Direct observation of a widely tunable bandgap in bilayer graphene

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Bandgap

- determines transport and optical properties of insulators and semiconductors.
- It governs the operation of devices such as p-n junctions, transsitors, photo diods and lasers.
- If tunable – allows flexibility in design an optimization of devices
- Conventional - determined by the crystal structure – no control over band gap

Graphene

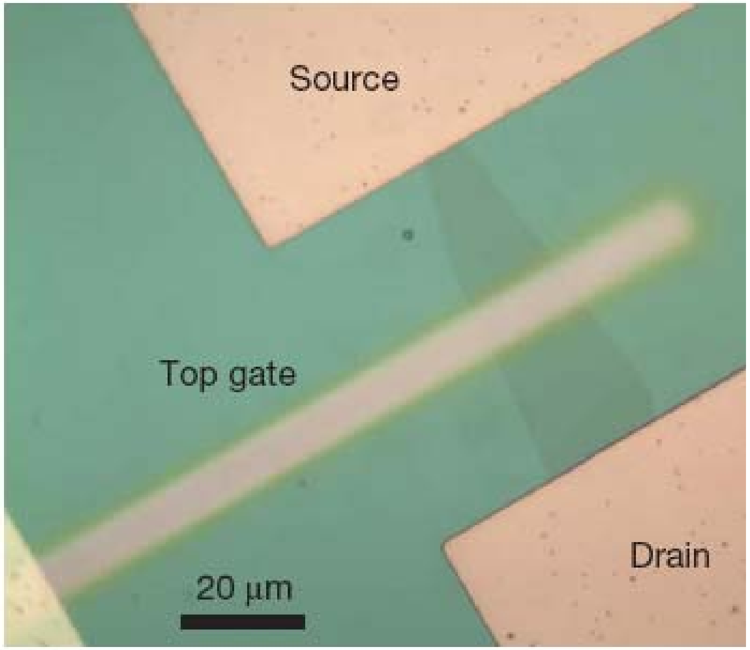
- Having no bandgap greatly limits graphene's uses in electronics.
- Can build FETs but CANT turn them OFF with ZERO band gap
- Non zero bandgap – good transistors, nano LEDs and nanooptical devices in IR region.
- Observation of non zero bandgap in bilayer graphene in which one of the layers were chemically doped
- Chemical doping – uncontrolled, not compatible with device application

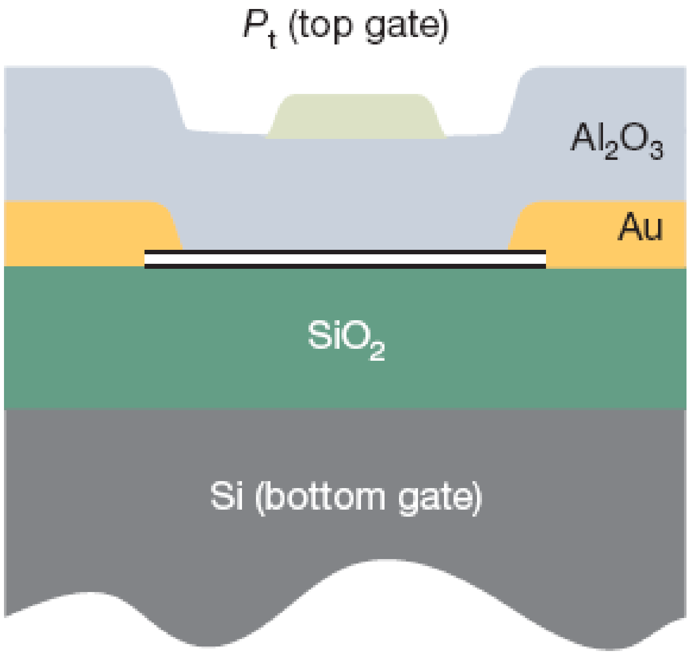
Present

- Bilayer graphene – tuning the band gap – electrical doping
- Appliation of perpendicular electric field – continuous tuning
- Single gated bilayer graphene FETs require refrigeration ~ 1K
- built a two-gated bilayer device, fabricated by Yuanbo Zhang and Tsung-Ta Tang of the UC Berkeley Department of Physics, which allowed the team to independently adjust the electronic bandgap and the charge doping
- Room temperature – continuously tunable bandgap upto 250 meV

Device

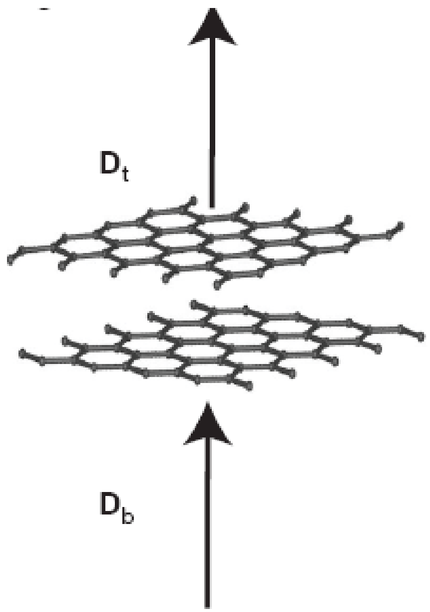
- Dual-gated field-effect transistor (FET), a type of transistor that controls the flow of electrons from a source to a drain with electric fields shaped by the gate electrodes.
- Nano-FET used a **silicon substrate** as the **bottom gate**, with a thin insulating layer of silicon dioxide between it and the stacked graphene layers.
- A transparent layer of aluminum oxide (sapphire) lay over the graphene bilayer; on top of that was the **top gate**, made of **platinum**

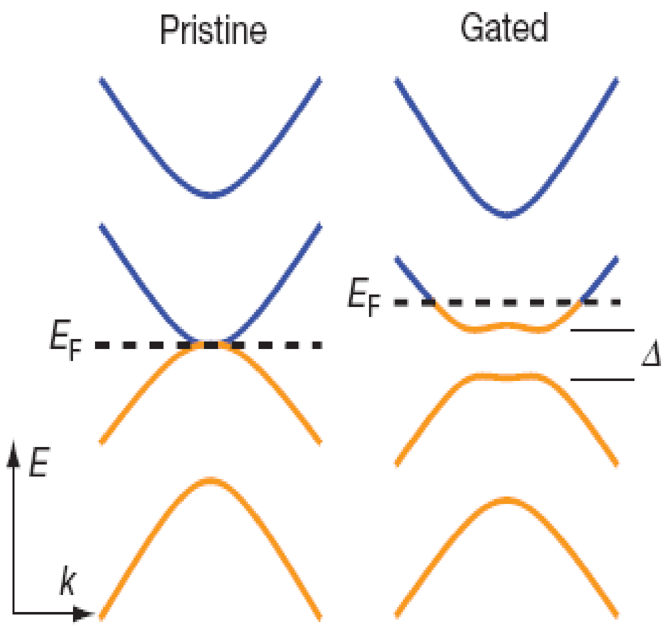




Optical Image

Schematic





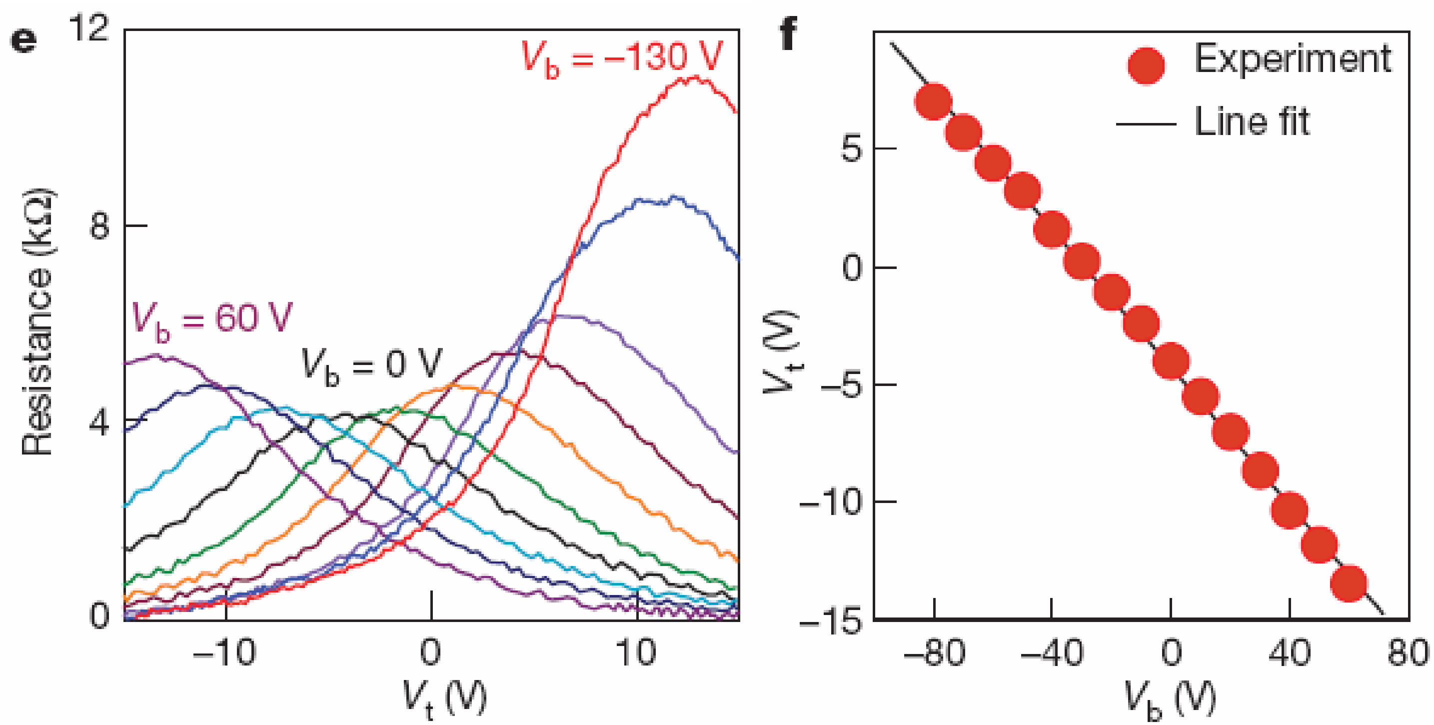
produce two effects,
δ = Db -Dt, leads to a net carrier doping, that is, a shift of the Fermi energy (EF).
D =(Db+Dt)/2 ,breaks the inversion symmetry of the bilayer and generates a non-zero bandgap.
*By setting d = 0, and varying D, we can tune the bandgap while keeping the bilayercharge neutral (**CNPs**).*
By varying d keeping D constant we can shift the Fermi level by injecting either holes or electrons without altering the band gap

Drain is grounded – the displacement fields are controlled by top and bottom gates alone

$$D_b = \varepsilon_b (V_b - V_b^0)/d_b$$

$$Dt = \varepsilon_t (V_t - V_t^0)/d_t$$

Eelctrical transport measurements

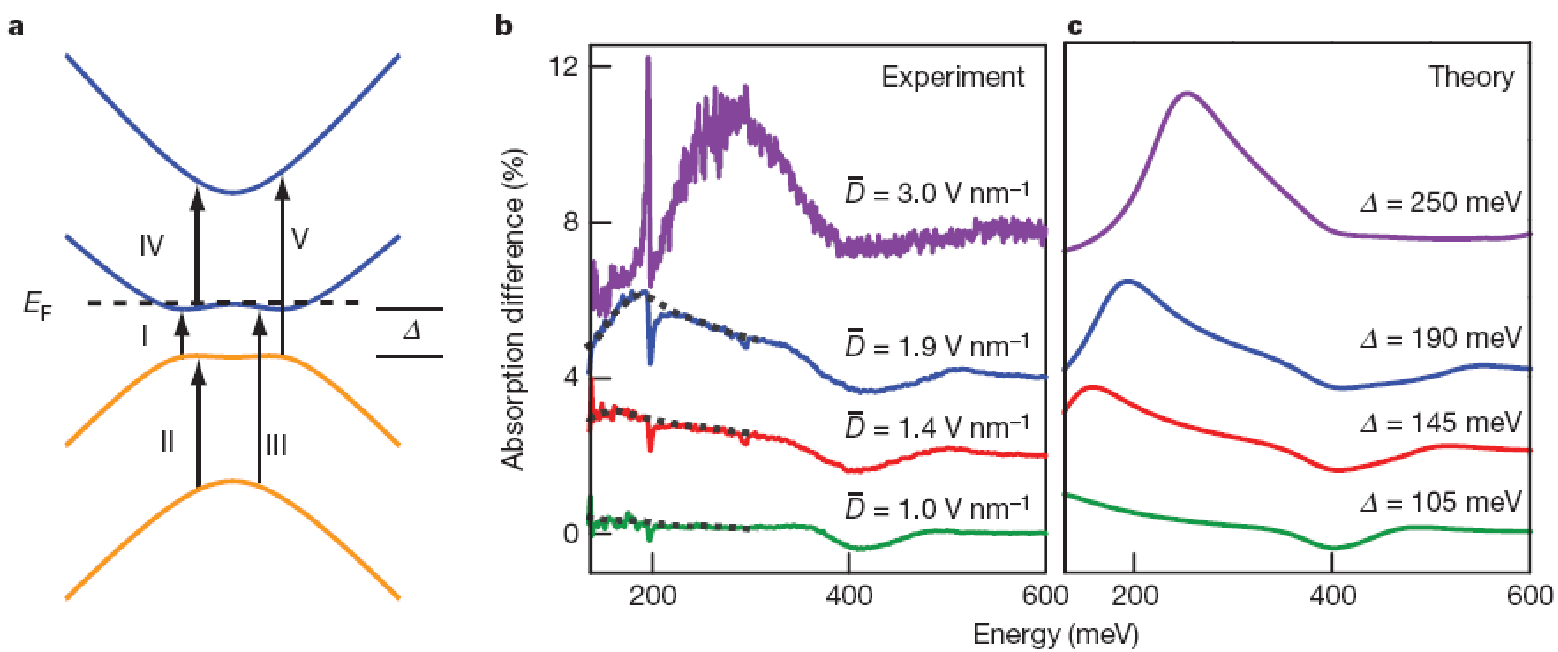


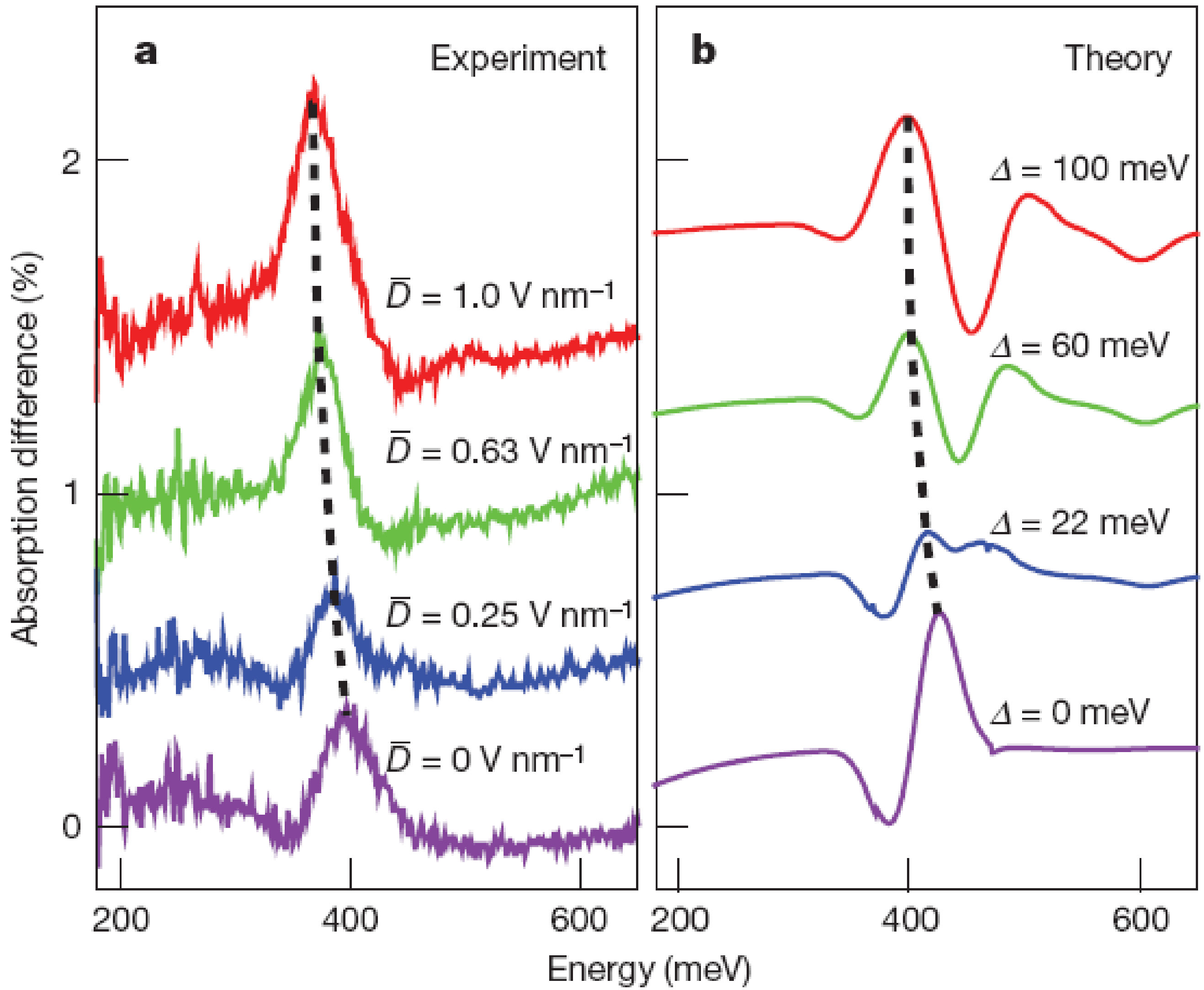
Instead of electrical resistance/transport, they choose to measure optical transmission – Advansed Light source, LBNL

- Transport measurements are too sensitive to defects

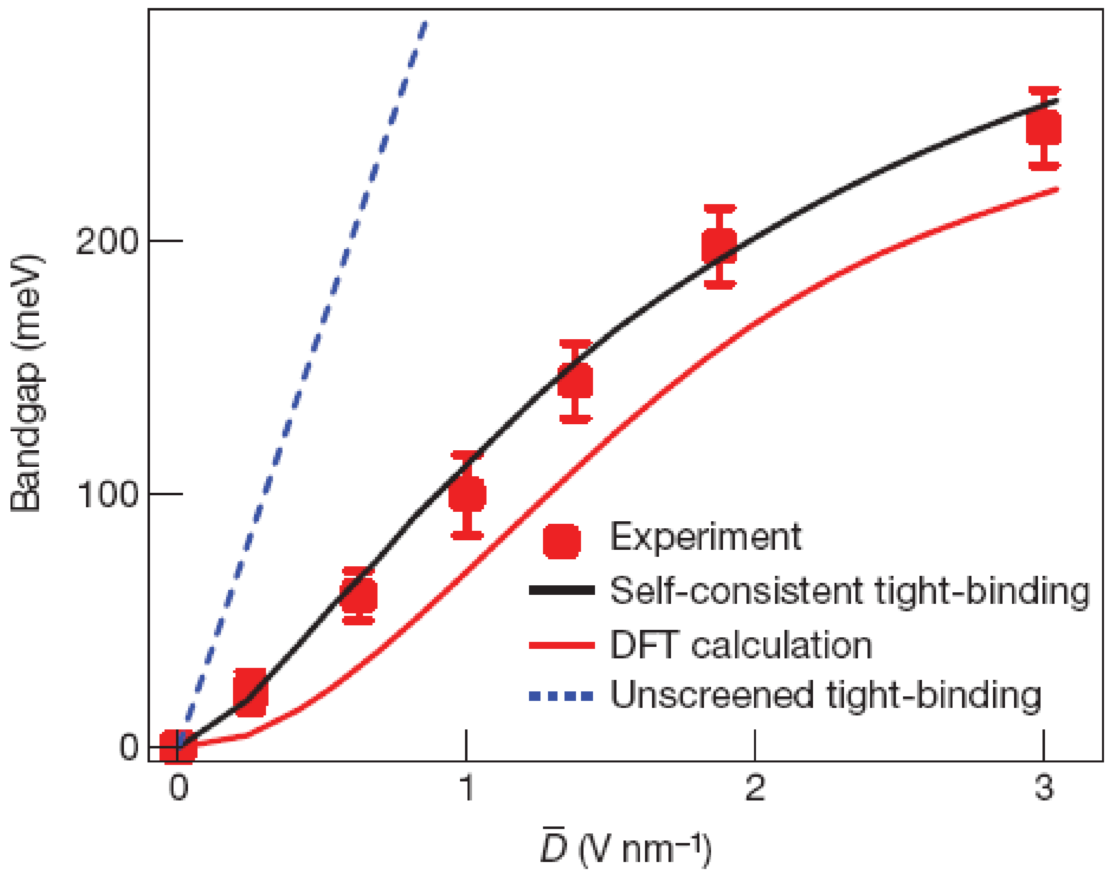
A tiny amount of impurity or defect doping can create a big change in the resistance of the graphene and mask the intrinsic behavior of the material.

- Using infrared beamline 1.4 at the ALS, they were able to send a tight beam of synchrotron light, focused on the graphene layers, right through the device. Beam very bright, could focus down to the diffraction limit.
- by tunig the electric field by precisely varying voltage of the GATE electrodes, measured the variation in light absorbed
- Absorption peak in each measurement gives the direct bandgap at each GATE voltage


a
b
c
E_F
I
II
III
IV
V
Δ
Experiment
Theory
$\bar{D}$ = 3.0 V nm−1
$\bar{D}$ = 1.9 V nm−1
$\bar{D}$ = 1.4 V nm−1
$\bar{D}$ = 1.0 V nm−1
Δ = 250 meV
Δ = 190 meV
Δ = 145 meV
Δ = 105 meV
Absorption difference (%)
0
4
8
12
200
400
600
Energy (meV)



a
Experiment
b
Theory
Absorption difference (%)
2
1
0
$\bar{D}$ = 1.0 V nm^{-1}
$\bar{D}$ = 0.63 V nm^{-1}
$\bar{D}$ = 0.25 V nm^{-1}
$\bar{D}$ = 0 V nm^{-1}
Δ = 100 meV
Δ = 60 meV
Δ = 22 meV
Δ = 0 meV
200
400
600
200
400
600
Energy (meV)



Bandgap (meV)
200
100
0
0
1
2
3
$\bar{D}$ (V nm^{-1})
Experiment
Self-consistent tight-binding
DFT calculation
Unscreened tight-binding

Thank You

Robin John
PH08D023