

Boron Nitride (BN)

William O'brien, Guowang Li

EE87024 Wide Bandgap Device Physics

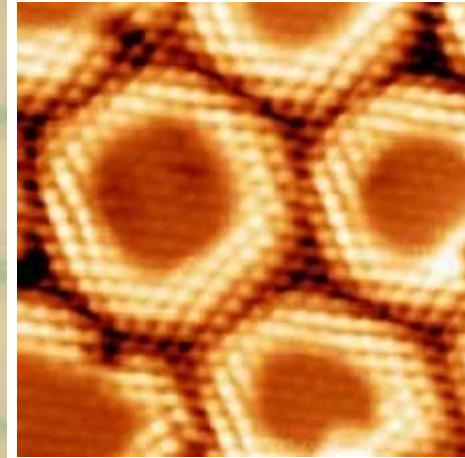
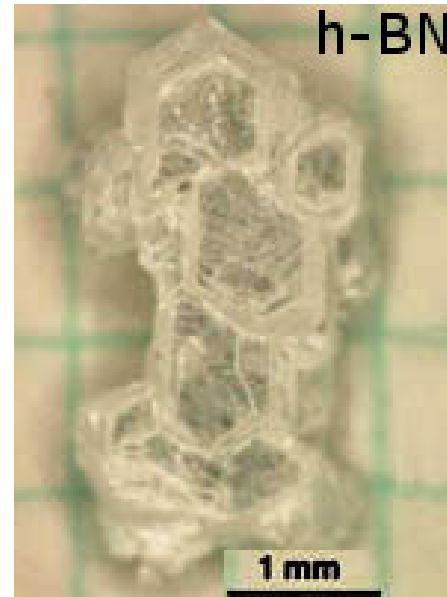
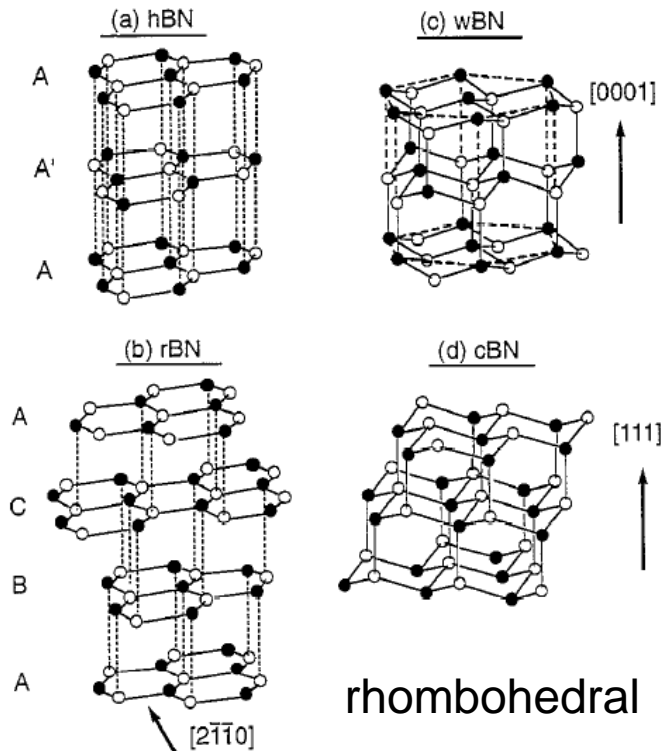
Instructor: Prof. Debdeep Jena

Outline

- Introduction
- Electrical properties of BN
- Optical properties of BN
- Future work

Introduction

- Wide applications
 - High-temperature coating ceramics
 - UV emission
 - Abrasive, cosmetics

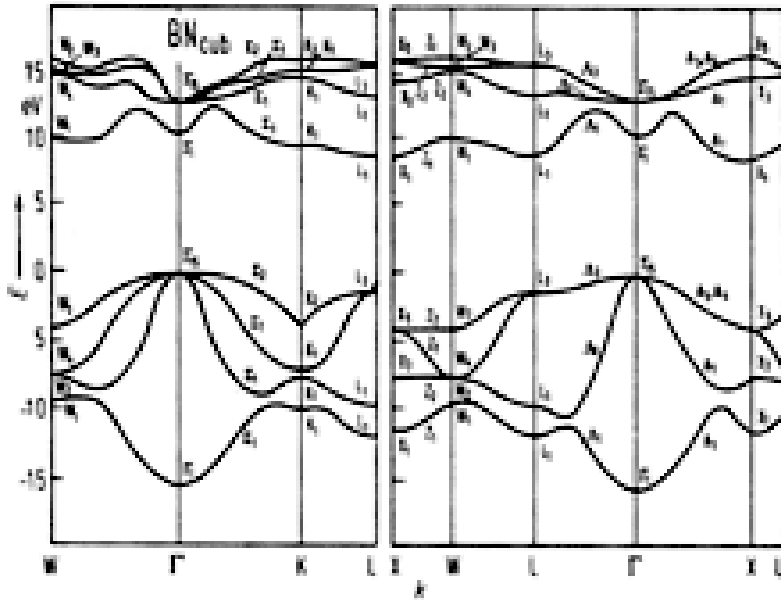


http://en.wikipedia.org/wiki/Boron_nitride



Kenji Watanabe *et al*, Nature photonics, Vol. 3, oct. 2009

Electrical properties of BN



$$a=3.6157(10) \text{ \AA}, m_e^*=1.2m_0, \omega_{op} \sim 130 \text{ meV},$$

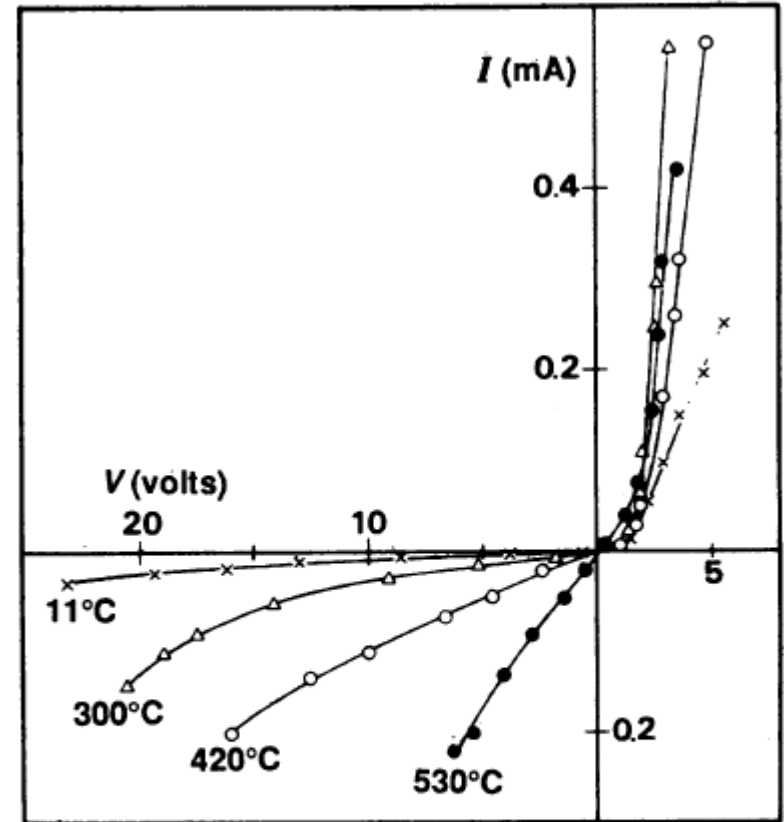
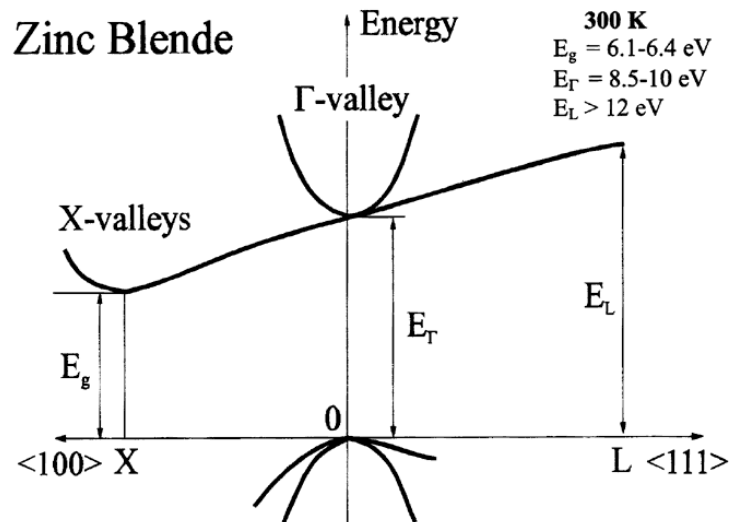
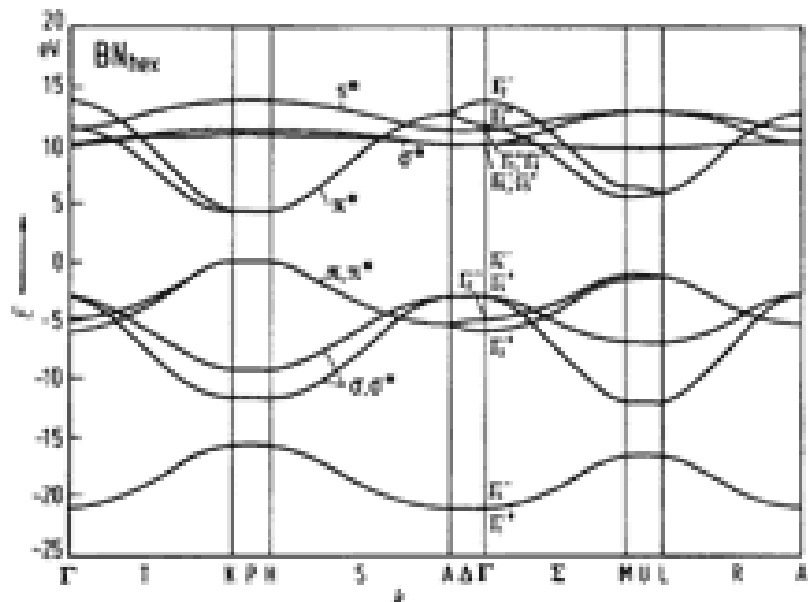


Fig. 1. Typical rectification characteristics and temperature dependence of the cBN p-n junction diode. The actual sample temperature might be slightly higher because of the large supplied power.

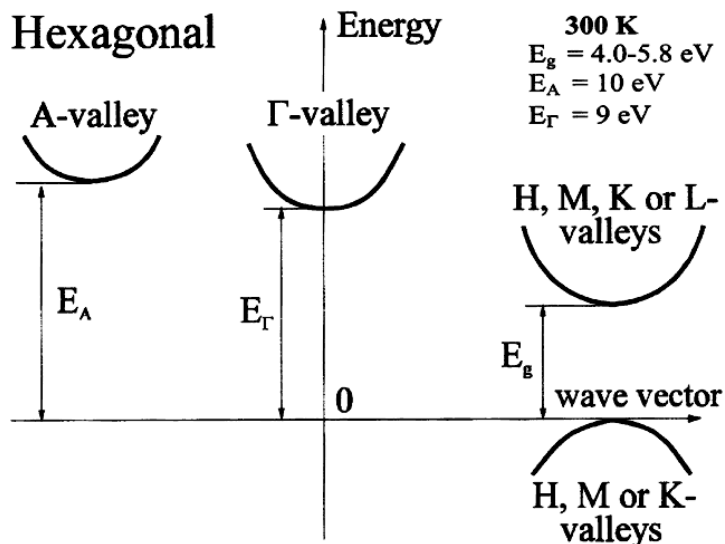
OSAMU MISHIMA *et al*, Science, Vol. 238. no. 4824, pp. 181 – 183, Oct. 1987

Electrical properties of BN

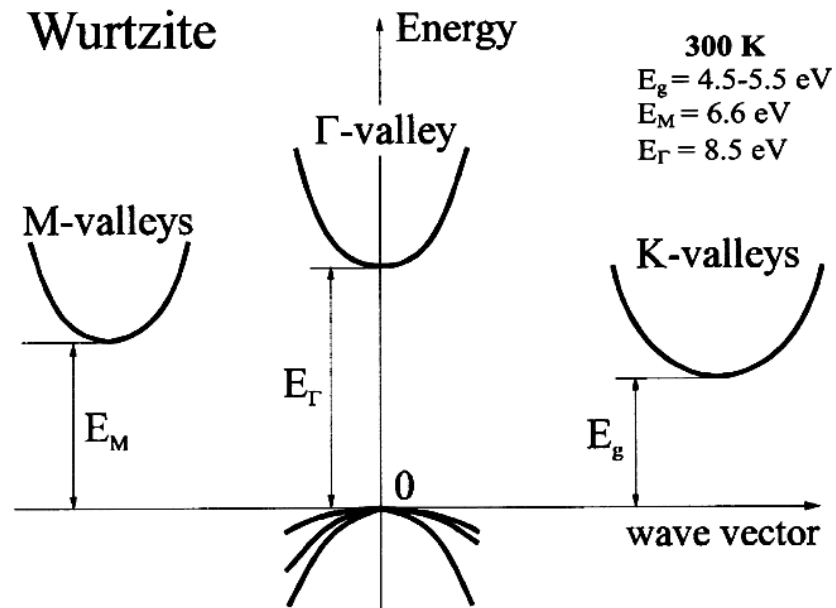


$a=2.5\sim 2.9$ Å, $c=6.66$ Å, $m_e^*=0.26m_0$

Hexagonal



Wurtzite



$a=2.55$ Å, $c=4.17$ Å,
 $m_e^*=0.35m_0$, $\omega_{op} \sim 130$ meV,

$$\mu_e \leq 200 \text{ cm}^2/\text{Vs}$$

$$\mu_h \leq 500 \text{ cm}^2/\text{Vs}$$

Optical properties of BN

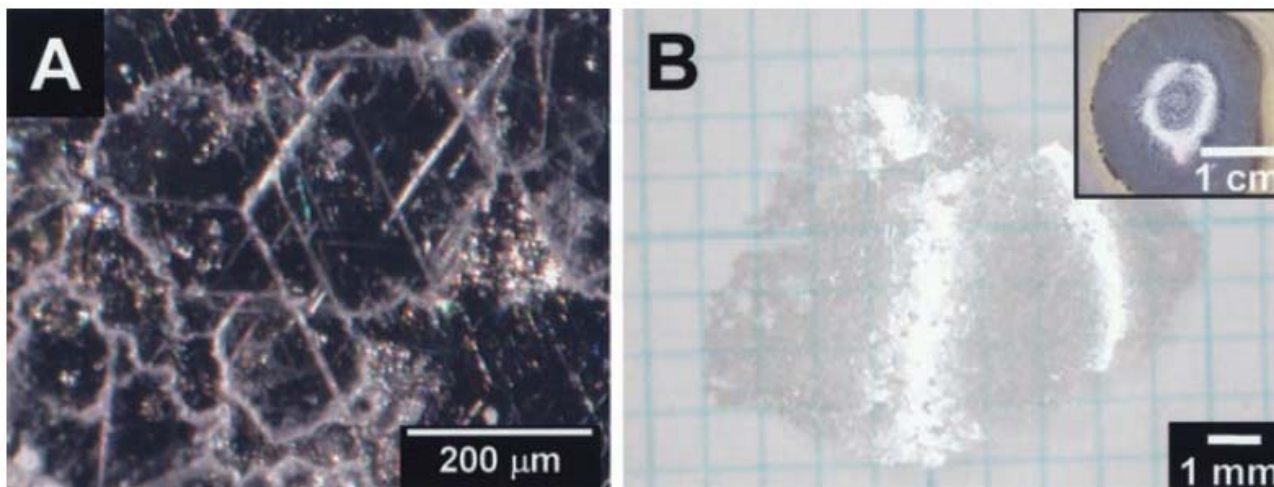
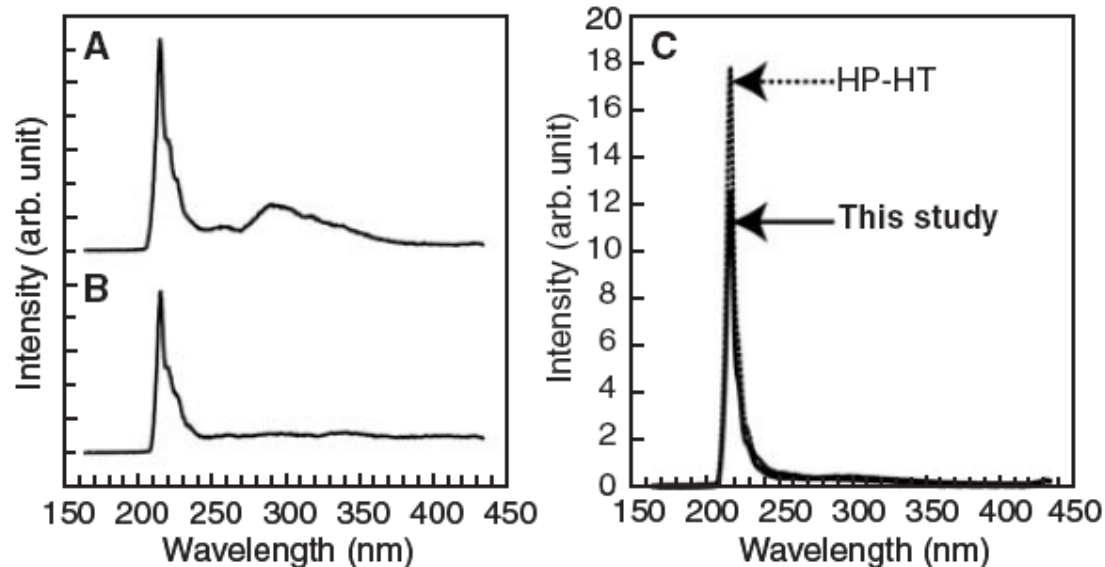


Fig. 1. Optical micrographs of recrystallized hBN obtained with a Ni-Mo solvent. **(A)** Typical hBN crystal on the solidified solvent (as grown). **(B)** A fragment of aggregate hBN crystals after acid treatment (the inset is an optical micrograph of a recovered sample). The shiny white regions are reflected light.

Yoichi
Kubota *et al*,
Science,
Vol. 317. no.
5840, pp.
932 – 934,
Aug. 2007

Fig. 3. Cathodoluminescence spectra of recrystallized hBN at room temperature. **(A)** hBN obtained with a Ni solvent. **(B)** hBN obtained with a Ni-Mo solvent. **(C)** Direct quality comparison of the emission characteristics. Solid line, hBN obtained with a Ni-Mo solvent at atmospheric pressure (in this study); dotted line, hBN obtained with a Ba-BN solvent at high pressure and high temperature (HP-HT).



Optical properties of BN

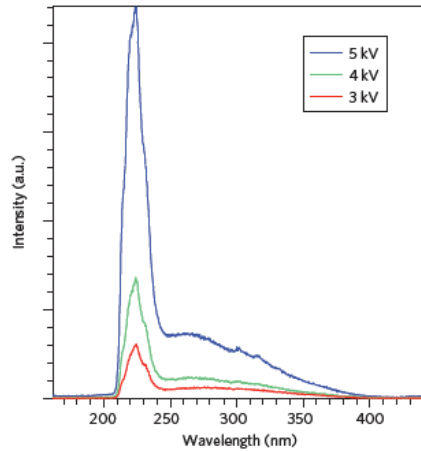


Figure 3 | Example of output spectra. Output spectra show a dominant peak at 225 nm. This broad far-ultraviolet band is a result of superposition of excitonic bands from 215 to 227 nm. The weak tail from 250 to 400 nm is a result of impurities and defect states.

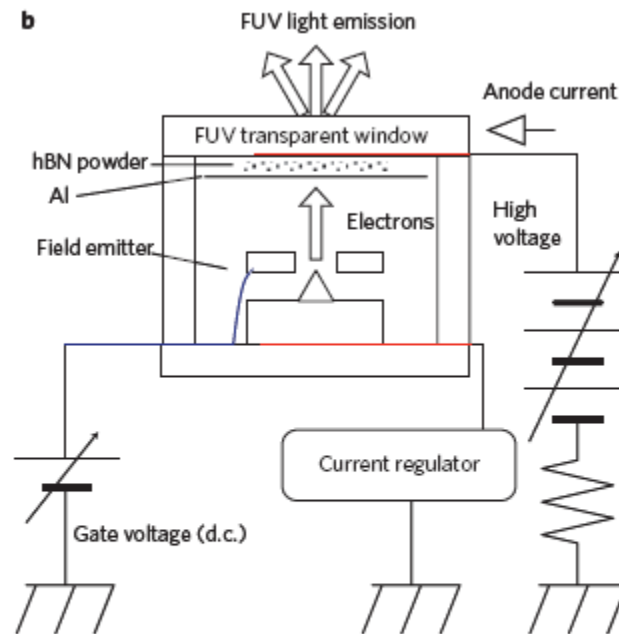
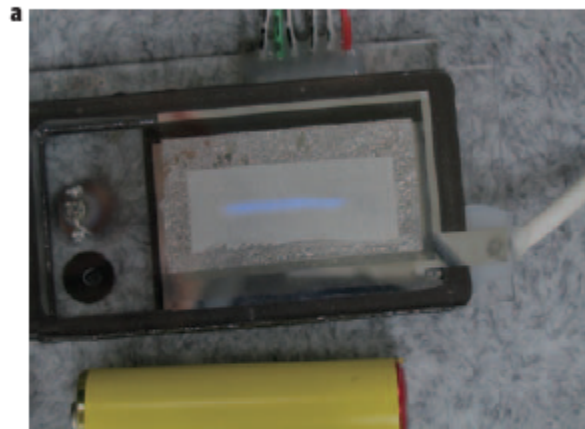


Figure 1 | Device appearance and structure. **a**, Photograph of a prototype far-ultraviolet (FUV) plane-emission device in operation. The filament, visible as a bluish-white line, shows FUV light emission over an area of $1.7 \times 0.16 \text{ cm}^2$. In this photograph, impure hBN powder, which emits blue light, was intentionally used for the fluorescent screen so that a clear image of the light-emitting part could be taken using a commercially available digital camera. A size-AA dry battery is shown for size comparison. **b**, Cross-sectional representation of an FUV plane-emission device and connected electric circuits. An aluminium thin film sealing the hBN powder protects the fluorescent screen from a build up of electrostatic charge

Kenji Watanabe *et al*, Nature photonics, Vol. 3, oct. 2009

Absorption coefficient of graphene

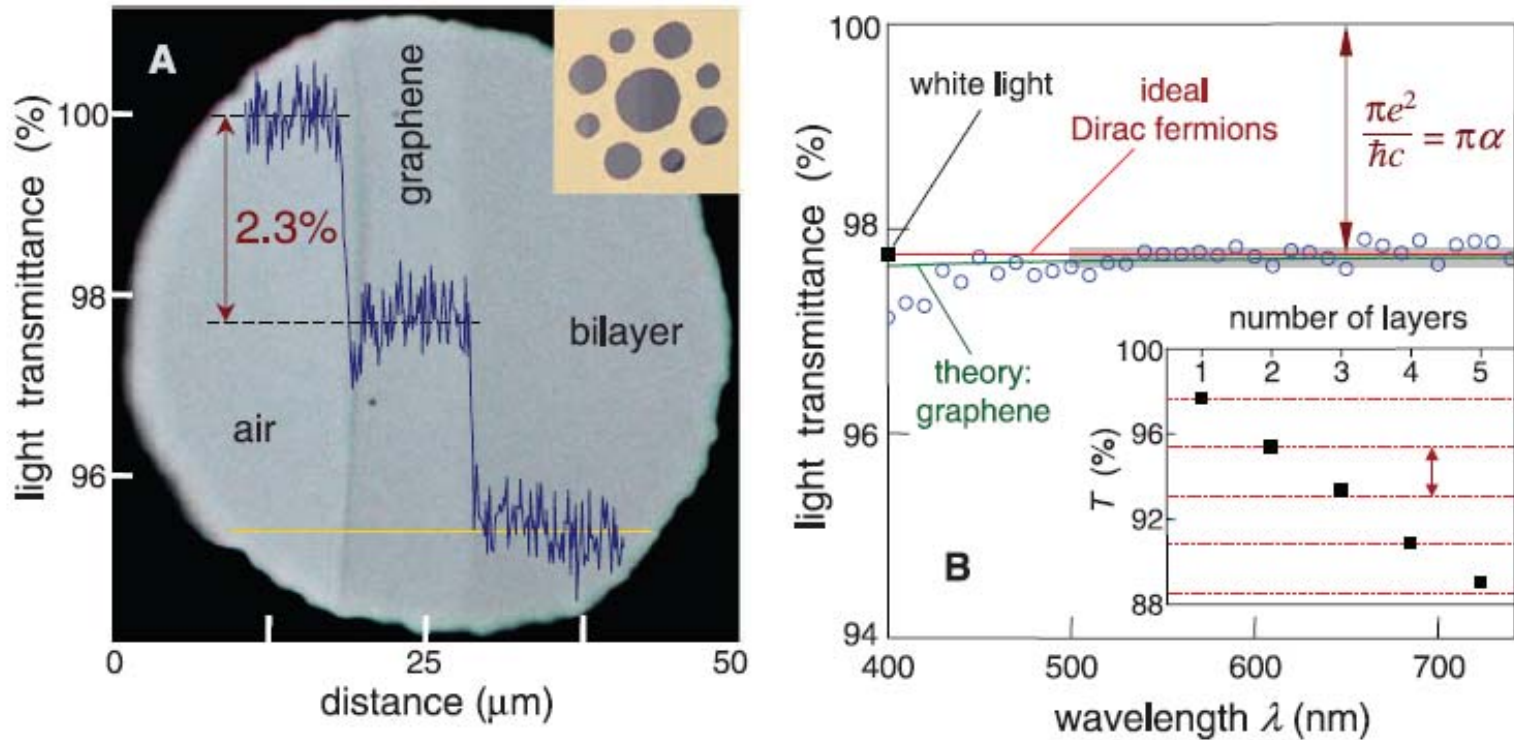


Fig. 1. Looking through one-atom-thick crystals. **(A)** Photograph of a 50- μm aperture partially covered by graphene and its bilayer. The line scan profile shows the intensity of transmitted white light along the yellow line. (Inset) Our sample design: A 20- μm -thick metal support structure has several apertures of 20, 30, and 50 μm in diameter with graphene crystallites placed over them. **(B)** Transmittance spectrum of single-layer graphene (open circles). Slightly lower transmittance for $\lambda < 500$ nm is probably due to hydrocarbon contamination (5). The red line is the transmittance $T = (1 + 0.5\pi\alpha)^{-2}$ expected for two-dimensional Dirac fermions, whereas the green curve takes into account a nonlinearity and triangular warping of graphene's electronic spectrum. The gray area indicates the standard error for our measurements (5). (Inset) Transmittance of white light as a function of the number of graphene layers (squares). The dashed lines correspond to an intensity reduction by $\pi\alpha$ with each added layer.

Absorption coefficient of graphene

The incident energy flux $W_i = \frac{c}{4\pi} |E|^2$

The absorbed energy flux $W_a = \eta \hbar \omega$

Fermi's golden rule $\eta = \frac{2\pi}{\hbar} |M|^2 D$

$$\widehat{H}_{int} = v_F \vec{\sigma} \cdot \frac{e}{c} \vec{A} = v_F \vec{\sigma} \cdot \frac{e}{i\omega} \vec{E}$$

$$|M|^2 = \left| \left\langle f \left| v_F \vec{\sigma} \cdot \frac{e}{i\omega} \vec{E} \right| i \right\rangle \right|^2$$

$$\sigma_x = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \quad \sigma_y = \begin{pmatrix} 0 & i \\ -i & 0 \end{pmatrix}$$

$$|i\rangle = \frac{1}{\sqrt{2}} \begin{pmatrix} 1 \\ -e^{i\theta'_k} \end{pmatrix} e^{i\vec{k}' \cdot \vec{r}}$$

$$|f\rangle = \frac{1}{\sqrt{2}} \begin{pmatrix} 1 \\ e^{i\theta_k} \end{pmatrix} e^{i\vec{k} \cdot \vec{r}}$$

$$\left| \left\langle f \left| \sigma_x E_x \right| i \right\rangle \right| = \left| \int \frac{1}{\sqrt{2}} \begin{pmatrix} 1 & e^{-i\theta_k} \end{pmatrix} e^{i\vec{k} \cdot \vec{r}} \cdot \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} E_x \cdot \frac{1}{\sqrt{2}} \begin{pmatrix} 1 \\ -e^{i\theta'_k} \end{pmatrix} e^{i\vec{k}' \cdot \vec{r}} \right|$$

Absorption coefficient of graphene

$$\eta = \frac{2\pi}{\hbar} \cdot \frac{e^2 V_F^2}{\omega^2} \cdot \left\{ |E_x|^2 \cdot g_v \cdot \int \frac{d^2 k}{(2\pi)^2} \frac{|e^{i\theta_k} + e^{-i\theta_k}|^2}{2} \delta(\varepsilon_k - \hbar\omega + \varepsilon_{k'}) \right. \\ \left. + |E_y|^2 \cdot g_v \cdot \int \frac{d^2 k}{(2\pi)^2} \frac{|e^{i\theta_k} - e^{-i\theta_k}|^2}{2} \delta(\varepsilon_k - \hbar\omega + \varepsilon_{k'}) \right\} \quad d^2 k = k dk d\theta$$

$$\eta = \frac{2\pi}{\hbar} \cdot \frac{e^2 v_F^2}{\omega^2} \cdot |E|^2 \cdot \left\{ 2\pi \cdot \frac{1}{(\hbar v_F)^2} \int \frac{\varepsilon d\varepsilon}{2(2\pi)^2} \delta\left(\varepsilon - \frac{\hbar\omega}{2}\right) \right\}$$

$$W_a = \eta \hbar \omega = \frac{e^2}{4\hbar} |E|^2$$

$$\text{Absorption coefficient } P = W_a / W_i = \frac{\pi e^2}{\hbar c}$$

Future work

- Calculate hBN band structure by tight-bonding model
- Use band structure to calculate absorption coefficient of hBN

Q && A