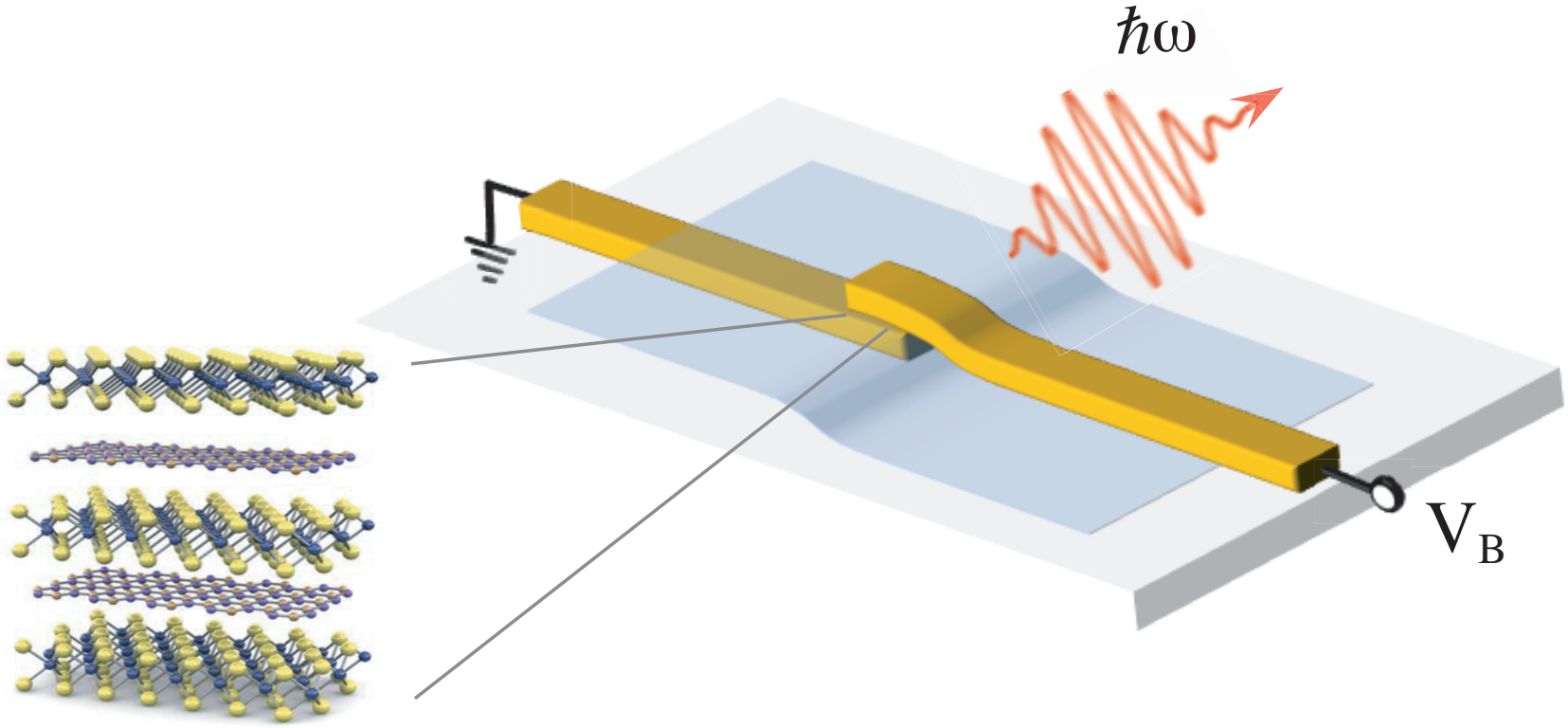
LIGHT-EMISSION FROM TWISTED GRAPHENE TUNNEL JUNCTIONS



OUTLINE

1: INTRODUCTION

2: TUNNEL-LEDs

3: TWISTED-GRAPHENE LEDs

4: OUTLOOK

ETH zürich

FNSNF
SWISS NATIONAL SCIENCE FOUNDATION

ACKNOWLEDGMENTS


Markus Parzefall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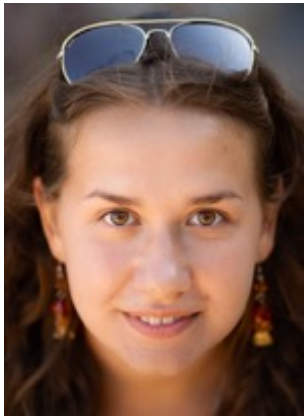
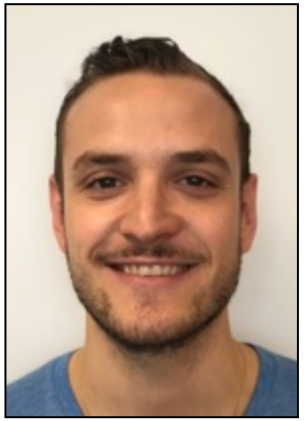

Anna Kuzmina


Cla-Duri Tschannen


Lujun Wang


Sotirios Papadopoulos

COLLABORATIONS:

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Jürg Leuthold (ETH)

Klaus Ensslin (ETH)

Atac Imamoglu (ETH)

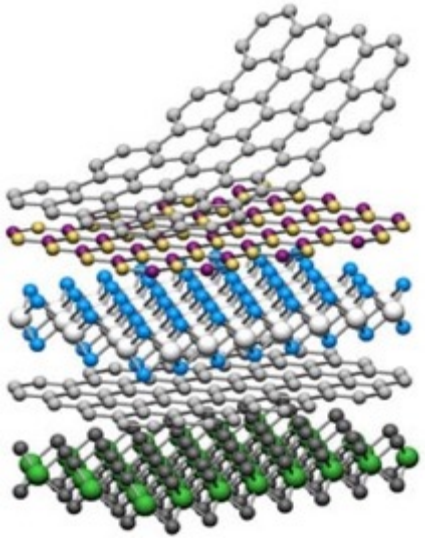
QSIT Quantum Science and Technology

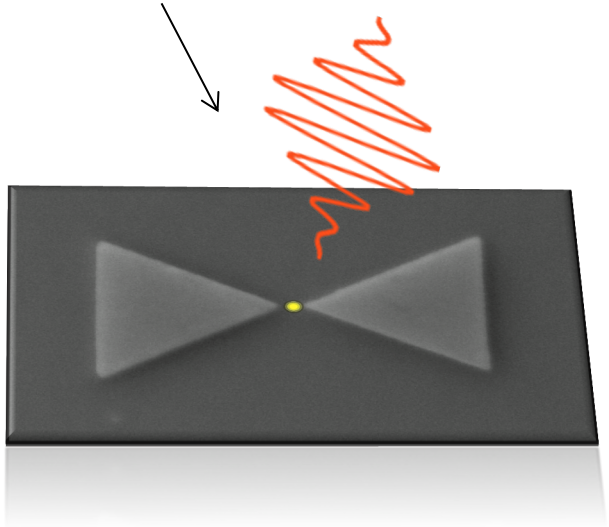
OBJECTIVE

$$\Gamma = \frac{\pi\,\omega}{3\hbar\varepsilon_o}\,|\langle g|\hat{\mathbf{p}}|e\rangle|^2\,\rho_{\mathbf{p}}(\mathbf{r}_m,\omega)$$

Matter

Field





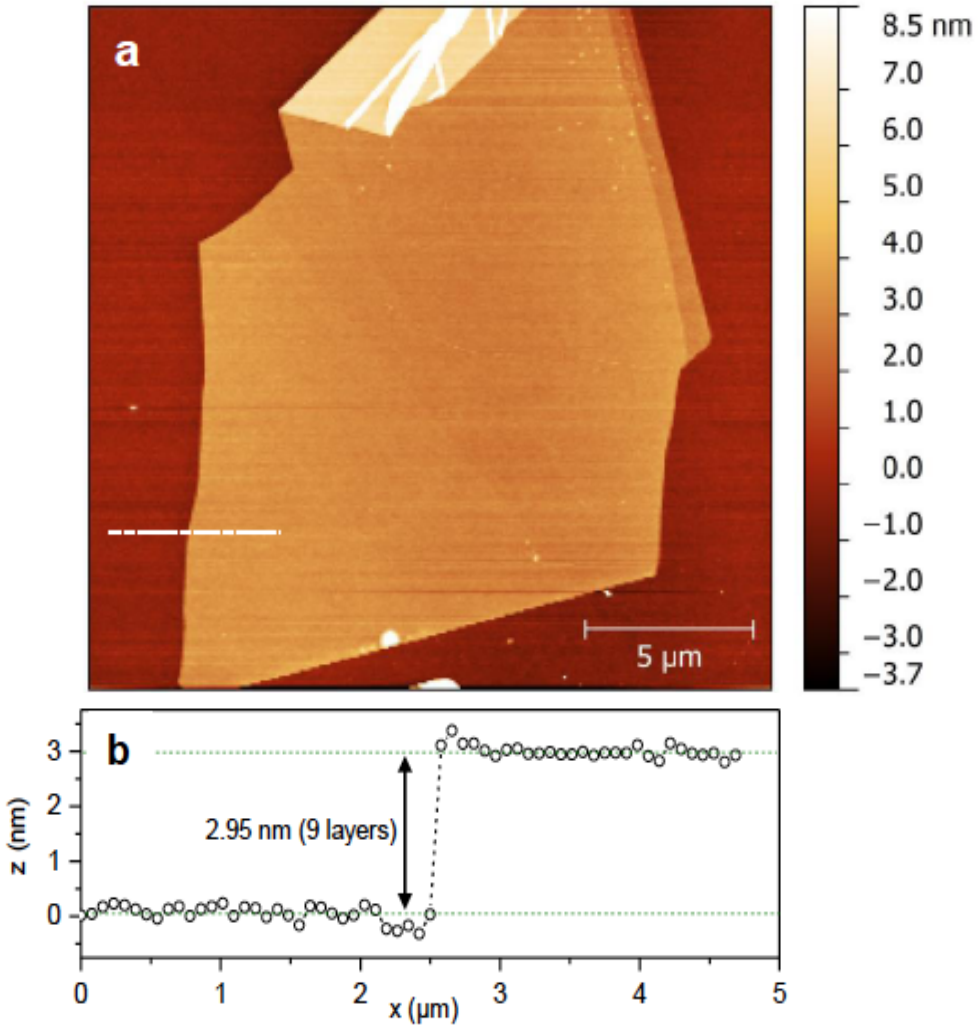
Energy transfer in surface enhanced luminescence

A. Wokaun, H.-P. Lutz, A. P. King, U. P. Wild, and R. R. Ernst

Physical Chemistry Laboratory, Swiss Federal Institute of Technology, CH 8092 Zürich, Switzerland
(Received 24 February 1983; accepted 22 March 1983)

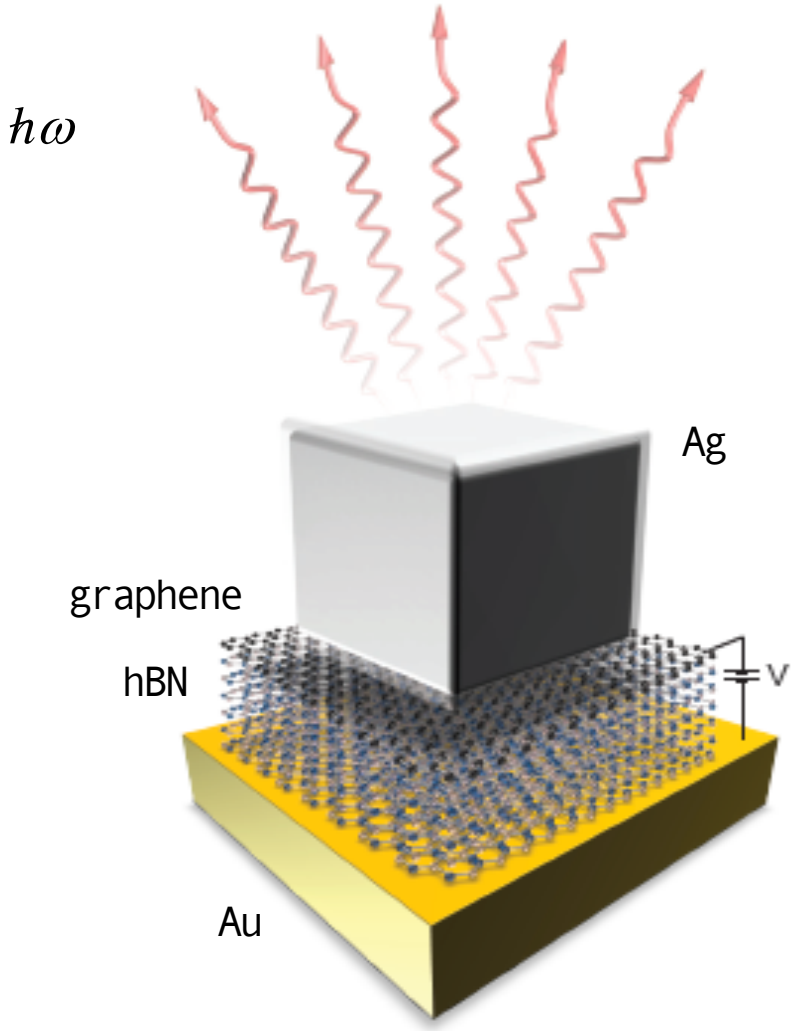
A low quantum yield molecule was chosen because (i) stronger enhancement of the luminescence can be obtained in this case,[17] and (ii) intermolecular interactions are less important compared to the fast intramolecular decay process.

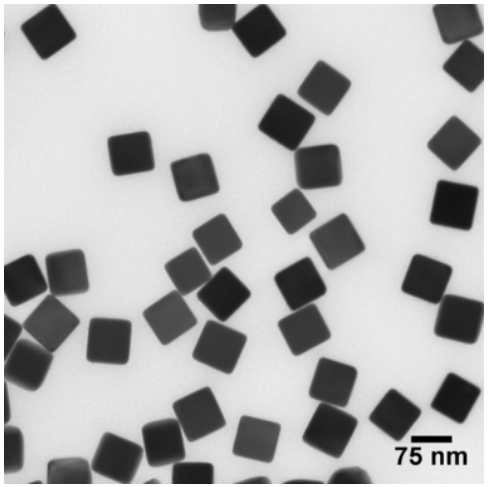
h-BN CRYSTALS

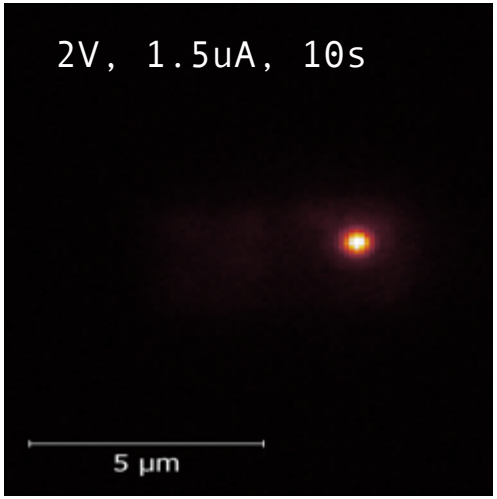


Source: K. Watanabe, T. Taniguchi, NIMS Tsukuba, Japan

TUNNEL LED WITH PATCH ANTENNA

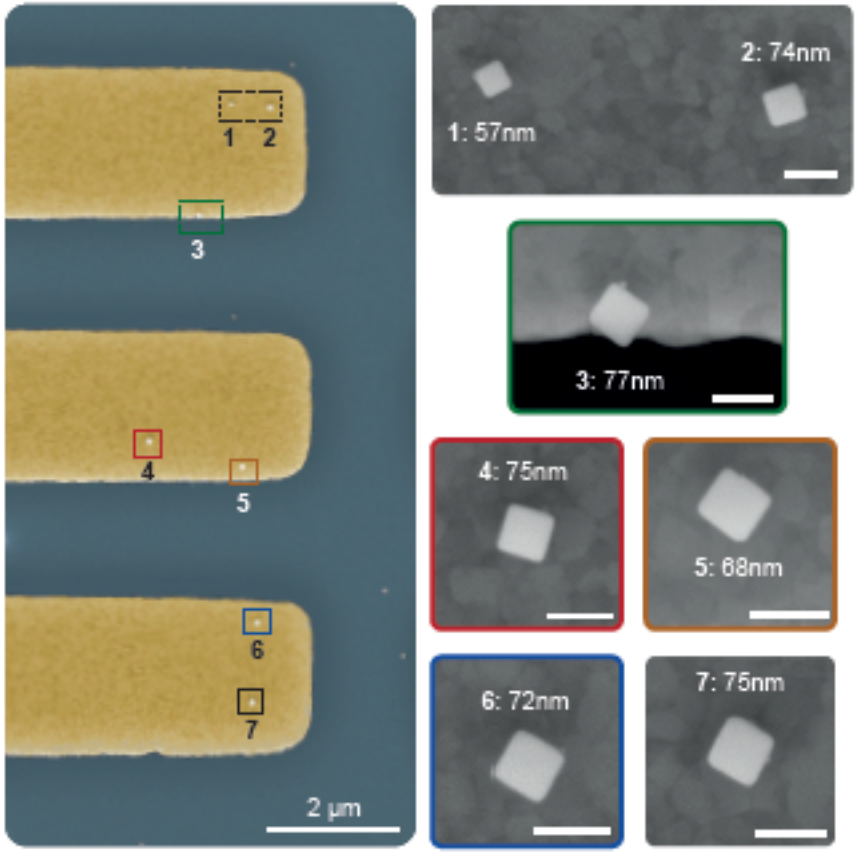


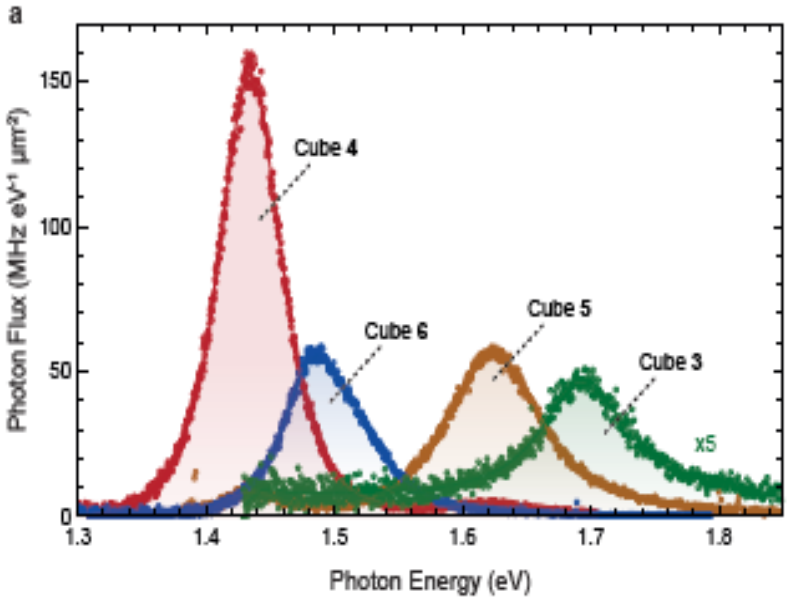




Nature Comm. **10**, 292 (2019)

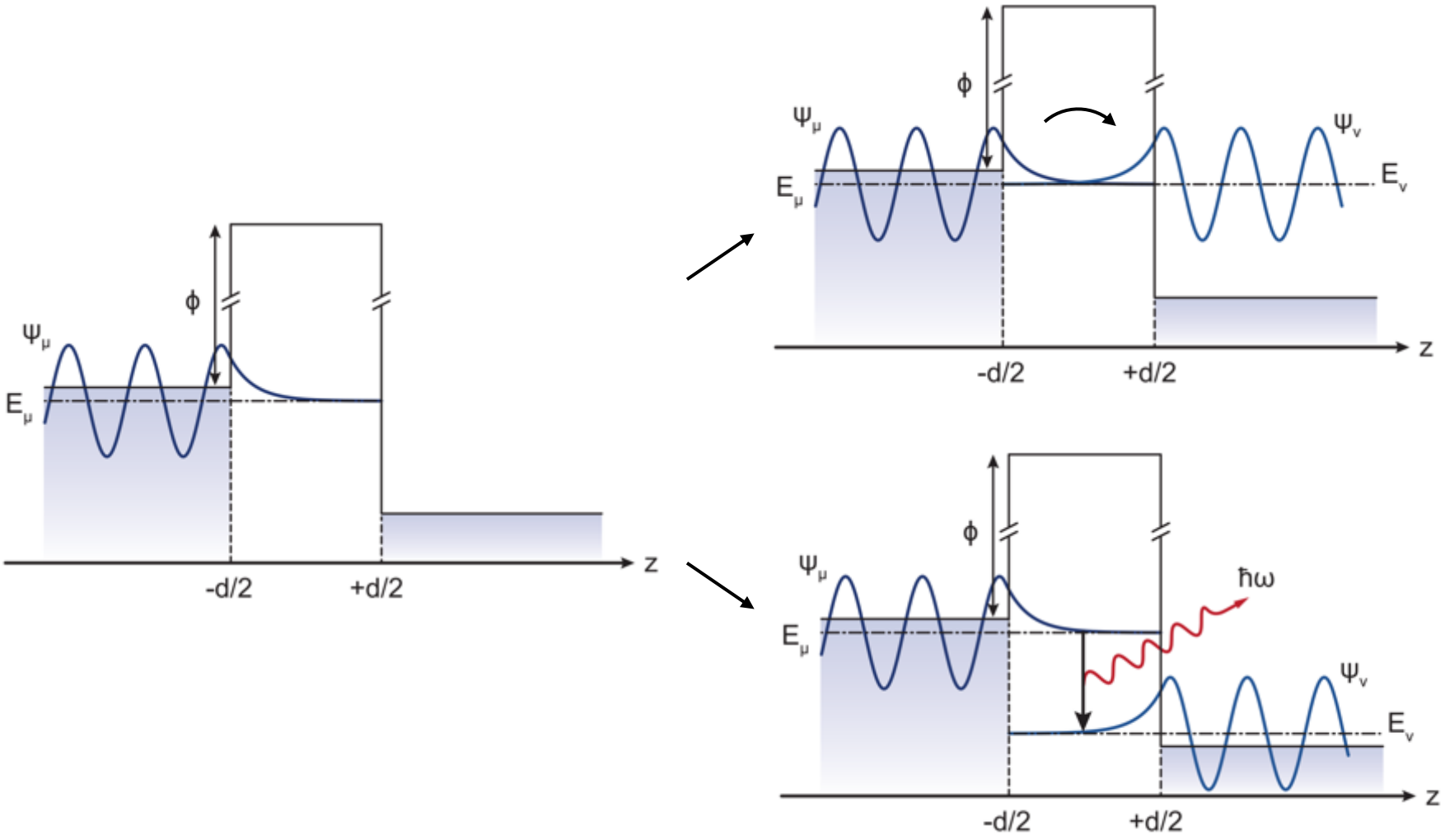
PATCH ANTENNA RESONANCES





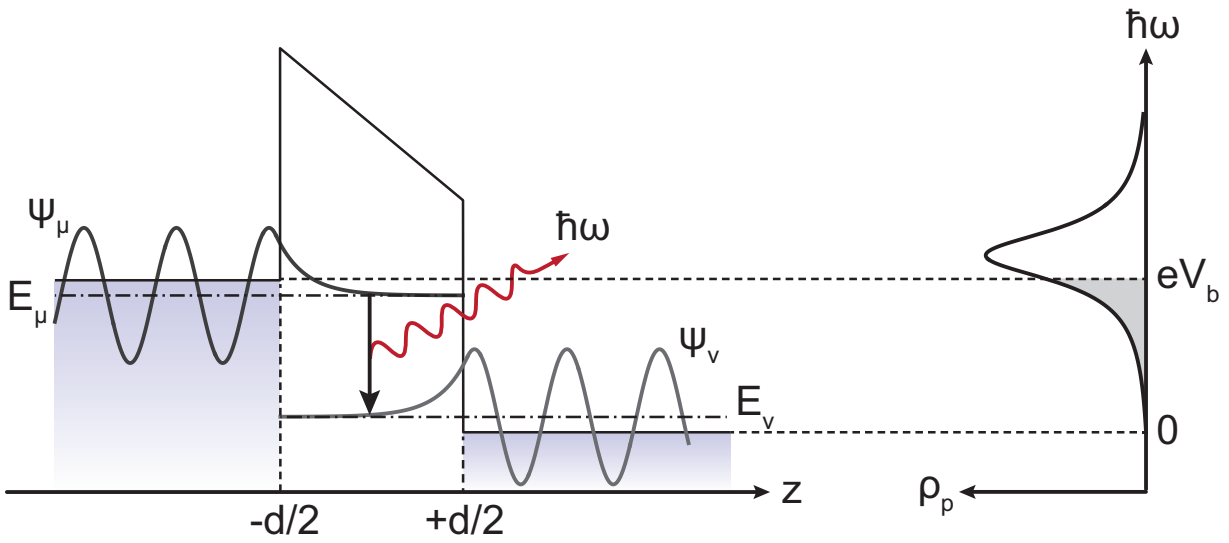
Nature Comm. **10**, 292 (2019)

INELASTIC ELECTRON TUNNELING



M. Parzefall *et al.* in *Quantum Plasmonics*, Springer Series in Solid-State Sciences **185** (2016)

THEORY OF INELASTIC ELECTRON TUNNELING



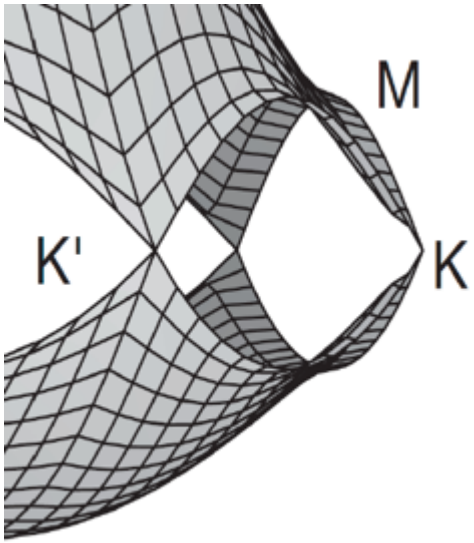
LDOS

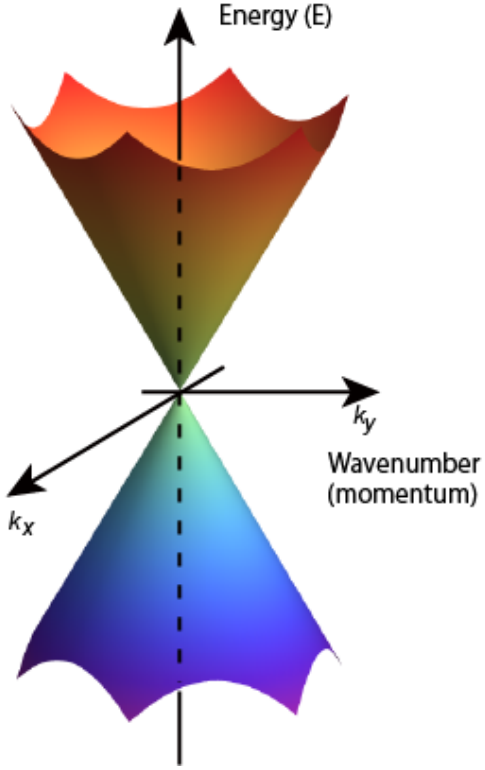
LDES

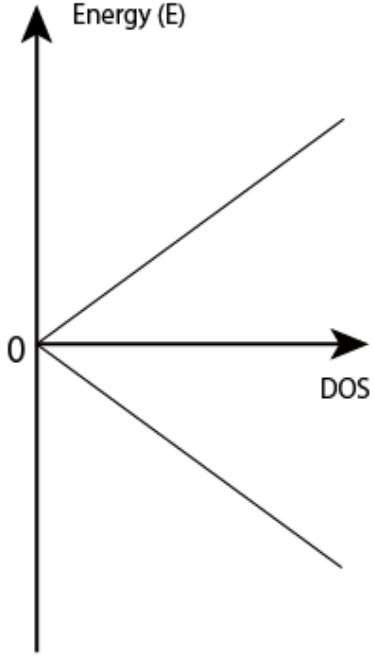
$$\gamma_{\mathrm{inel}}(\hbar\omega) = \frac{\pi e^2}{3\hbar\omega m^2 \varepsilon_0} \rho_{\mathrm{opt}}(\hbar\omega) \int_{\hbar\omega}^{eV_\mathrm{b}} |\mathcal{P}(E,\hbar\omega)|^2 \, \rho_\mathrm{L}(E-\hbar\omega)\, \rho_\mathrm{R}(E)\, \mathrm{d}E$$

M. Parzefall *et al.* in *Quantum Plasmonics*, Springer Series in Solid-State Sciences **185** (2016)

HOW TO GET LIGHT FROM GRAPHENE ?







HOW TO GET LIGHT FROM GRAPHENE ?

Thermal emission:

M. Freitag *et al. Nature Nano.* **5**, 497 (2010)

Y.D. Kim *et al. Nano Lett.* **18**, 934 (2018)

Bilayers:

Y. Zhang *et al. Nature* **459**, 820 (2009)

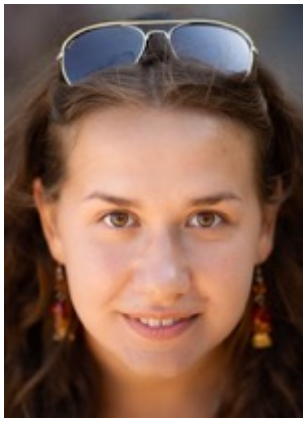
H. Patel *et al. Nature Comm.* **10**, 1445 (2019)

IR Plasmons:

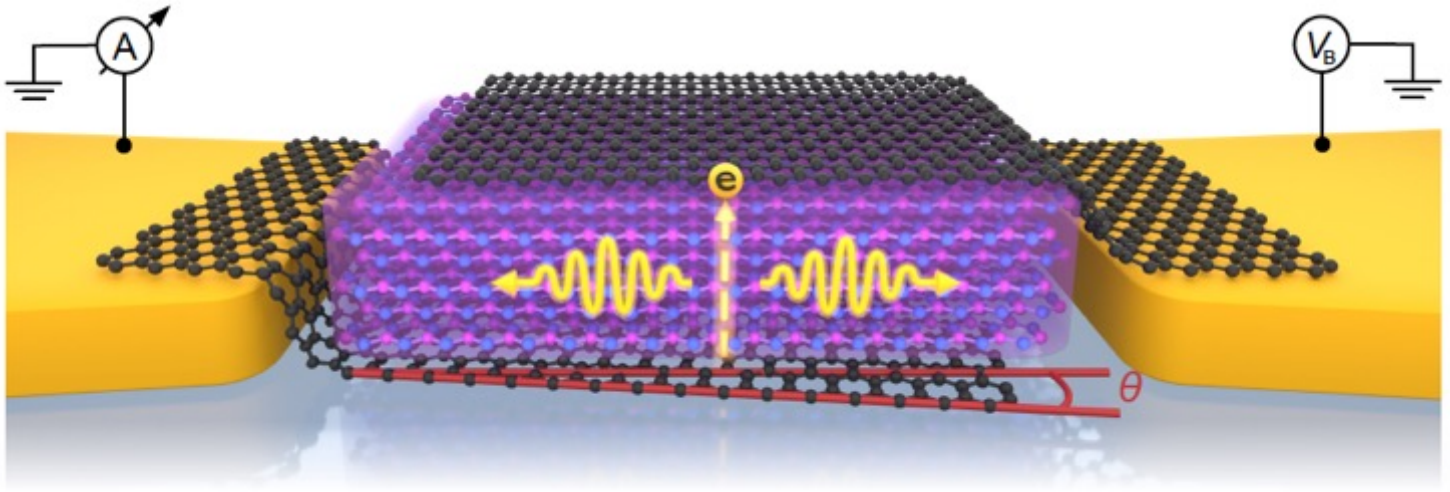
S. De Vega and F.J. Garcia de Abajo, *ACS Photonics* **4**, 2367 (2017)

A. Woessner *et al. ACS Photonics* ***4***, 3012 (2017)

LIGHT EMISSION FROM TWISTED GRAPHENE TUNNEL JUNCTIONS

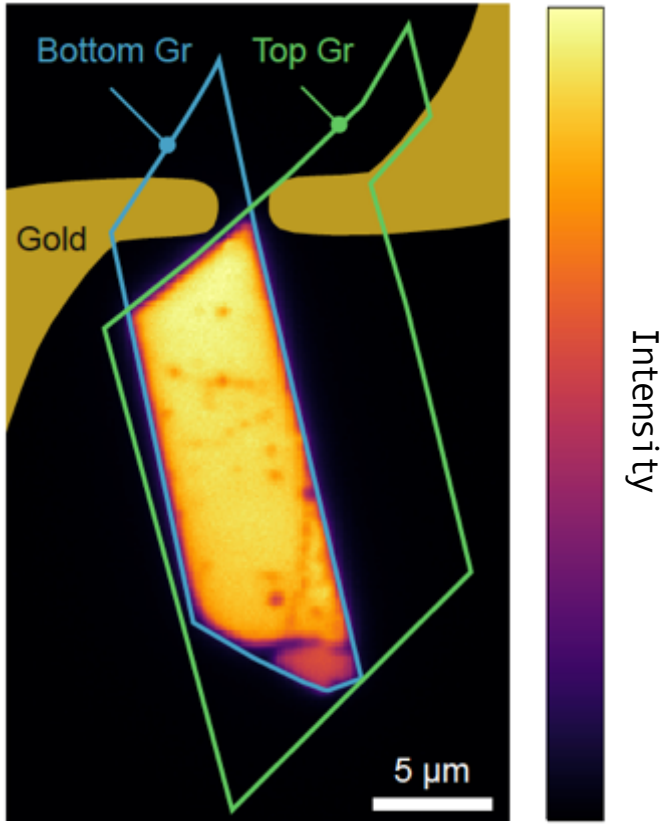


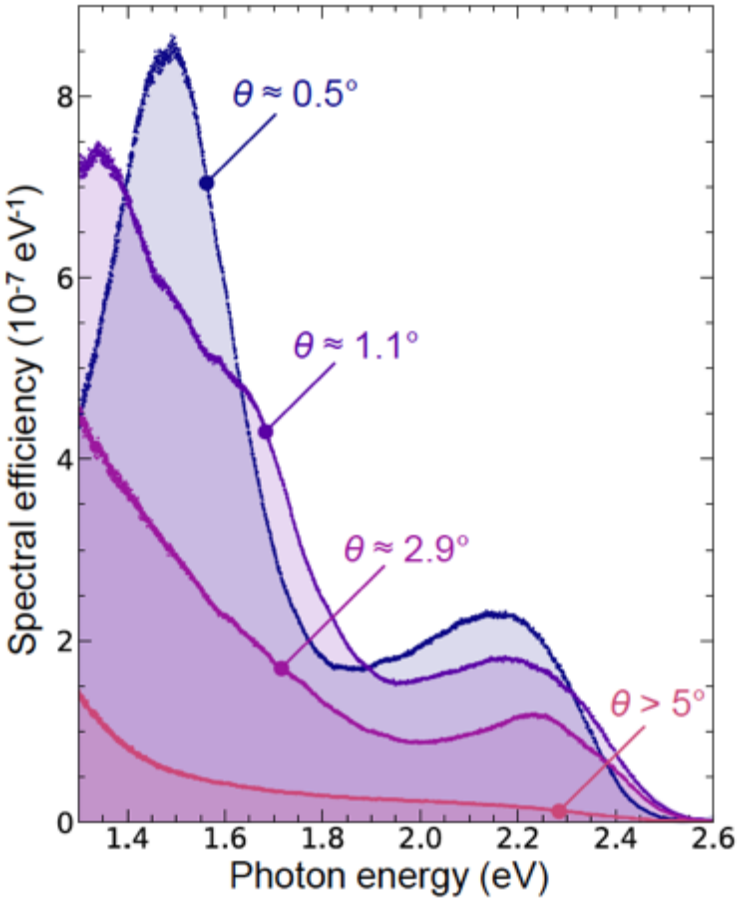
Anna Kuzmina



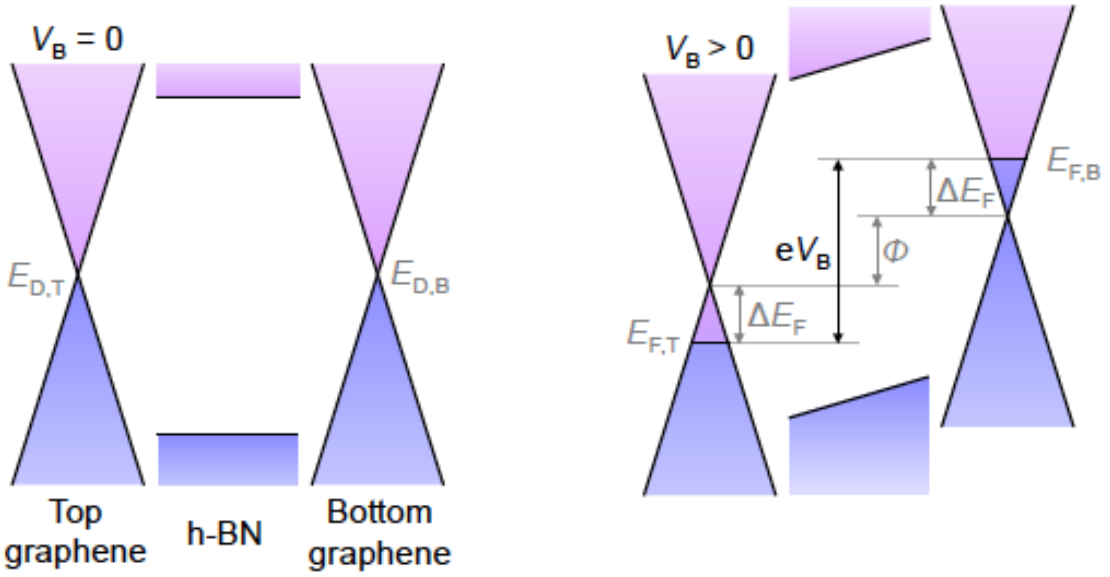
A. Kuzmina *et al.*
Nano Lett. **21**, 8332 (2021)

LIGHT EMISSION FROM TWISTED GRAPHENE TUNNEL JUNCTIONS





VOLTAGE DROP ACROSS DEVICE



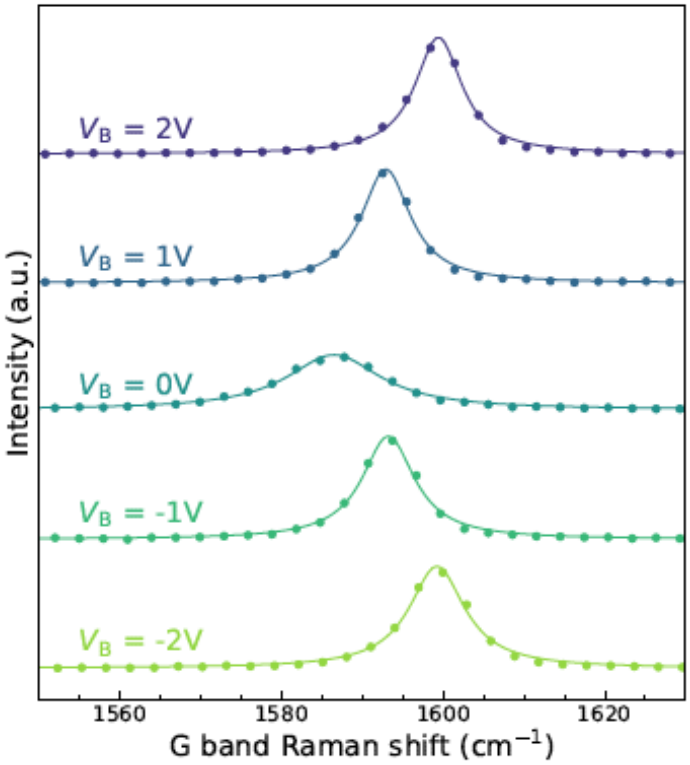
induced carrier density

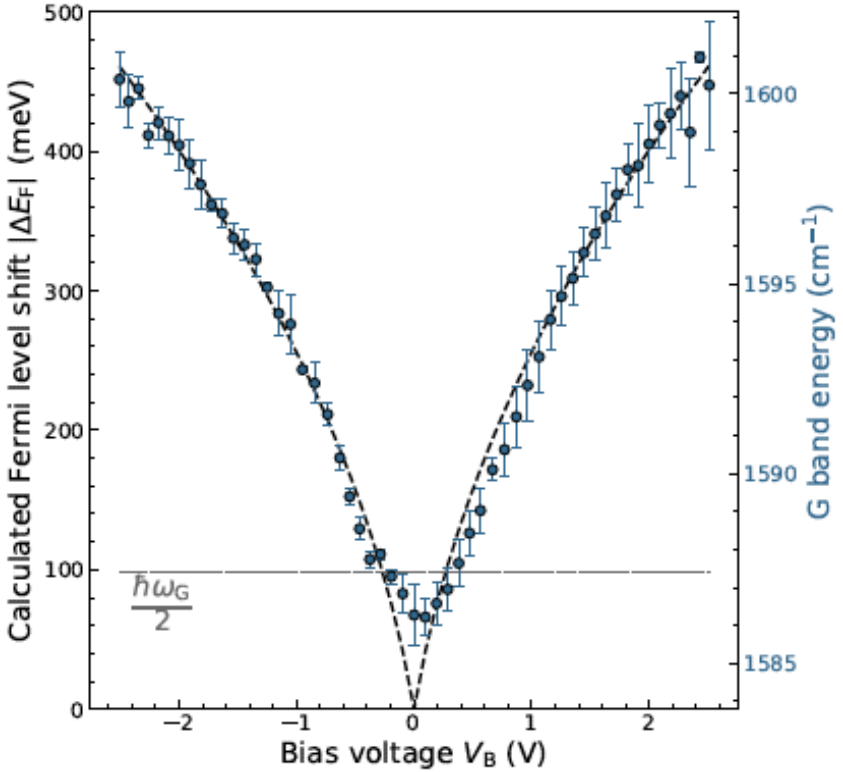
$$eV_B = \Phi + 2\Delta E_F = e\left(\frac{en_{Gr}}{C_G}\right) + 2\Delta E_F$$

geometric capacitance

$$= \frac{\mathrm{sgn}(\Delta E_F)e^2}{\pi\hbar^2 v_F^2}\frac{d_{BN}}{\varepsilon_0\varepsilon_{BN}}\Delta E_F{}^2 + 2\Delta E_F$$

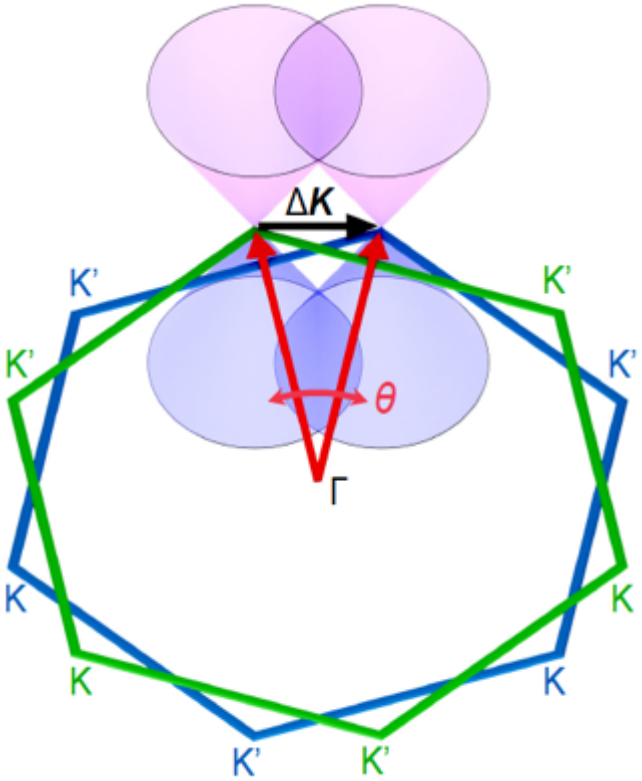
FERMI ENERGY MEASURED VIA RAMAN G-BAND FREQUENCY





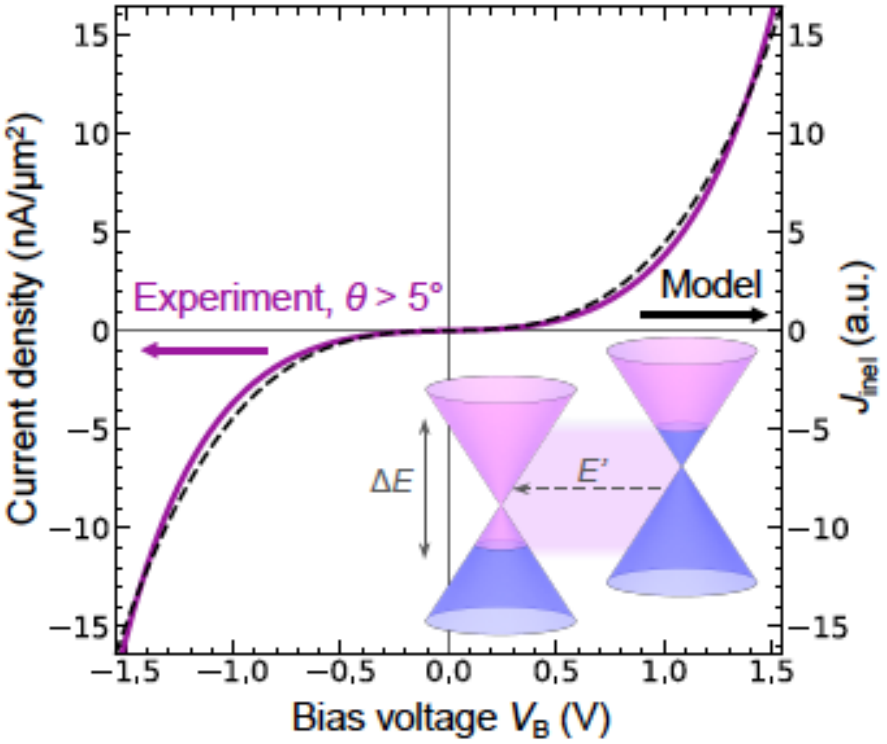
cf. J. Yan *et al. Phys. Rev. Lett.* **98**, 166802 (2007)

TWIST-ANGLE DEPENDENT TUNNELING



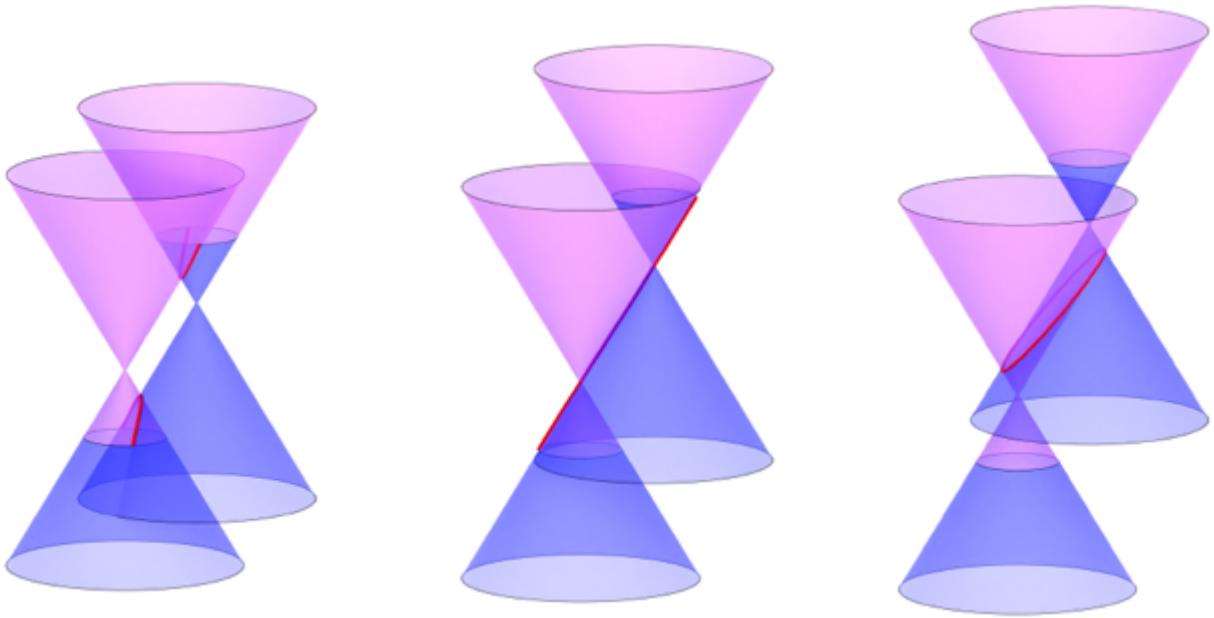
$$|\Delta \boldsymbol{K}| = \sqrt{2}\,|\boldsymbol{K}|\sqrt{1-\cos\theta}$$

CONE-CONE TUNNELING



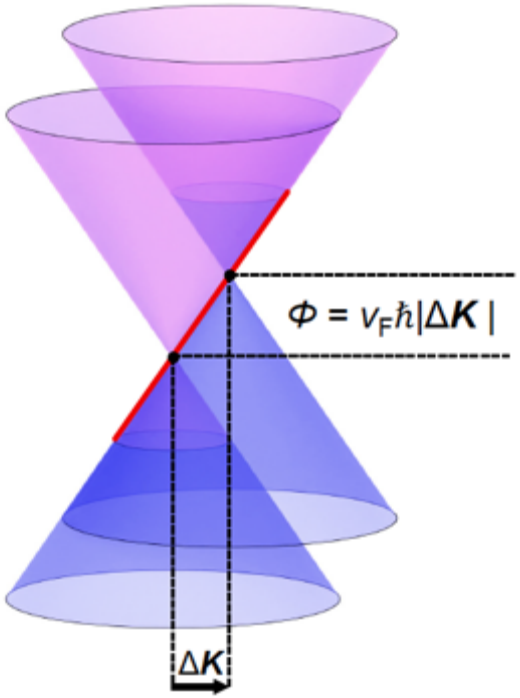
phonon-assisted inelastic tunneling
(momentum non-conserving)

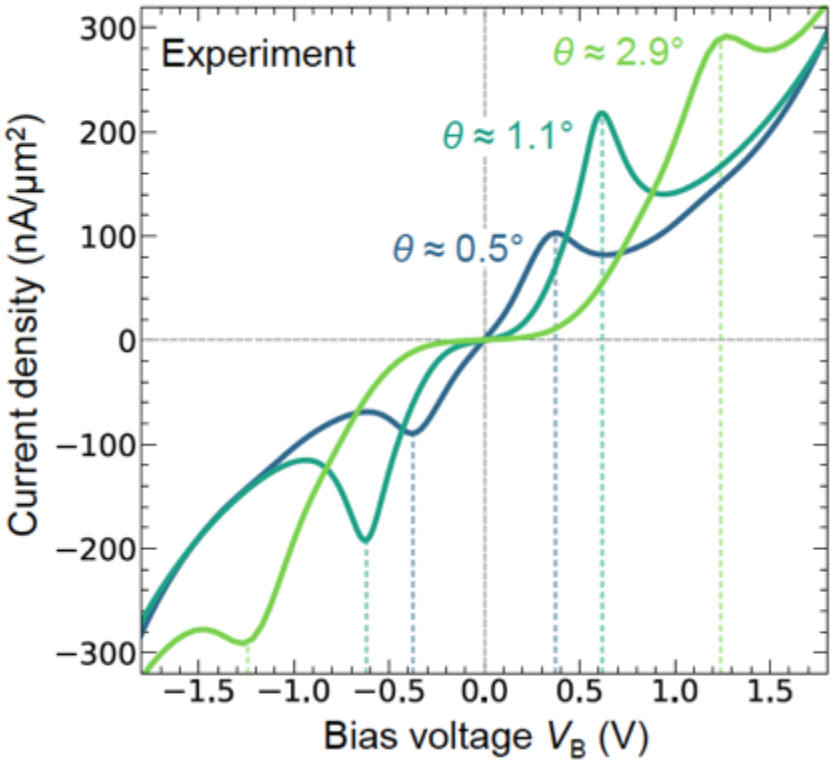
MOMENTUM MATCHING TUNNELING



negative differential
conductance (NDC)

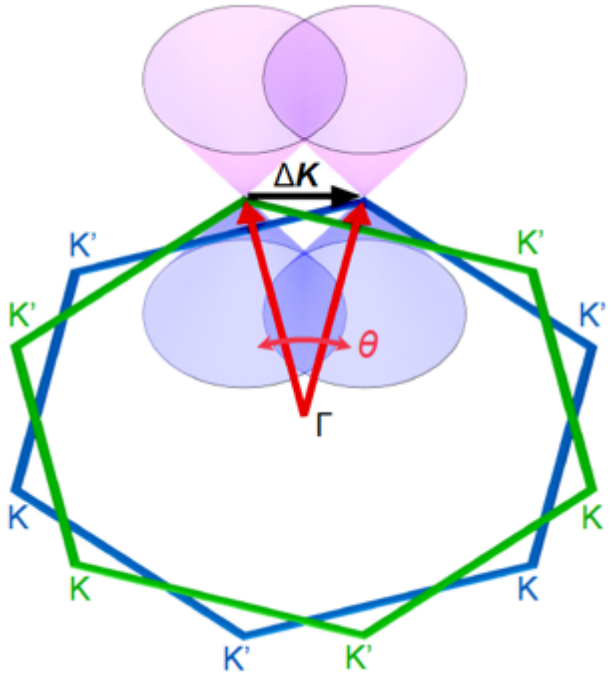
NEGATIVE DIFFERENTIAL CONDUCTIVITY PEAK

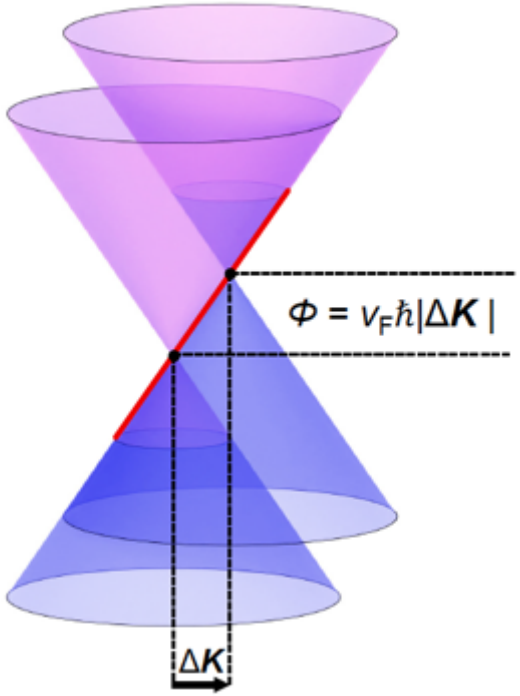




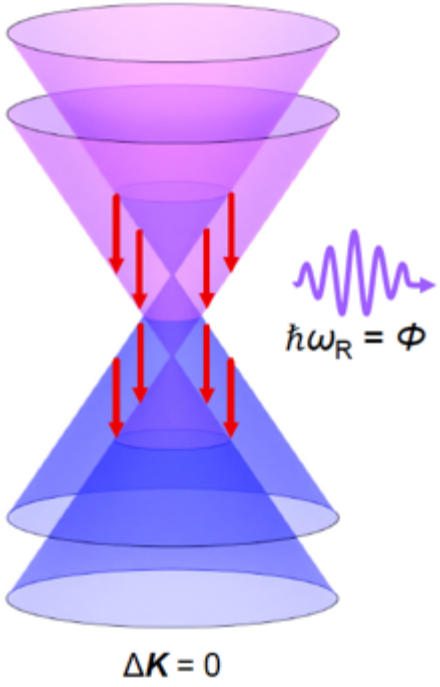
cf. A. Mishchenko *et al. Nature Nano* **9**, 808 (2014)

MOMENTUM MATCHING TUNNELING (PHOTON ASSISTED)



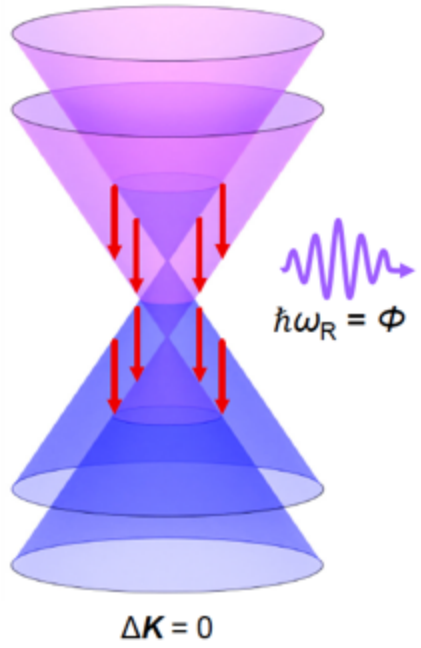


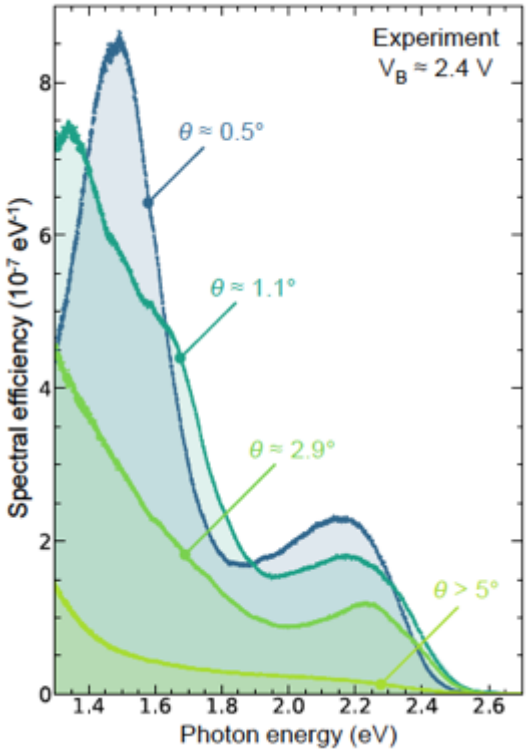
resonant
elastic
tunneling

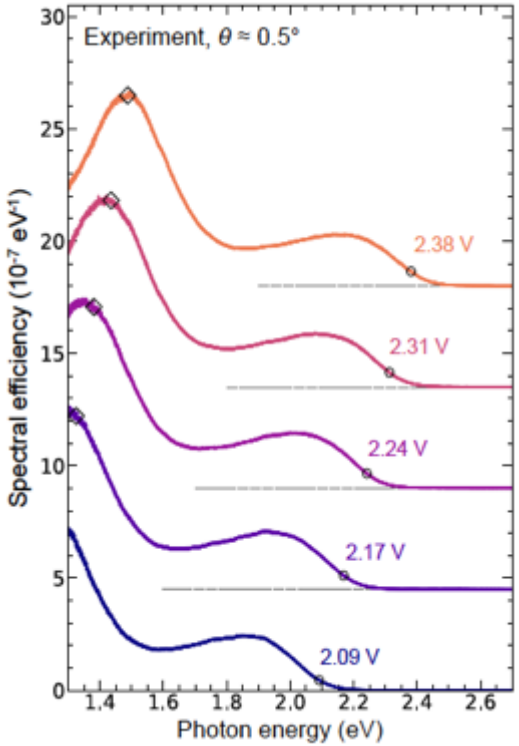


photon-assisted
inelastic
tunneling

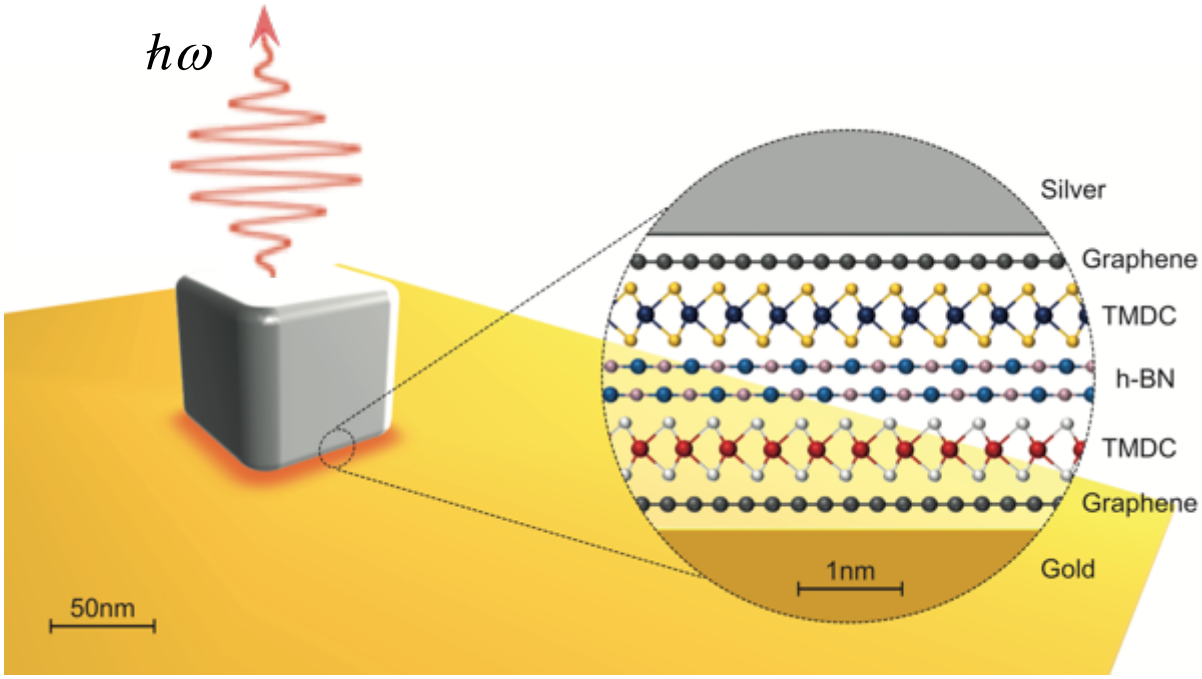
LIGHT EMISSION FROM TWISTED GRAPHENE





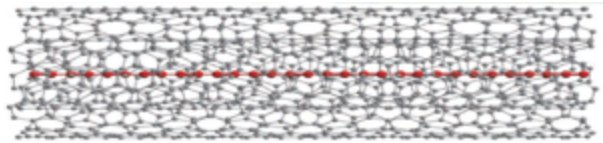


VAN DER WAALS TUNNEL JUNCTIONS



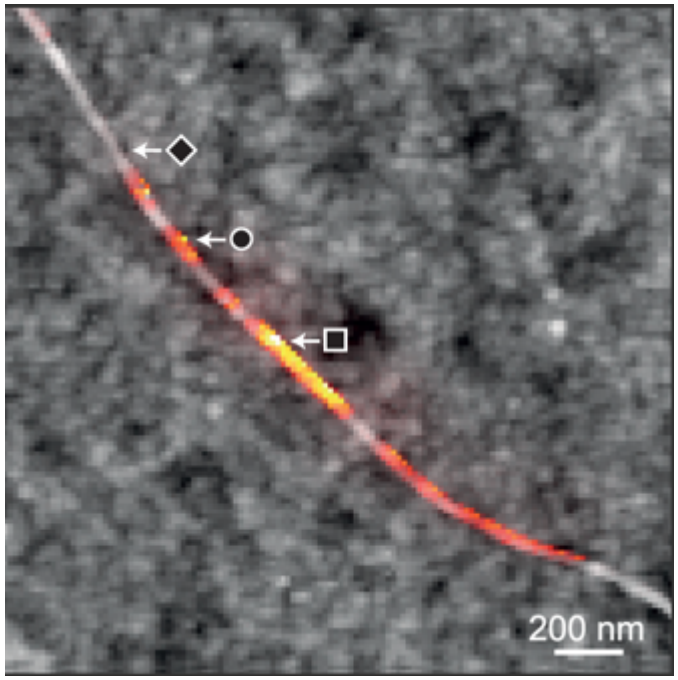
Objective: small + fast + efficient

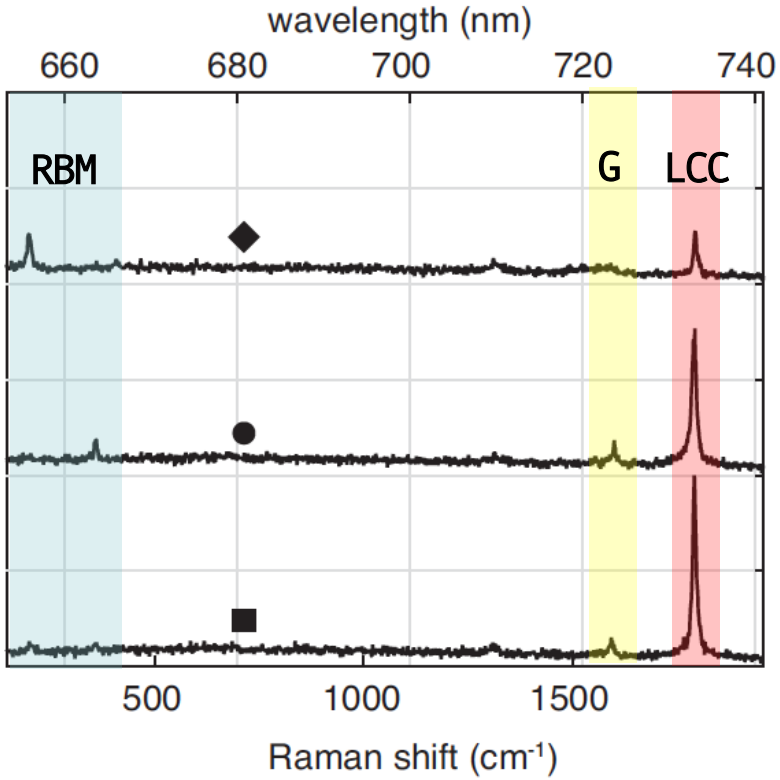
LINEAR CARBON CHAINS



with Thomas Pichler
University of Vienna

Cla Duri Tschannen





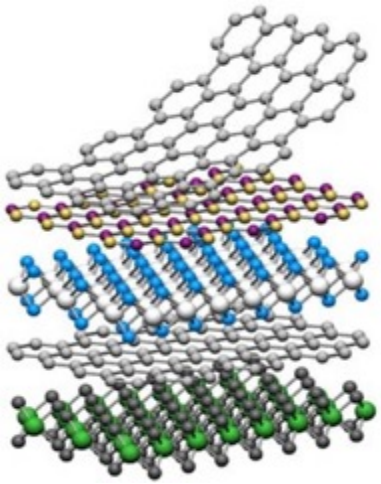
Faraday Discuss. **184**, 193 (2015)

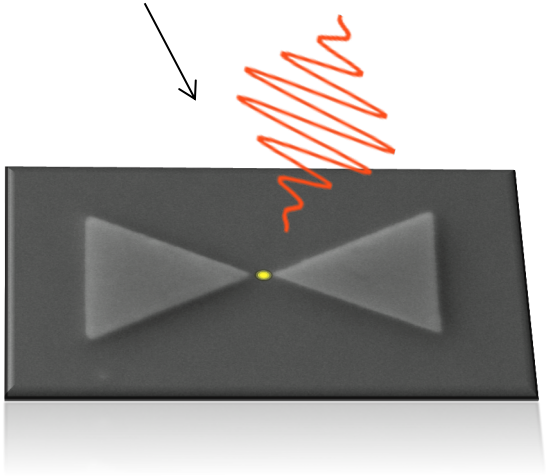
SUMMARY

$$\Gamma = \frac{\pi\,\omega}{3\hbar\varepsilon_o}\,|\langle g|\hat{\mathbf{p}}|e\rangle|^2\,\rho_{\mathbf{p}}(\mathbf{r}_m,\omega)$$

Matter

Field





CURRENT WORK:

Twisted bilayer LEDs