Transport in adatom-decorated graphene

Erik Henriksen
Chandni U
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(and EAH)

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University
in St. Louis

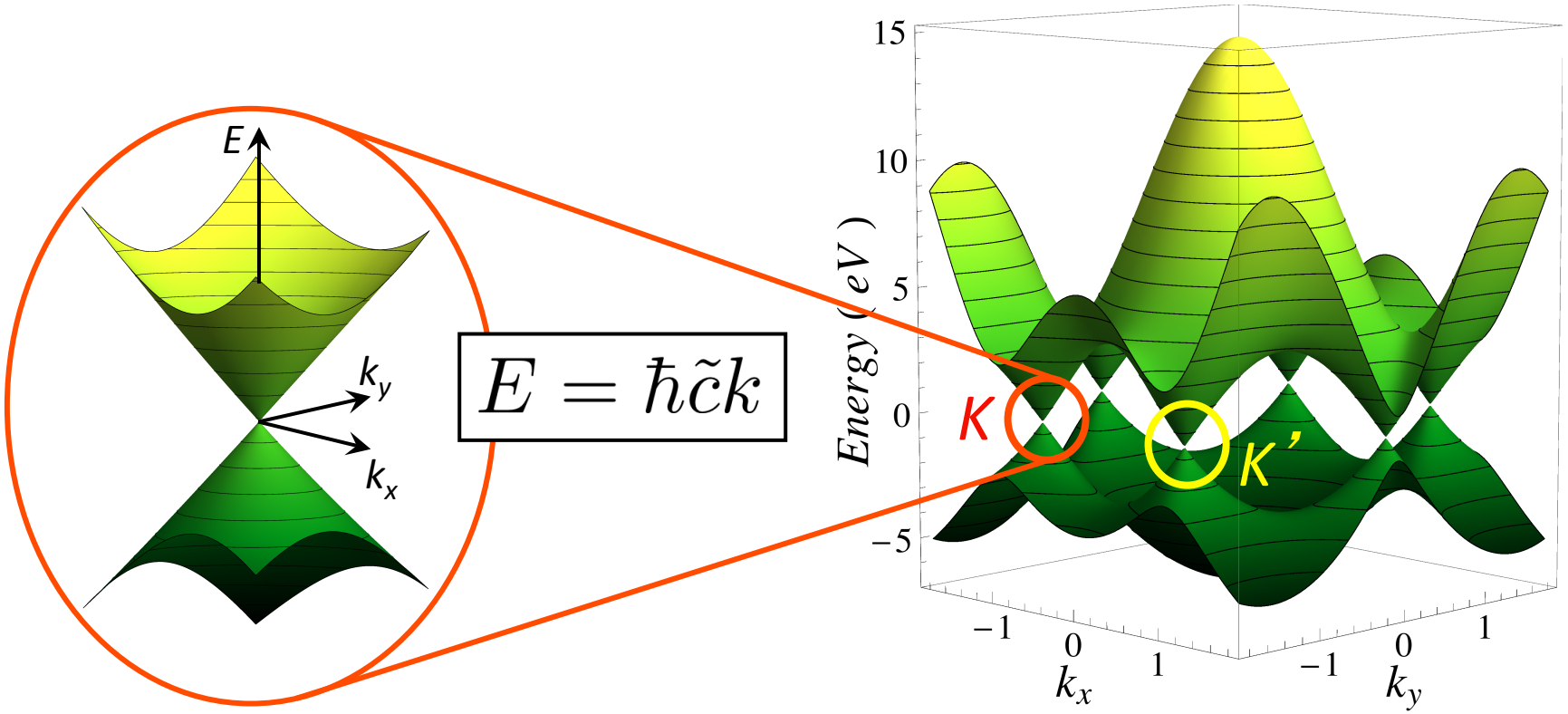
Outline

I. **Motivation**
   topological physics from adatoms on graphene

II. Indium atoms on graphene (Caltech)
   experimental apparatus for *in situ* deposition
   results

III. 5*d* atoms on graphene (Wash. U.)
   2nd generation apparatus
   initial findings

Graphene



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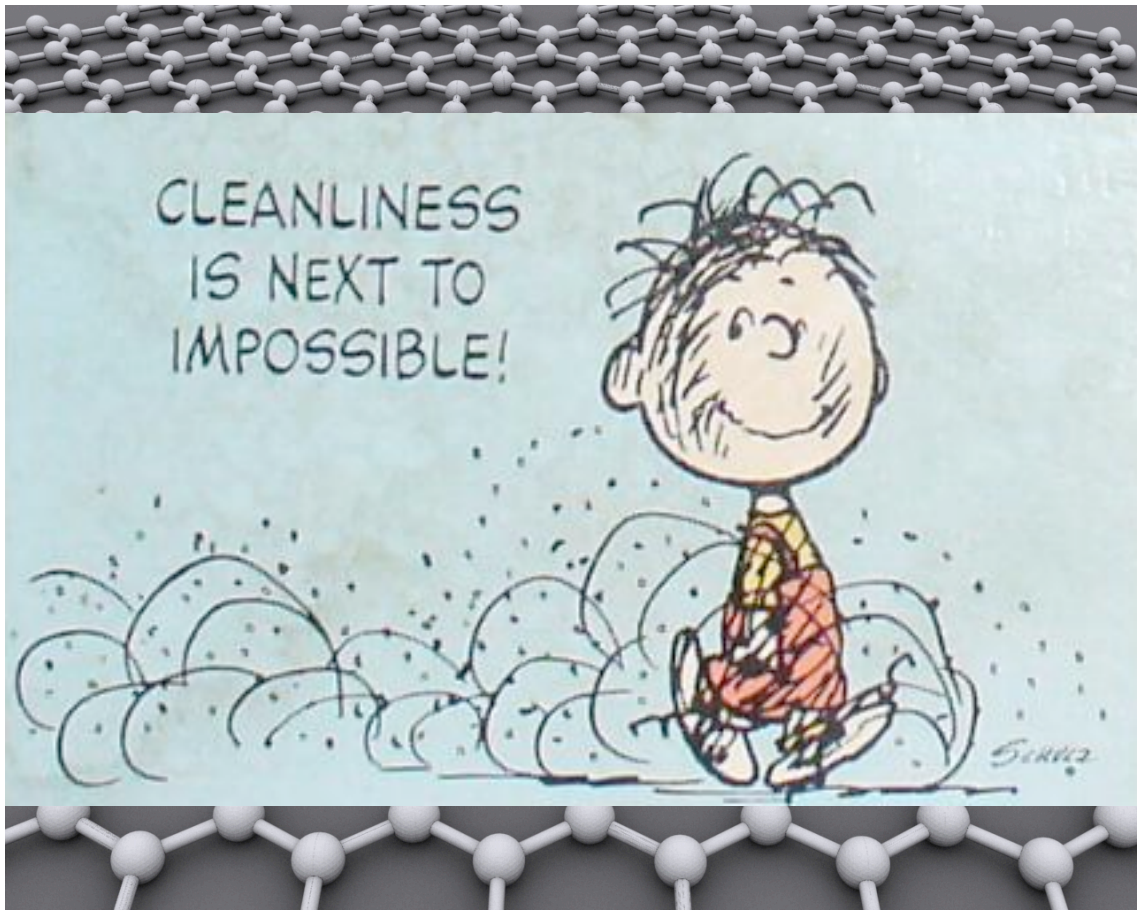

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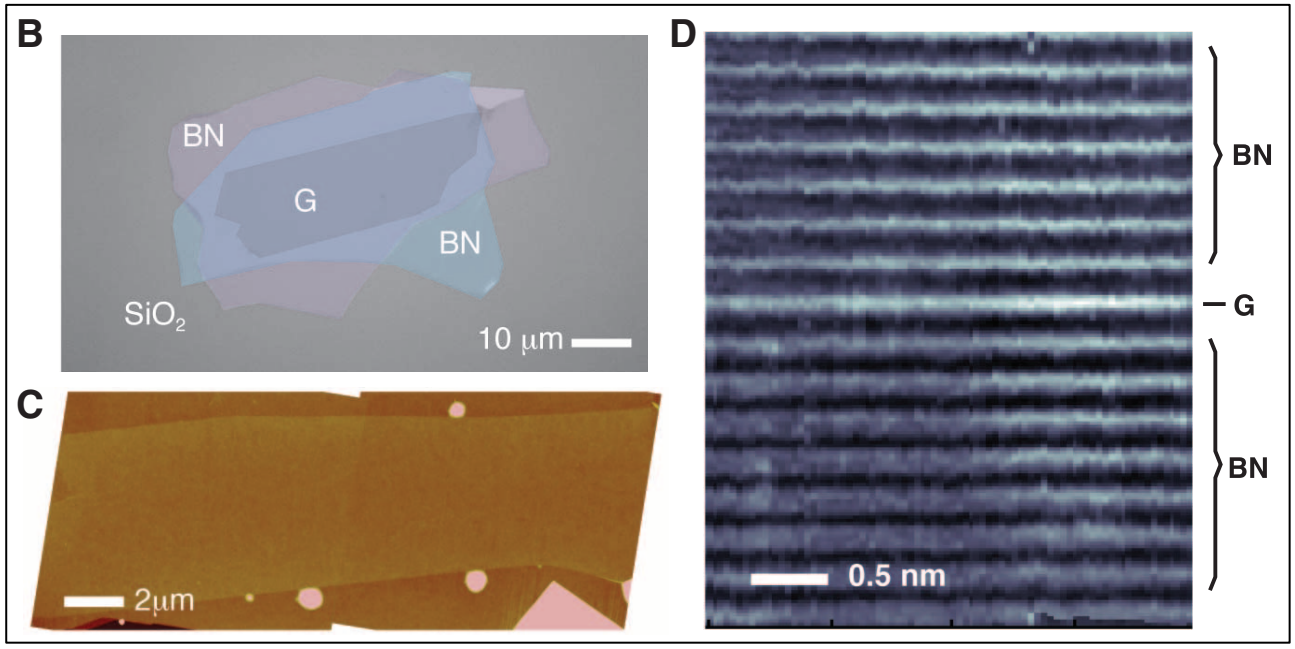
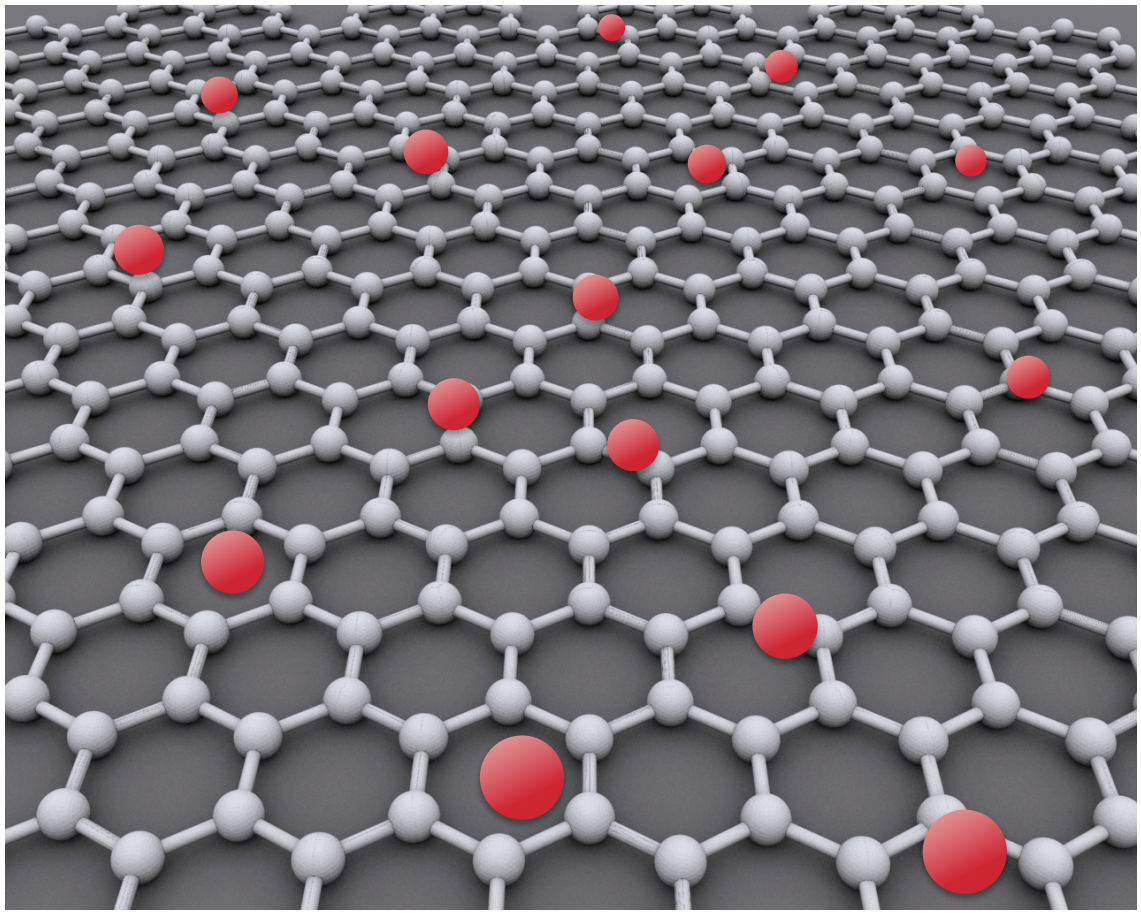
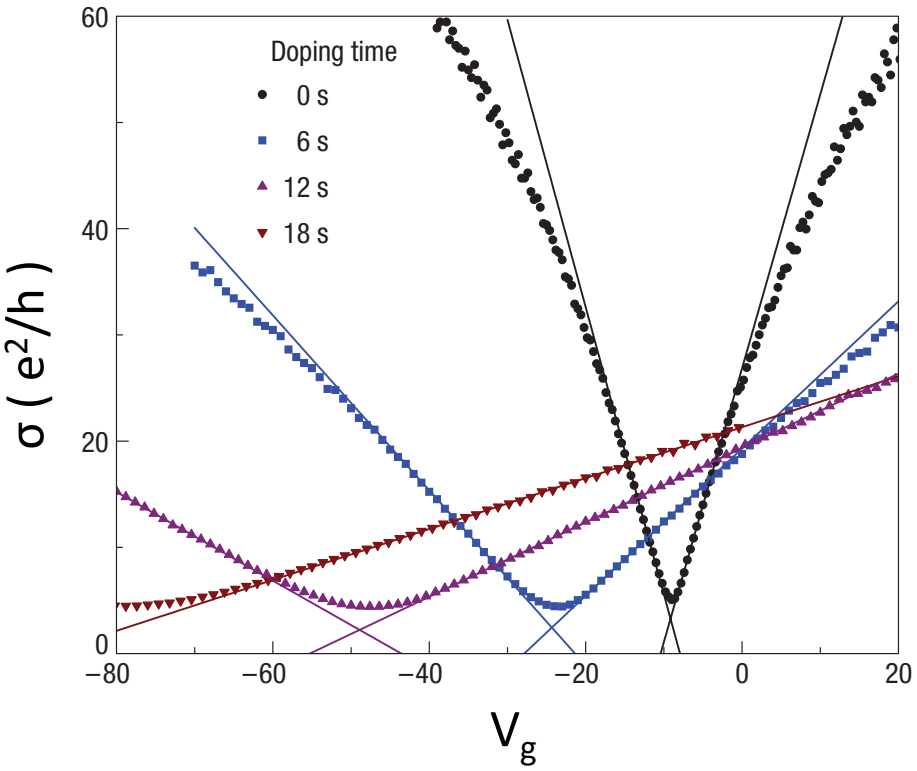


Wang *et al.*, Science **342**, 614 (2013)

Graphene



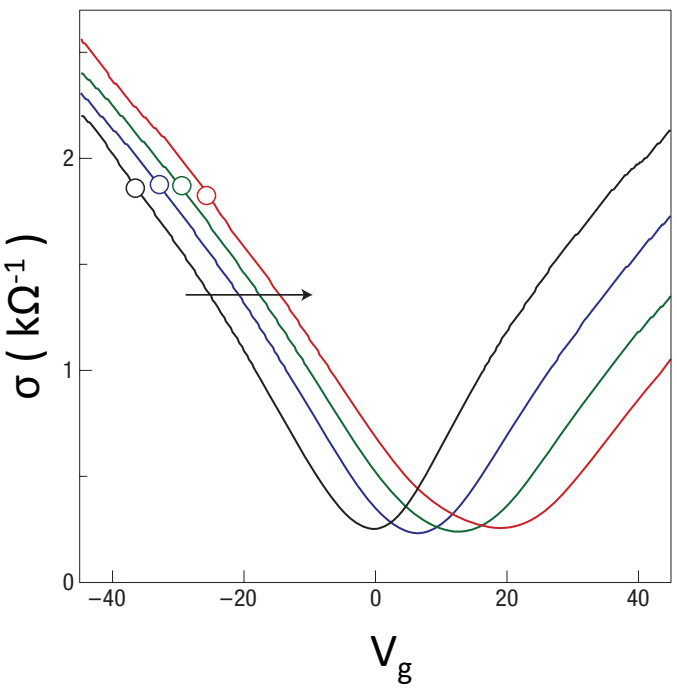
Deposition of *K* atoms

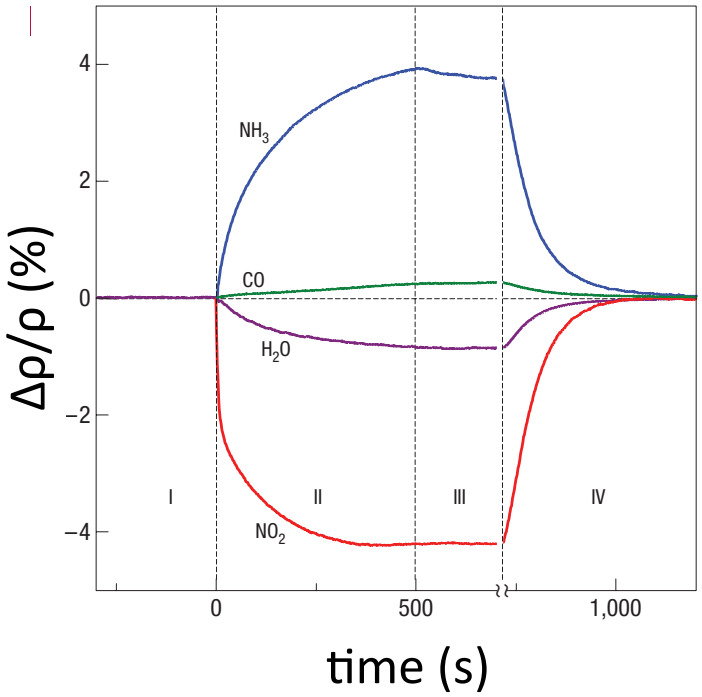


Chen *et al*., Nature Phys **4**, 377 (2008)

also Yan & Fuhrer, PRL **107**, 206601 (2011)

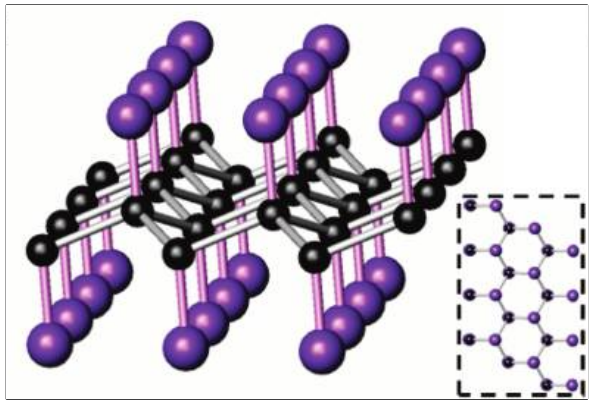
Adsorption of molecules





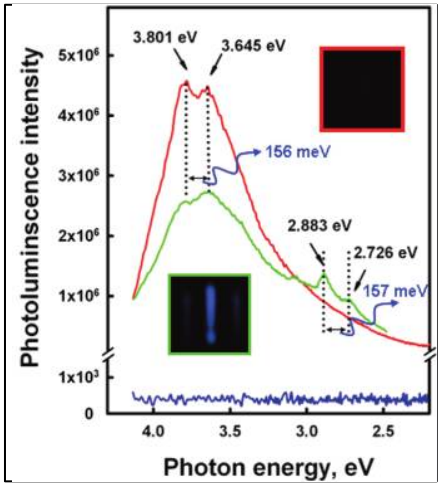
Schedin *et al.*, Nature Materials **6**, 652 (2007)

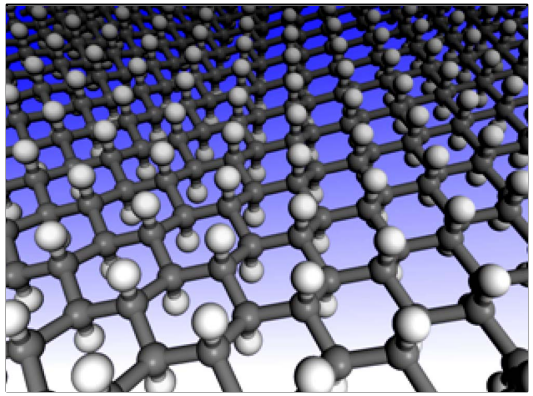
Chemical functionalization



fluorinated and fluoro-graphene

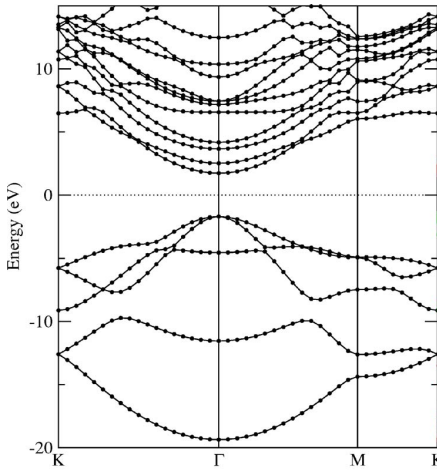
Nair *et al.*, Small **6,** 2877 (2010)
Jeon *et al.*, ACS Nano **5**, 1042 (2011)
Hong *et al.*, PRB **83,** 085410 (2011)





graphane

Sofo *et al.*, Phys. Rev. B **75**, 153401 (2007)
Elias *et al.*, Science **323**, 610 (2009)

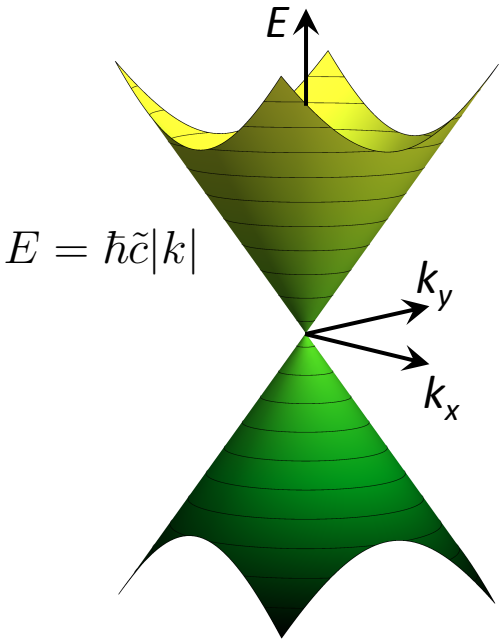


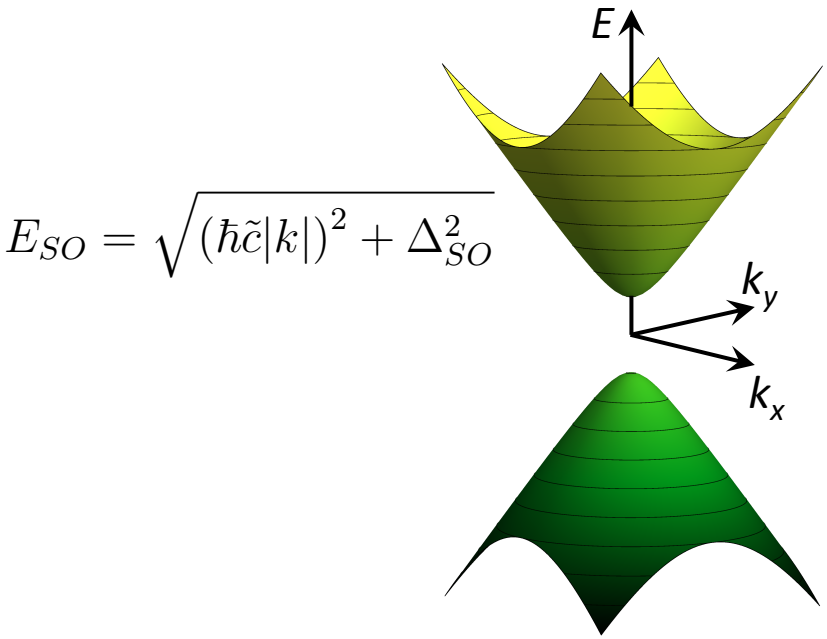
Graphene topological insulator

Kane & Mele, Phys. Rev. Lett. **95**, 226801 (2005)

$$H = \hbar\tilde{c}\begin{pmatrix} 0 & k_x - ik_y \\ k_x + ik_y & 0 \end{pmatrix}$$

$$H = \hbar\tilde{c}\begin{pmatrix} \Delta_{SO} & k_x - ik_y \\ k_x + ik_y & -\Delta_{SO} \end{pmatrix}$$





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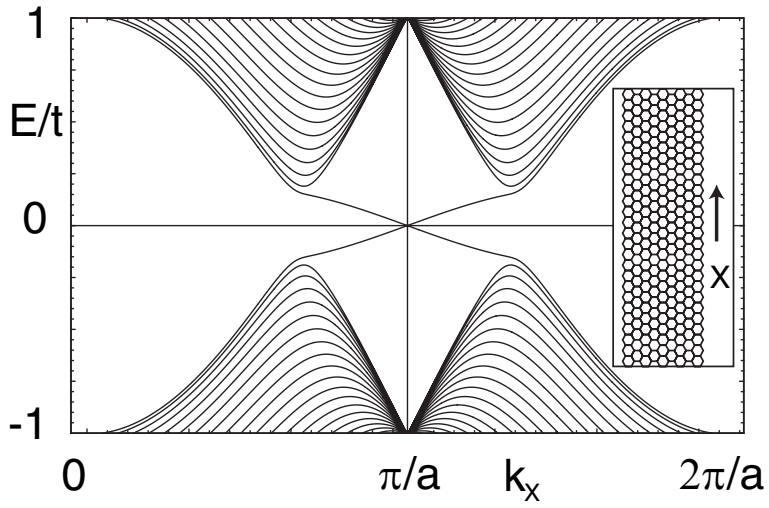
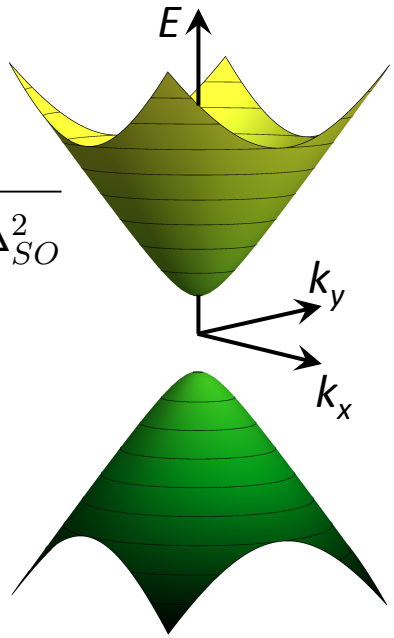
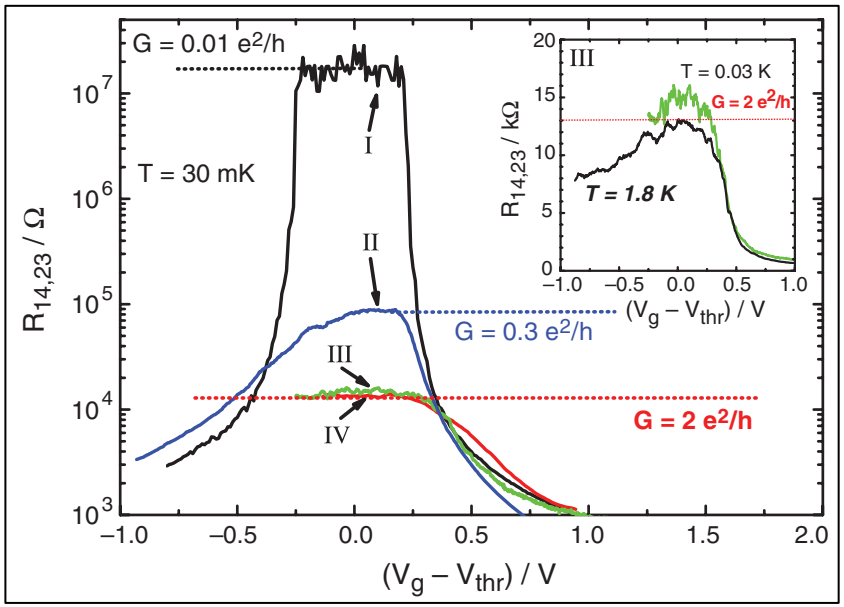


$$E_{SO} = \sqrt{(\hbar\tilde{c}|k|)^2 + \Delta_{SO}^2}$$



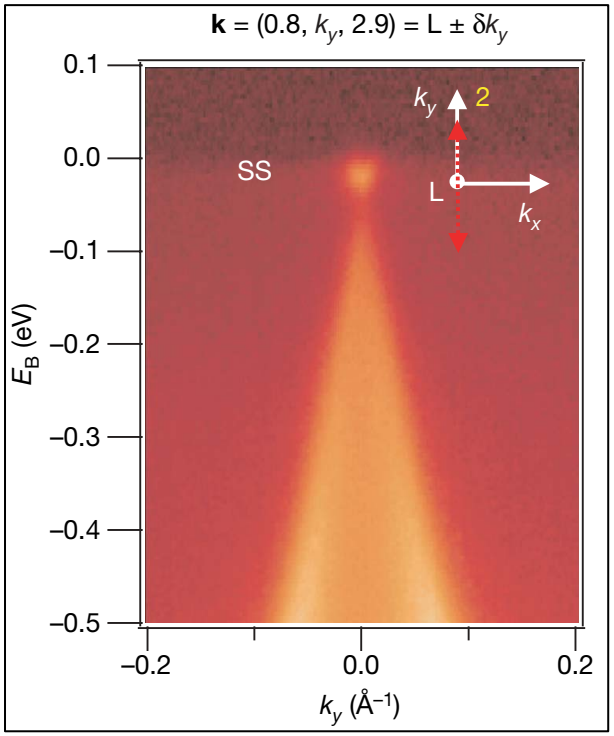
Topological insulators

2D



König *et al.*, Science **318**, 766 (2007)

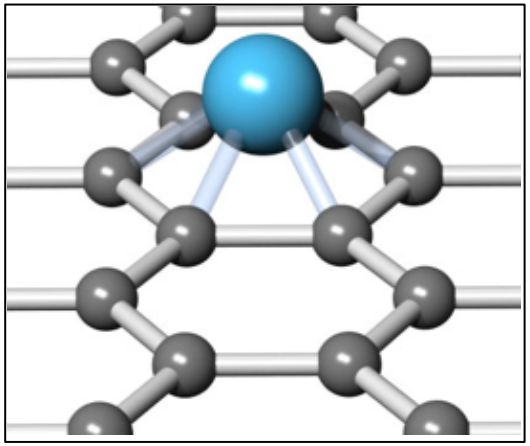
3D

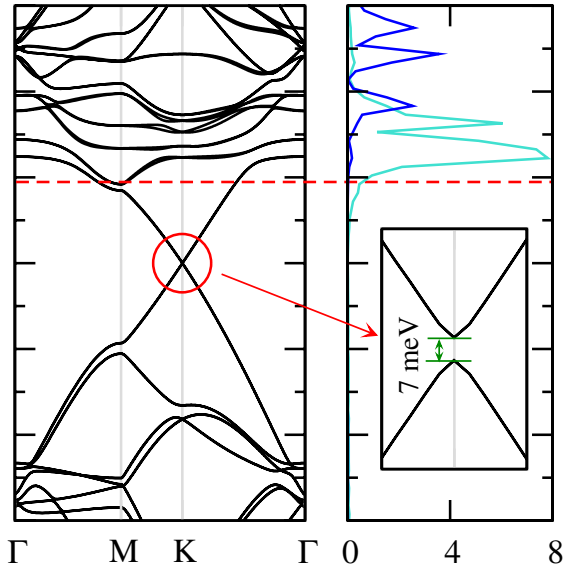


Hsieh *et al.*, Nature **452**, 970 (2008)

Graphene topological insulator

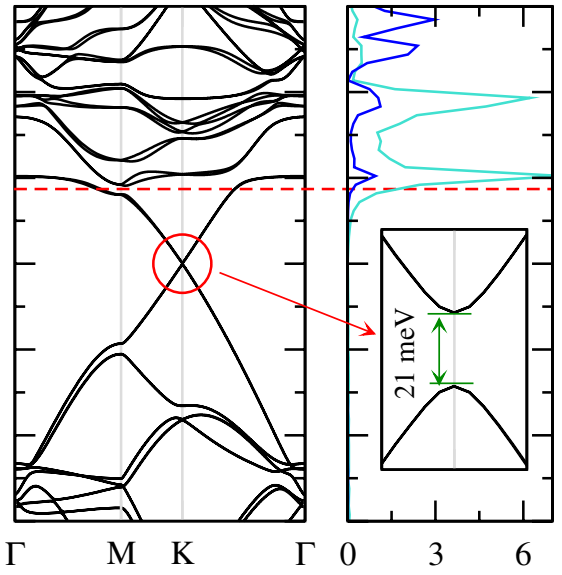
Weeks *et al.*, PRX **1**, 021001 (2011)





indium

7 meV gap

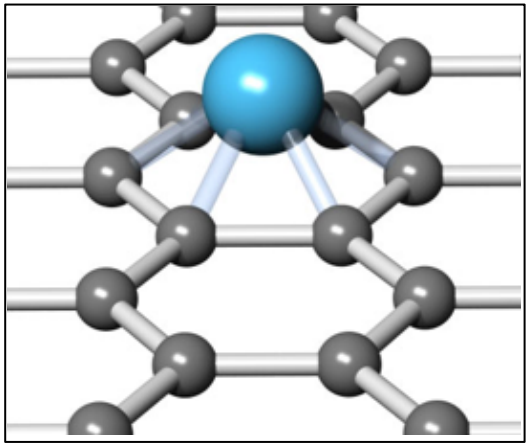


thallium

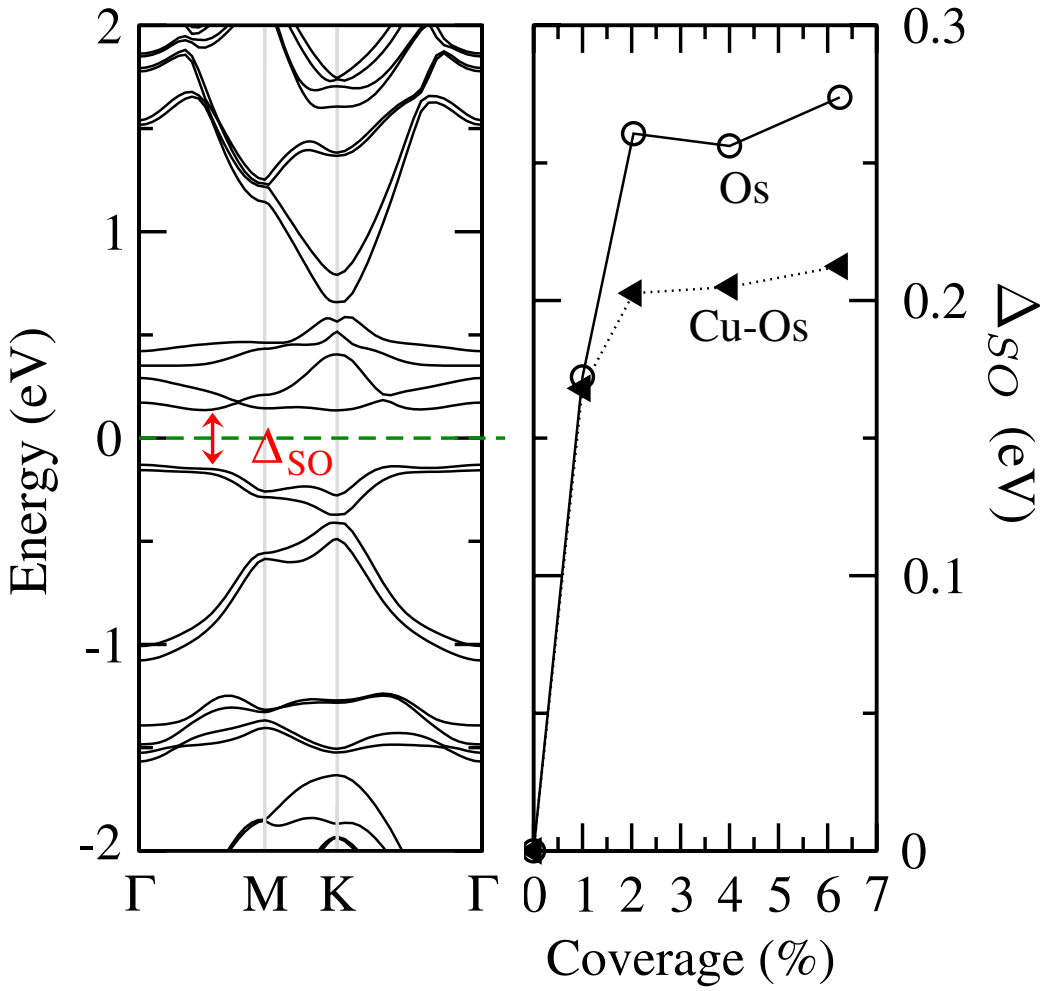
21 meV gap

Graphene topological insulator

Weeks *et al.*, PRX **1**, 021001 (2011)
Hu *et al.*, PRL **109**, 266801 (2012)



with 5*d* atoms e.g. osmium



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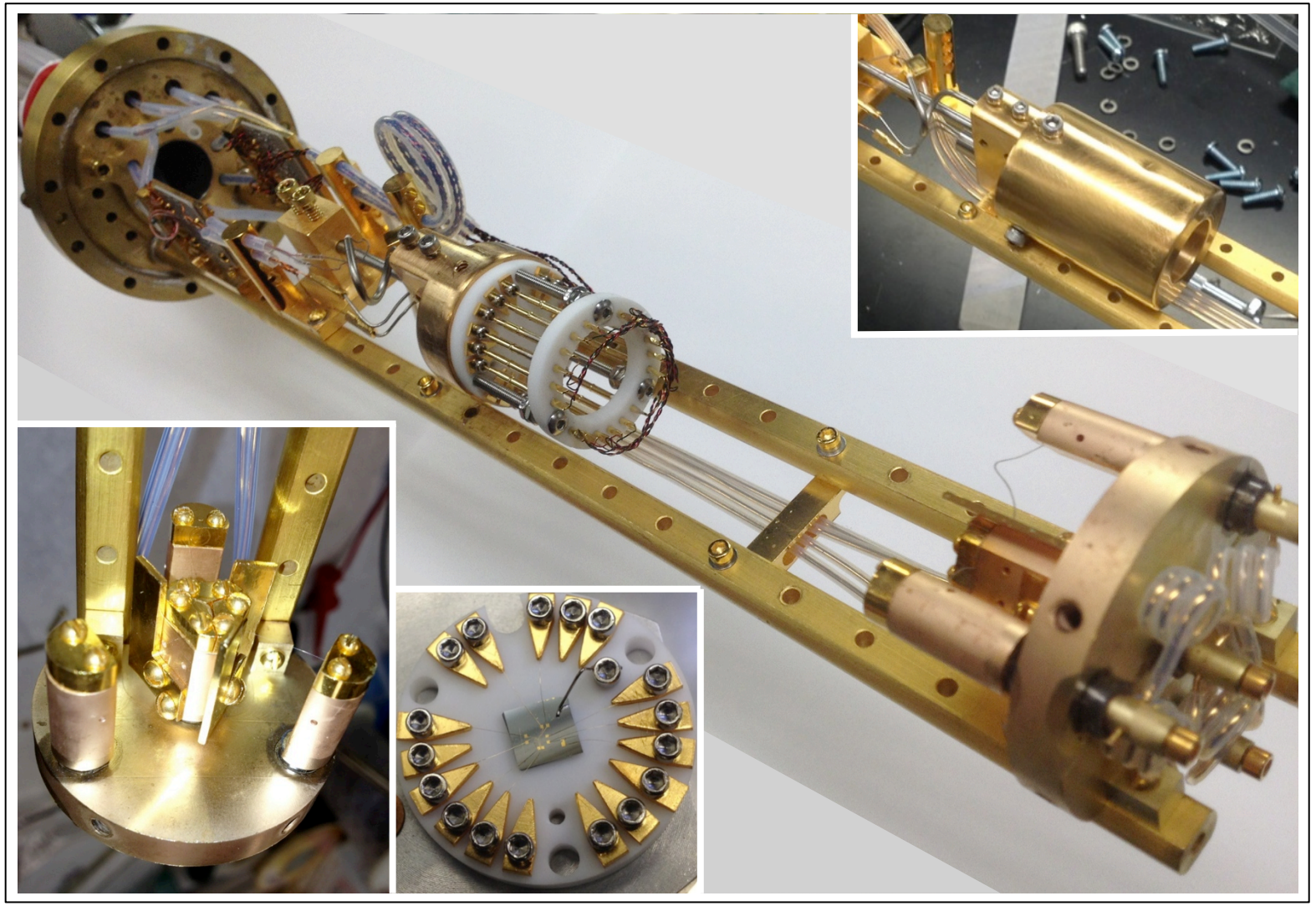
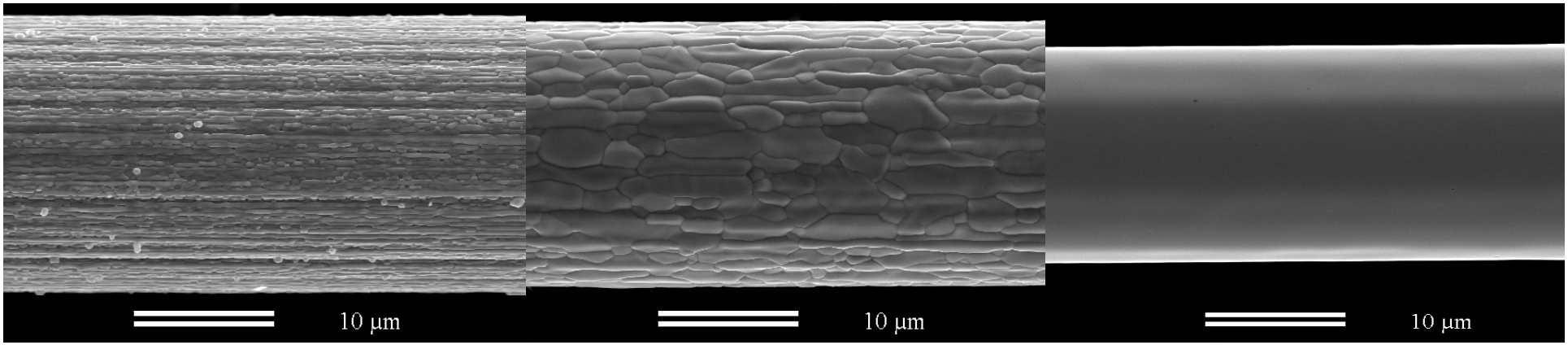
   initial findings

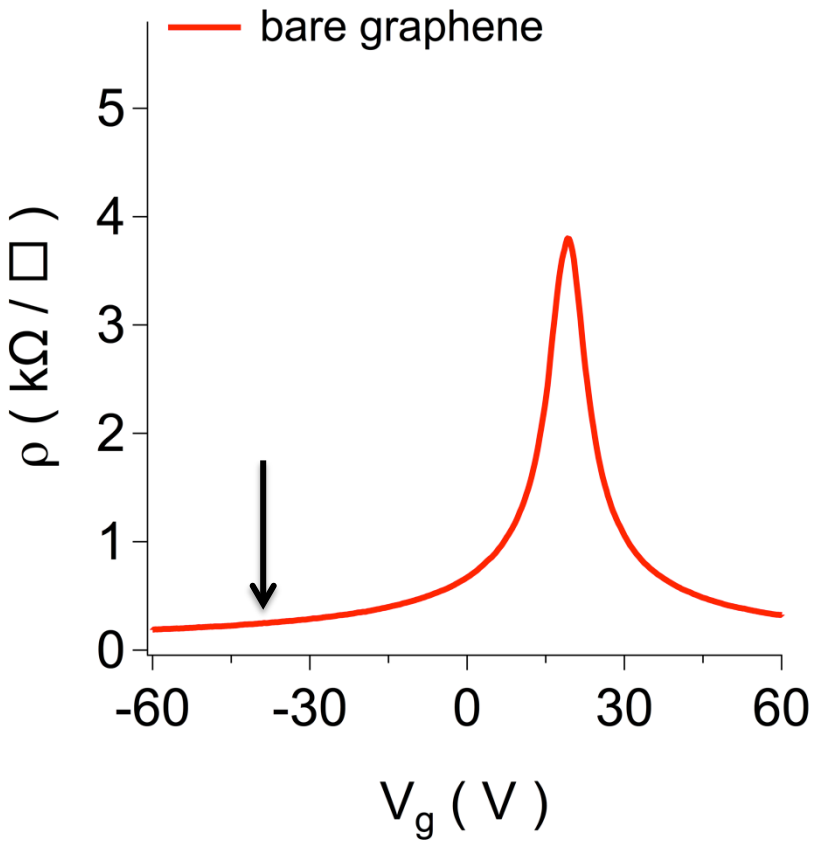
In situ evaporation

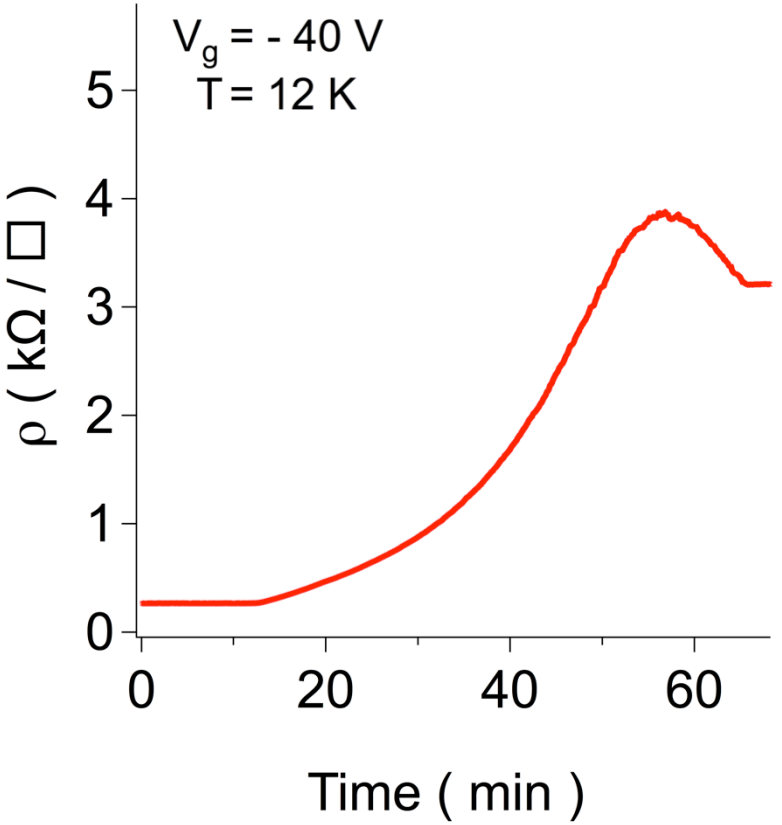


Evaporation sources

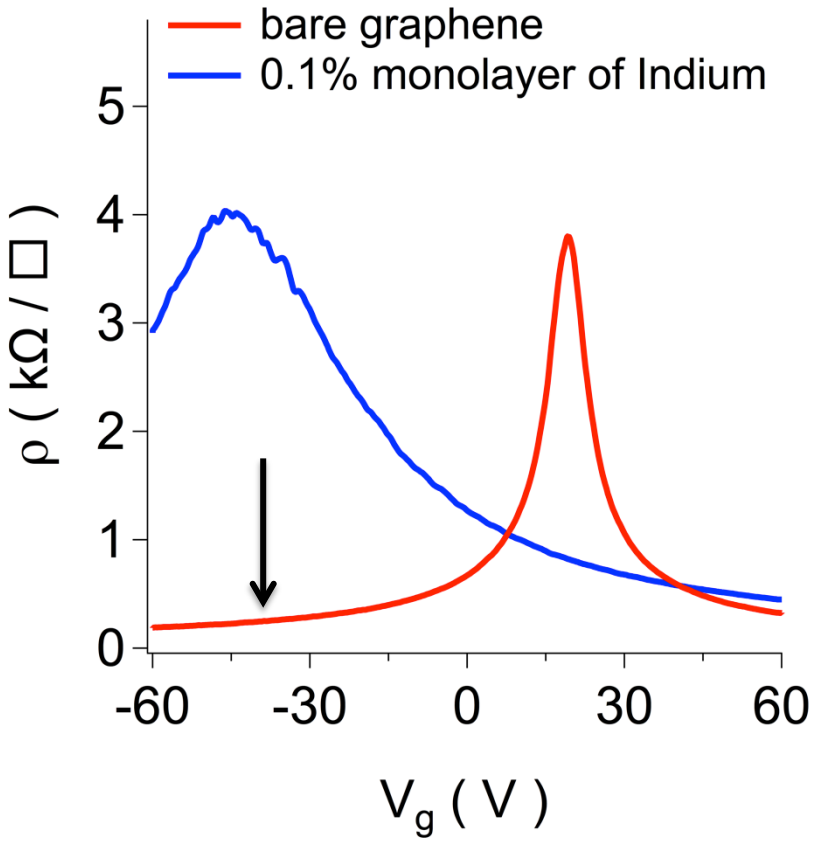


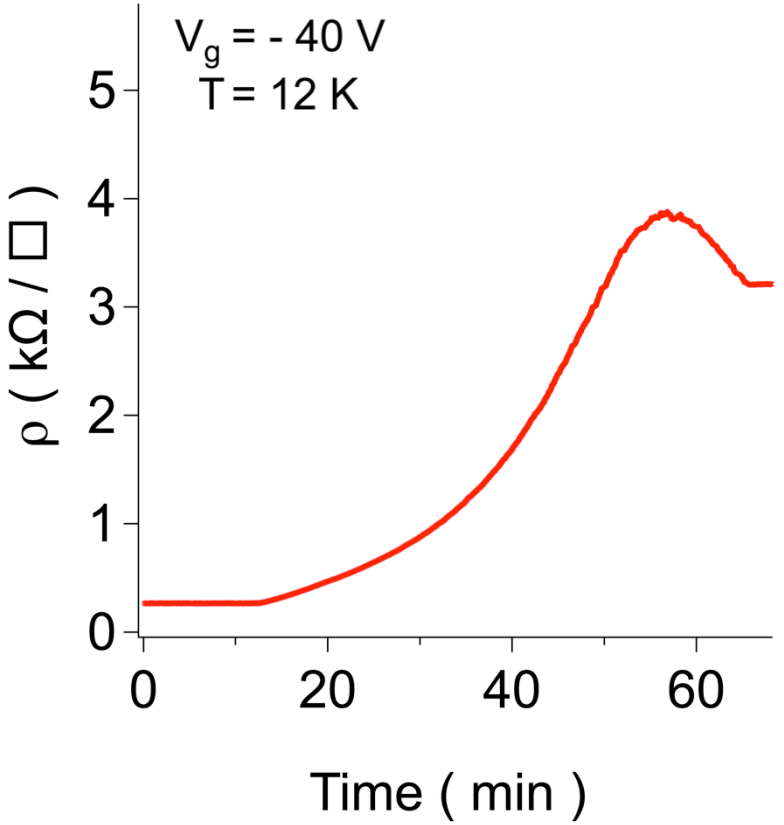
Indium deposition





Indium deposition





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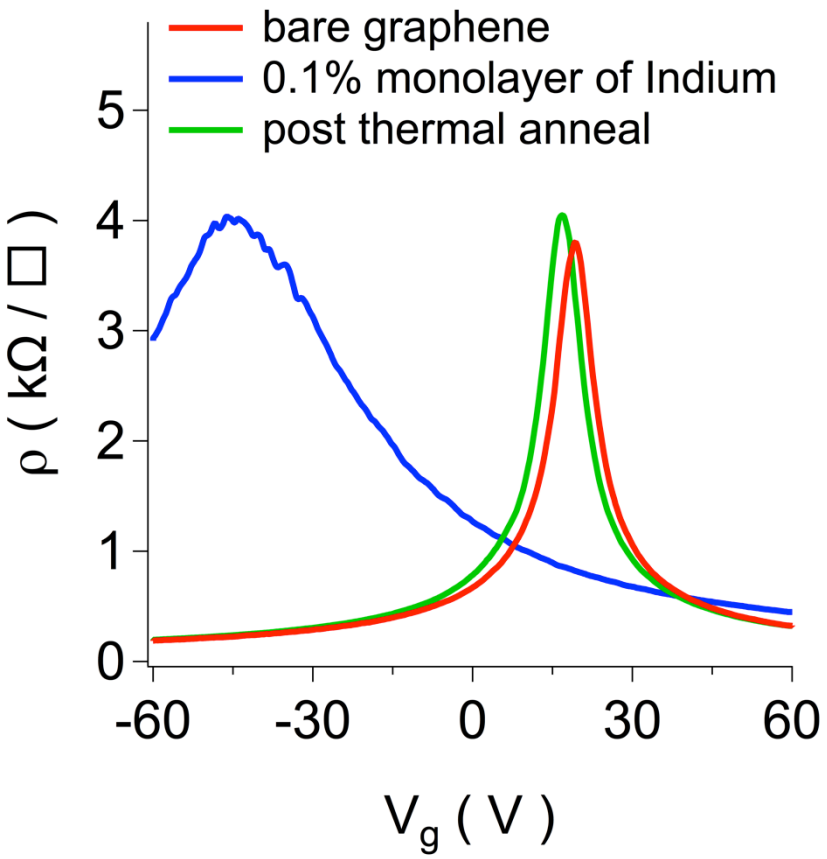

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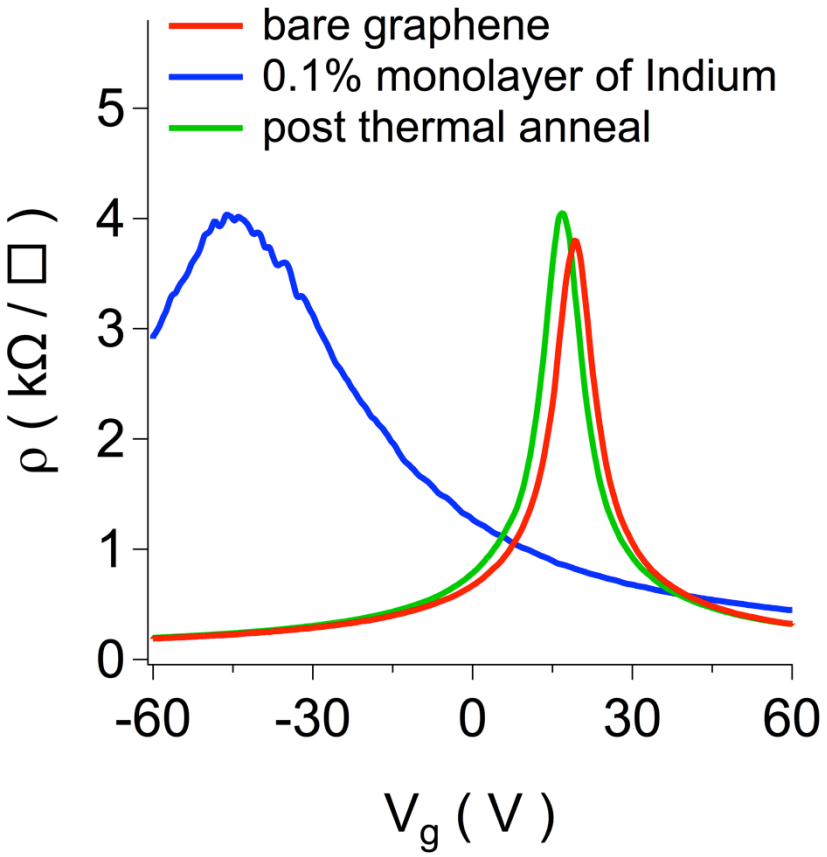

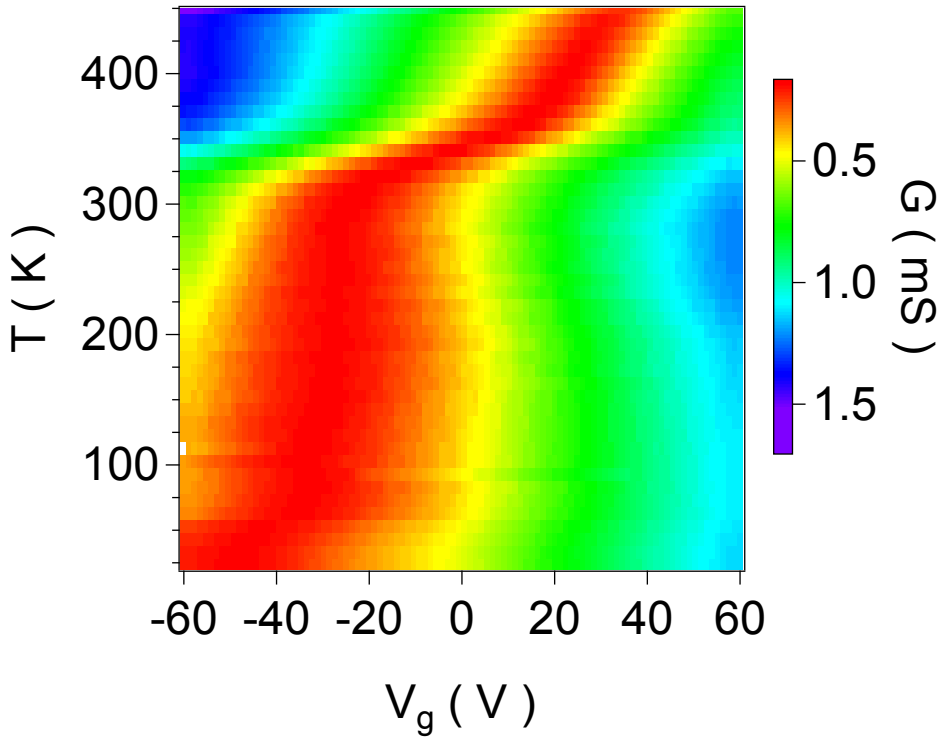

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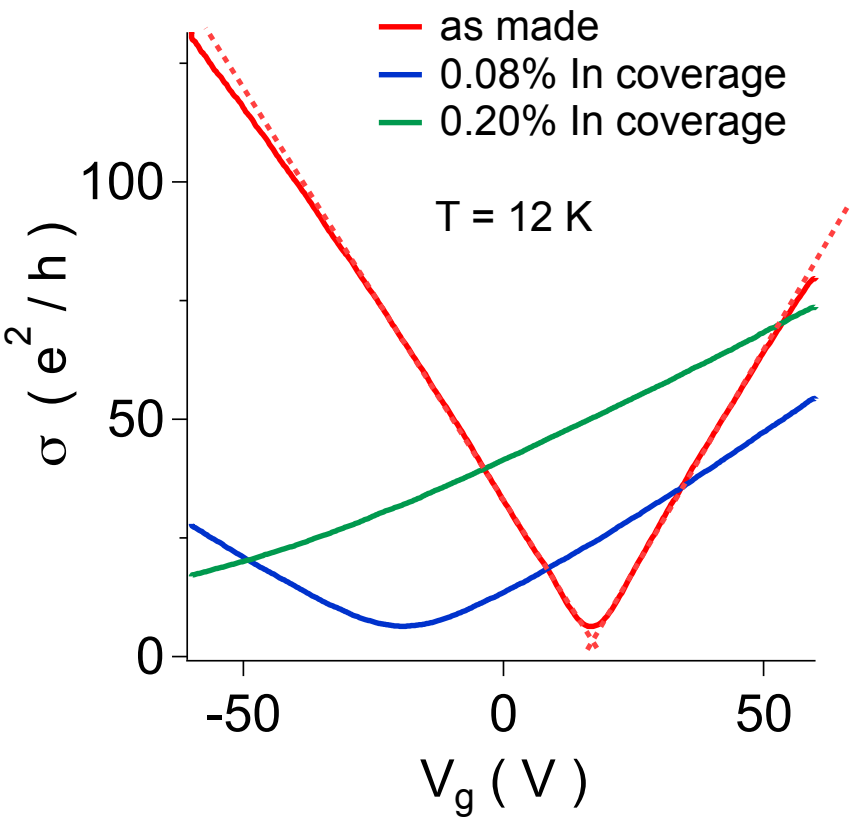
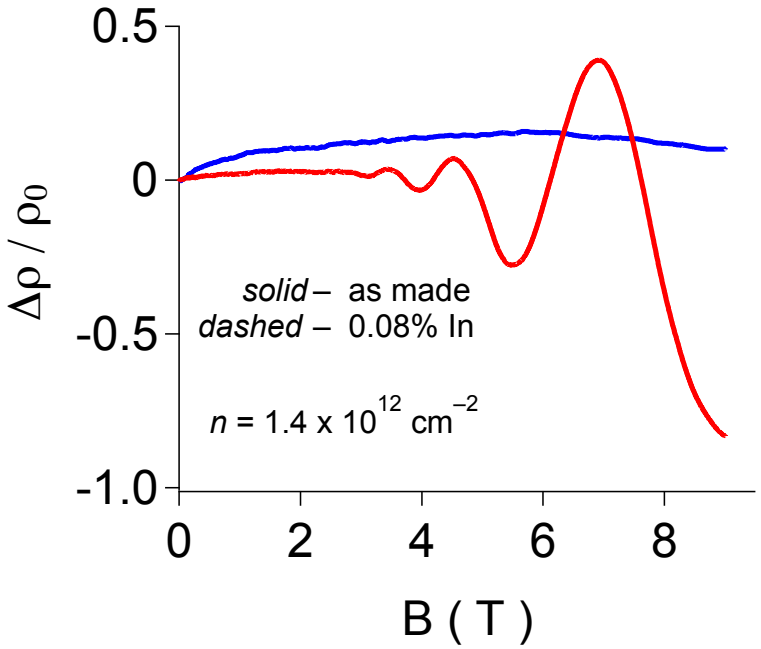
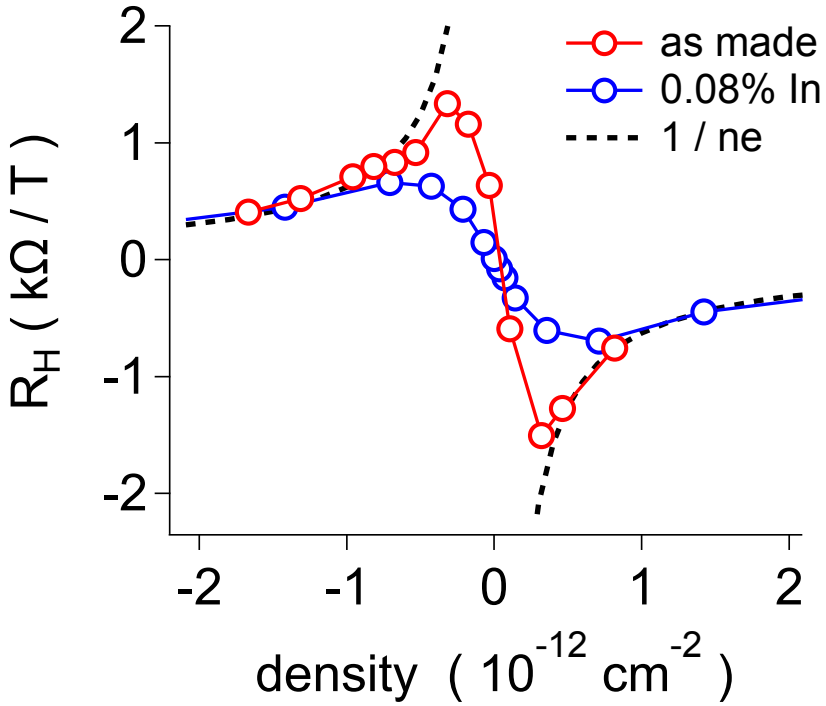


Magnetoresistance





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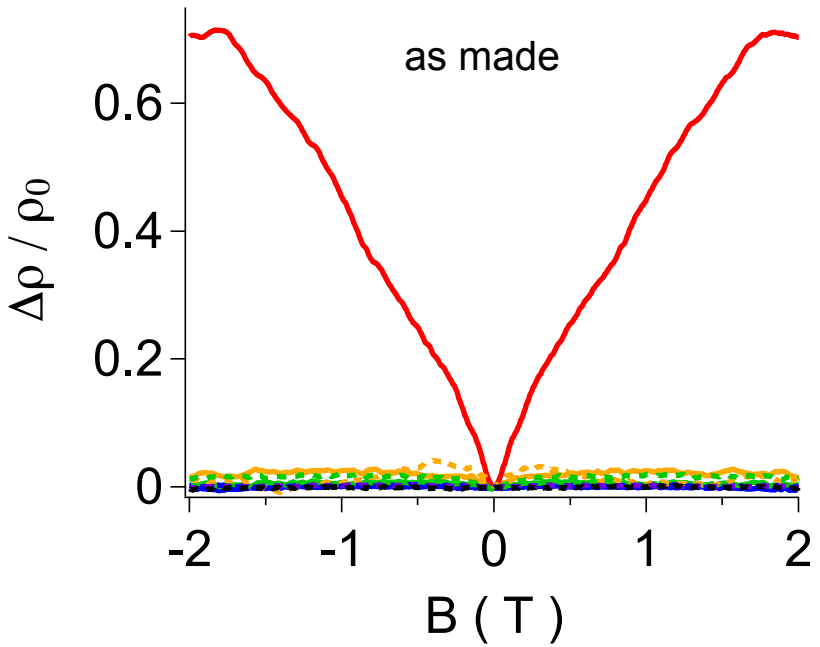
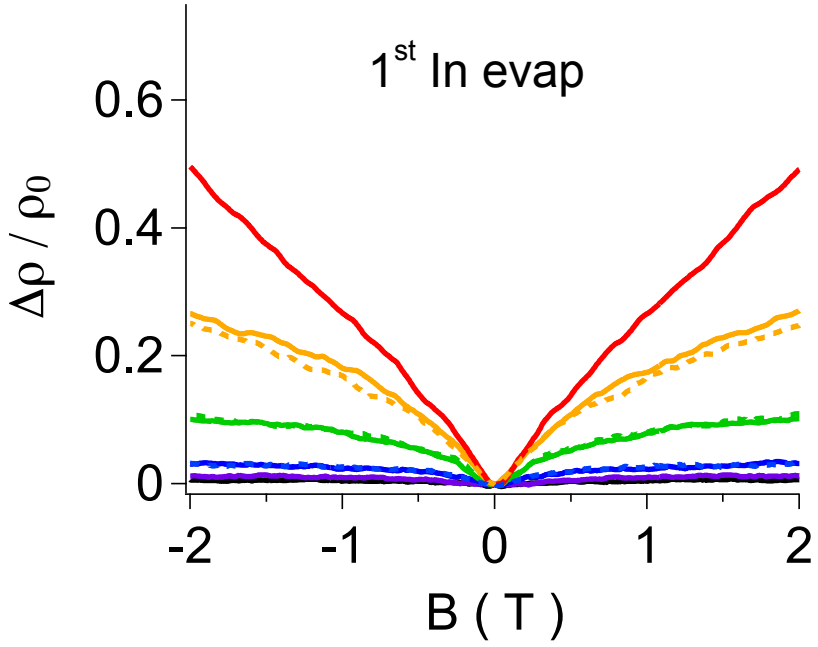




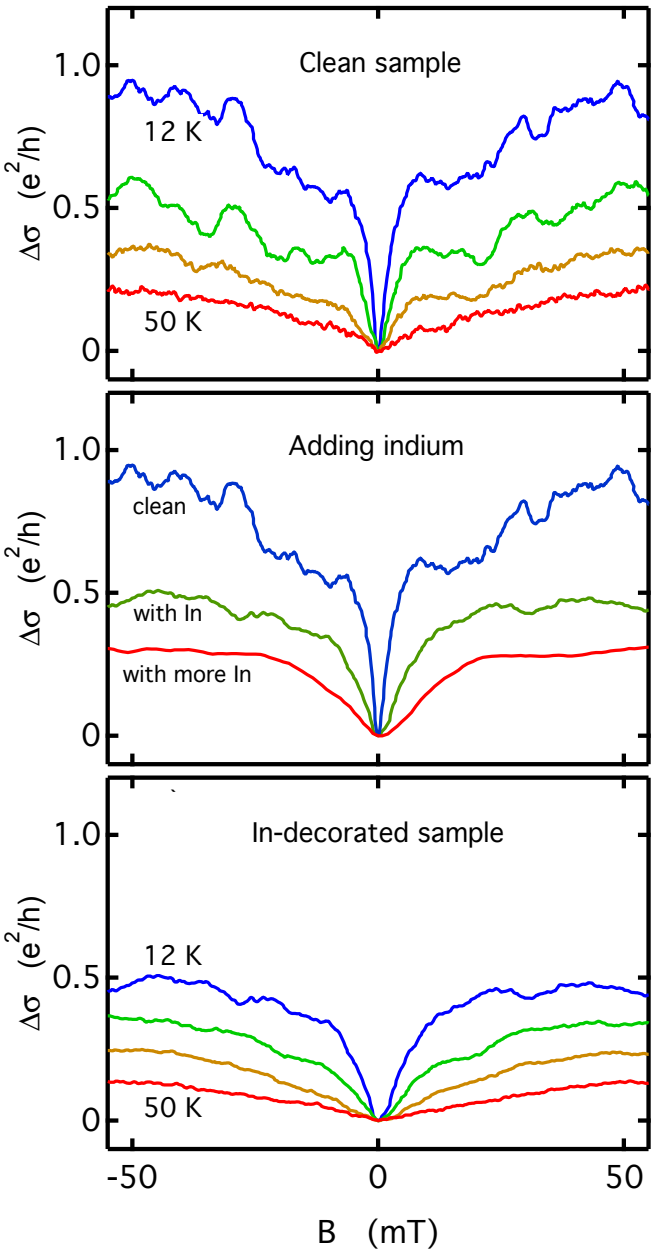
n (10^{12} cm^{-2}):

- 0
- ± 0.7
- ± 1.4
- ± 2.8
- ± 4.2
- ± 5.6

electron-hole puddle transport in EMA?

Stroud PRB **71**, 201304
Das Sarma PRB **79**, 245423

Weak localization



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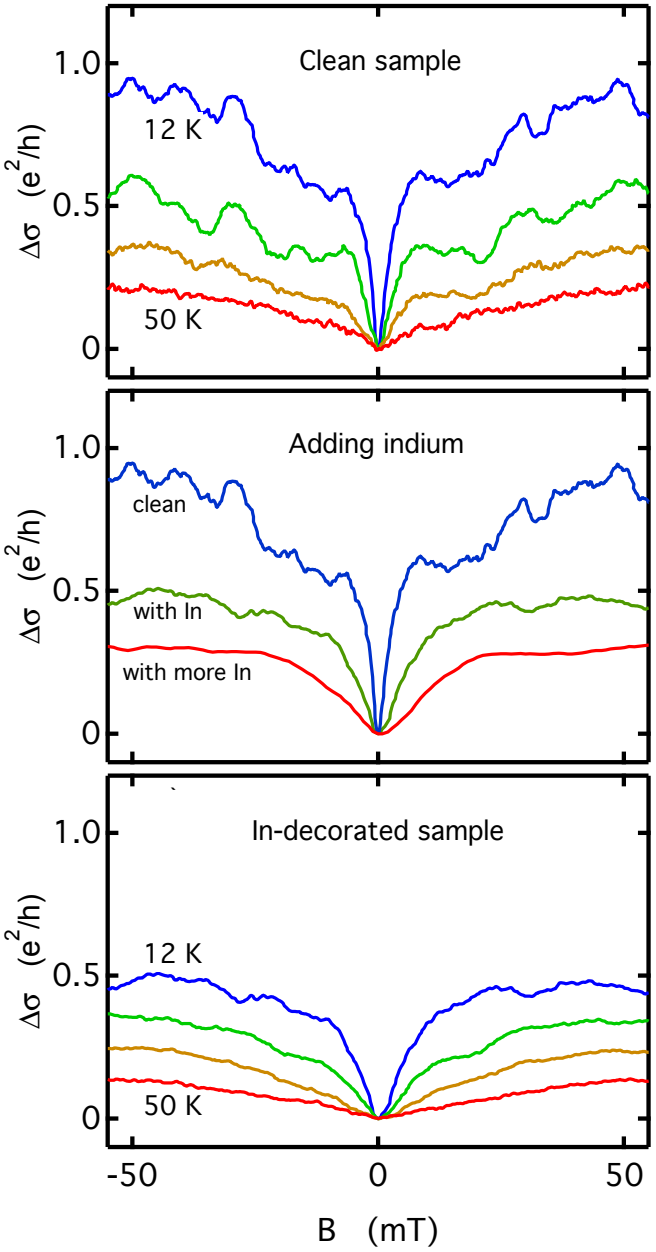
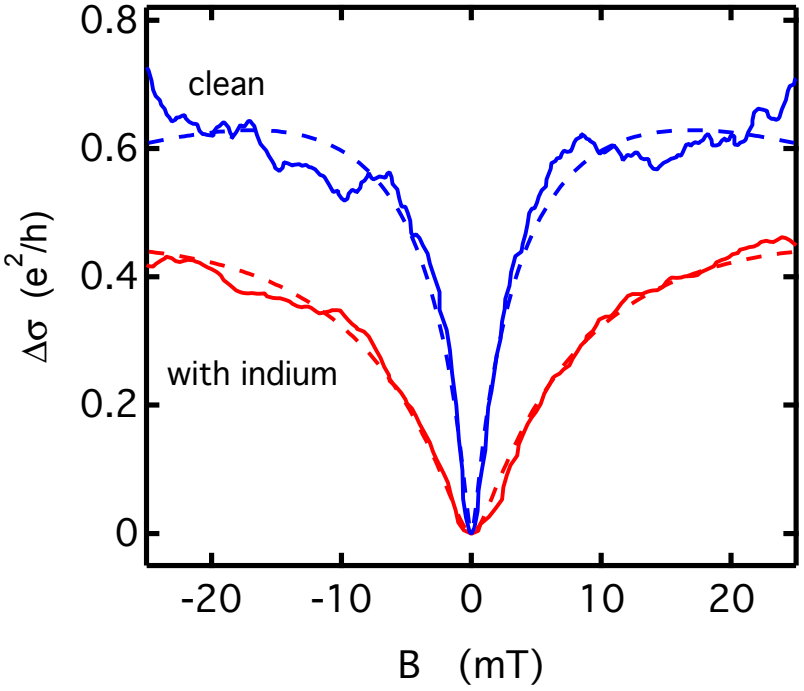


modified fit based on McCann *et al.*, PRL **97**, 146805 (2006):

$$\Delta\sigma = \frac{e^2}{\pi h}[F(\frac{B}{B_\phi}) - F(\frac{B}{B_\phi + 2B_i}) - 2F(\frac{B}{B_\phi + B_i})]$$

$$F(z) = \ln(z) + \psi(\frac{1}{2} + \frac{1}{z}), \quad B_{\phi,i} = \frac{\hbar}{4De}\tau_{\phi,i}^{-1}$$

limit to fit: $l_\mu^2 < l_B^2$



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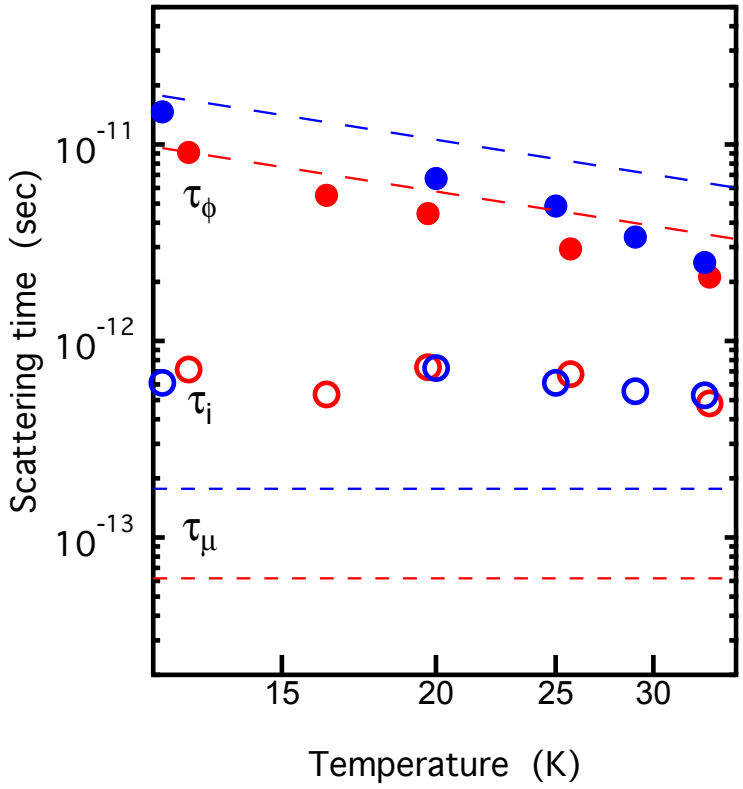

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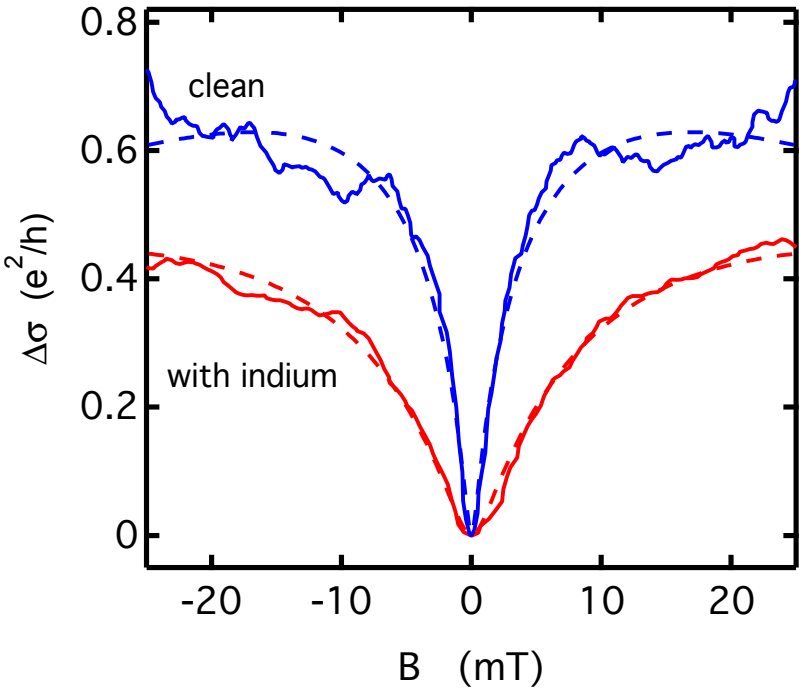

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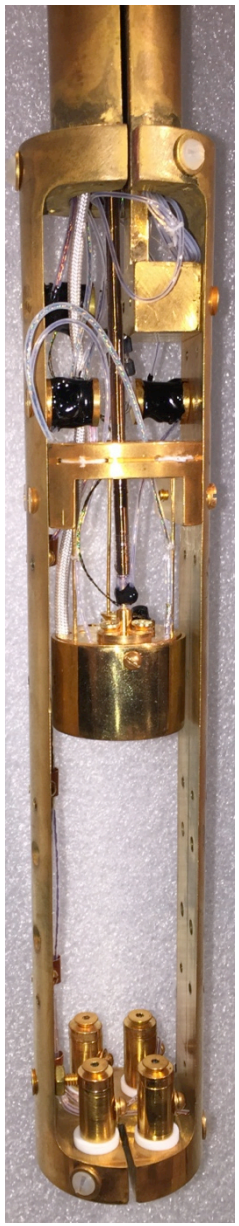
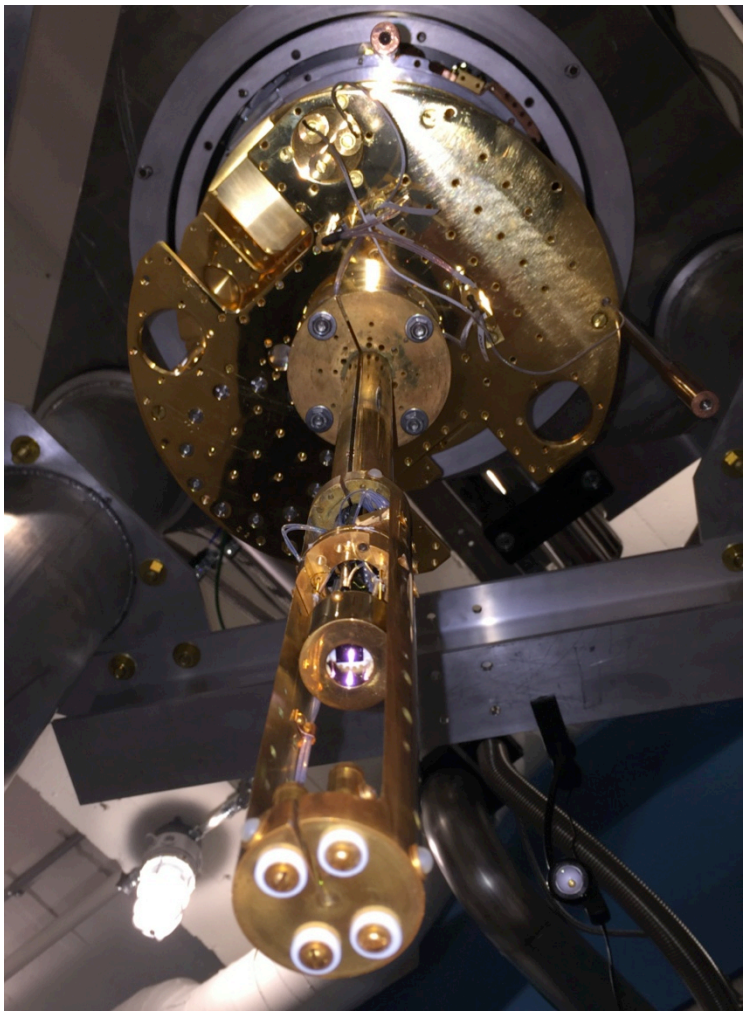
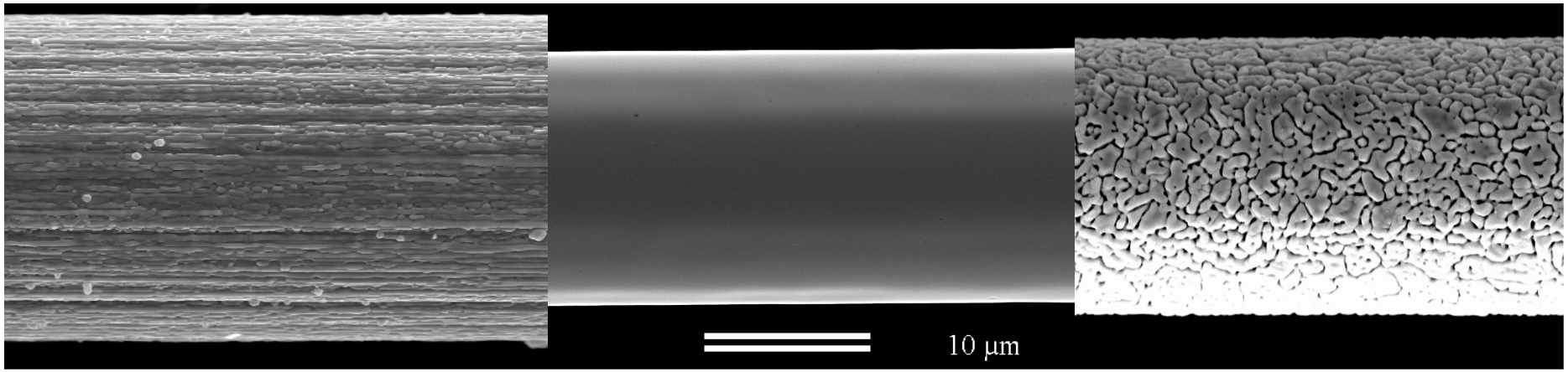
2nd generation evaporator



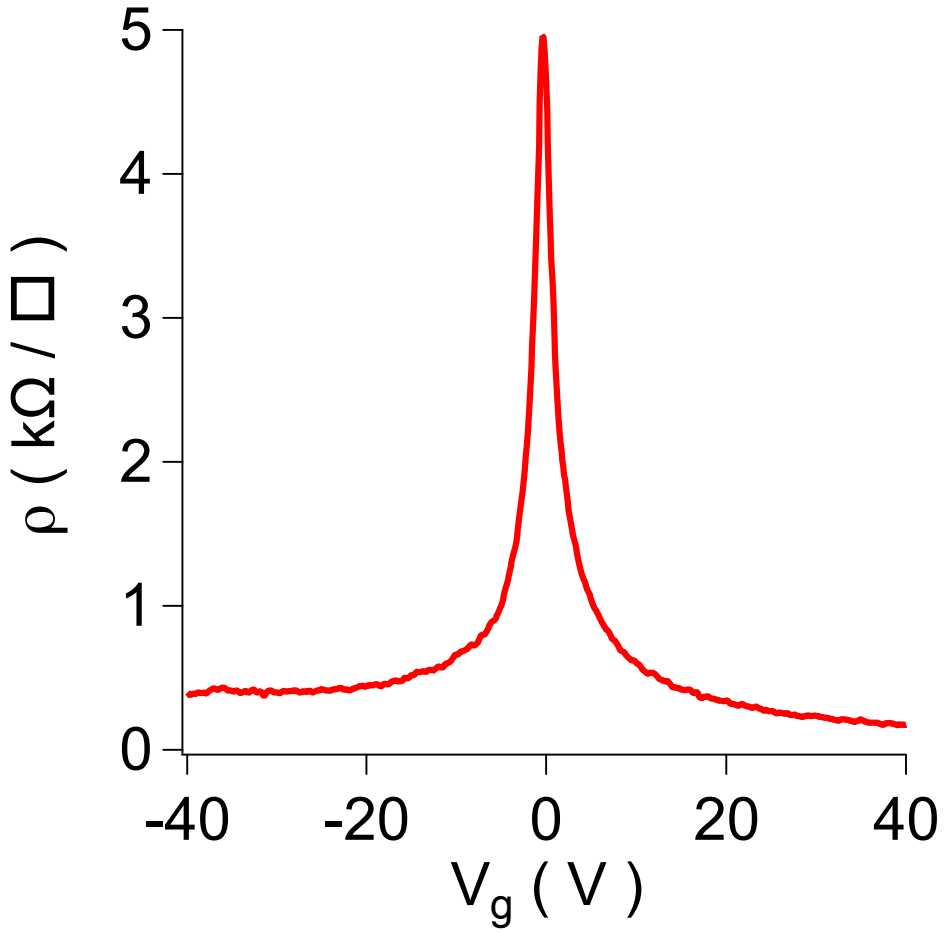


Osmium evaporation sources

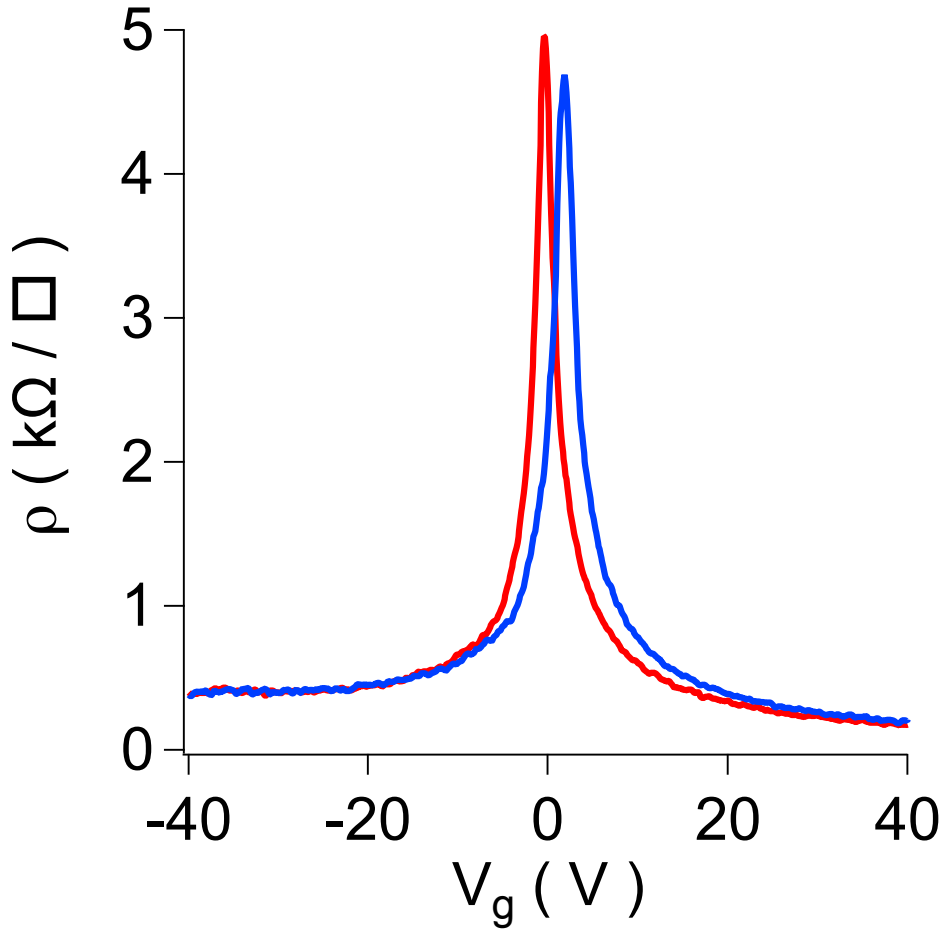


tungsten *annealed tungsten* *coated with osmium*

g-BN devices



Osmium deposition



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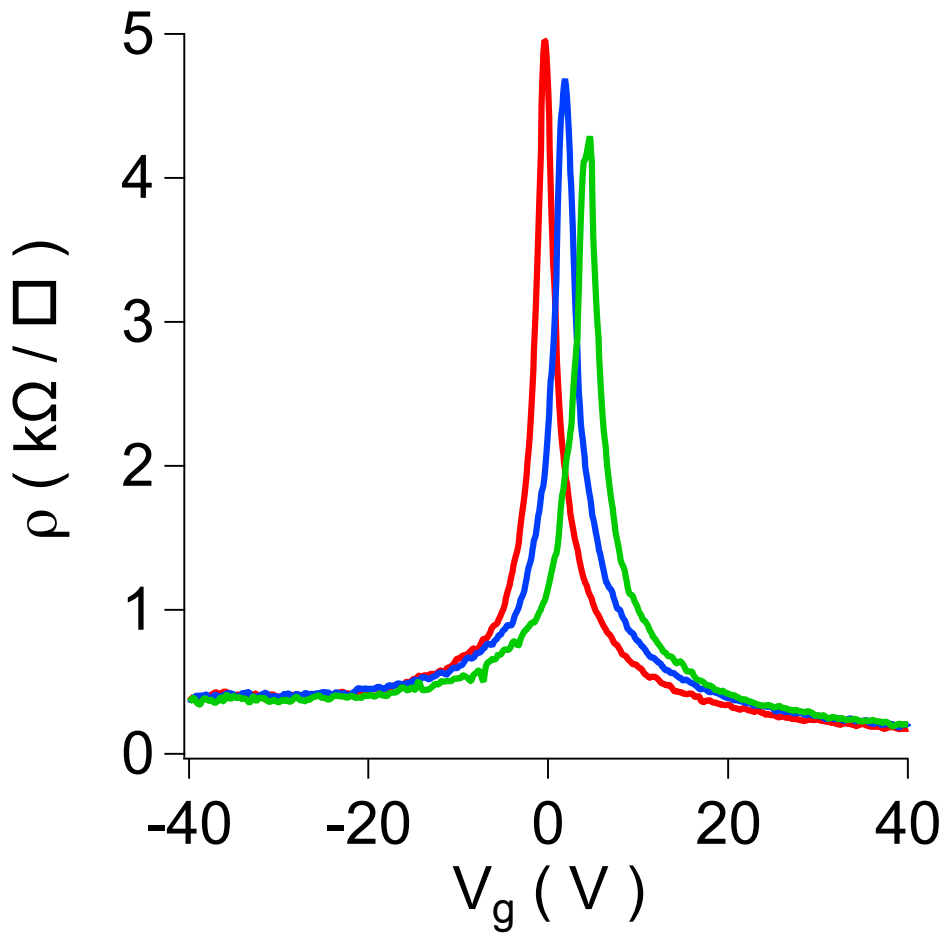

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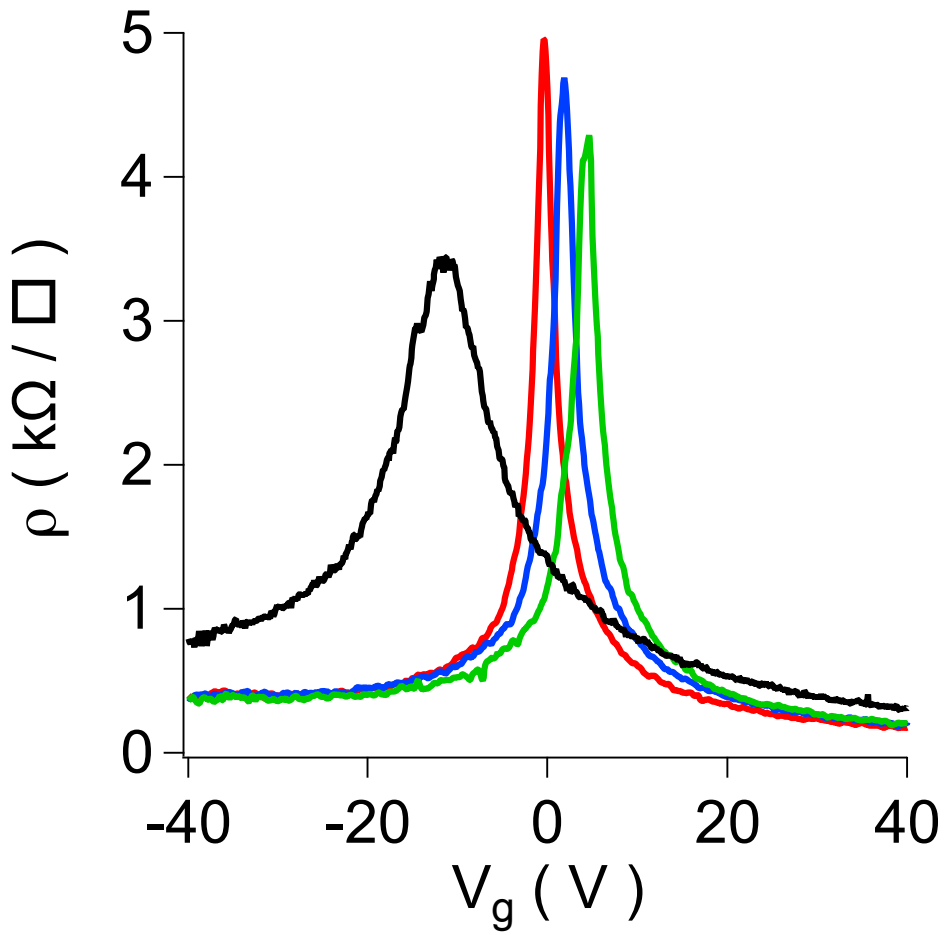

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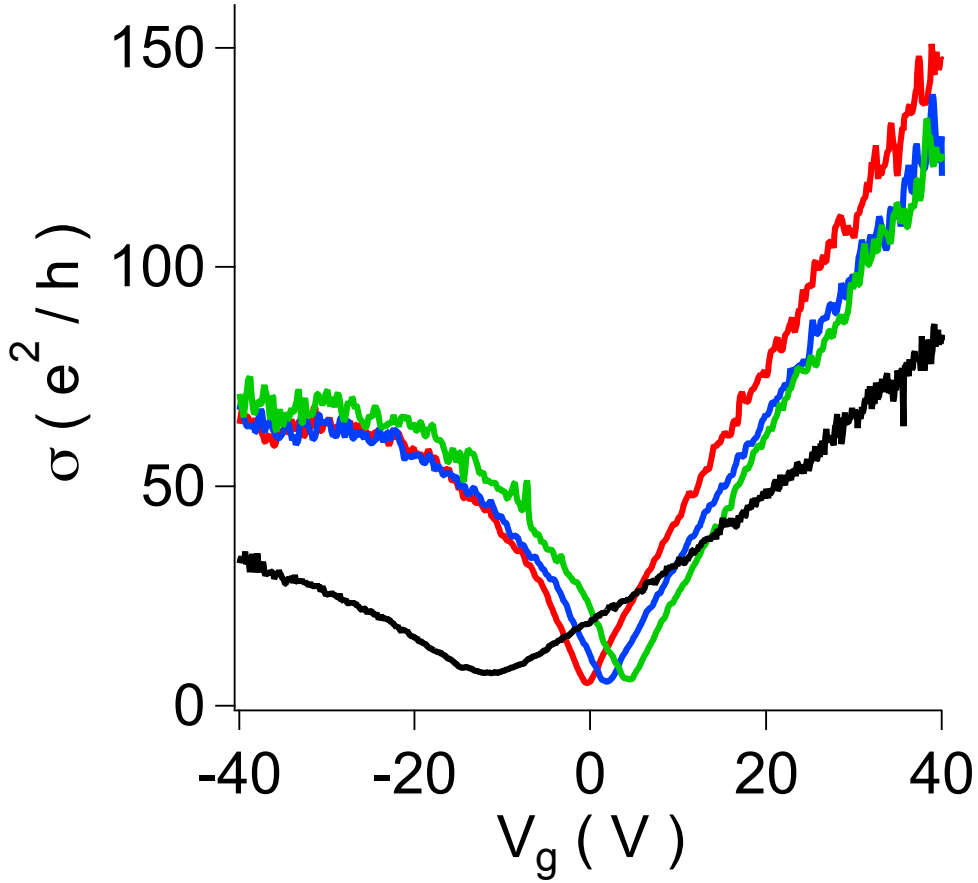

The end. *Thank you!*

Measurements: Chandni U, EAH, J.P. Eisenstein at Caltech arxiv: 1503.04191
Jamie Elias, EAH at Washington University

Many thanks to:

Caltech
Jason Alicea
Keith Schwab
Johannes Pollanen
Debaleena Nandi
KC Fong
Ari Weinstein

Washington University
Jordan Russell
Nero Zhou
Todd Hardt

Columbia University
Cory Dean

Bard College
Paul Cadden-Zimansky