Rapid Bacterial Detection Using Graphene-Based Biosensors

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Objectives

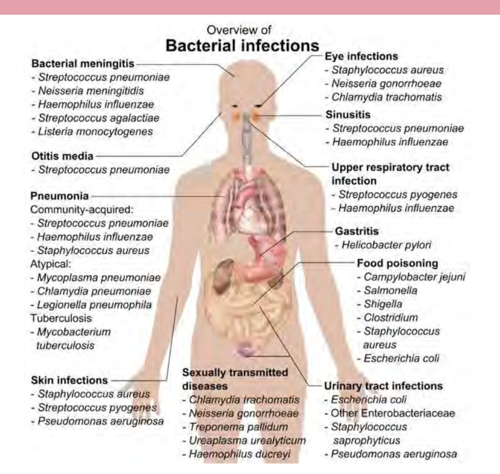
This research aims at developing graphene field-effect transistors (G-FETs) biosensors for bacterial detection. The followings have been investigated:

1. To design and fabricate aptamer-modified G-FETs (APG-FETs) biosensors for *Escherichia coli* (*E. coli*) detection;
2. To functionalize graphene with pyrene-tagged DNA aptamer;
3. To analyze and optimize the carrier mobility, which correlates the gate voltage to the electrical signal of the APG-FETs;
4. To study the selectivity and stability of the device.

Background and Motivation

Existence of Foodborne Pathogens[1] (*E. coli*)

- Threat to food safety and public health
- Cause various diseases to human body



Source: Wikipedia Bacteria # Pathogens

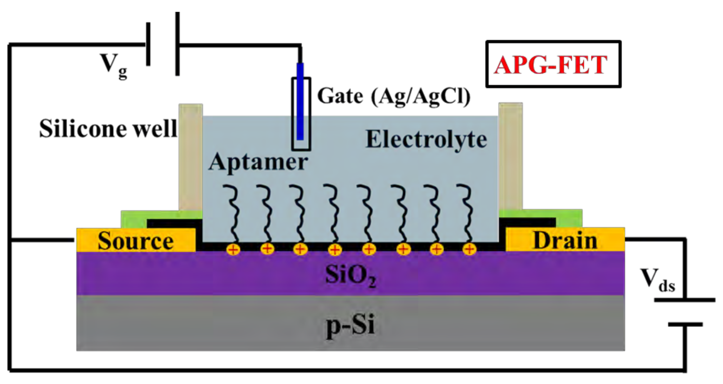
Detection and Recognition

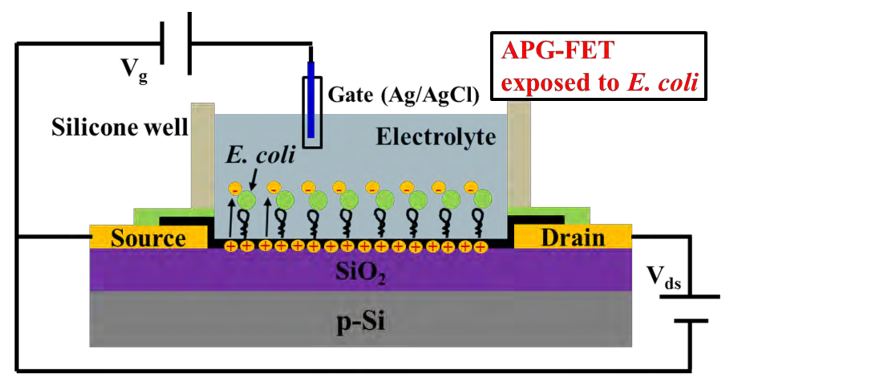
- Traditional methods:
  Gram staining, PCR, immunoreaction, etc.
- New strategies:
  Optical/electrochemical/magnetic senor,
  electronic sensor (field-effect transistor)[2]
- Sensing materials:
  Nanoparticles, nanotube, **graphene**, etc.


Source: Antibiotic Resistance Threats in the United States, 2013

Graphene Biosensors

Sensor structure: **FET** | Gate structure: **Liquid gate**
Sensing material: **Graphene** | Sensing probe: **Pyrene-tagged DNA aptamer**

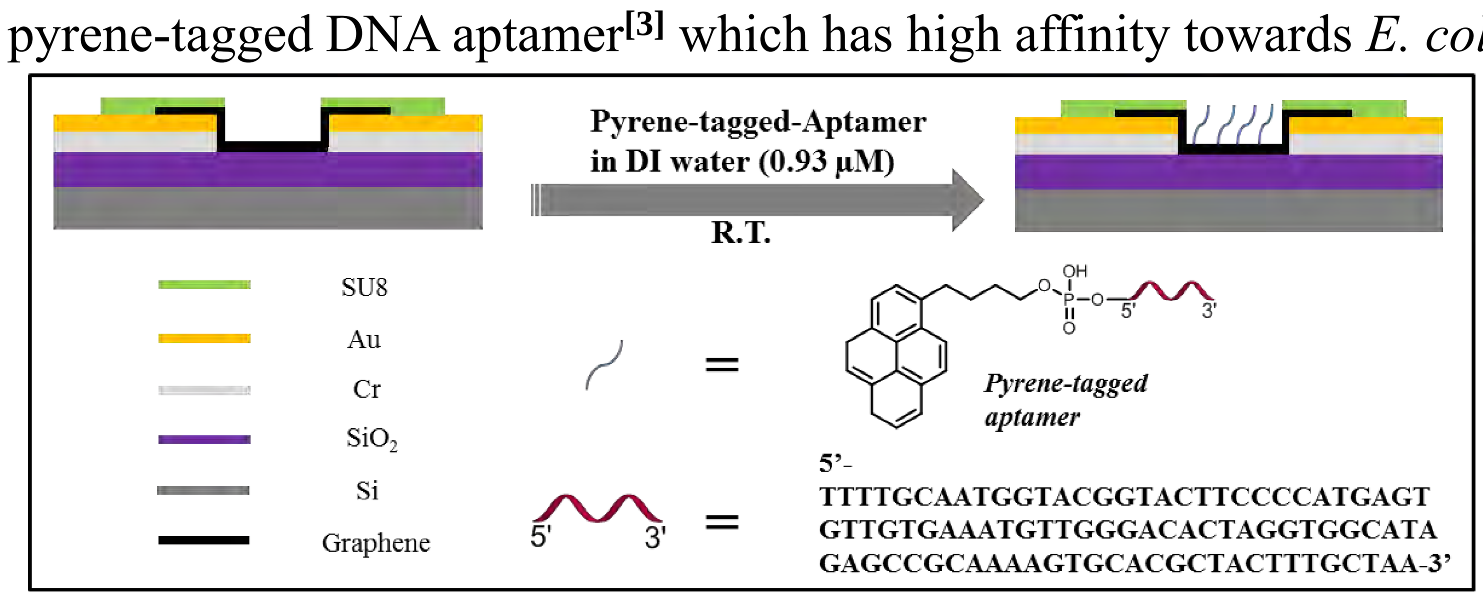




Functionalization and Characterization

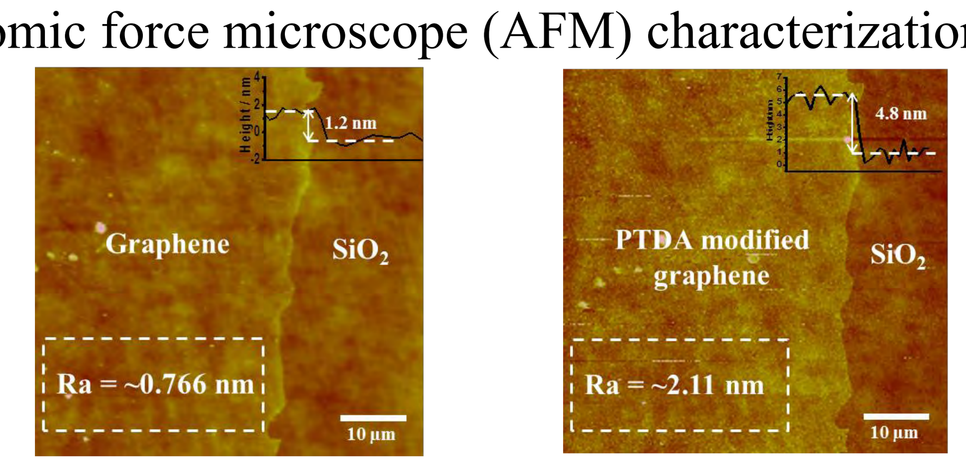
Surface Functionalization

To achieve a sensitive and specific detection, graphene was modified with the pyrene-tagged DNA aptamer[3] which has high affinity towards *E. coli*.

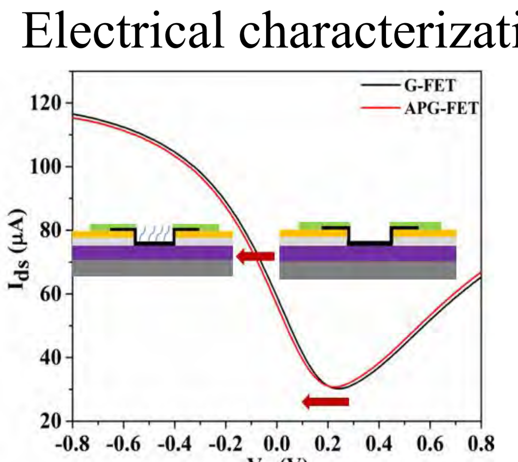


Characterization

Atomic force microscope (AFM) characterization

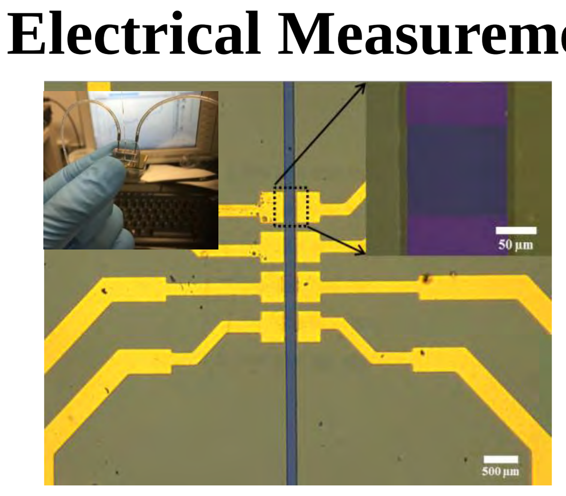


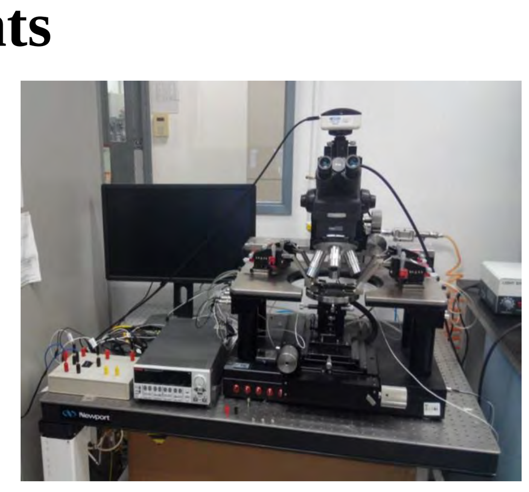
Electrical characterization

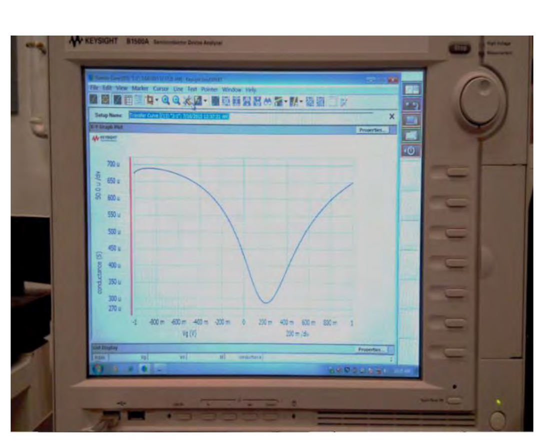


- The height of graphene is about 1.2 nm.
- The entire height of pyrene-tagged DNA aptamer is about 3.6 nm.
- The left-shift of Dirac point is attributed to the adsorbed aptamer.

Electrical Measurements


Device structure


Probe station


Semiconductor analyzer

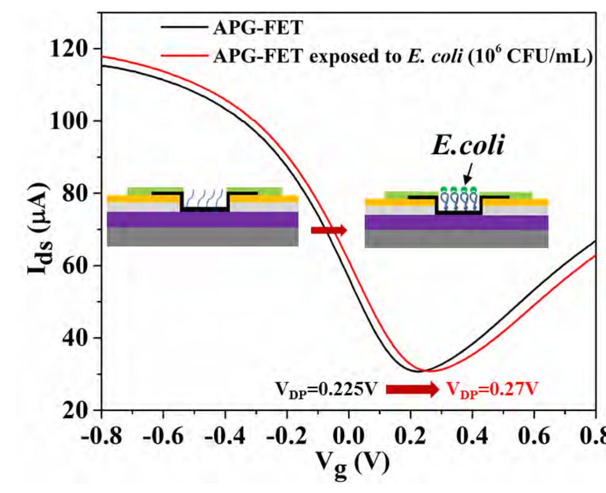
Electrical Response

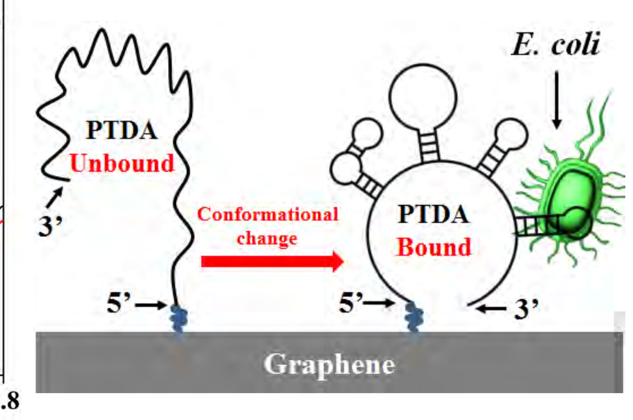
Electrical Detection of *E. coli*

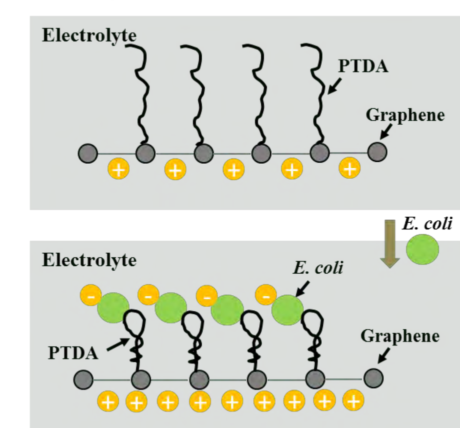
- General equation[4] of source-drain current (ΔI_{ds}) change for FET structure

$$\Delta I_{ds} = \frac{w}{l}\cdot e\cdot \mu \cdot V_{ds}\cdot \Delta n \propto N$$

w: width of the graphene channel;
l: length of the graphene channel;
μ: the carrier mobility of graphene;
e: elementary charge;
V_{ds}: the the source-drain voltage;
Δn: change of the carrier density;
N: the number of targets

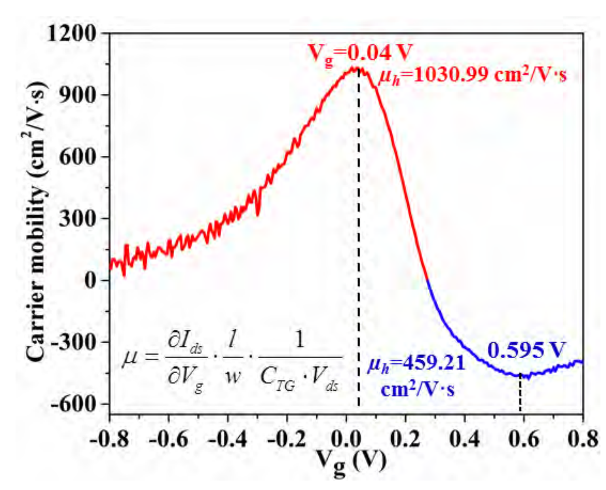


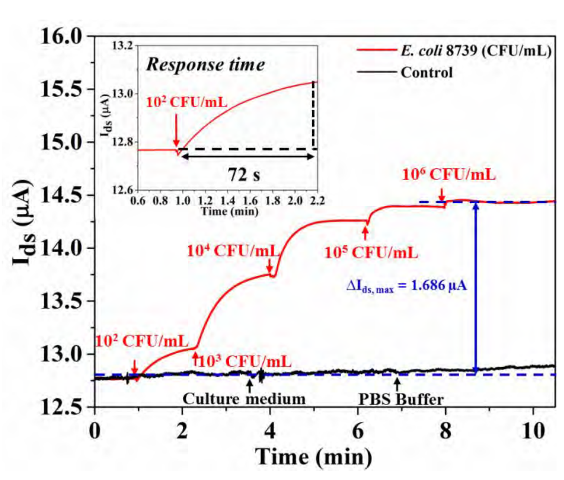


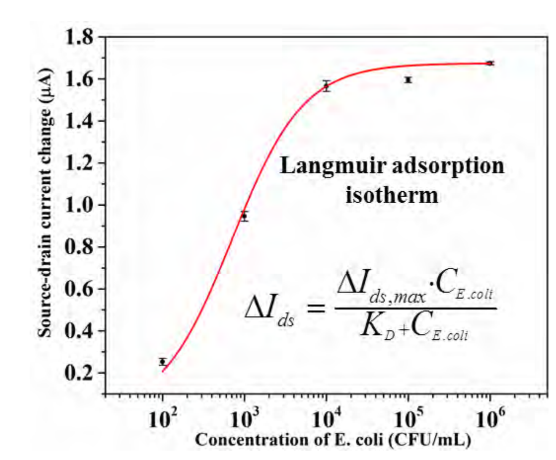


- The negatively charged *E. coli* imposes an external electric field which shifts the Fermi level of graphene downwards, and the Dirac point shifts to the right.

Gate-Dependent Carrier Mobility and Real-Time Monitoring



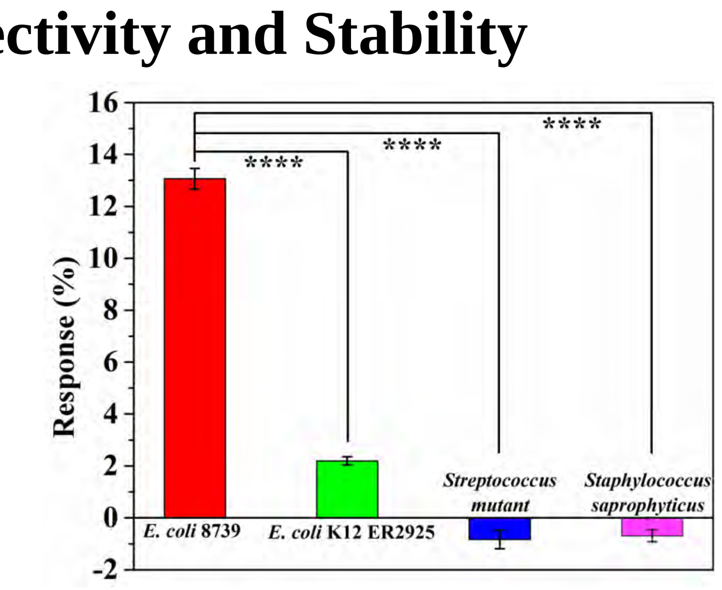


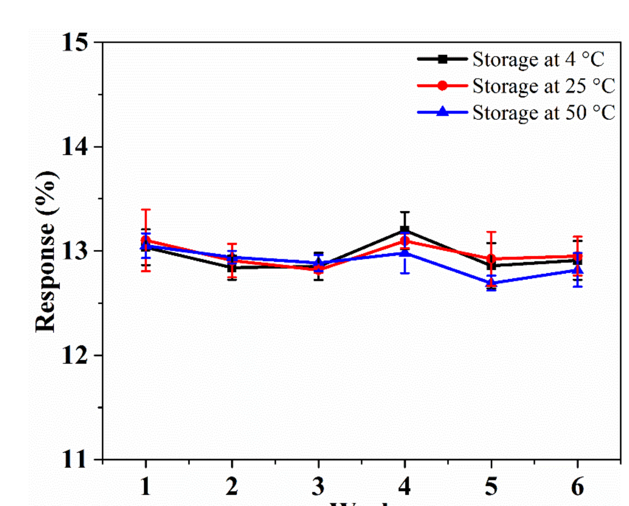


- The $\Delta \boldsymbol{I_{ds}}$ is regulated by the gate voltage ($\boldsymbol{V_g}$).
- The $\boldsymbol{V_g}$ affording the largest $\boldsymbol{\mu}$ is chosen to control the device signal.
- The detection limit is 10^2 CFU/mL.

Immobilized system	Device	Signal readout	Detection limit (CFU/mL)
Antibody	Fluorescence assay[5]	Fluorescence	8×10^4
Potato lectin	Silver nanoparticles[6]	SPR	1.5×10^4
Peptides	hRGO-FETs[7]	Electric signal	10^4
Aptamer	G-FETs (**this work**)	Electric signal	10^2

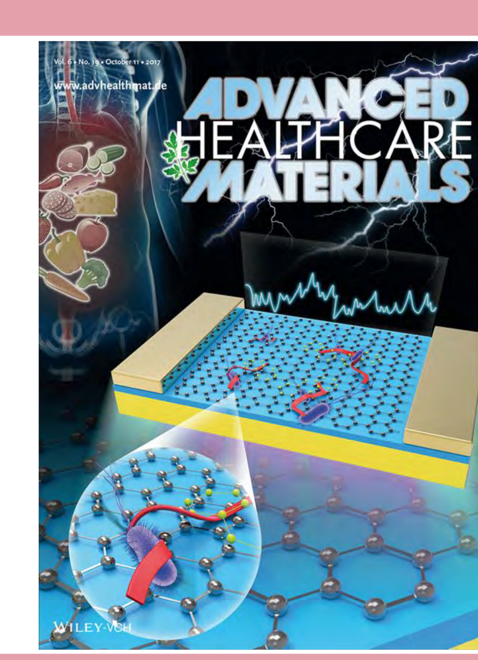
Selectivity and Stability





Conclusions

- The aptamer-modified graphene biosensors for *E. coli* detection performance was demonstrated.
- The APG-FETs biosensors enabled to detect *E. coli* with a detection limit of 10^2 CFU/mL.
- The carrier mobility, which correlates the gate voltage to the signal of APG-FETs, was analyzed and optimized.
- The biosensors exhibited high selectivity and stability for *E. coli* detection.



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Acknowledgements

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