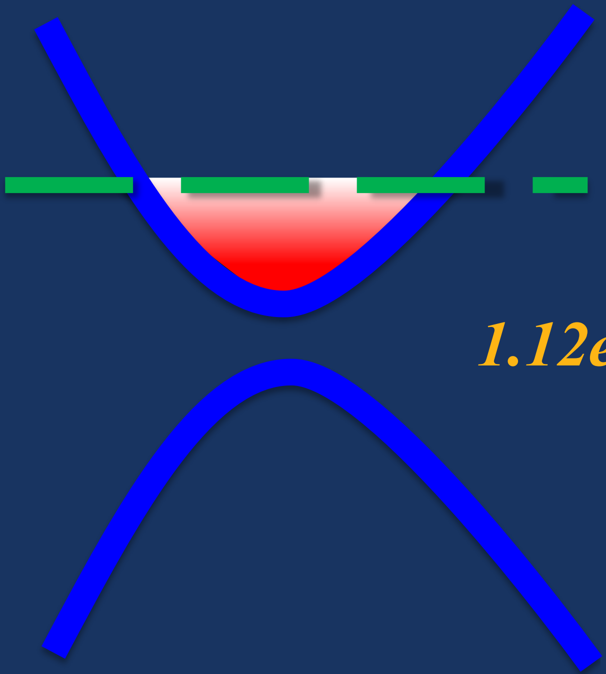
$$R_{DS} = (ne\mu)^{-1}\frac{L}{W}$$

Lone pair e-

R_{DS} Changes

0eV Band gap

Graphene

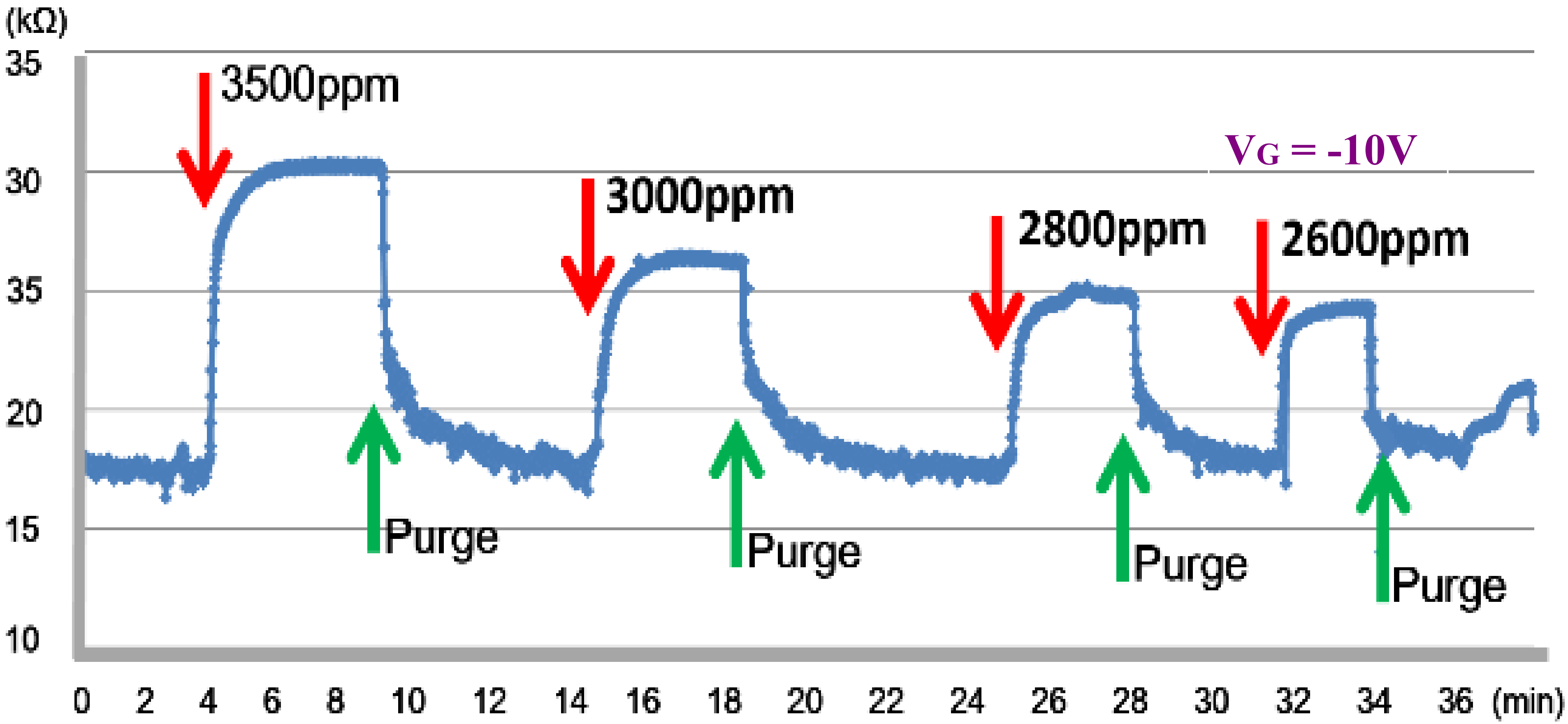


1.12eV Band gap

Silicon

Constant Gate Voltage

Experimental Results



Sensitivity = 0.00428/ppm (ΔR/R0)

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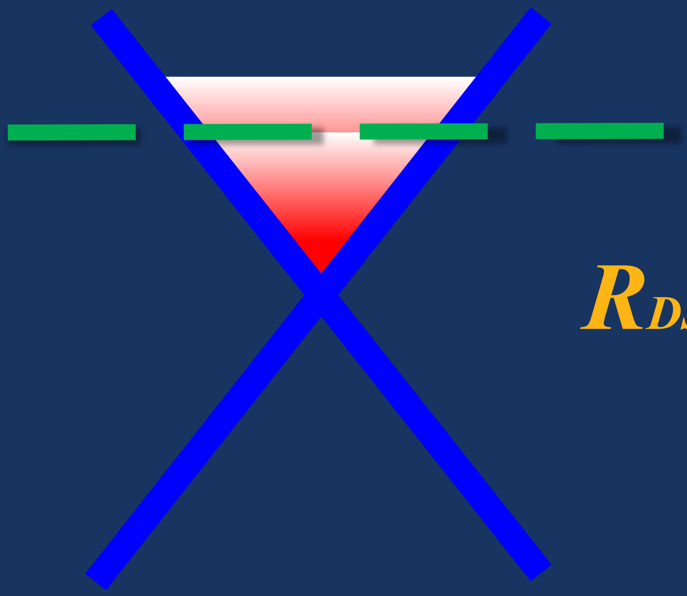
Responses Based on Gate Voltage

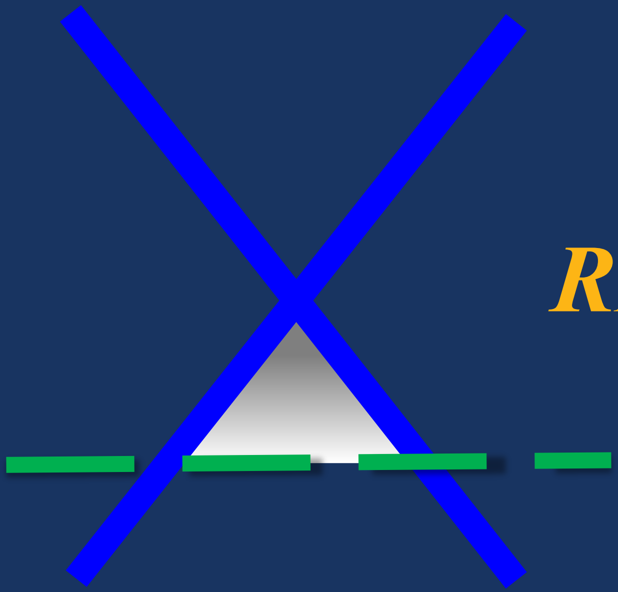
e-   e-



R_{DS} ↓

$V_G = 10V$

Electrons

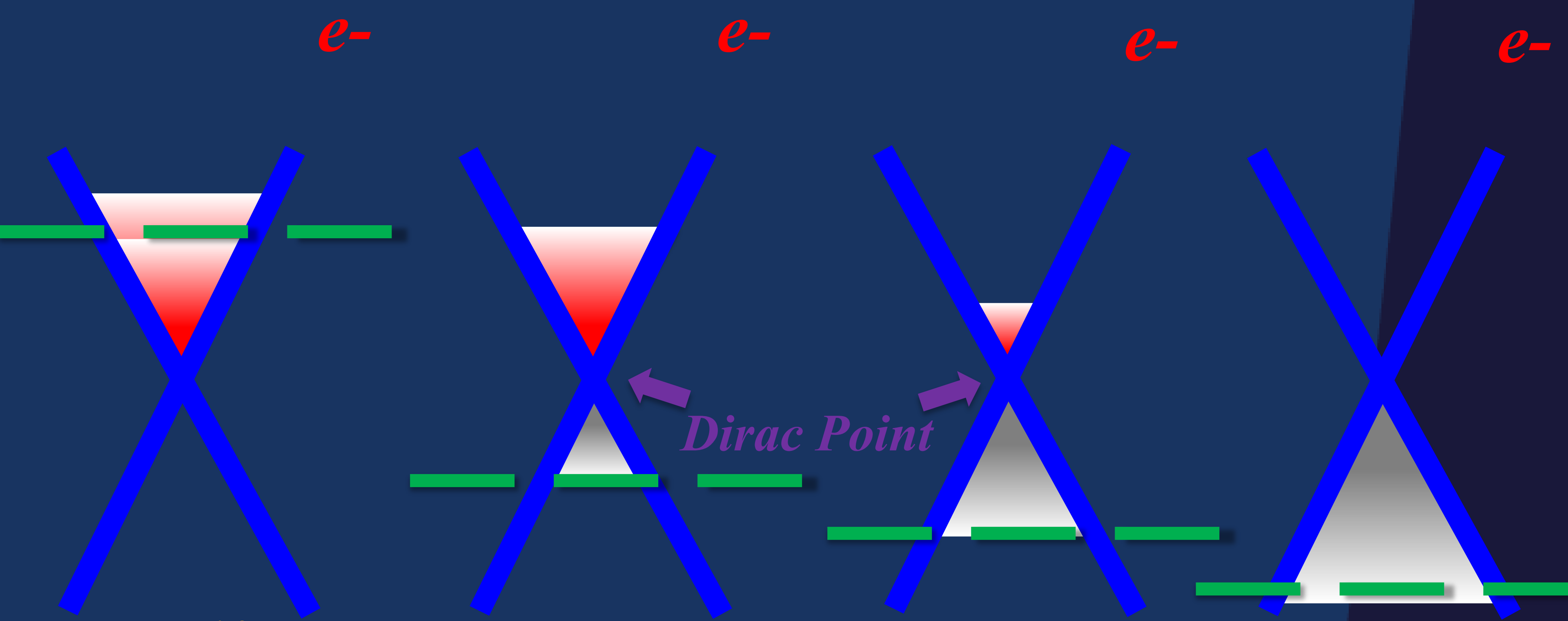


R_{DS} ↑

$V_G = -10V$

Holes

Four Possible Responses



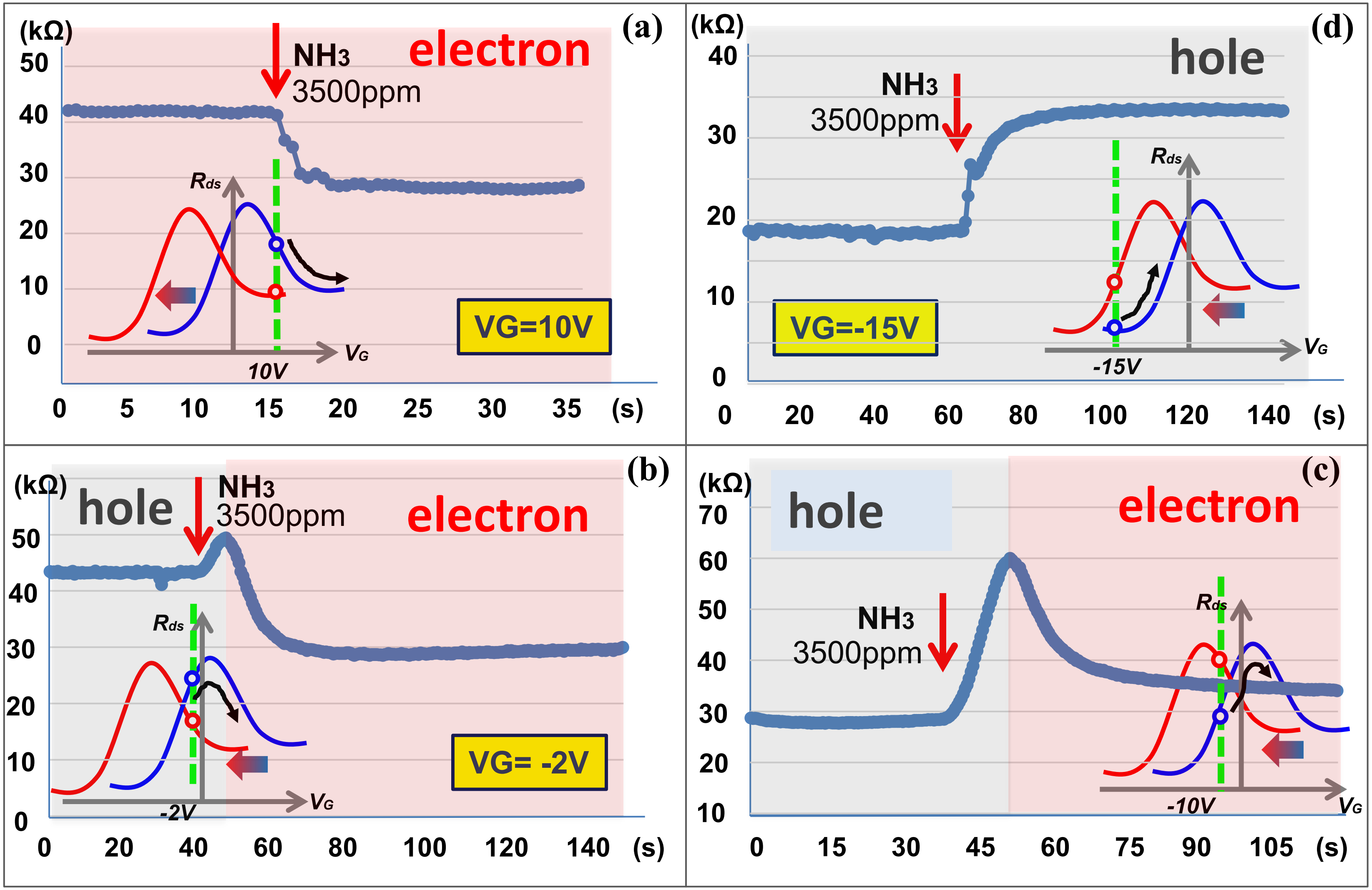
$V_G = 10V$
Electrons
↓
Electrons

$V_G = -2V$
Holes
↓
Electrons

$V_G = -10V$
Holes
↓
Electrons

$V_G = -15V$
Holes
↓
Holes

Experimental Results



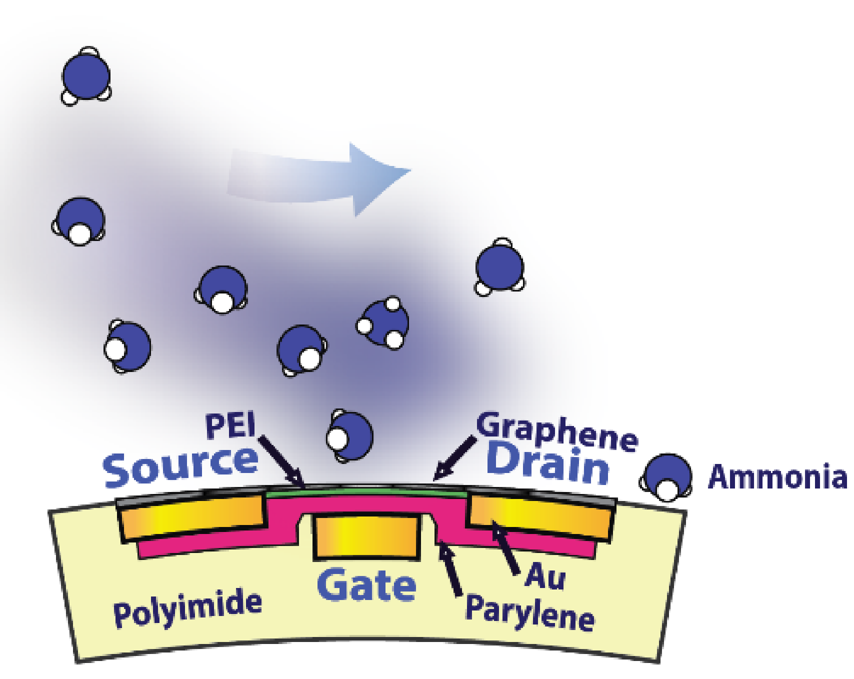
Short Summary

1. Demonstration of a **flexible graphene FET gas sensor**

2. Using polymer of **parylene and polyethylenimine (PEI) as the gate dielectrics and channel dopant**, respectively

3. Demonstration of **four types of responses** induced by ammonia exposure

	Rigid CMOS	*Flexible GFET*
Substrate	*Wafer*	*Polyimide*
Dielectrics	*Oxide*	*Parylene*
Dopant	*B/P*	*PEI*
Channel	*Silicon*	*Graphene*



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A Versatile Gas Sensor with Selectivity using Single Graphene Transistor

What’s your favorite smell?

Skin | Touch sensitive screen

Eye | Camera

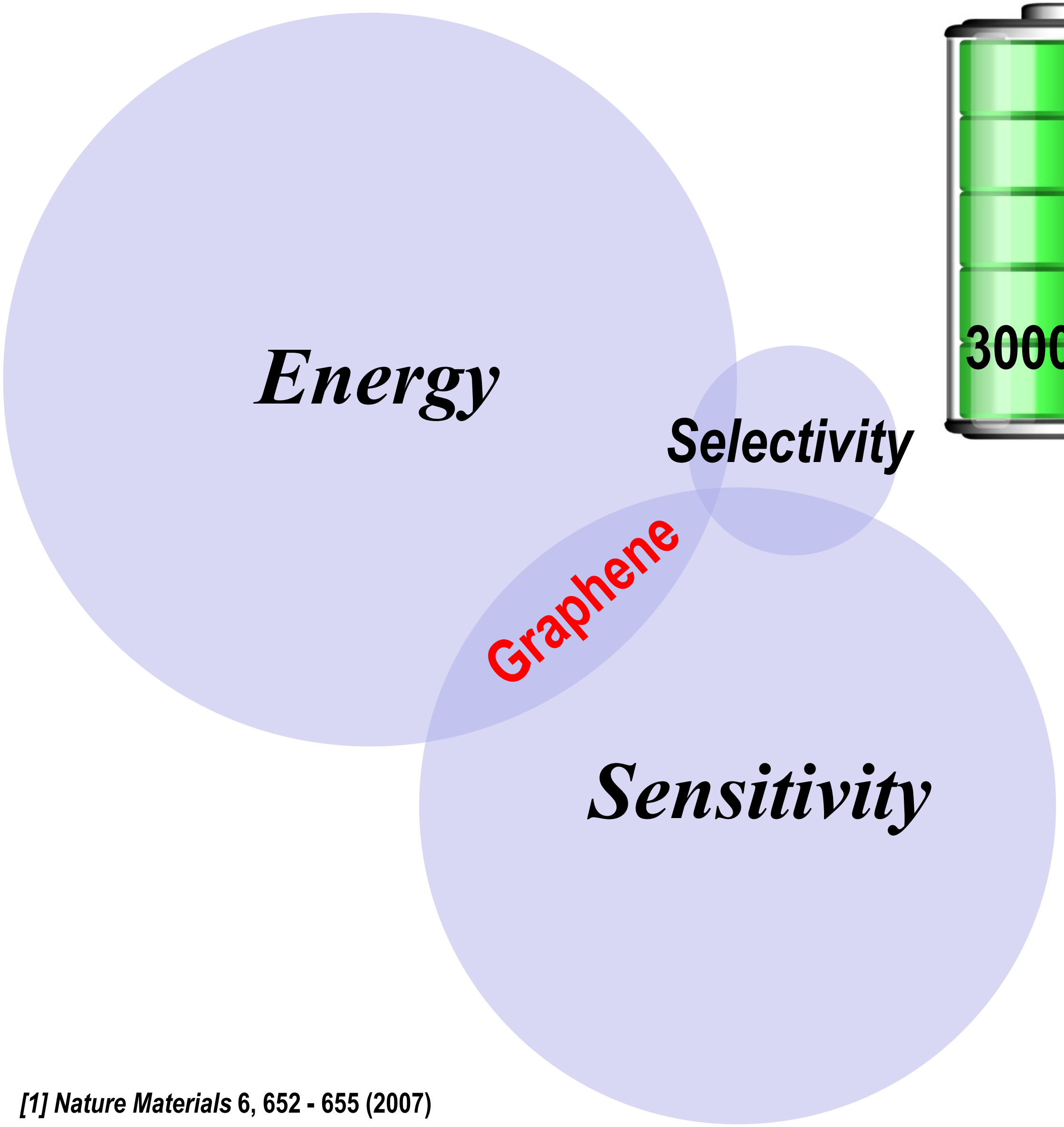
Ear | Microphone

Mouth | Loud Speaker

Nose | E-nose?

The "information" is ignored.

Portable Gas Sensor Desirable Features

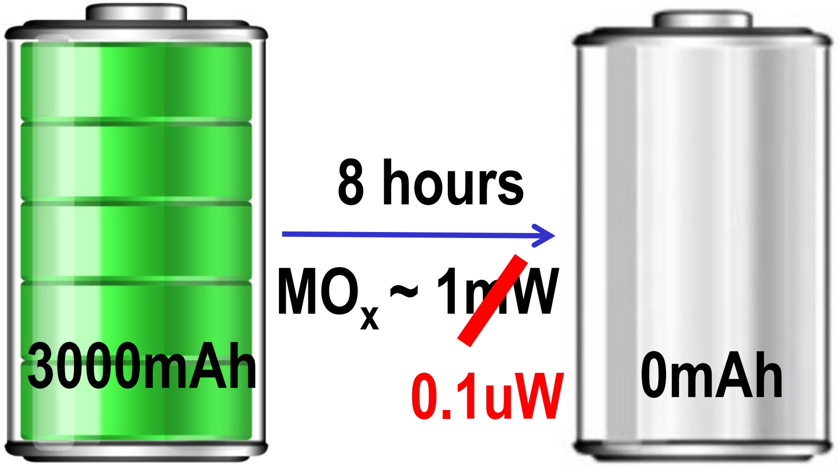


Energy

Selectivity

Graphene

Sensitivity



3000mAh

8 hours

MO$_x$ ~ 1~~m~~W

0.1uW

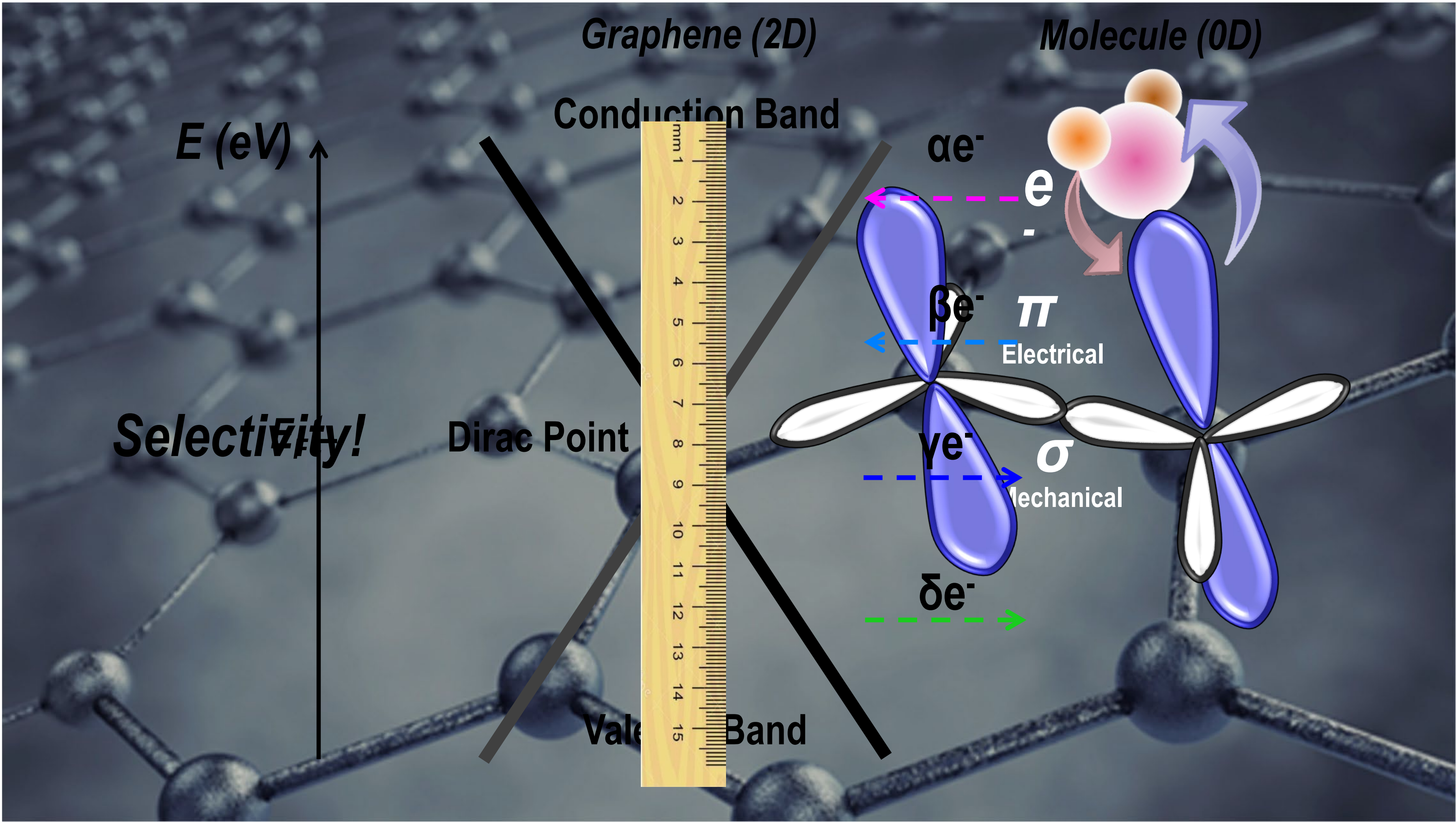
0mAh

Echem~ 1~~p~~pb

Single molecule[1]

[1] *Nature Materials* 6, 652 - 655 (2007)

Principles of Graphene and Gas Sensing



Electron transferred per molecule

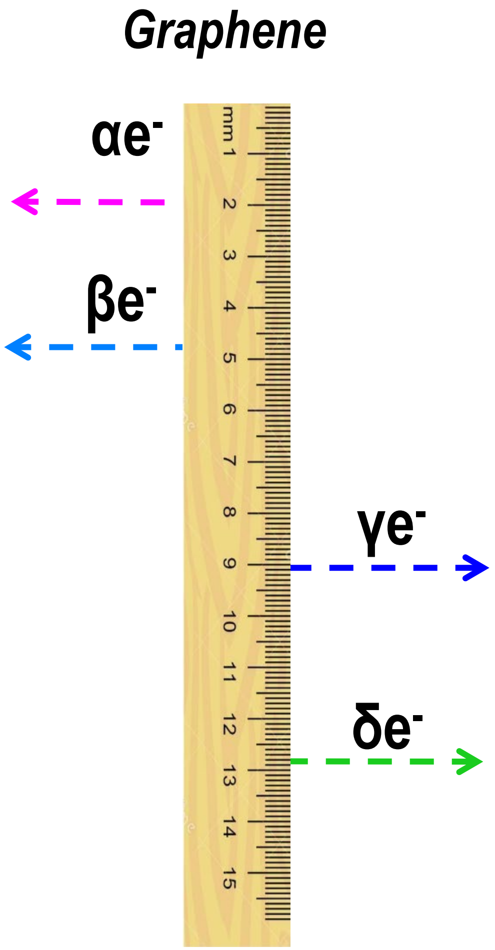
Linear Factor As Sensing Scale

Unknown for unknown gas

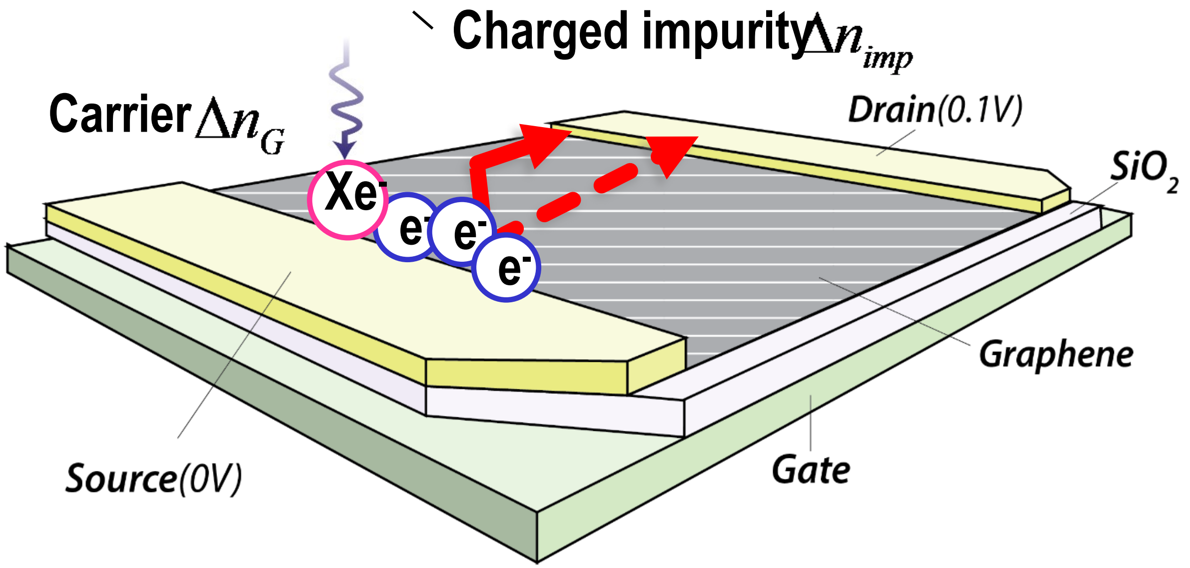
Total carrier change

$$\text{Linear Factor} = \frac{\Delta n_G}{\Delta n_{imp}} = \frac{X}{X'}$$

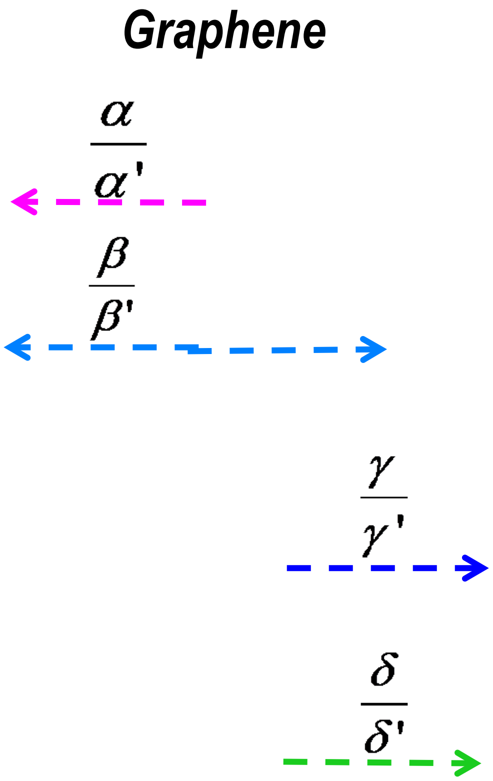
Total impurity change



Electron transferred per molecule



Linear Factor As Sensing Scale



Graphene

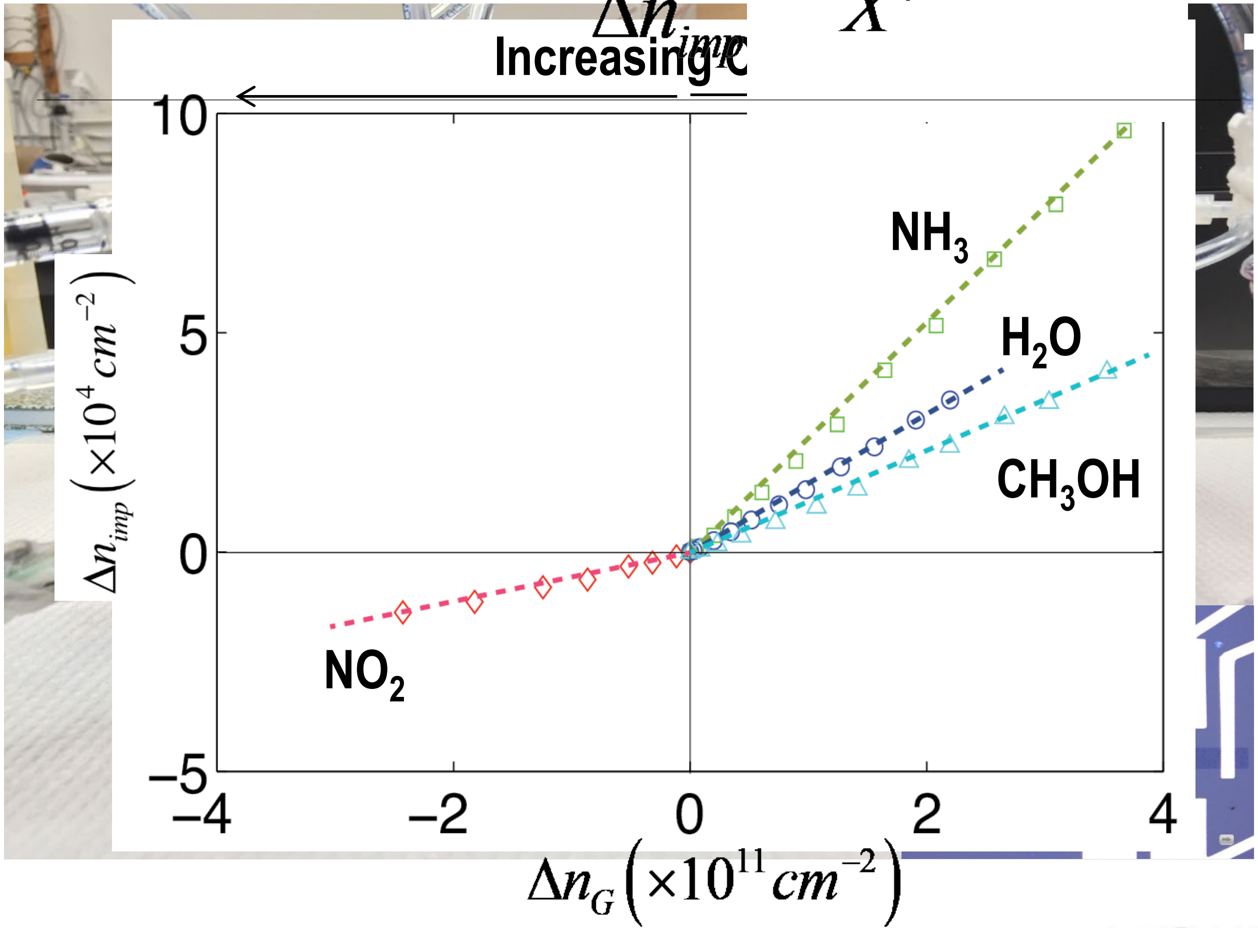
$\frac{\alpha}{\alpha'}$

$\frac{\beta}{\beta'}$

$\frac{\gamma}{\gamma'}$

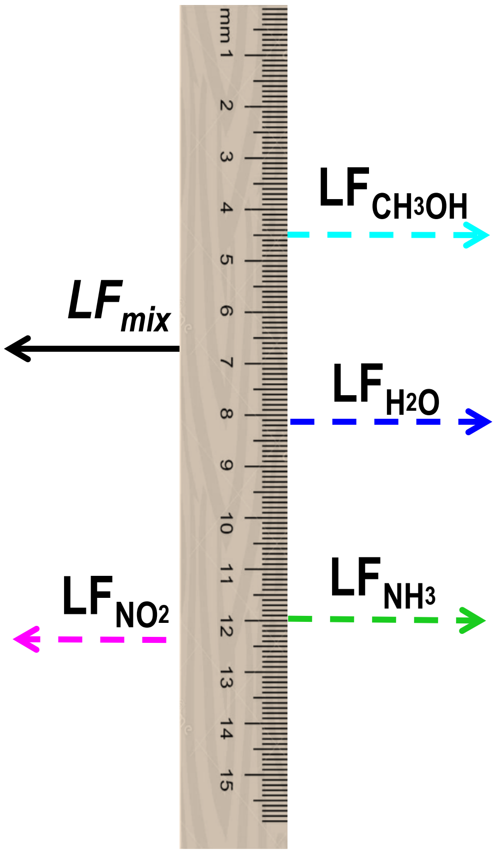
$\frac{\delta}{\delta'}$

Linear Factor = $\frac{\Delta n_G}{\Delta n_{imp}} = \frac{X}{X'}$



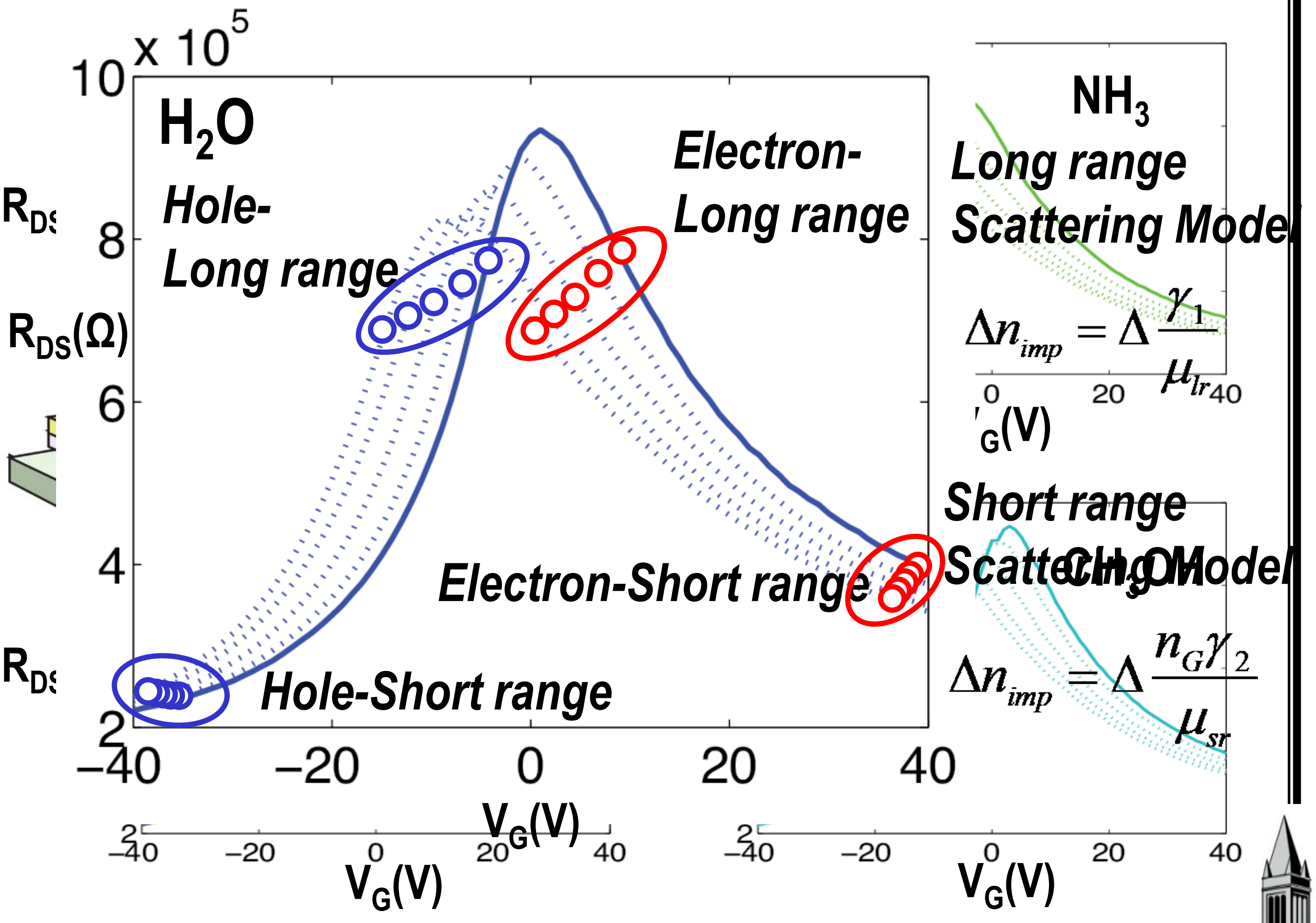
Future Work: Decoupling Interference

Graphene



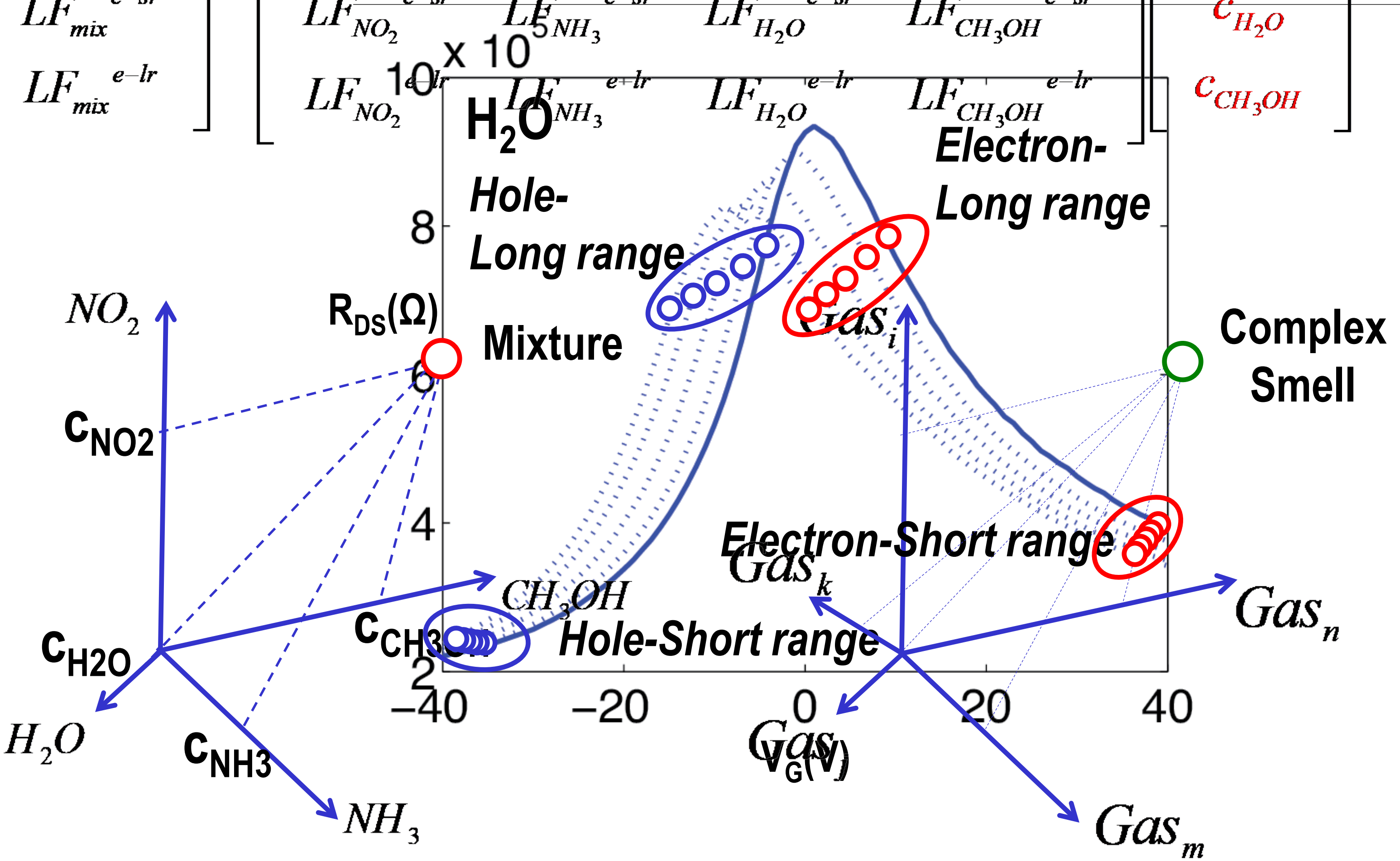
Linear Factor

$$LF_{mix} = c_{NO_2} LF_{NO_2} + c_{NH_3} LF_{NH_3} + c_{H_2O} LF_{H_2O} + c_{CH_3OH} LF_{CH_3OH}$$

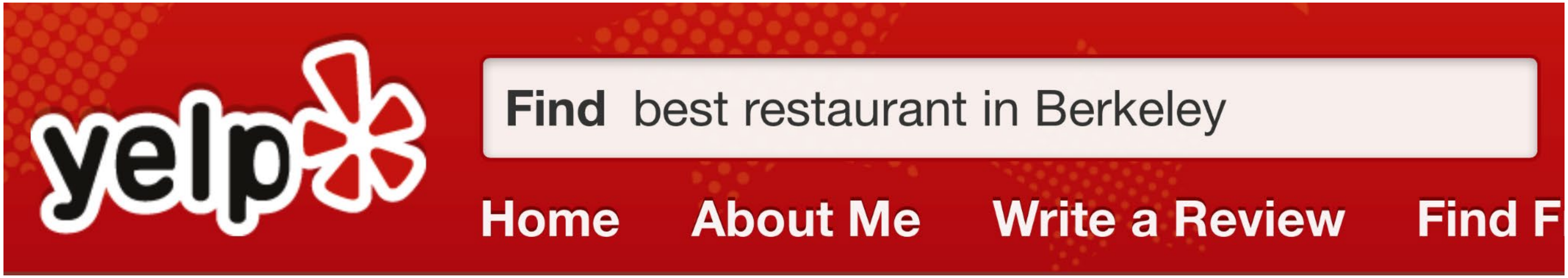


Future Work: Decoupling Interference

$$\begin{bmatrix} LF_{mix}^{h-sr} \\ LF_{mix}^{h-lr} \\ LF_{mix}^{e-sr} \\ LF_{mix}^{e-lr} \end{bmatrix} = \begin{bmatrix} LF_{NO_2}^{h-sr} & LF_{NH_3}^{h-sr} & LF_{H_2O}^{h-sr} & LF_{CH_3OH}^{h-sr} \\ LF_{NO_2}^{h-lr} & LF_{NH_3}^{h-lr} & LF_{H_2O}^{h-lr} & LF_{CH_3OH}^{h-lr} \\ LF_{NO_2}^{e-sr} & LF_{NH_3}^{e-sr} & LF_{H_2O}^{e-sr} & LF_{CH_3OH}^{e-sr} \\ LF_{NO_2}^{e-lr} & LF_{NH_3}^{e-lr} & LF_{H_2O}^{e-lr} & LF_{CH_3OH}^{e-lr} \end{bmatrix} \begin{bmatrix} c_{NO_2} \\ c_{NH_3} \\ c_{H_2O} \\ c_{CH_3OH} \end{bmatrix}$$

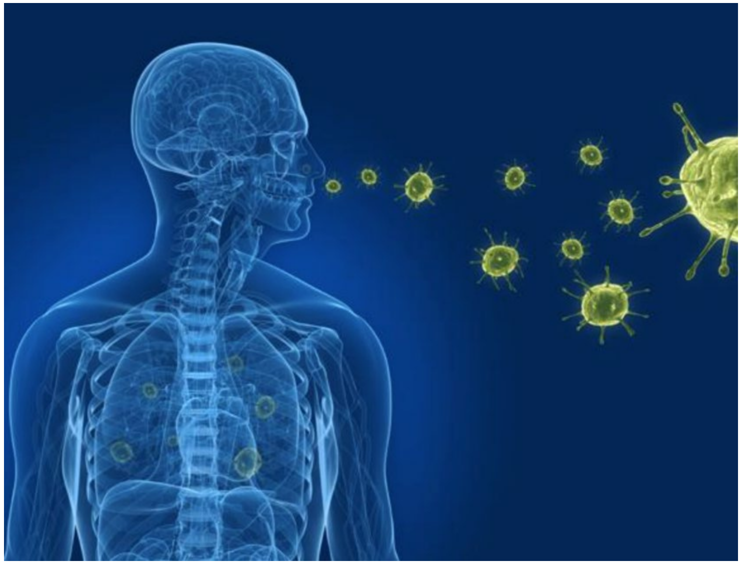


The Future Market of Gas Sensing



Find best restaurant in Berkeley

Smell the importance!



Diagnose lung cancer by the exhaled breath (70% success rate in late stage)[1]

Gas_j Monitor air quality wherever you go…

Gas_m

[1] http://www.medicalnewstoday.com/articles/63857.php

Outline

- **Graphene synthesis by local CVD**
  - **Overview, synthesis methods, local CVD …**
- **Graphene synthesis by droplet CVD**
  - **Continuous graphene sheet? Application example ...**

→Carbon sp^2+sp^3 technology?

→Manufacturing technology

→New sensing insights?

- **Graphene-on-Diamond Thin Film UV Detector**
  - **Concept, fabrication, sensor testing results …**

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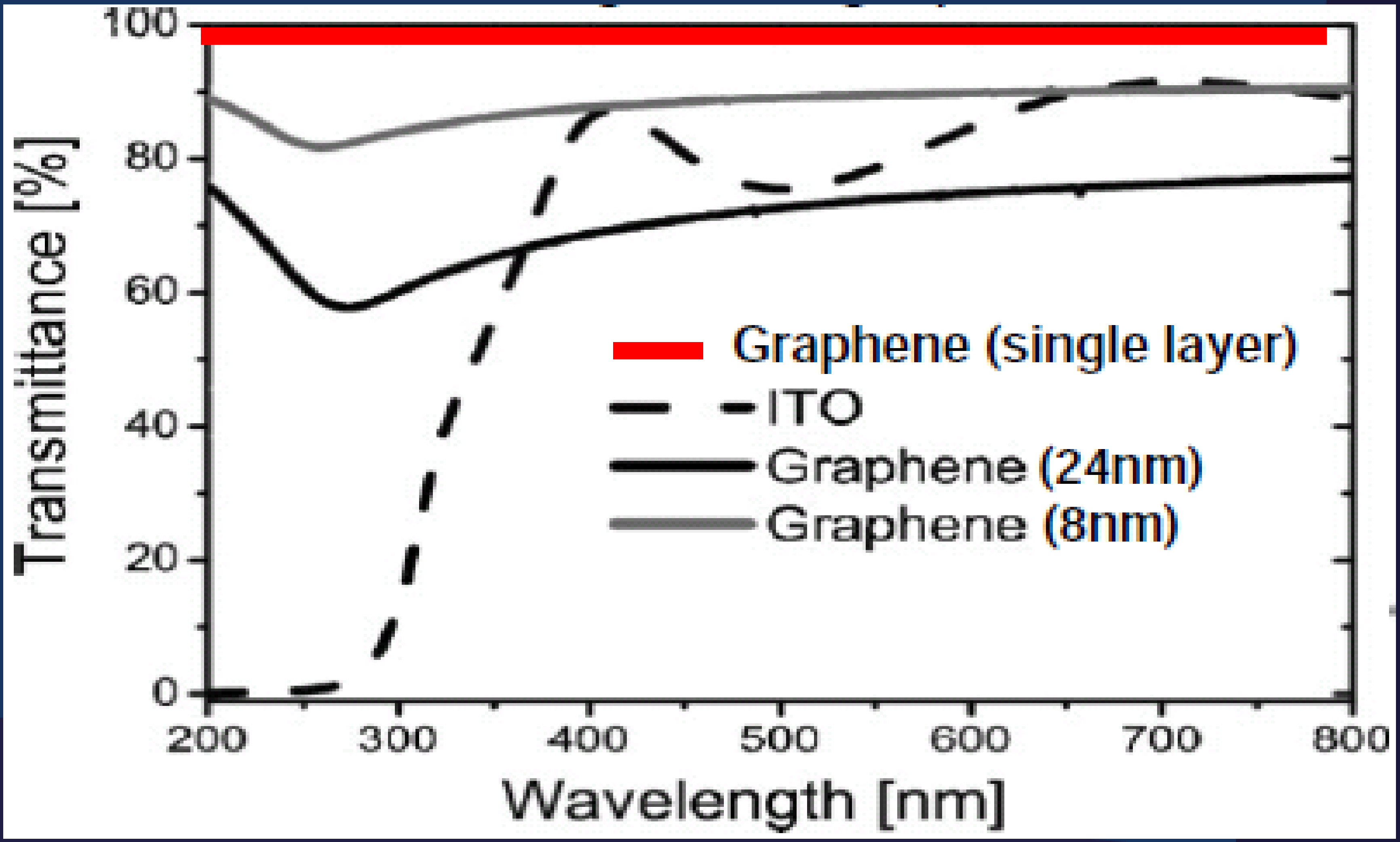
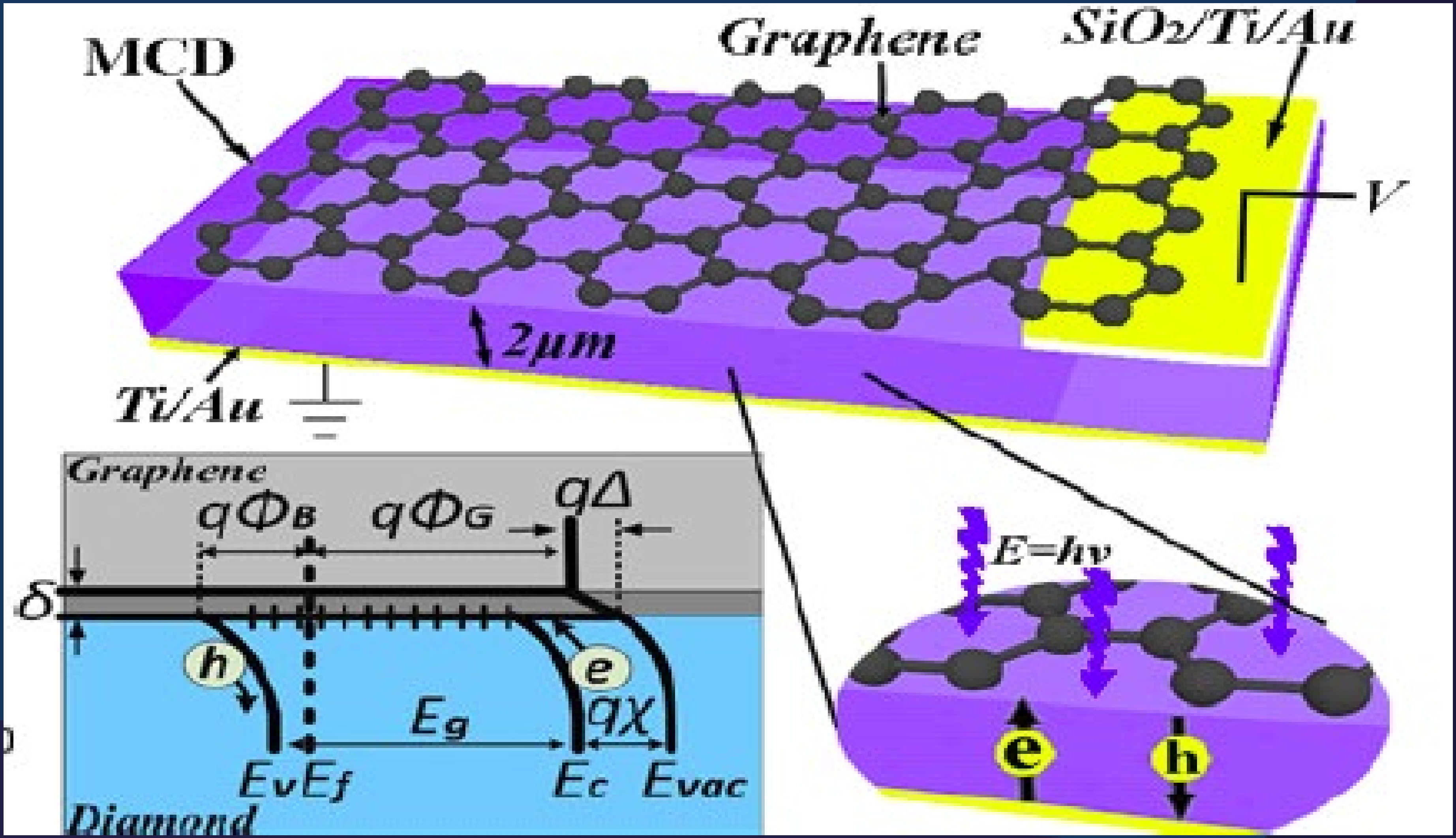
Transparent Electrode

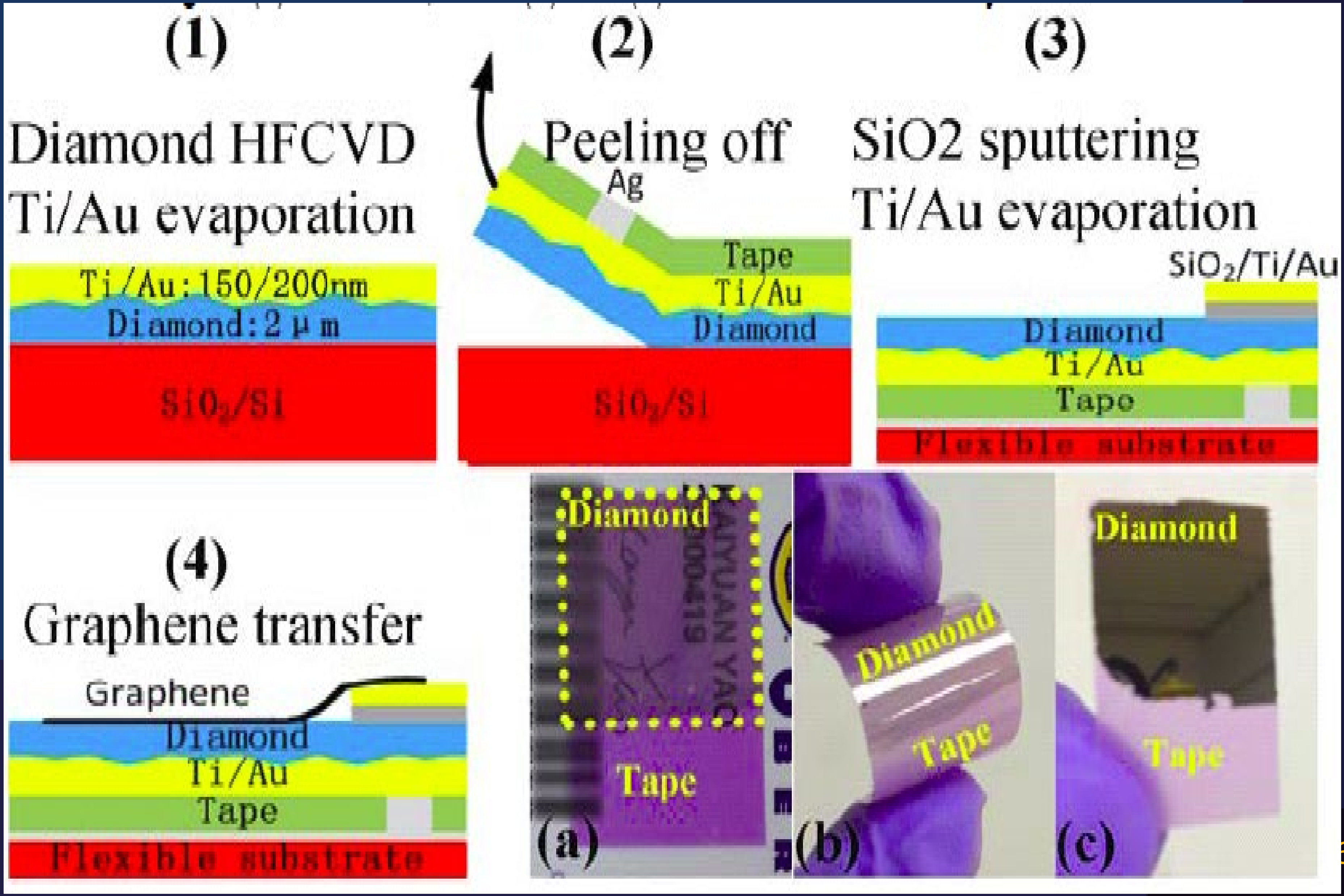


$Sp^2 + Sp^3$ Carbon Technology

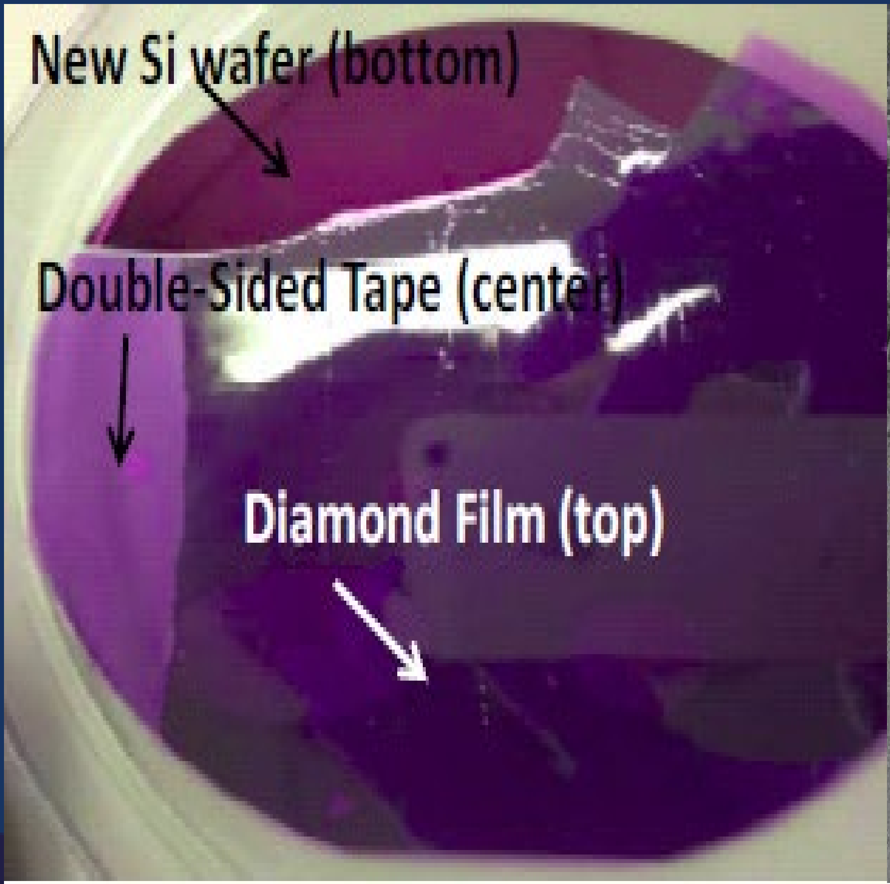


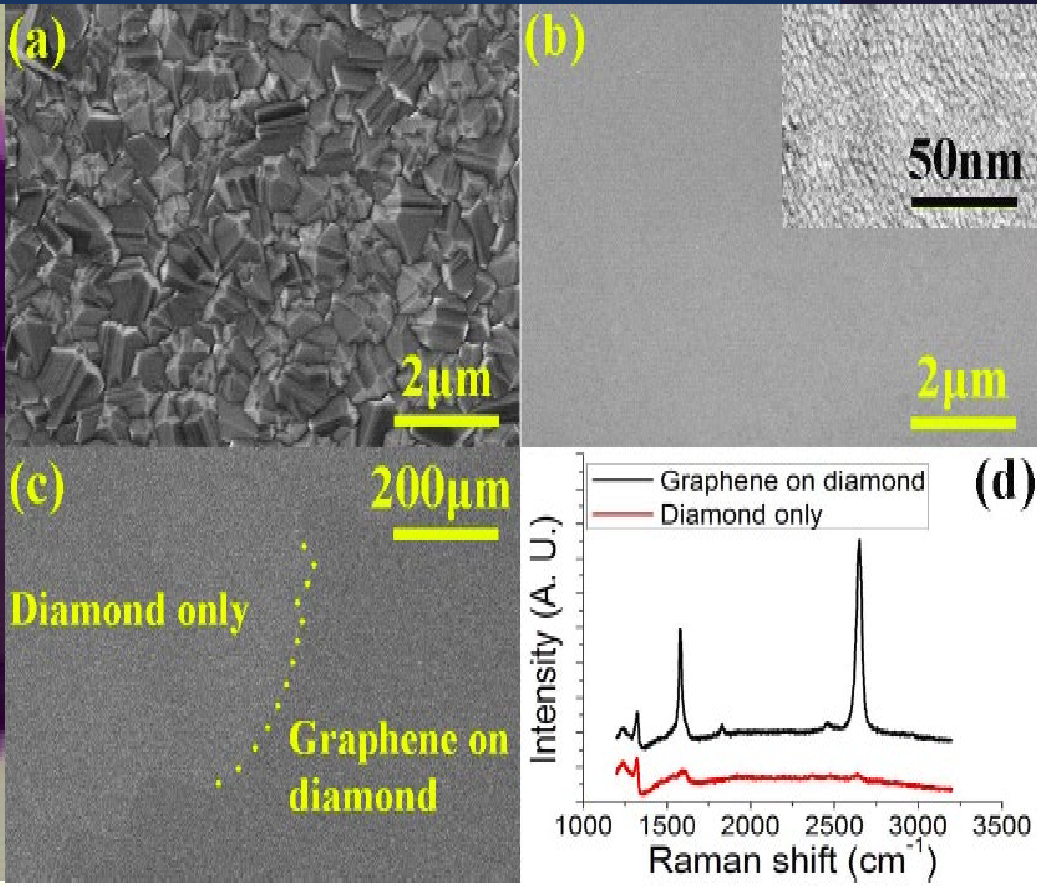
Schottky-like heterojunction at the interface

Fabrication Process



Process Details

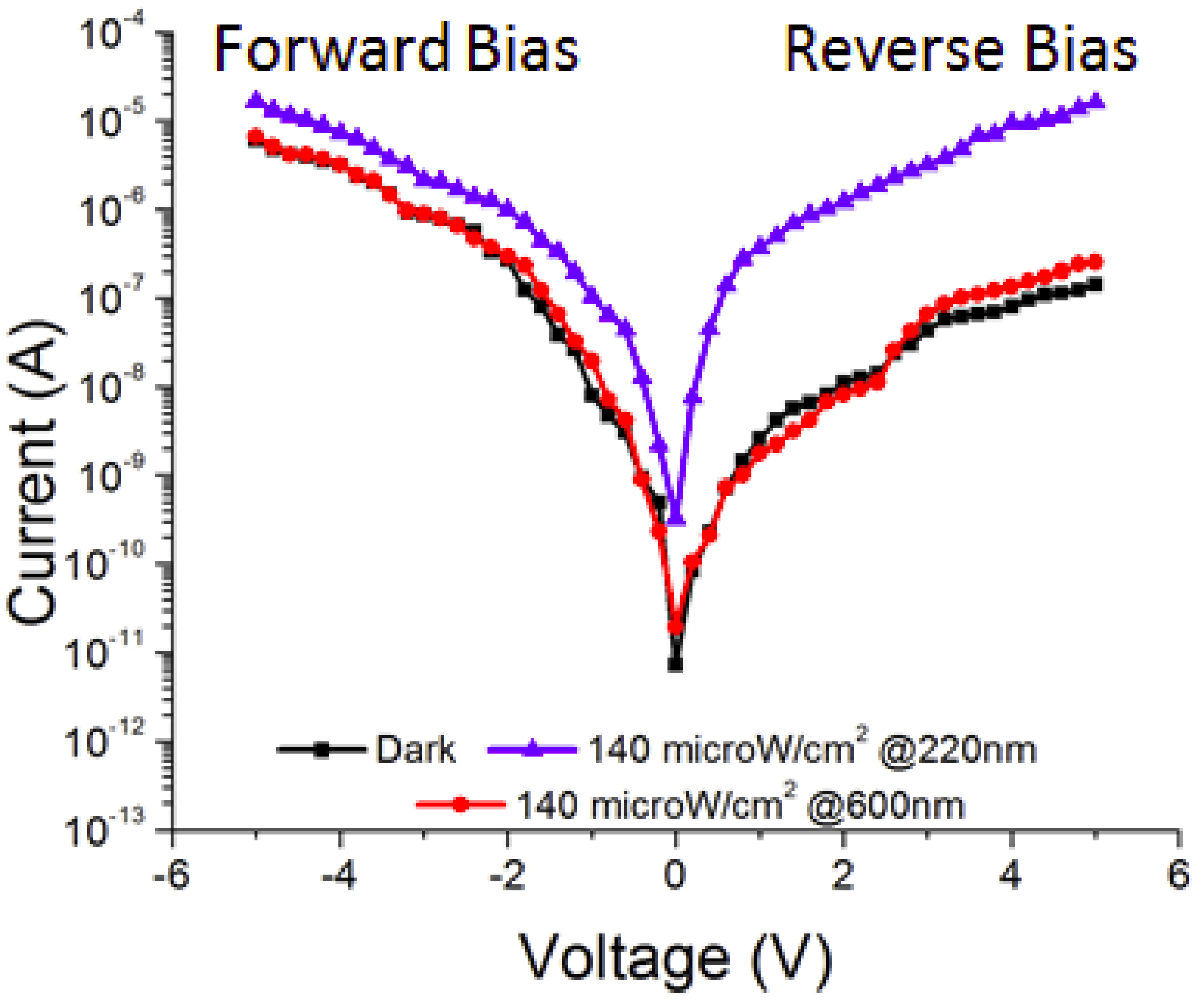




Diamond Film Peel-and-Break

Graphene-on-Diamond

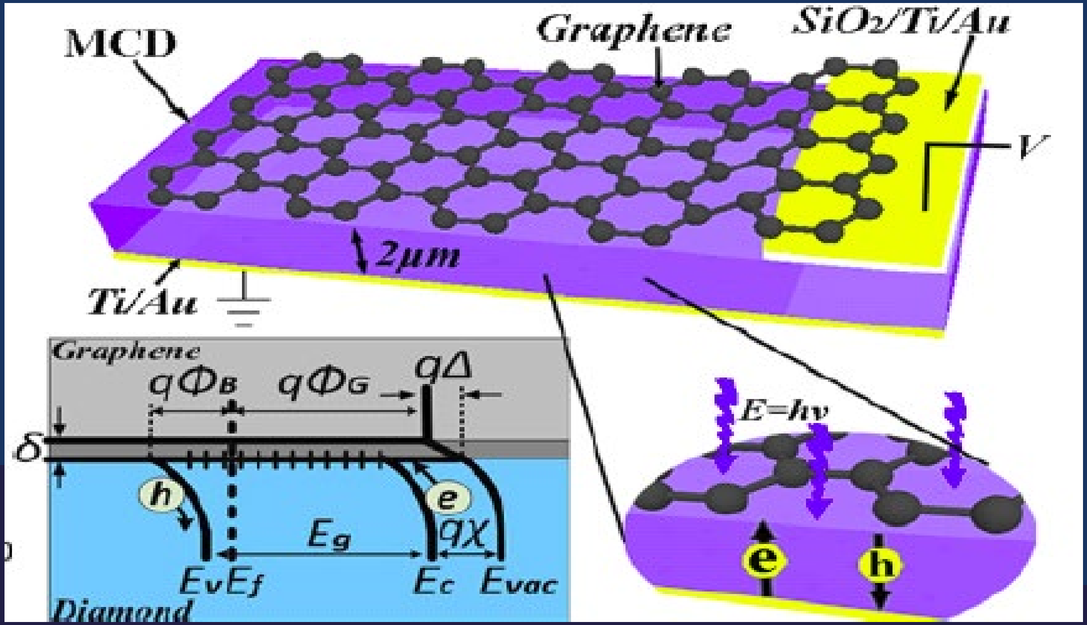
Experimental Characterizations

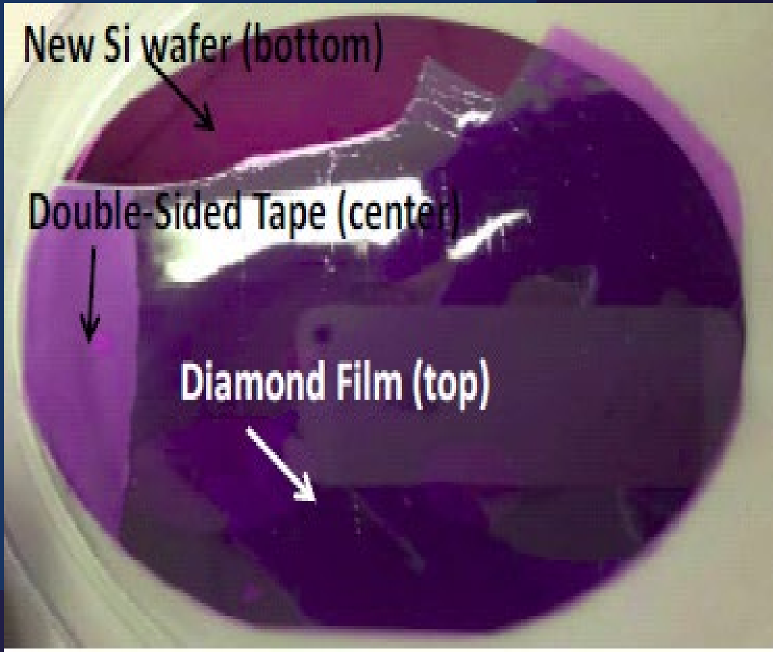


Large photocurrent and signal-to-noise ratio are achieved in reverse bias region → photo-responsivity increases rapidly due to (1) enlargement of absorption depth, and (2) enhanced carrier states in graphene under reversed bias

Short Summary

1. Demonstration of a **graphene-on-diamond UV detector**
2. Demonstration of **peel-and-break** diamond film process
3. Large **photo-current** and **signal-to-noise ratio** generated by graphene-diamond heterojunction





Conclusions

- **Graphene synthesis by local CVD**
  - Overview, synthesis methods, local CVD …
- **Graphene synthesis by droplet CVD**
  - Continuous graphene sheet? Application example ...
- **Near-Field Electrospinning for Graphene based p- and n-type FETs**
  - Electrospinning, graphene FETs, characterizations …
- **Flexible gas sensors based on graphene FETs**
  - Flexible substrate, graphene FETs, sensing characterizations …
- **Graphene-on-Diamond Thin Film UV Detector**
  - Concept, fabrication, sensor testing results …