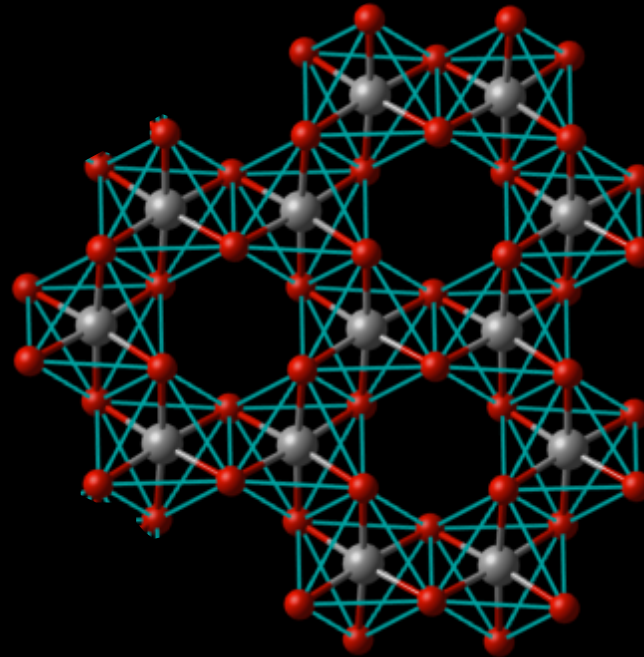


Modulation Doping via a 2D Crystalline Acceptor



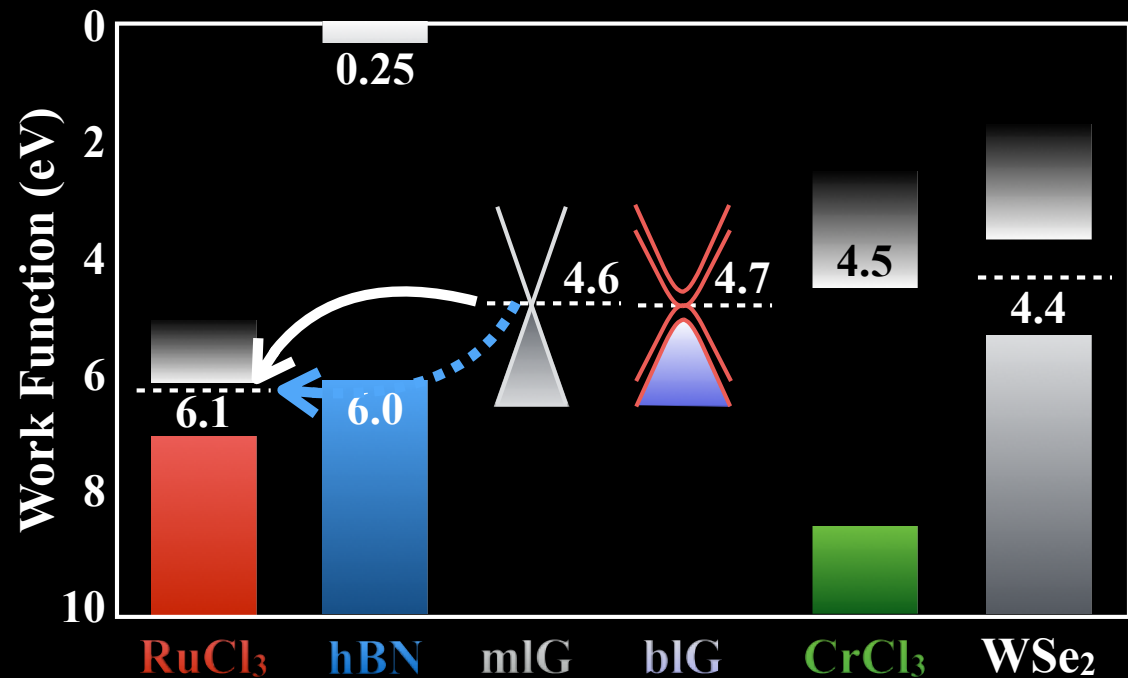
Modulation Doping via a 2D Crystalline Acceptor

- **Charge**
- **Sharp**
- **Highlights**



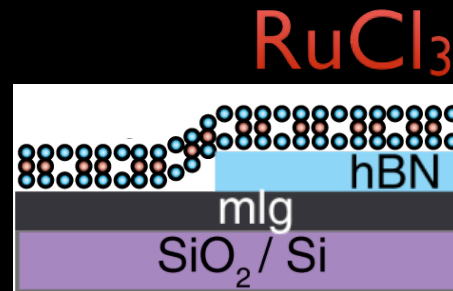
Modulation Doping via a 2D Crystalline Acceptor

- Charge
- Sharp
- Highlights



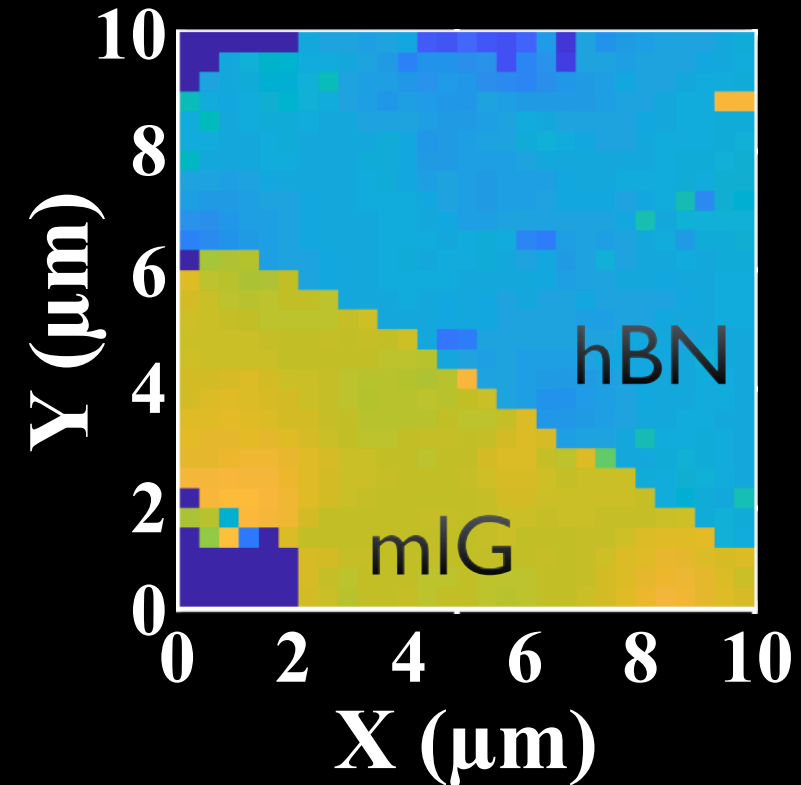
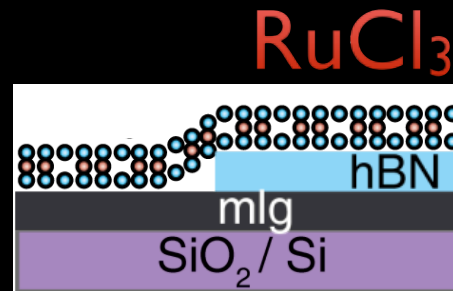
Modulation Doping via a 2D Crystalline Acceptor

- Charge
- Sharp
- Highlights



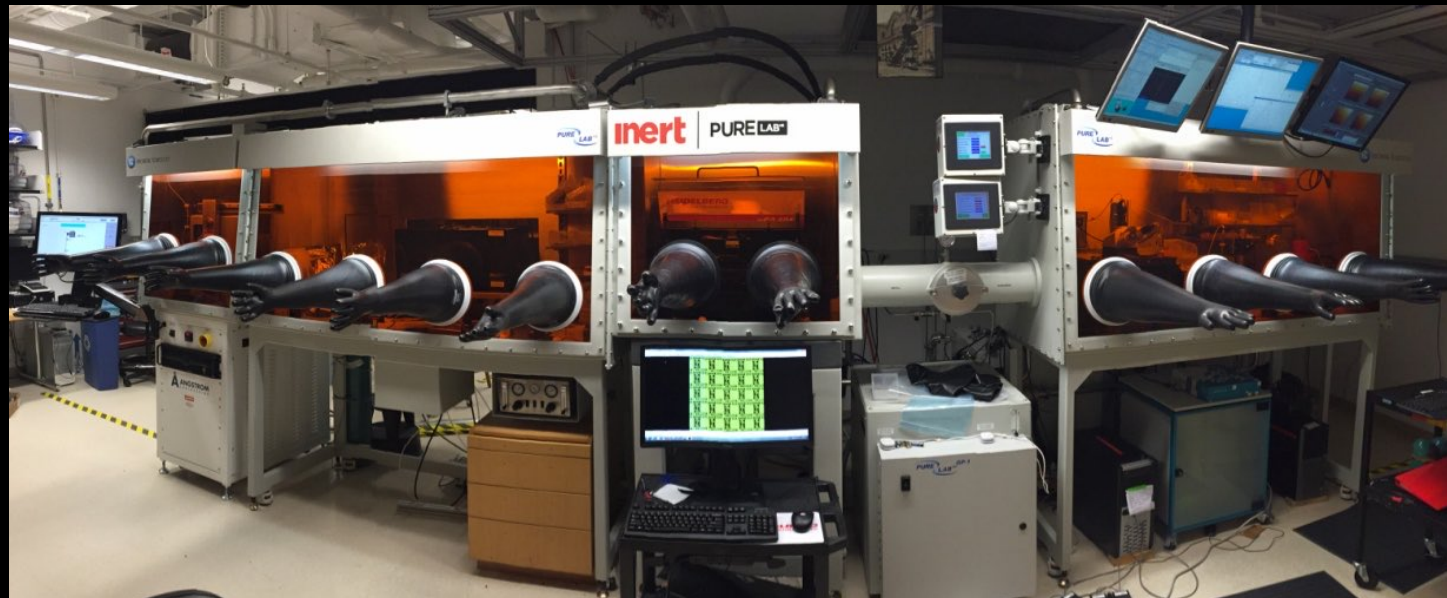
Modulation Doping via a 2D Crystalline Acceptor

- Charge
- Sharp
- Highlights



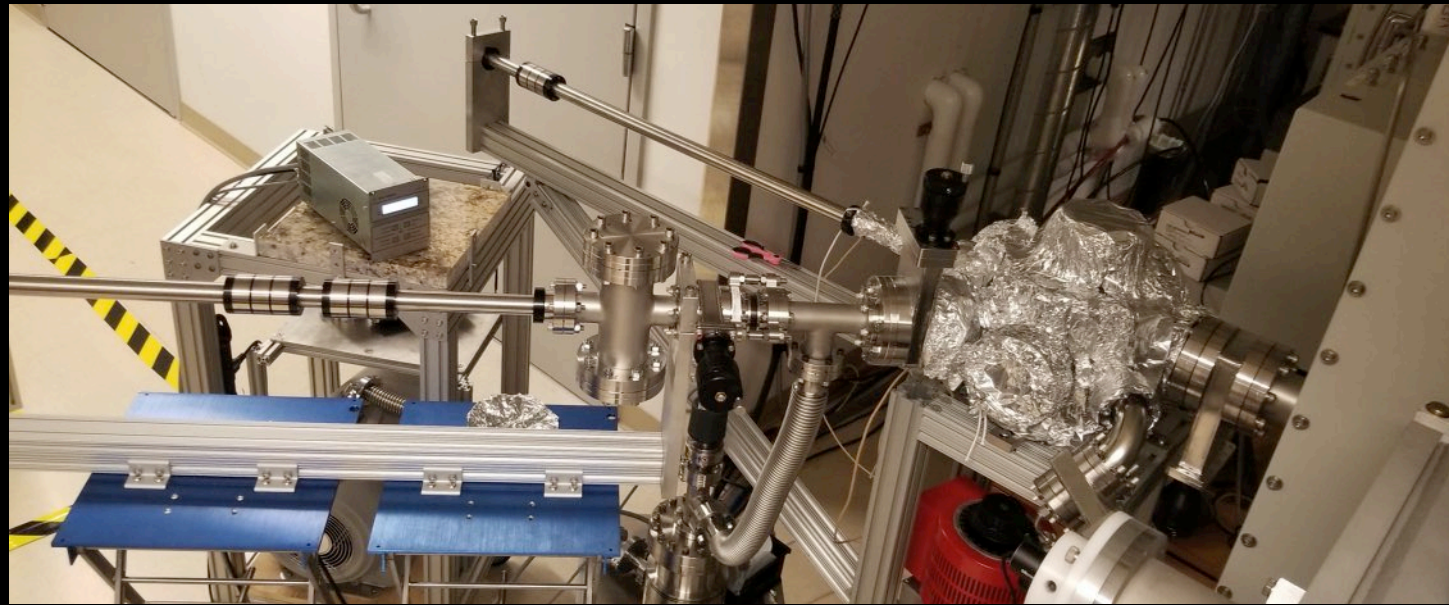
Modulation Doping via a 2D Crystalline Acceptor

- Charge
- Sharp
- Highlights



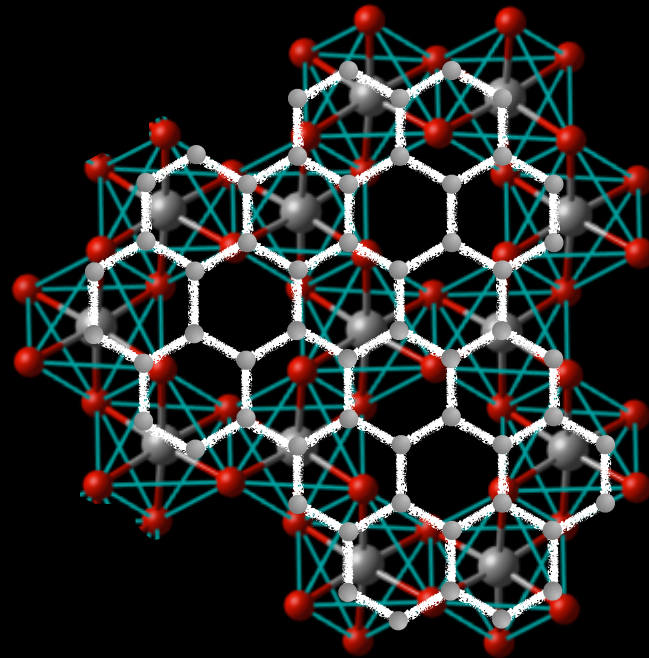
Modulation Doping via a 2D Crystalline Acceptor

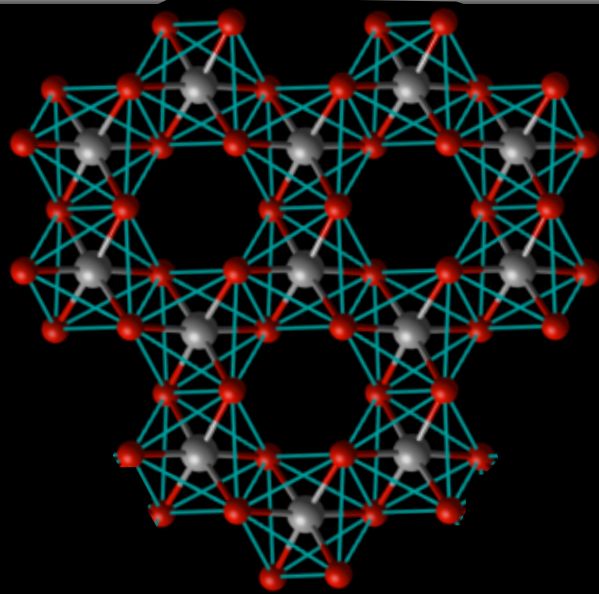
- Charge
- Sharp
- Highlights



Modulation Doping via a 2D Crystalline Acceptor

- Charge
- Sharp
- Highlights



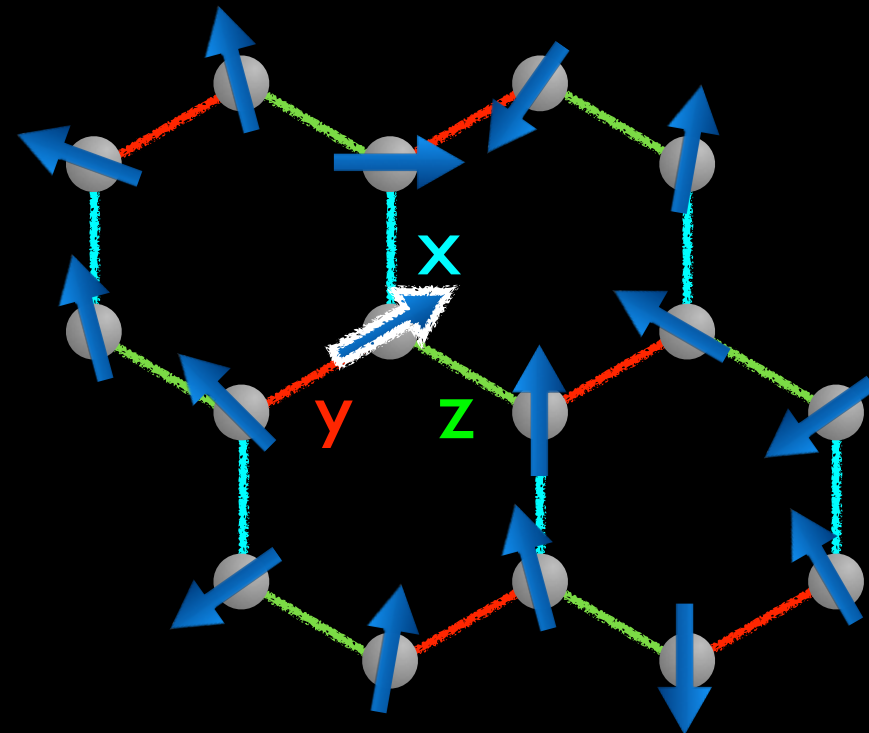
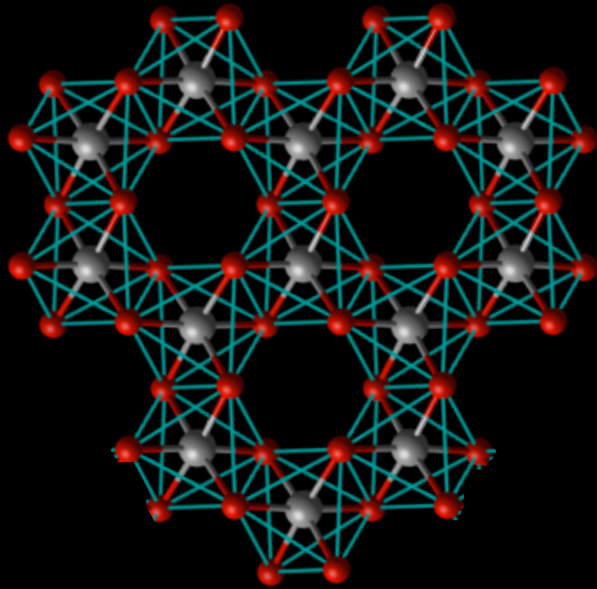


Y. Wang, KSB, Nat. Quantum Materials (2020)

T.T. Mai et al, PRB 100, 134419 (2019)....& more...

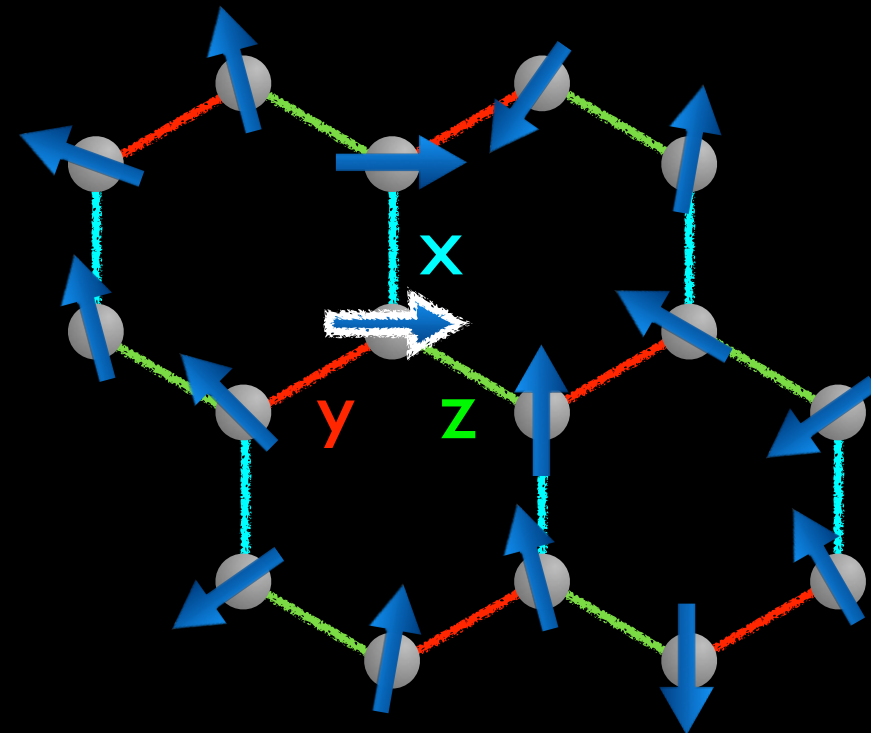
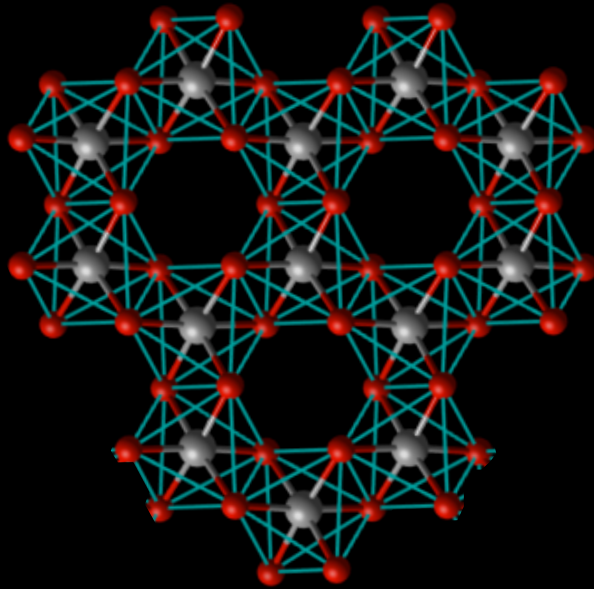
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T.T. Mai et al, PRB 100, 134419 (2019)....& more...



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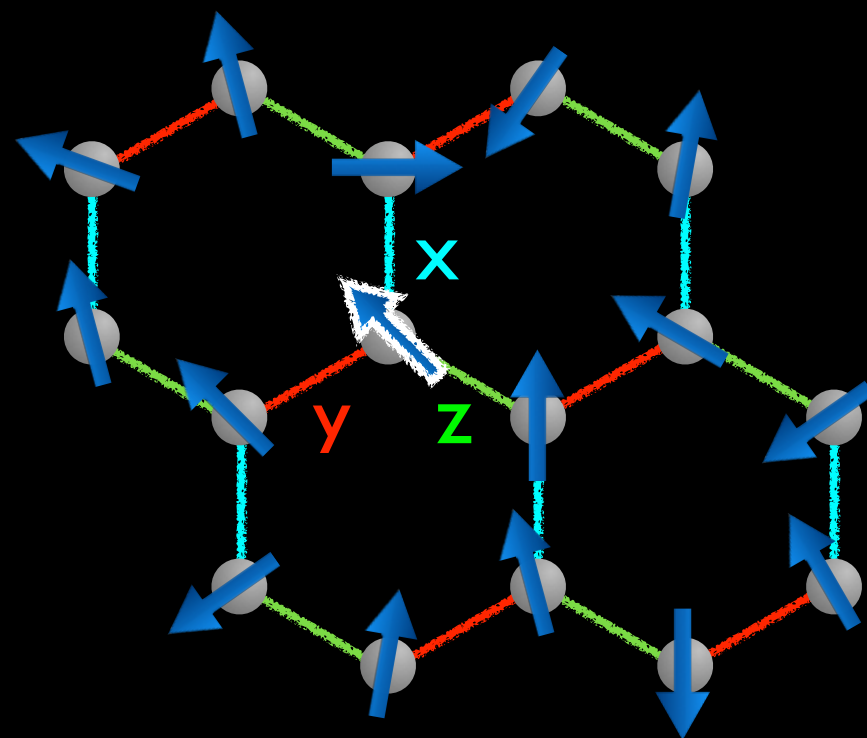
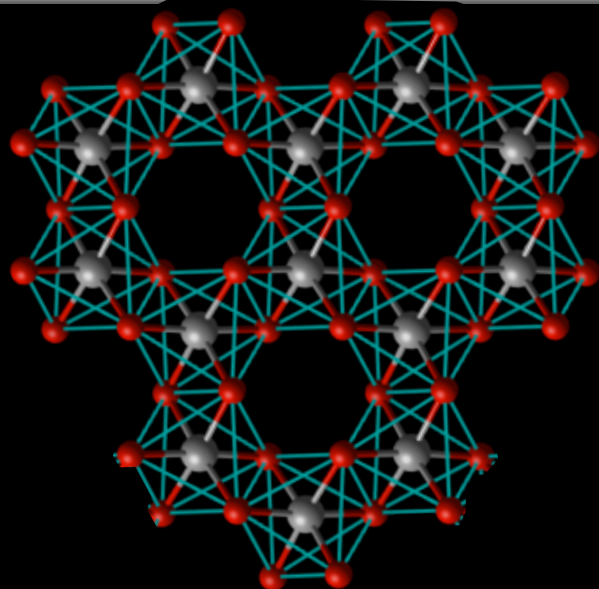
T.T. Mai et al, PRB 100, 134419 (2019)....& more...



$$H = -J_x \sum_{j,k} \sigma_j^x \sigma_k^x$$

Y. Wang, KSB, Nat. Quantum Materials (2020)

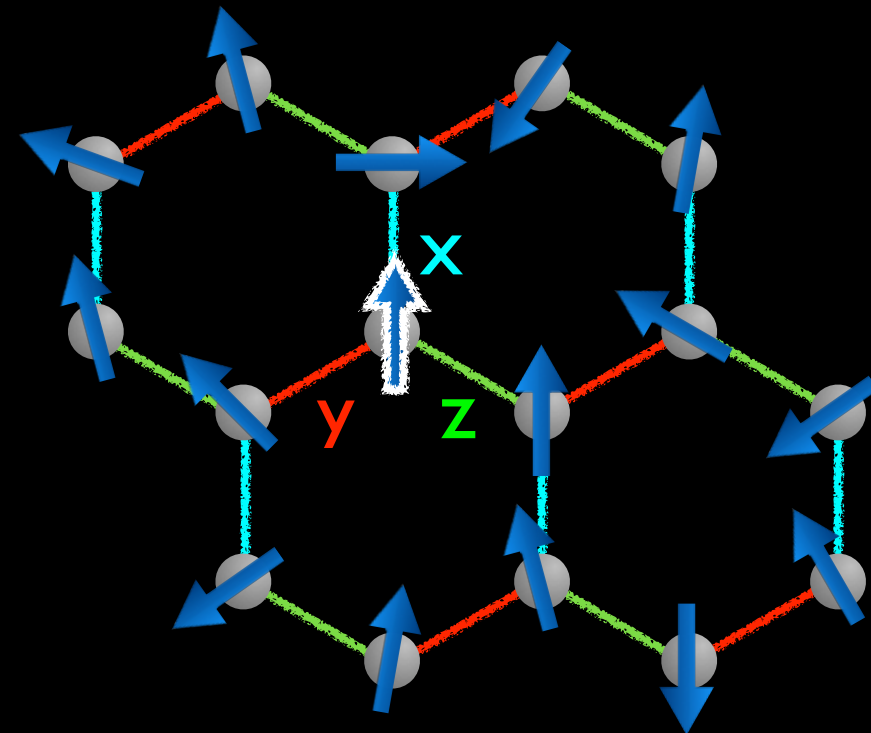
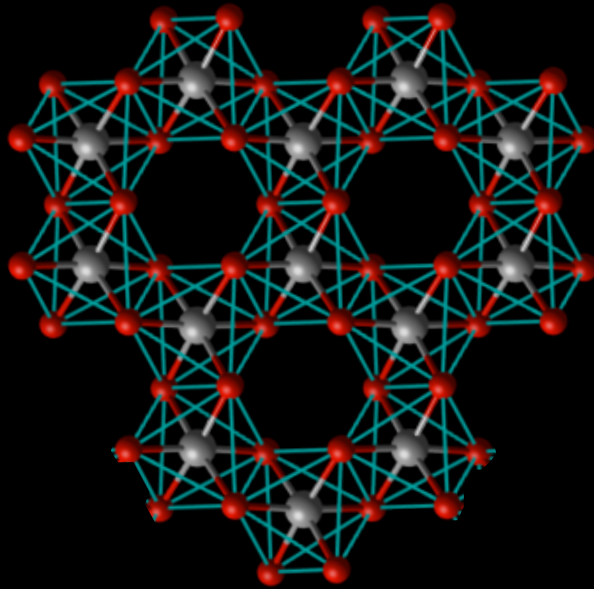
T.T. Mai et al, PRB 100, 134419 (2019)....& more...



$$H = -J_x \sum_{j,k=\text{cyan}} \sigma_j^x \sigma_k^x - J_y \sum_{j,k=\text{red}} \sigma_j^y \sigma_k^y$$

Y. Wang, KSB, Nat. Quantum Materials (2020)

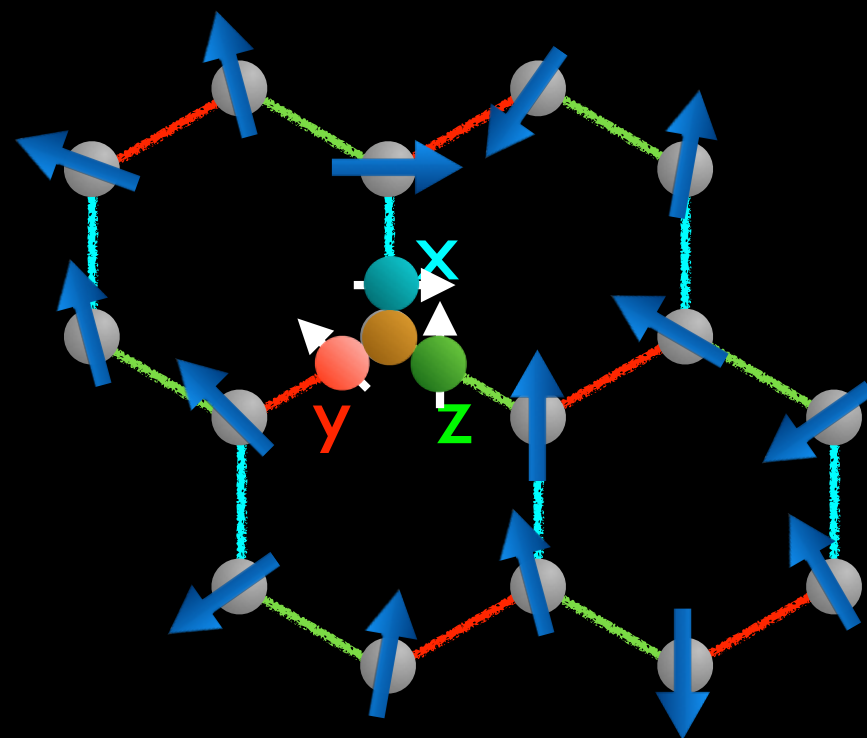
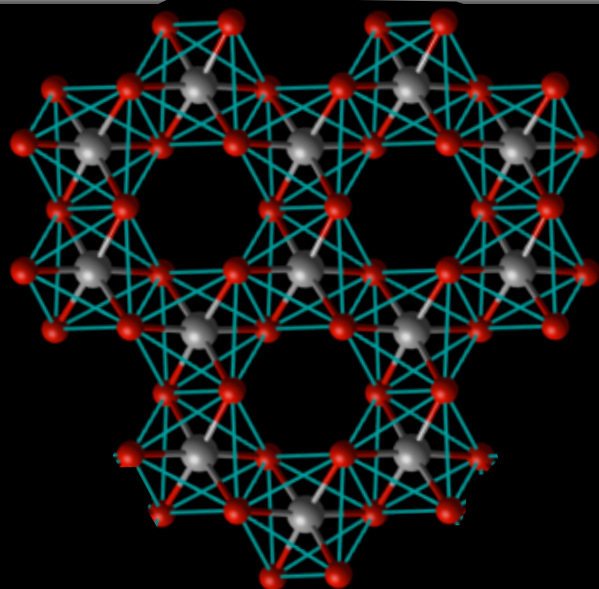
T.T. Mai et al, PRB 100, 134419 (2019)....& more...



$$H = -J_x \sum_{j,k=\text{cyan}} \sigma_j^x \sigma_k^x - J_y \sum_{j,k=\text{red}} \sigma_j^y \sigma_k^y - J_z \sum_{j,k=\text{green}} \sigma_j^z \sigma_k^z$$

Y. Wang, KSB, Nat. Quantum Materials (2020)

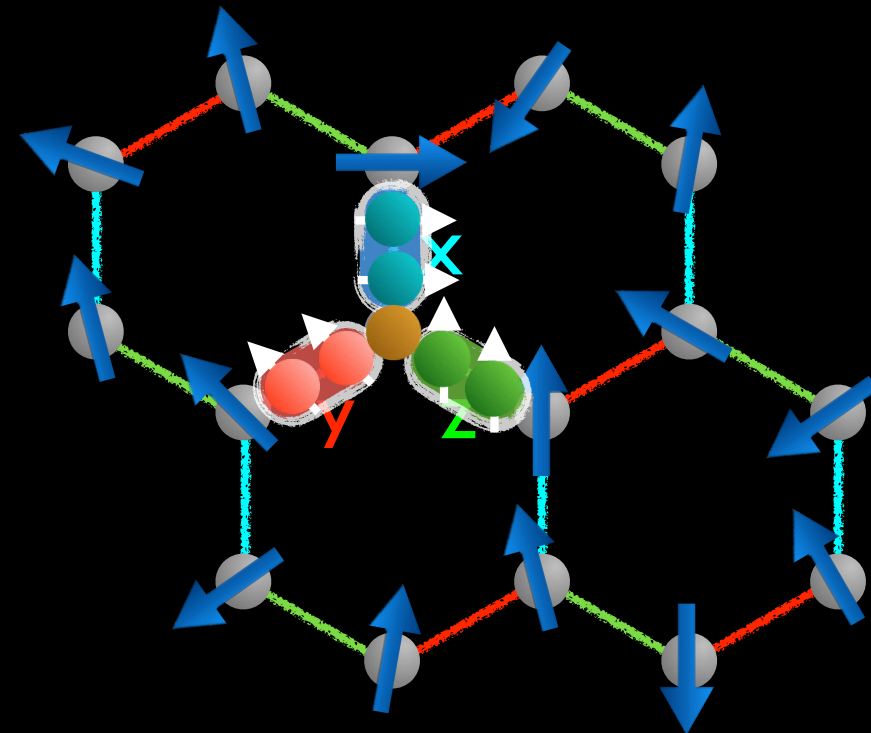
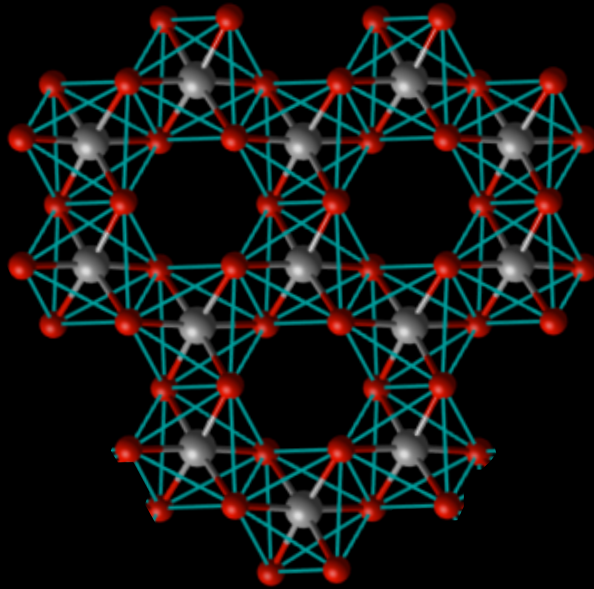
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$$H = -J_x \sum_{j,k=\text{cyan}} \sigma_j^x \sigma_k^x - J_y \sum_{j,k=\text{red}} \sigma_j^y \sigma_k^y - J_z \sum_{j,k=\text{green}} \sigma_j^z \sigma_k^z$$

Y. Wang, KSB, Nat. Quantum Materials (2020)

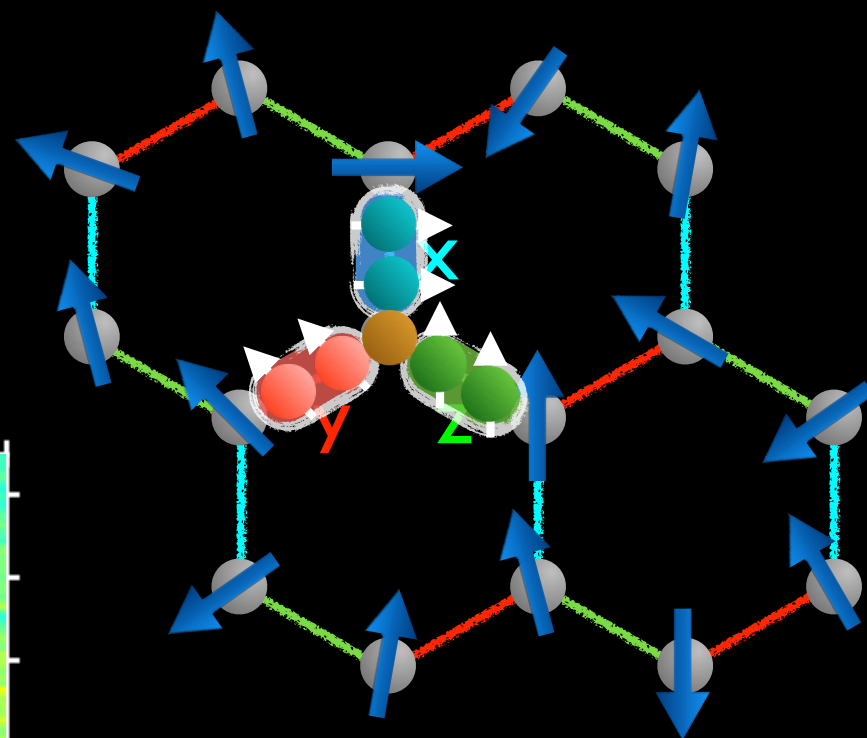
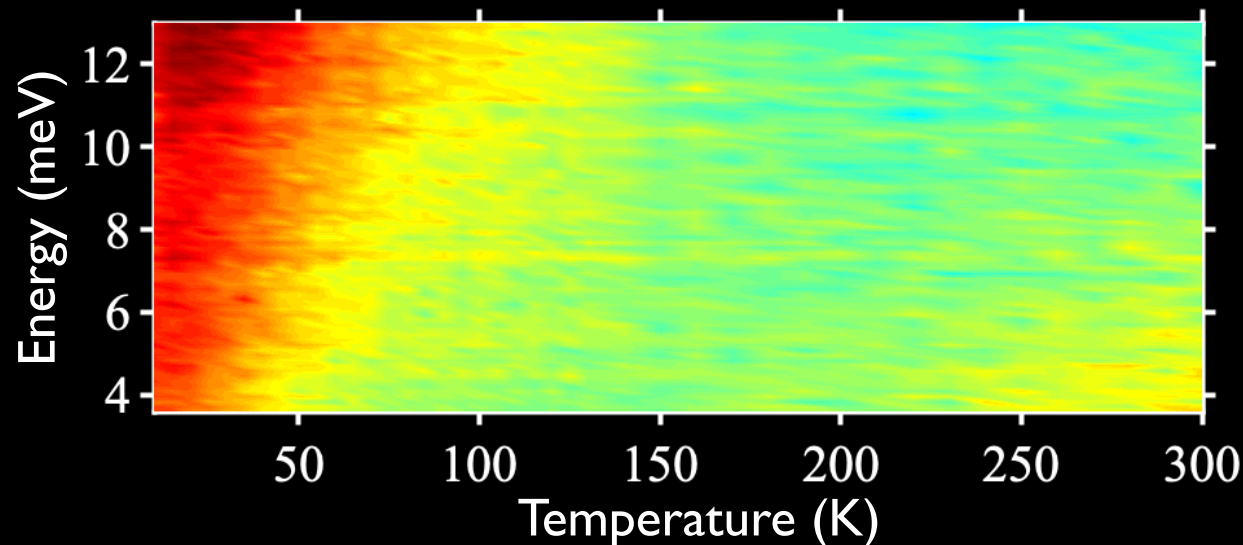
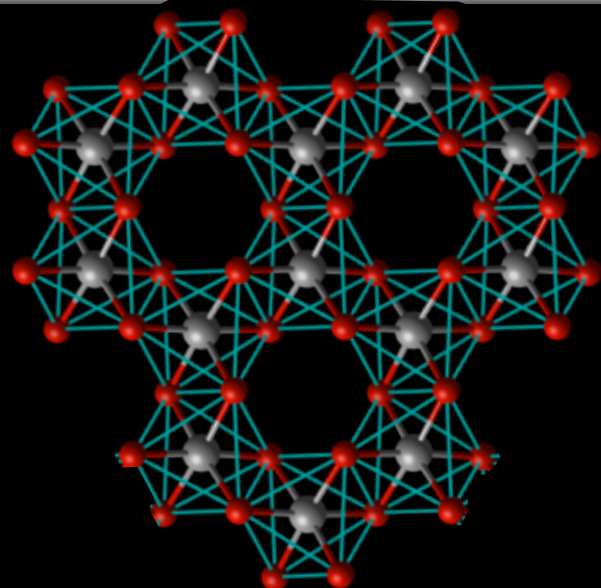
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$$H = -J_x \sum_{j,k=\text{cyan}} \sigma_j^x \sigma_k^x - J_y \sum_{j,k=\text{red}} \sigma_j^y \sigma_k^y - J_z \sum_{j,k=\text{green}} \sigma_j^z \sigma_k^z$$

Y. Wang, KSB, Nat. Quantum Materials (2020)

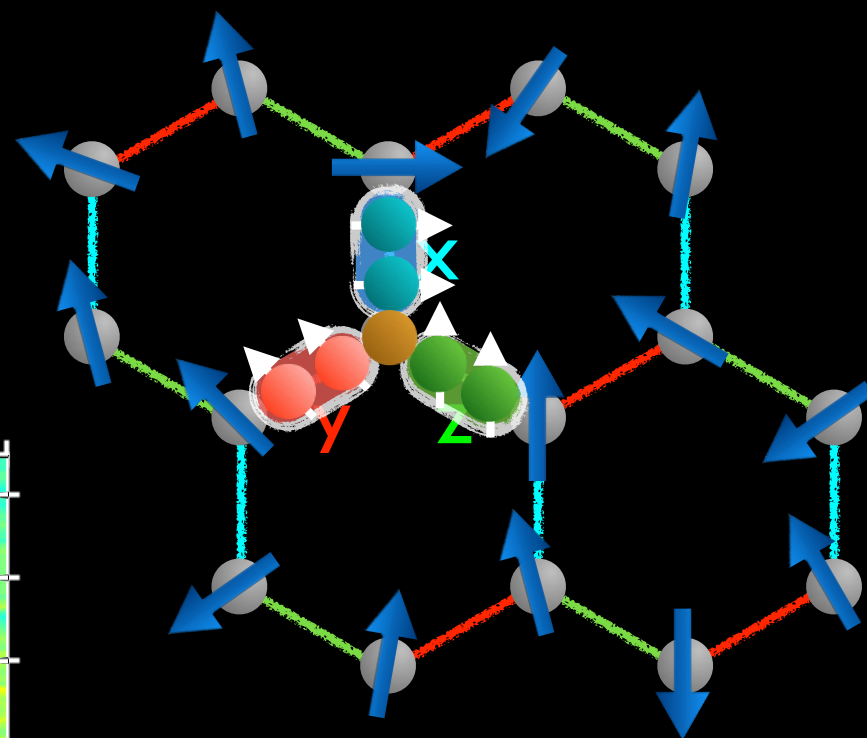
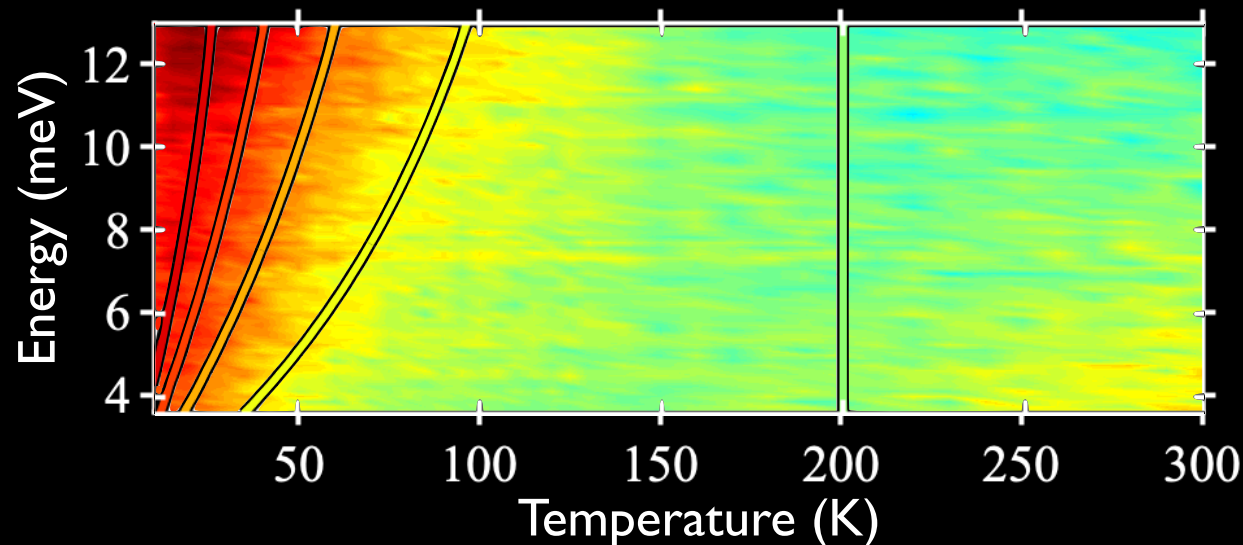
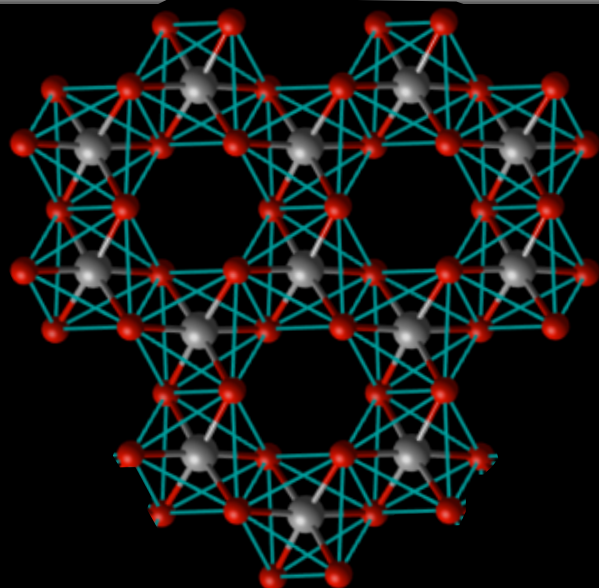
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$$H = -J_x \sum_{j,k=\text{cyan}} \sigma_j^x \sigma_k^x - J_y \sum_{j,k=\text{red}} \sigma_j^y \sigma_k^y - J_z \sum_{j,k=\text{green}} \sigma_j^z \sigma_k^z$$

Y. Wang, KSB, Nat. Quantum Materials (2020)

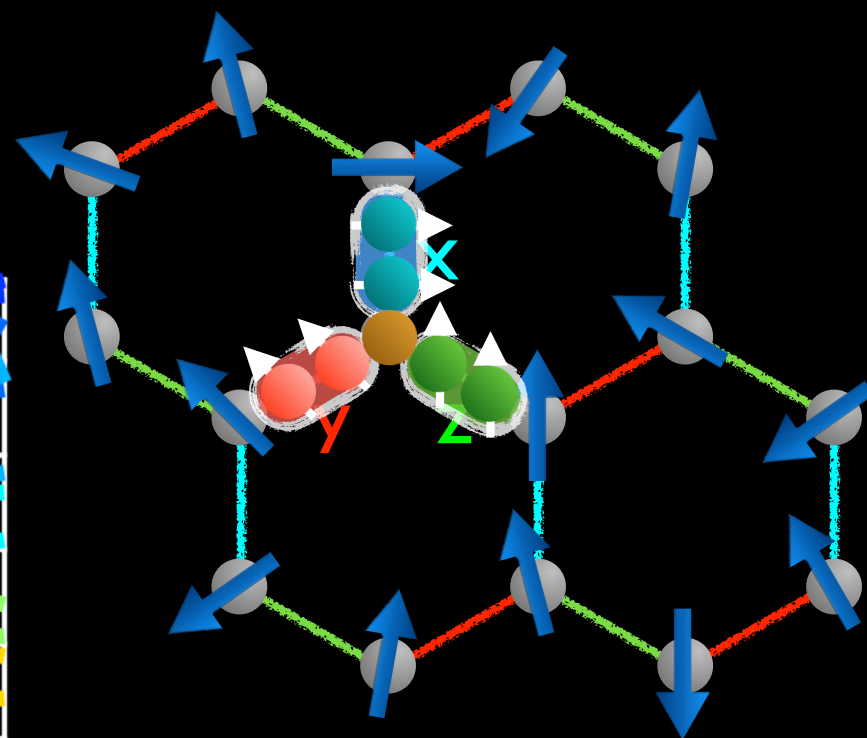
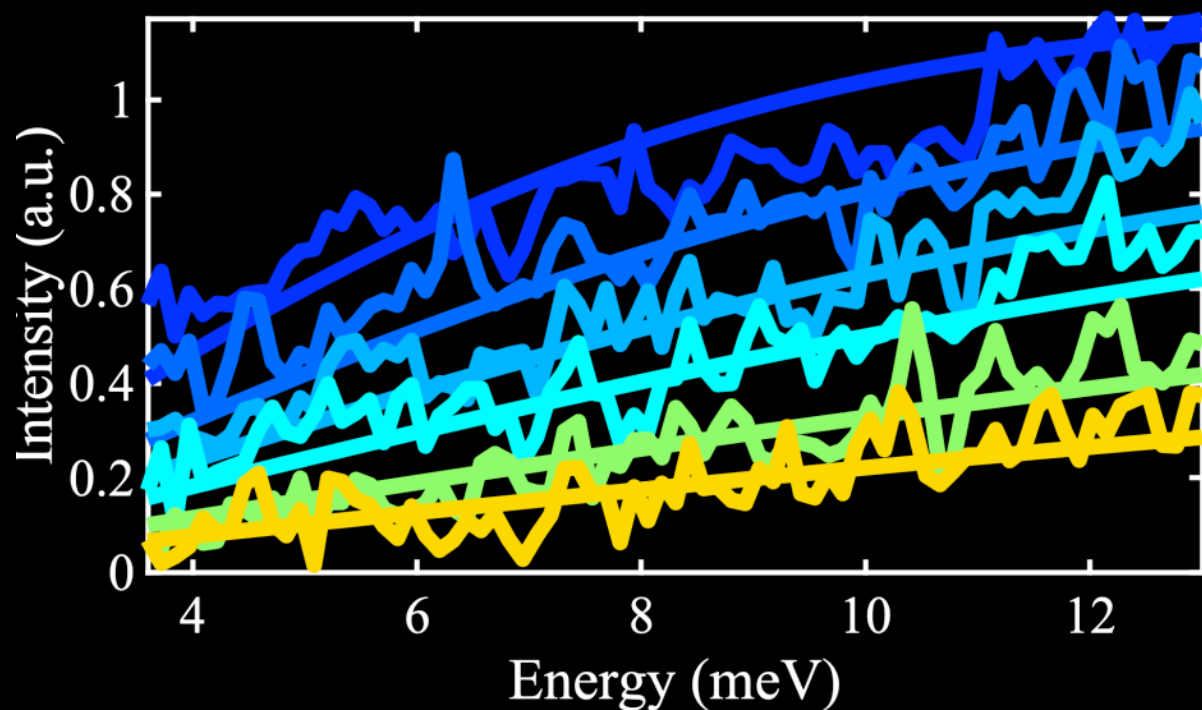
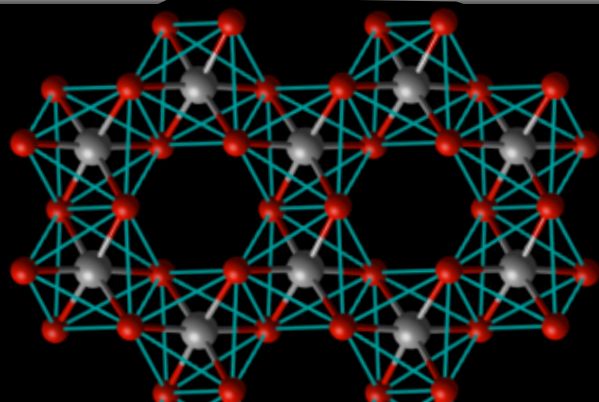
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$$H = -J_x \sum_{j,k=\text{cyan}} \sigma_j^x \sigma_k^x - J_y \sum_{j,k=\text{red}} \sigma_j^y \sigma_k^y - J_z \sum_{j,k=\text{green}} \sigma_j^z \sigma_k^z$$

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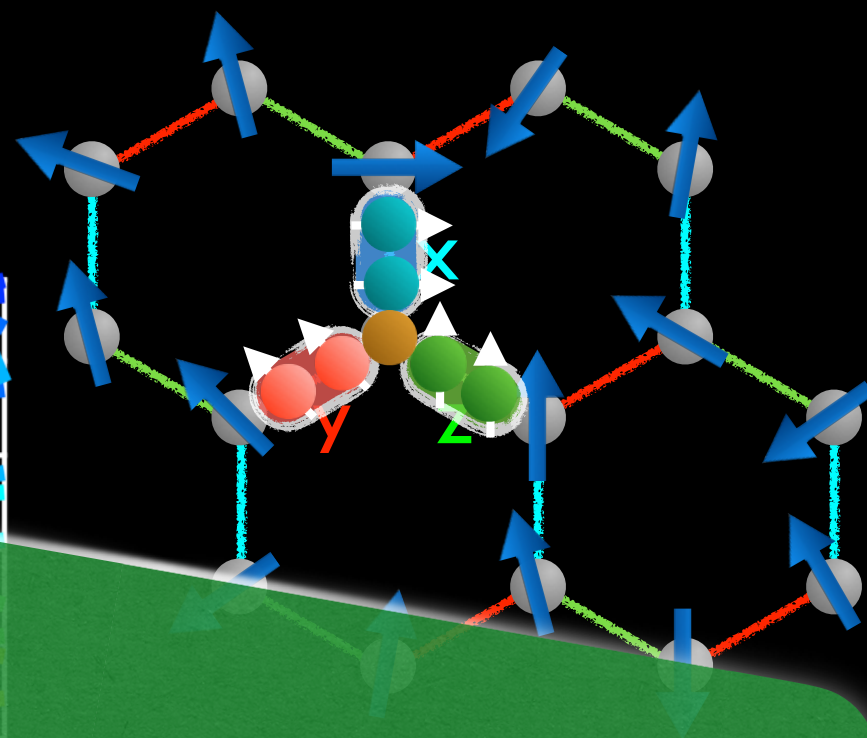
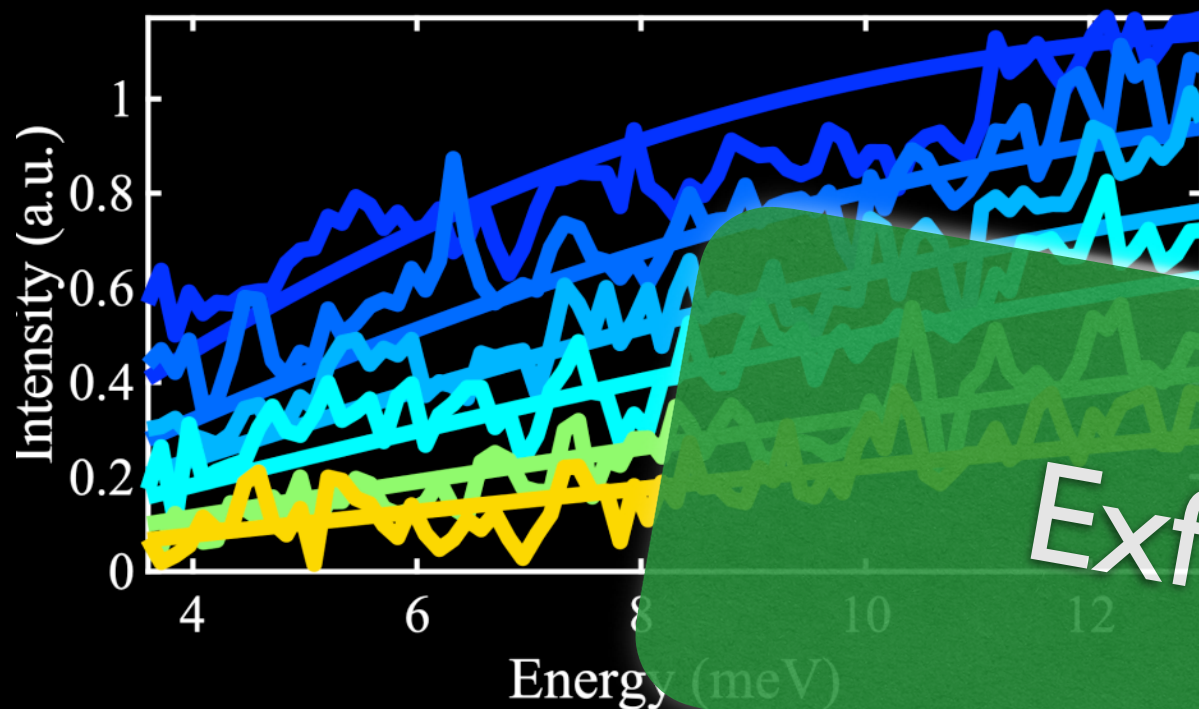
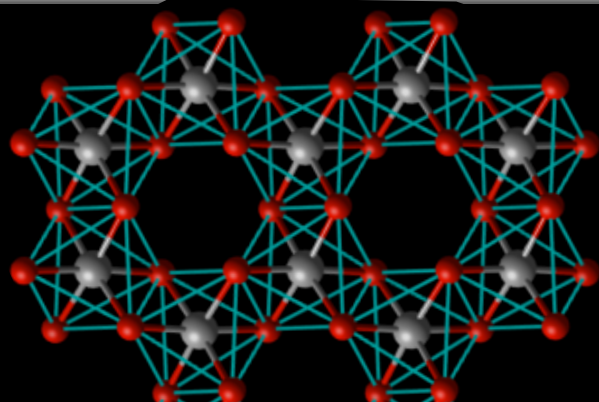
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$$H = -J_x \sum_{j,k=\text{cyan}} \sigma_j^x \sigma_k^x - J_y \sum_{j,k=\text{red}} \sigma_j^y \sigma_k^y - J_z \sum_{j,k=\text{green}} \sigma_j^z \sigma_k^z$$

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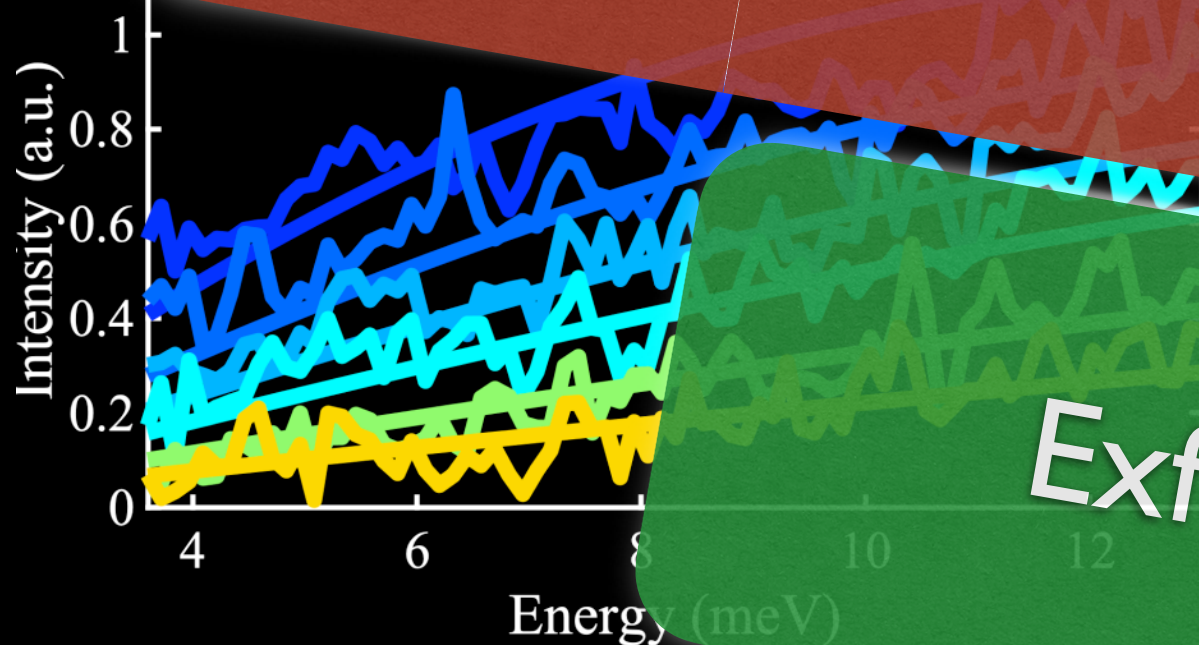
Exfoliation?

$$H = -J_x \sum_{j,k} \sigma_j^x \sigma_k^x - J_y \sum_{j,k} \sigma_j^y \sigma_k^y - J_z \sum_{j,k} \sigma_j^z \sigma_k^z$$

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T.T. Mai et al, PRB 100, 134419 (2019)....& more...

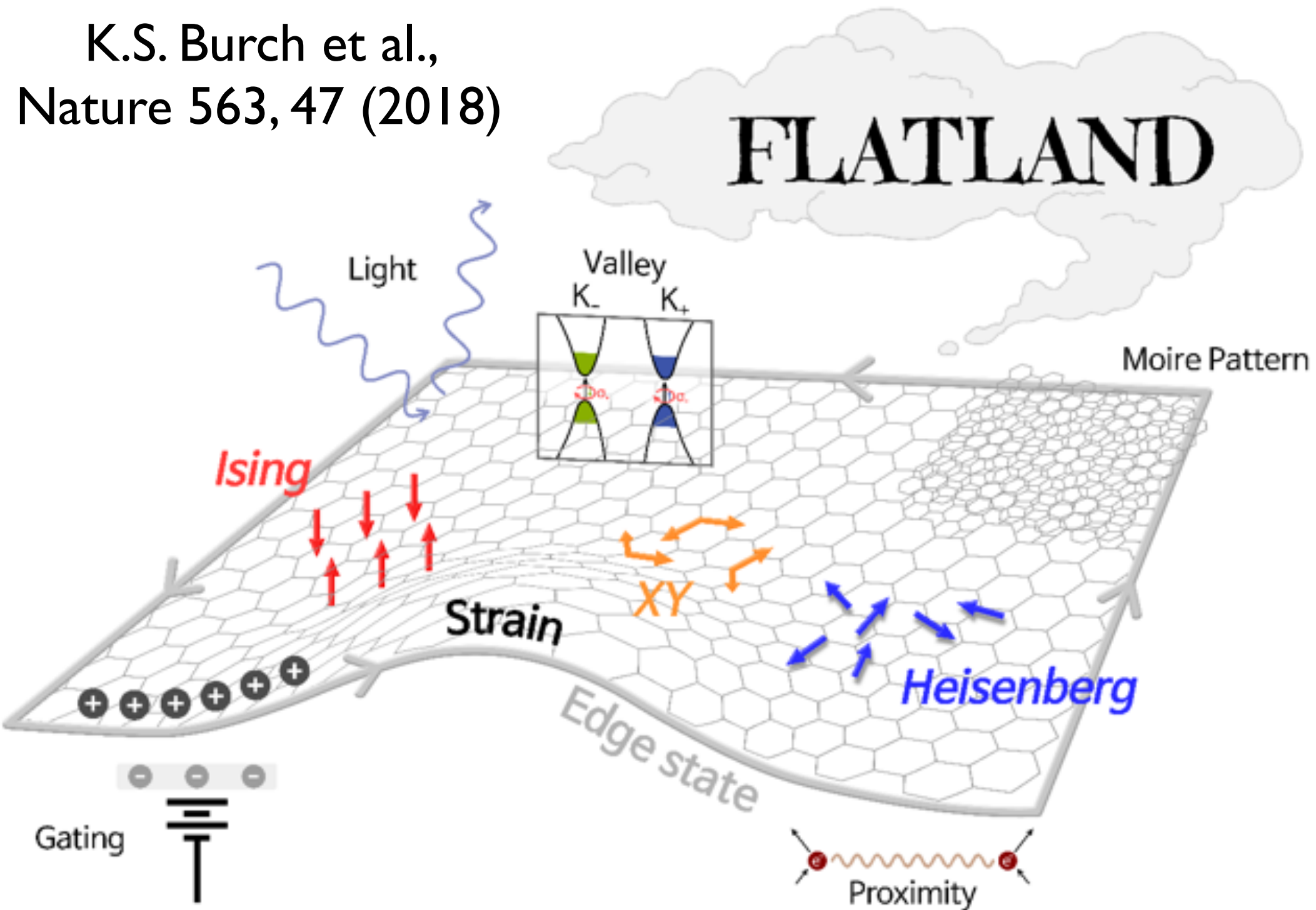
Heterostructures

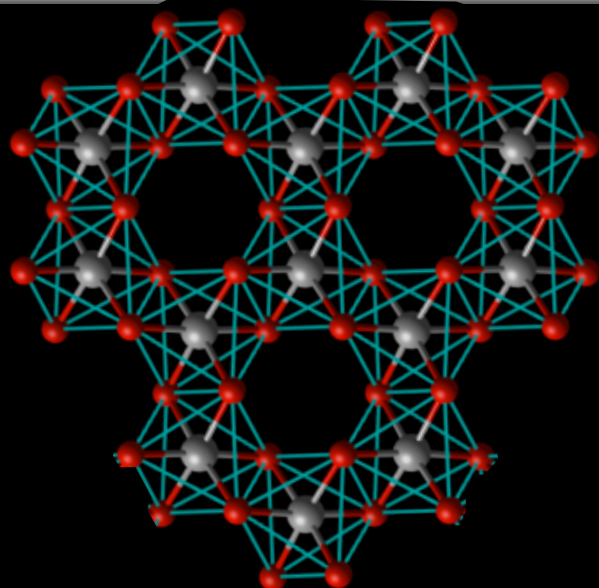


Exfoliation?

$$H = -J_x \sum_{j,k} \sigma_j^x \sigma_k^x - J_y \sum_{j,k} \sigma_j^y \sigma_k^y - J_z \sum_{j,k} \sigma_j^z \sigma_k^z$$

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I. Pollini et. al, PRB 53 12769 (1996)

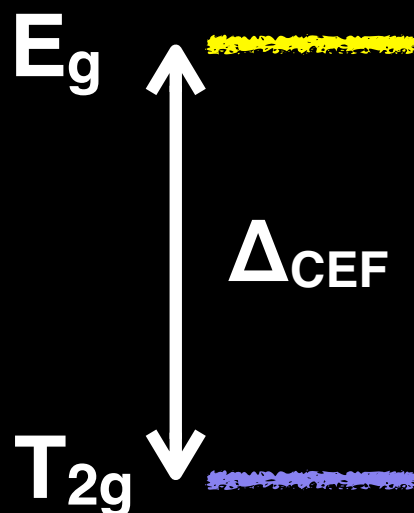
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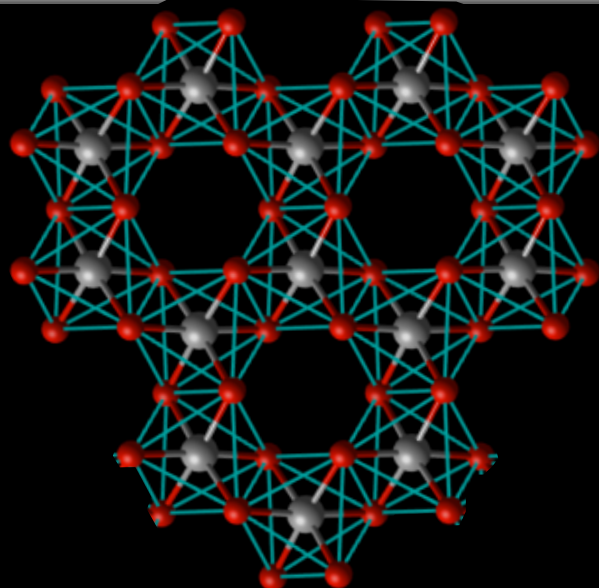
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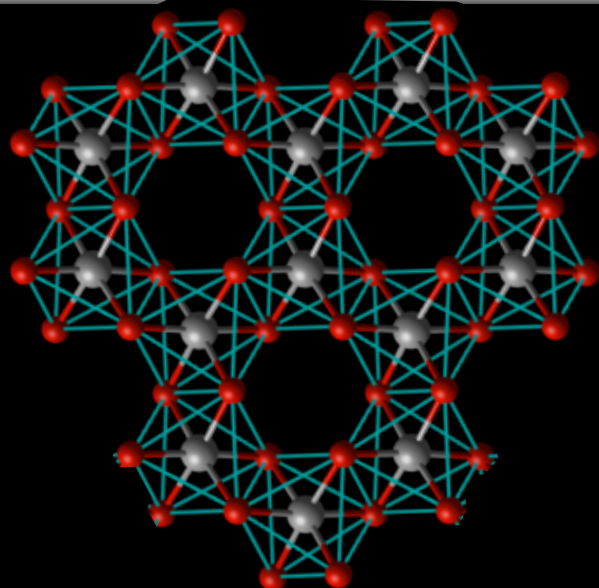
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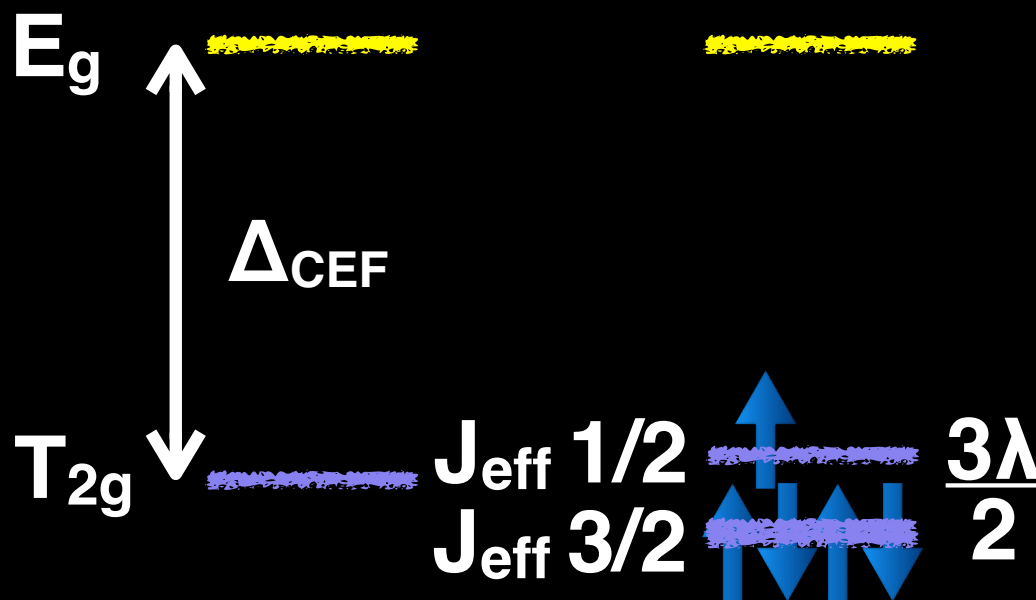
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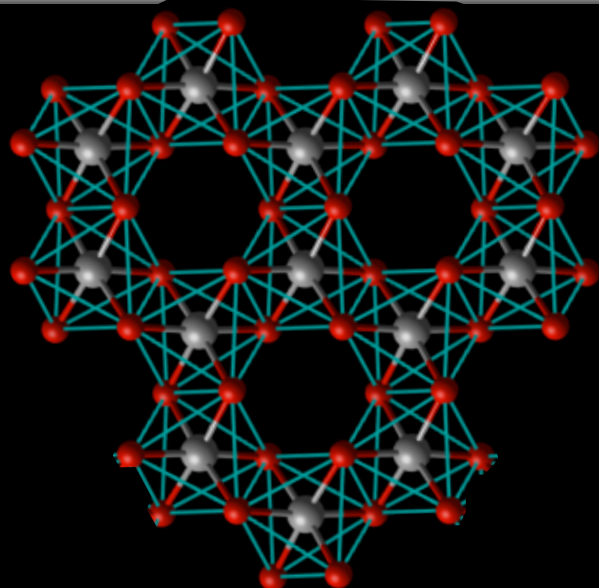
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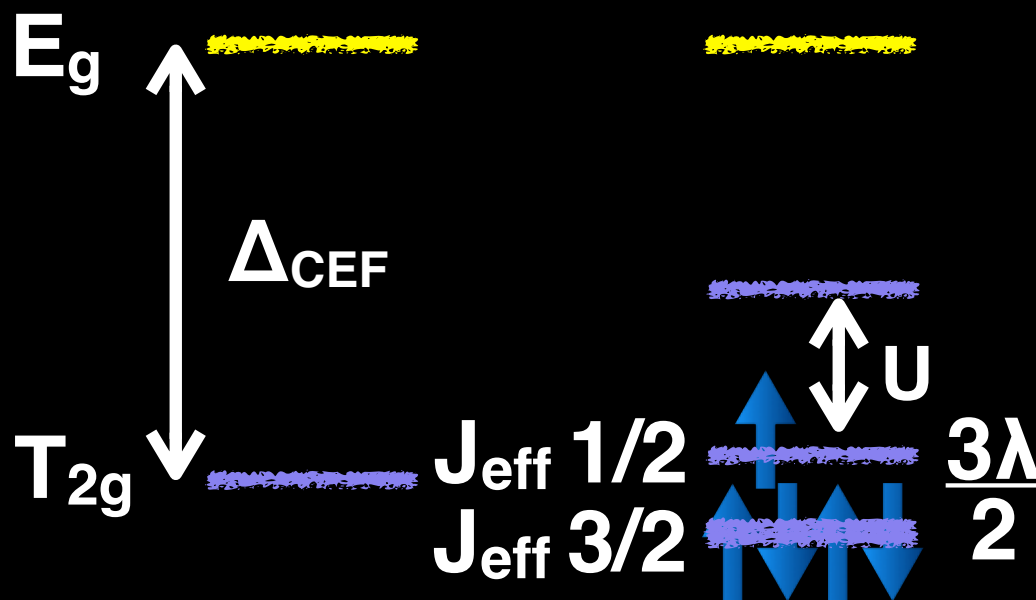


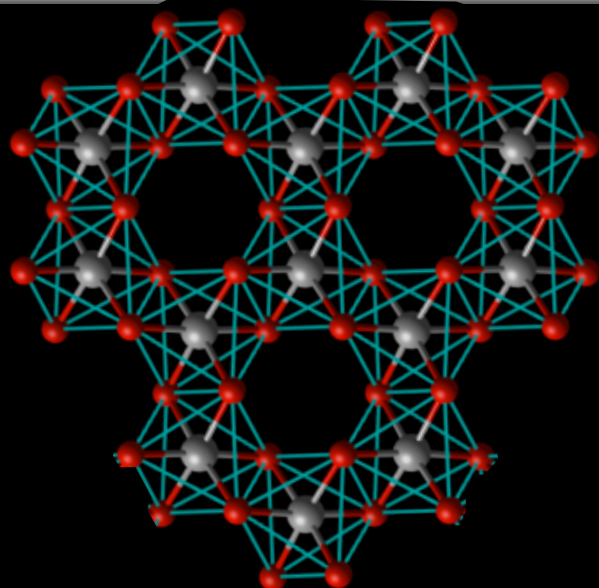
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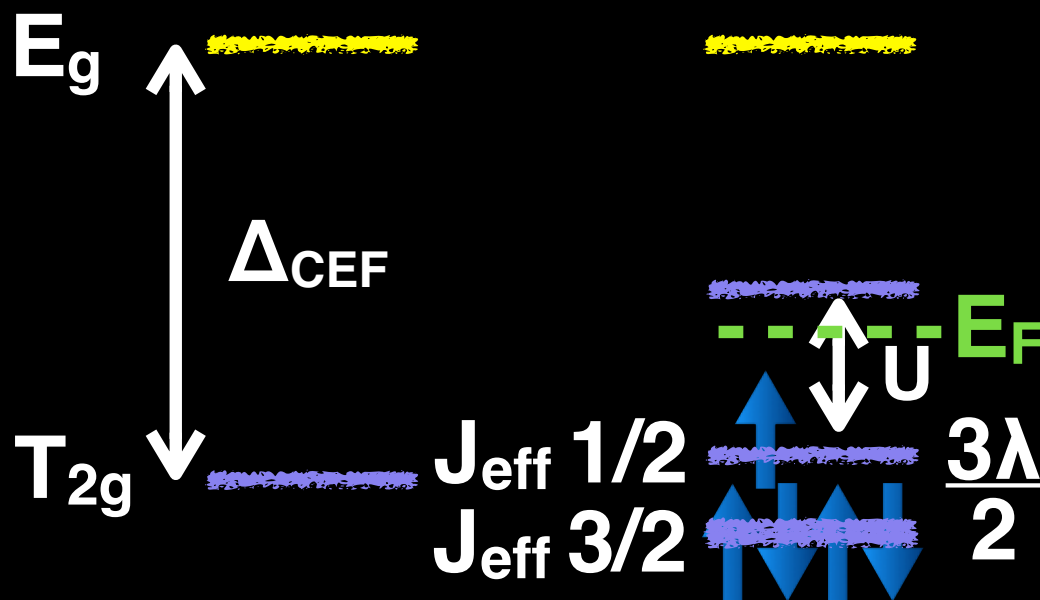
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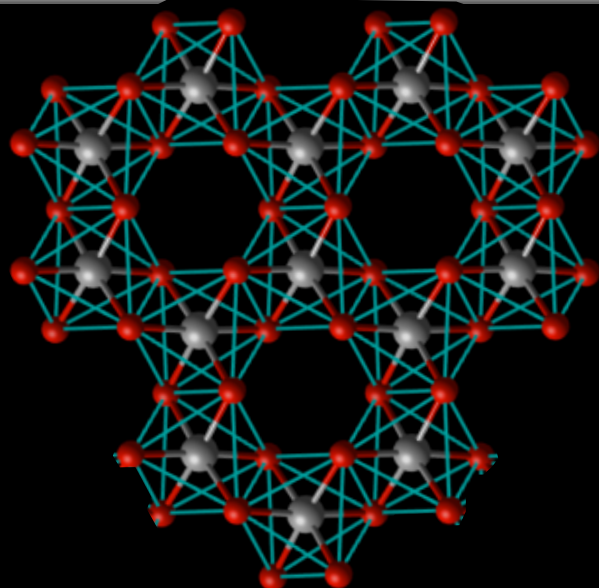
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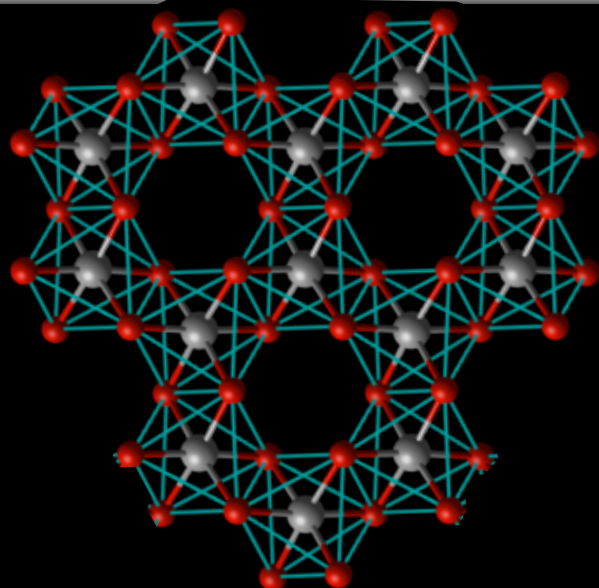




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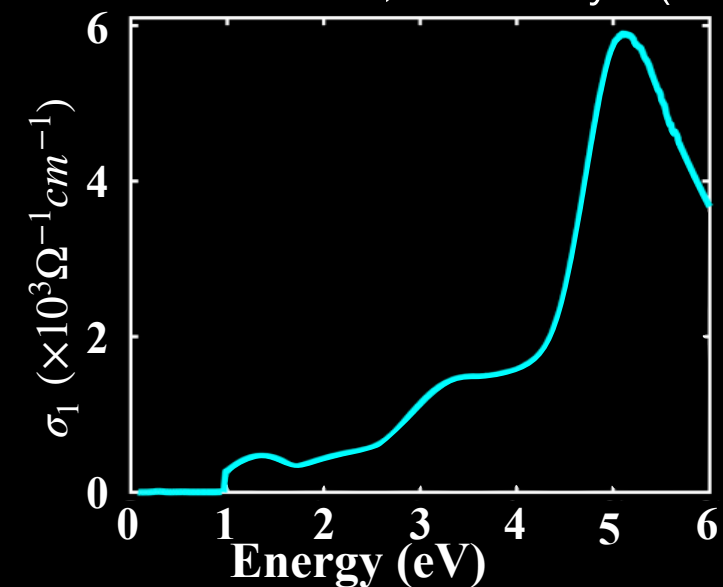
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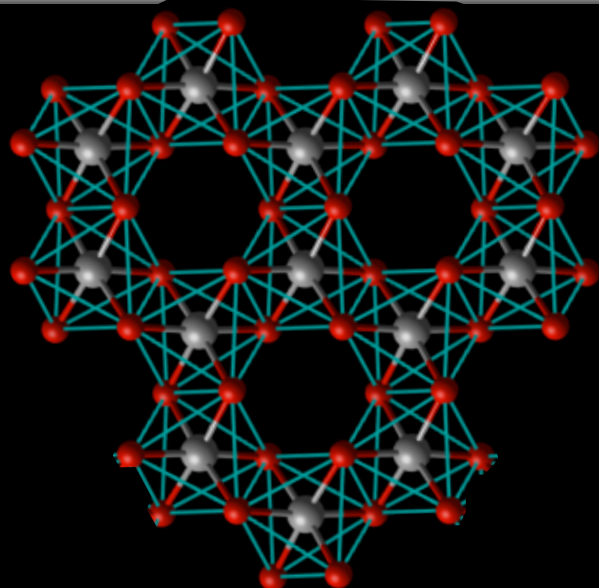




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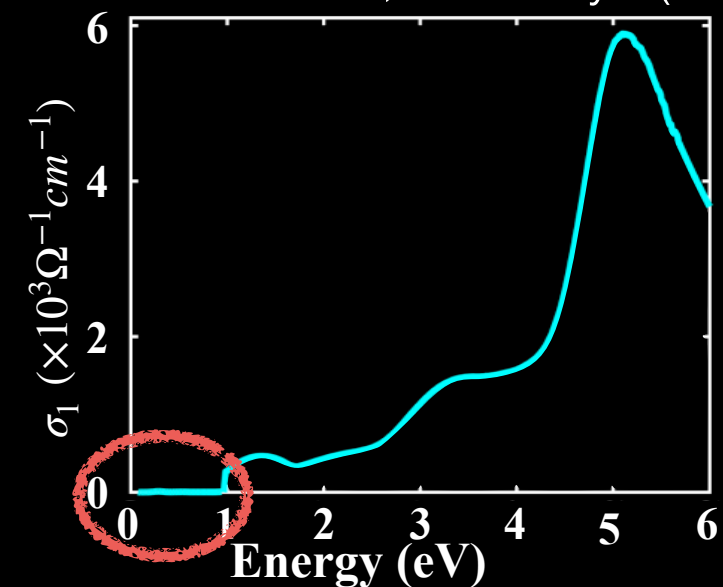
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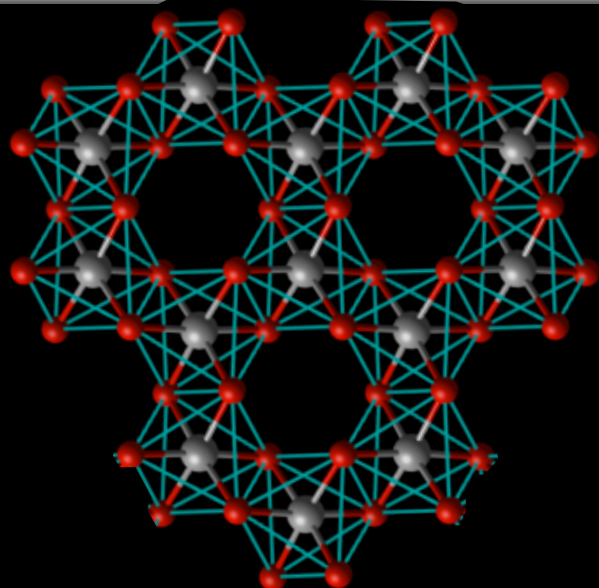




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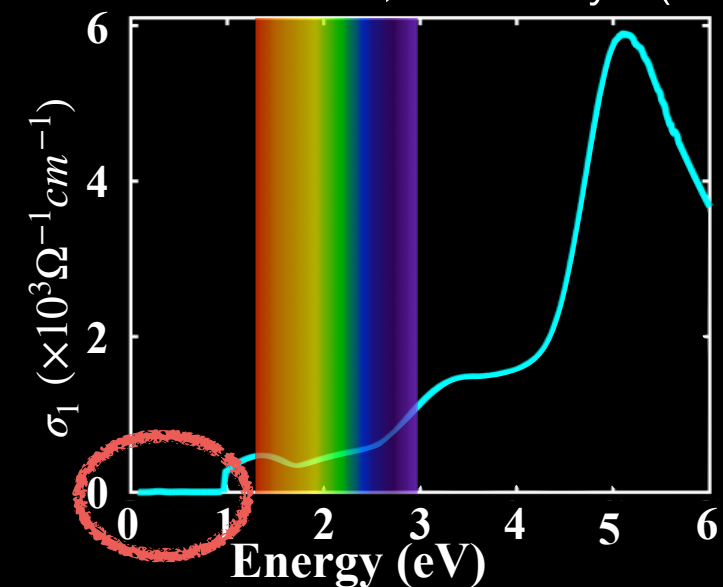
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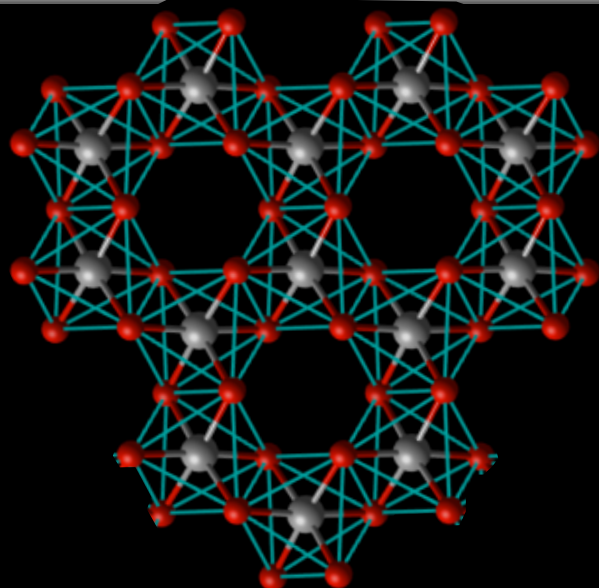




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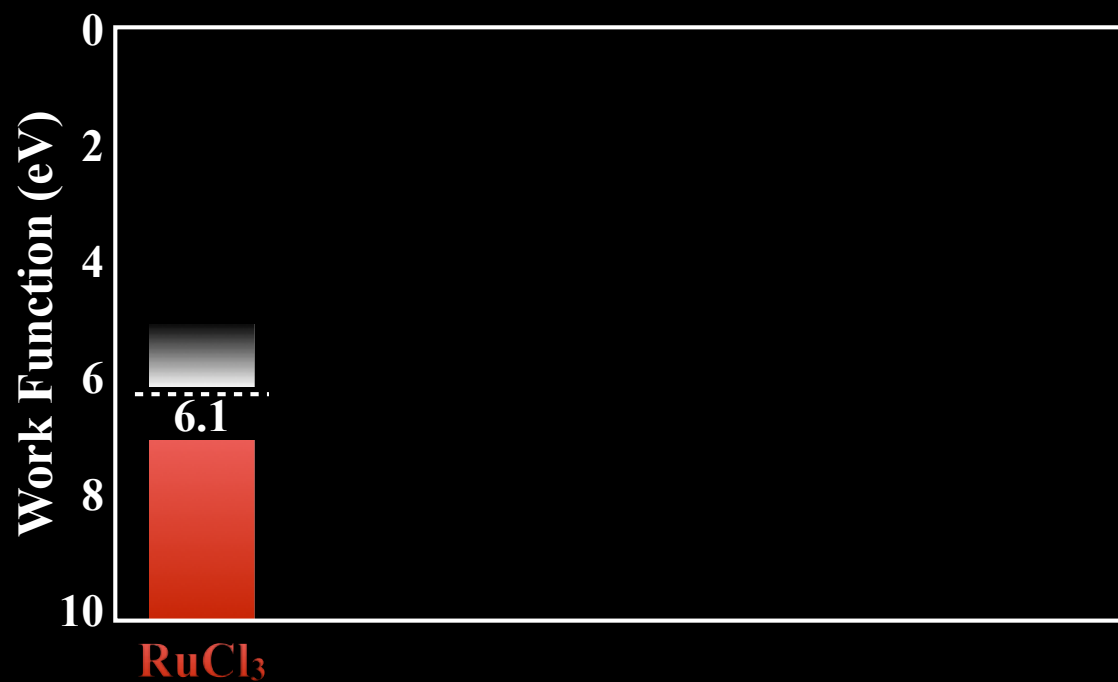
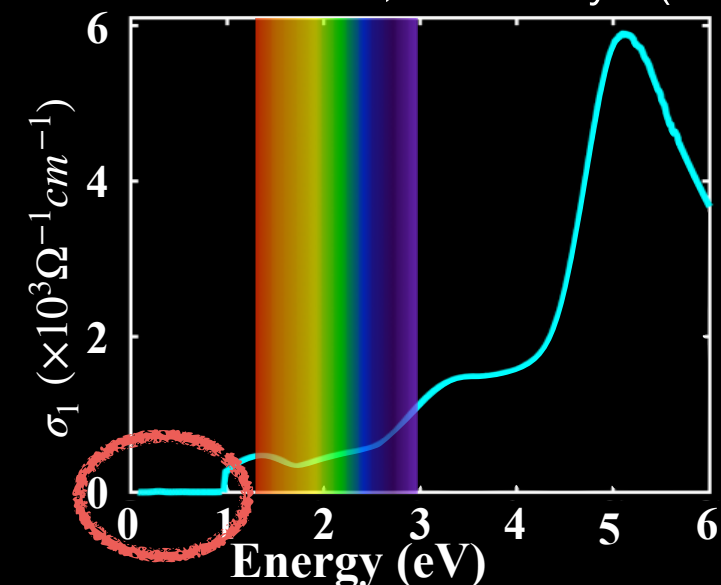
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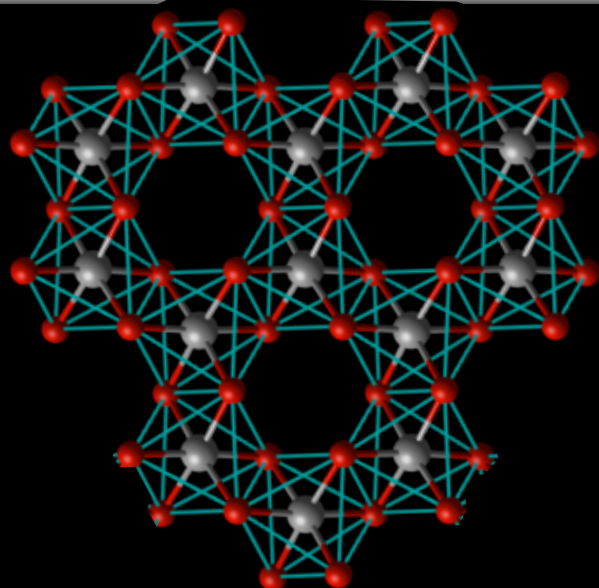




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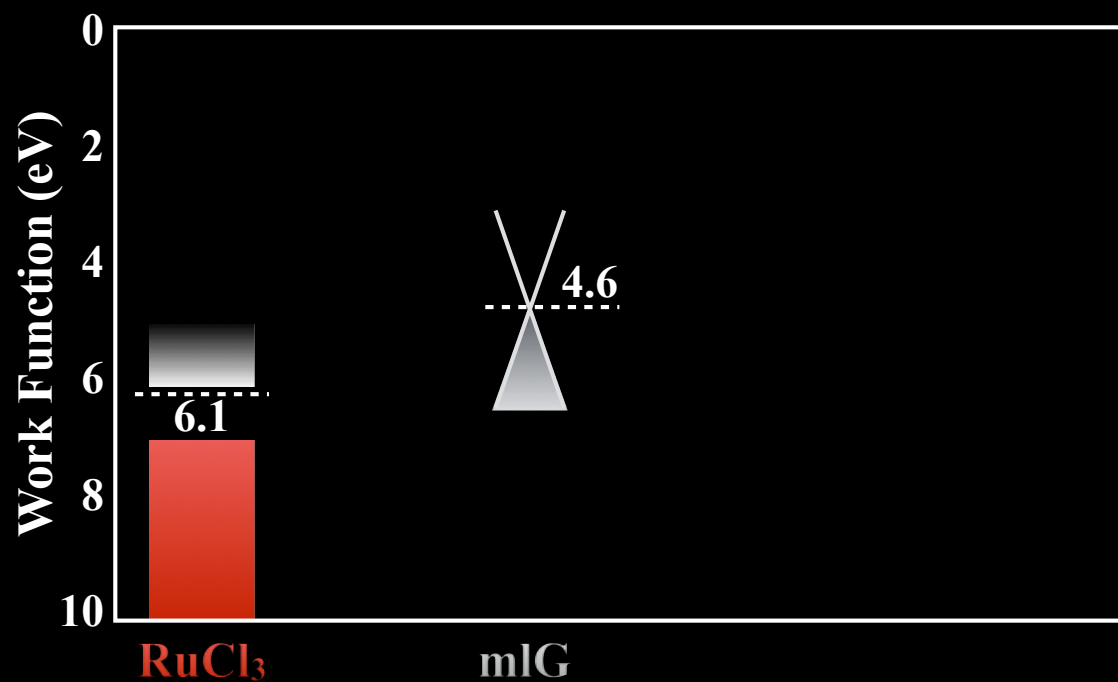
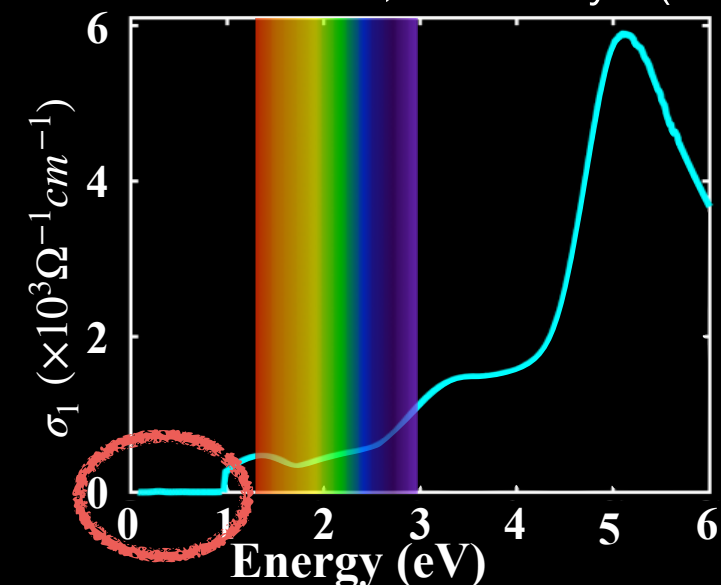
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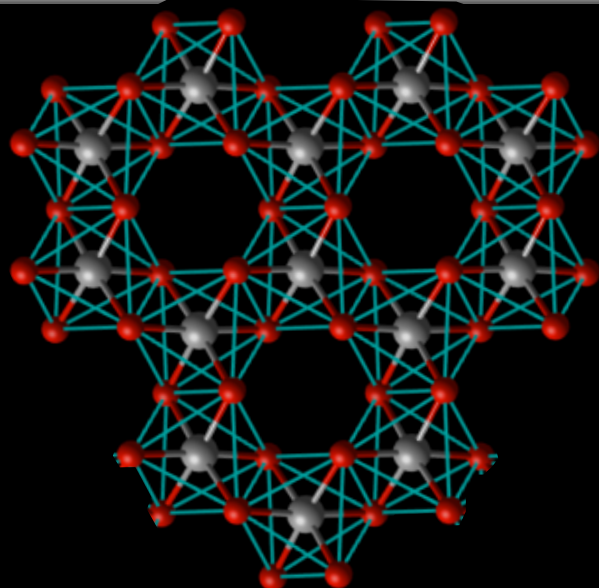




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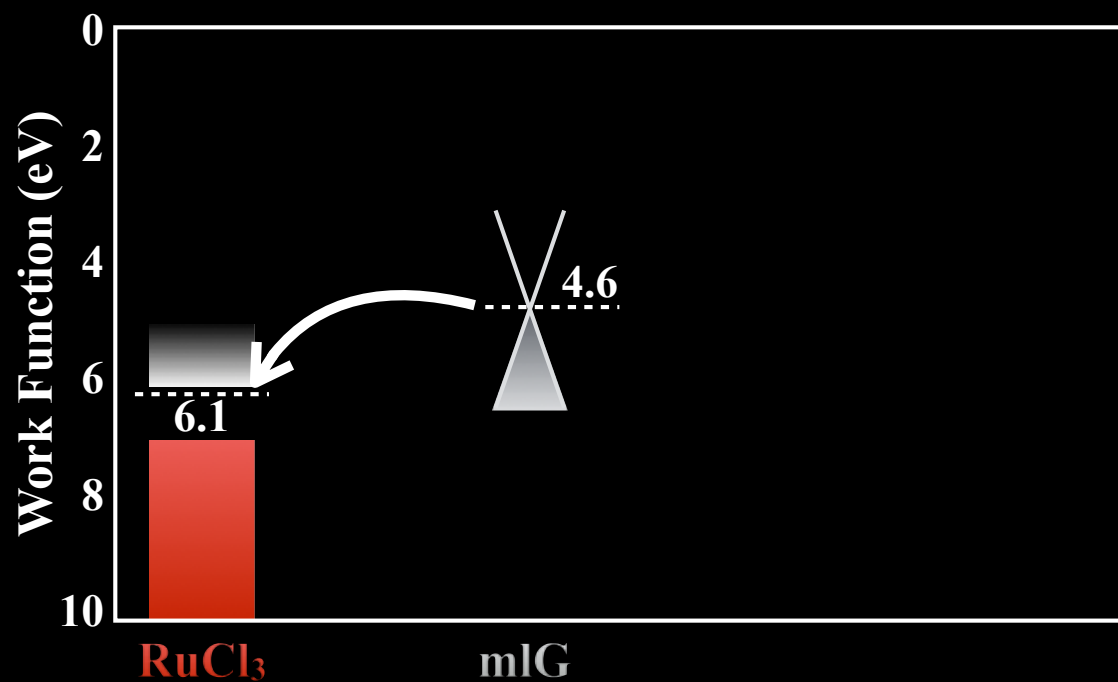
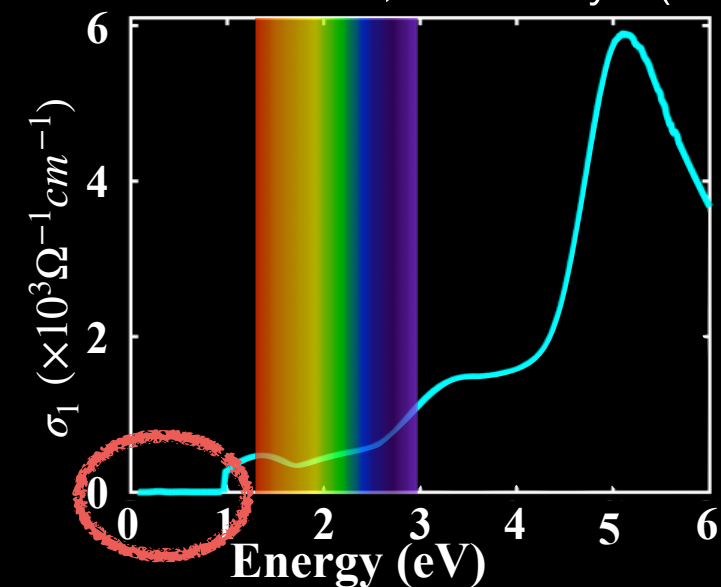
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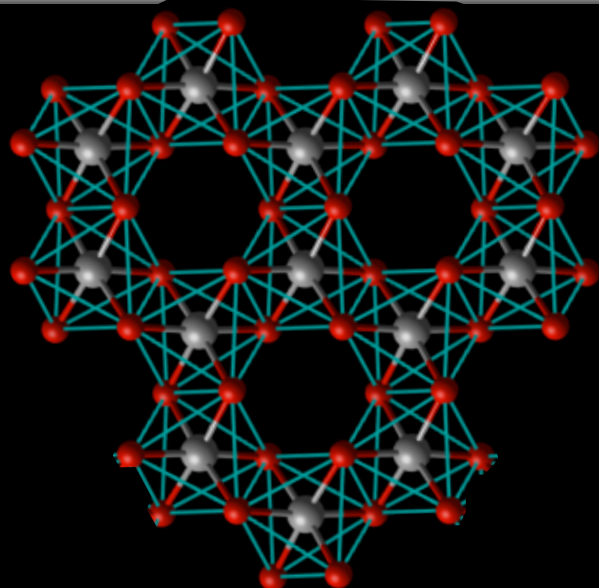




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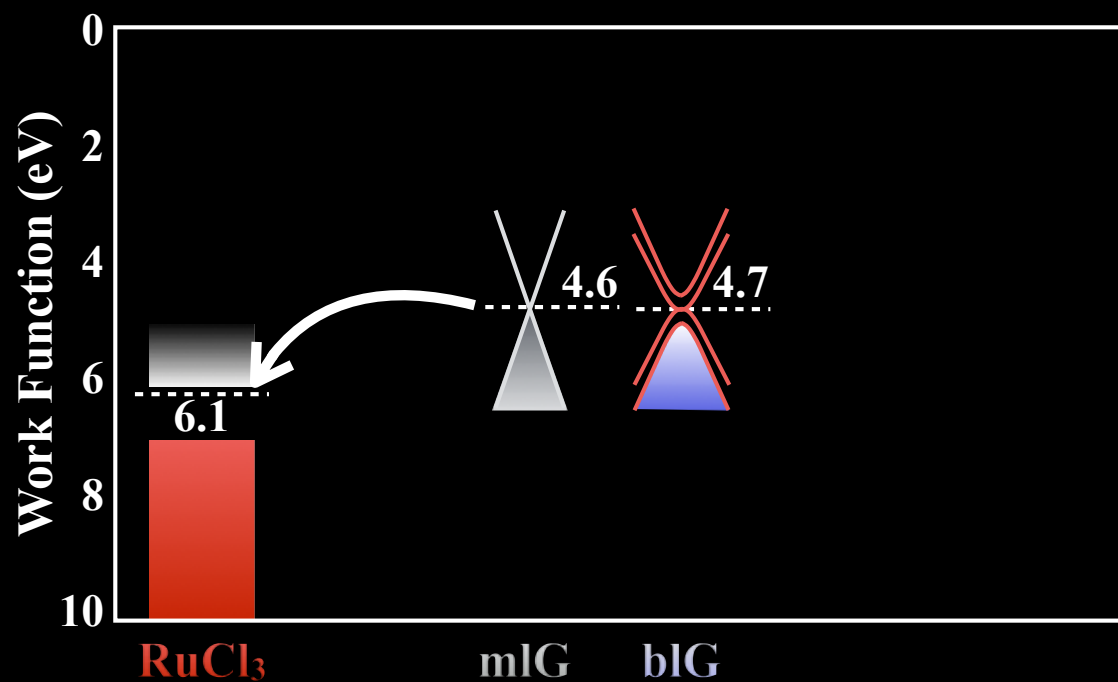
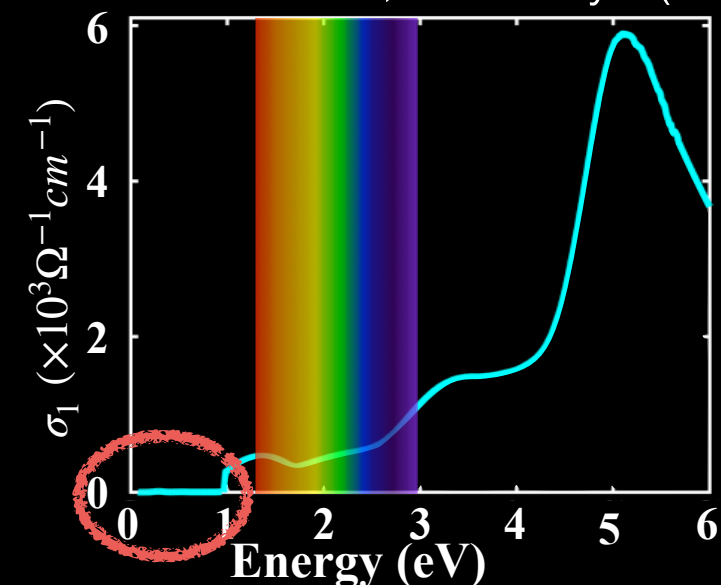
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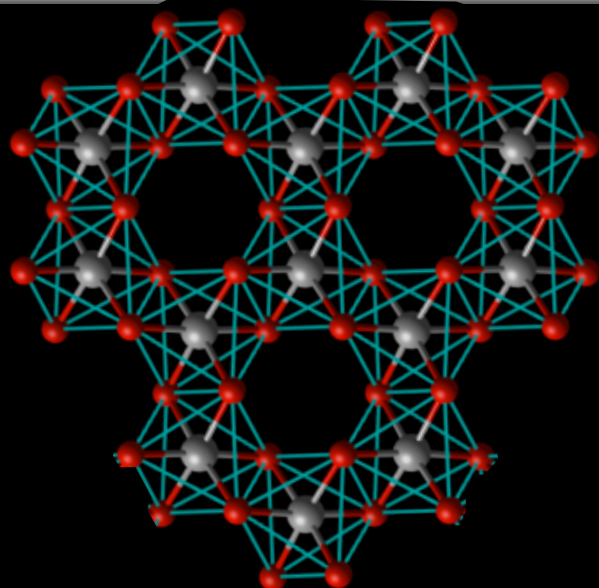




PRB 93, 075144 (2016)

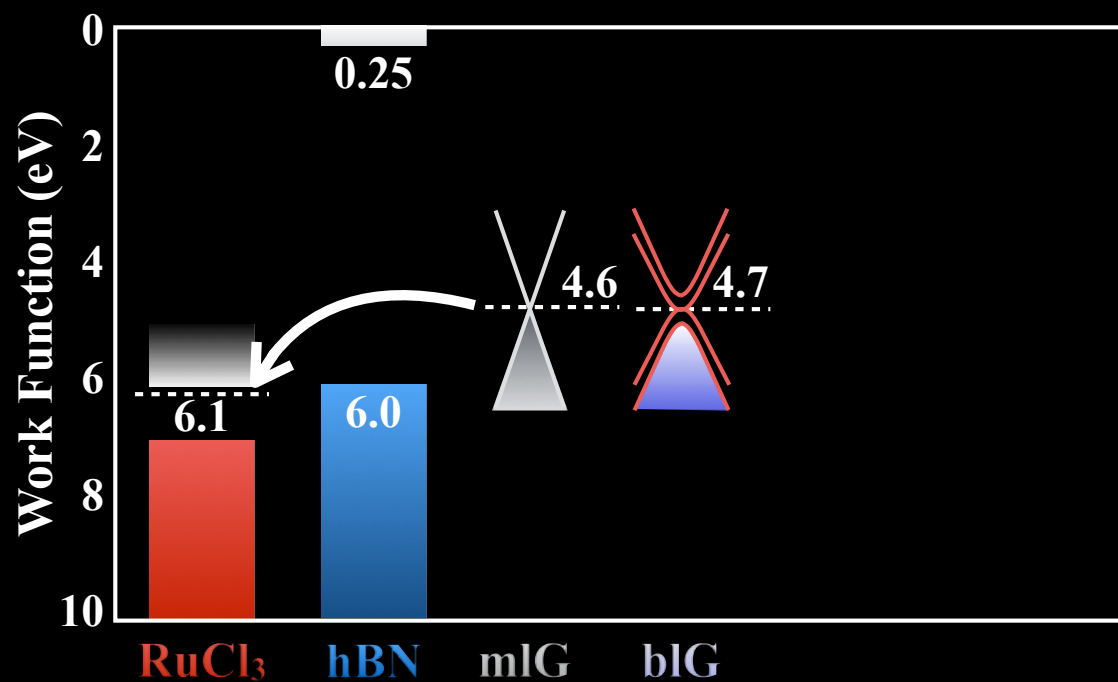
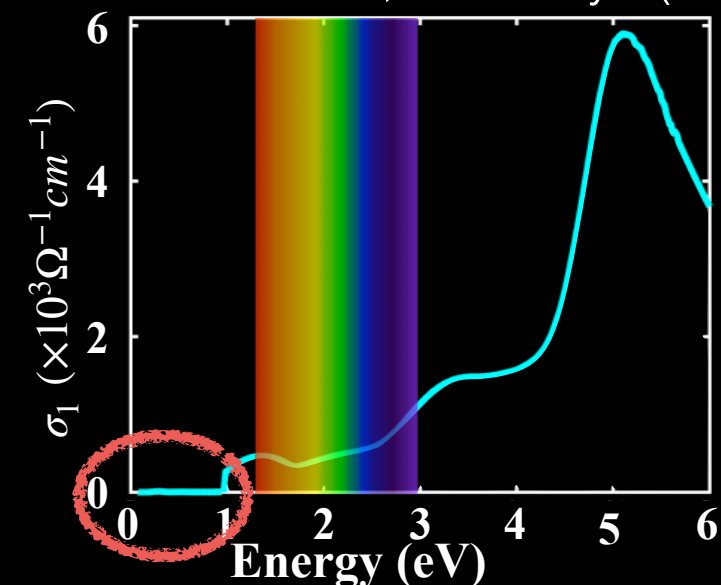
J. Sears et. al, Nat. Phys (2020)

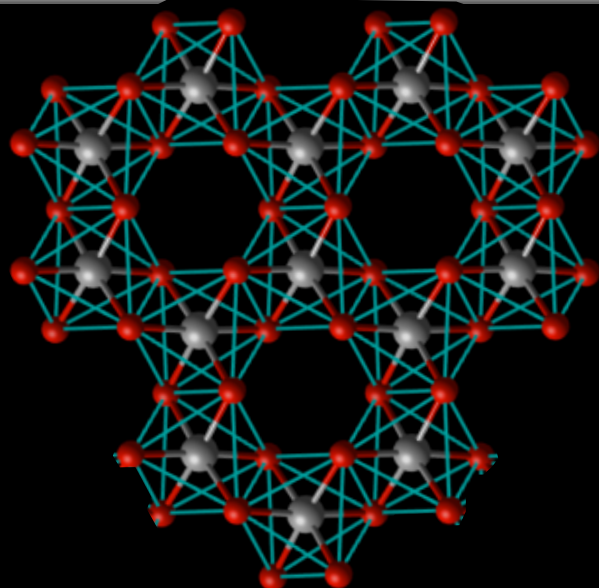




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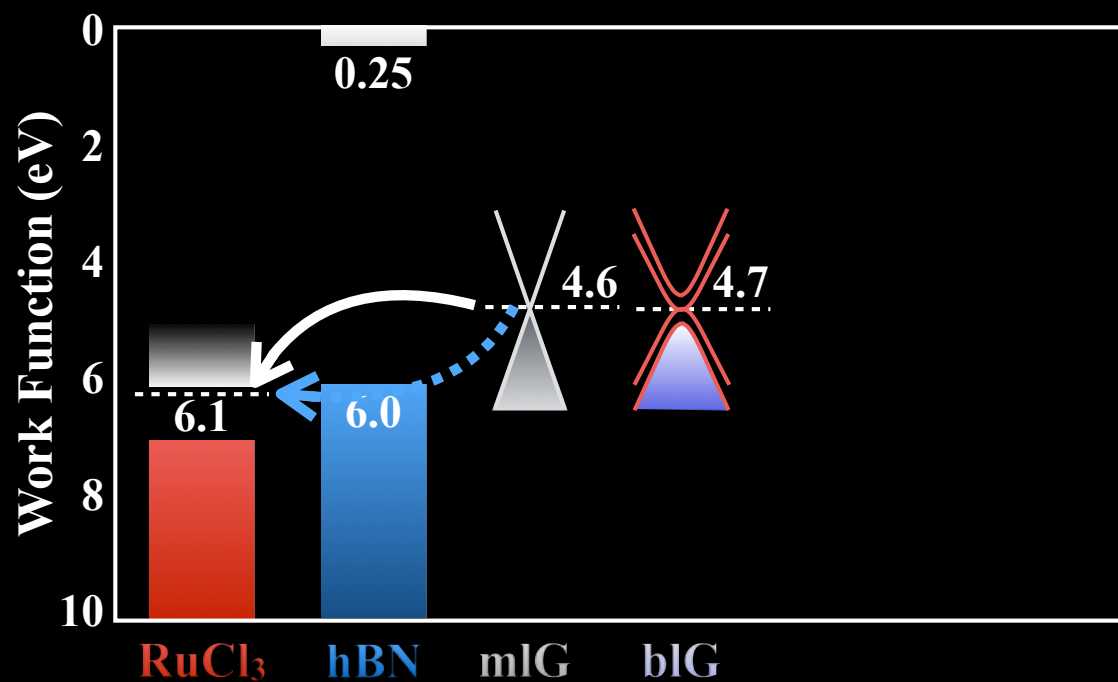
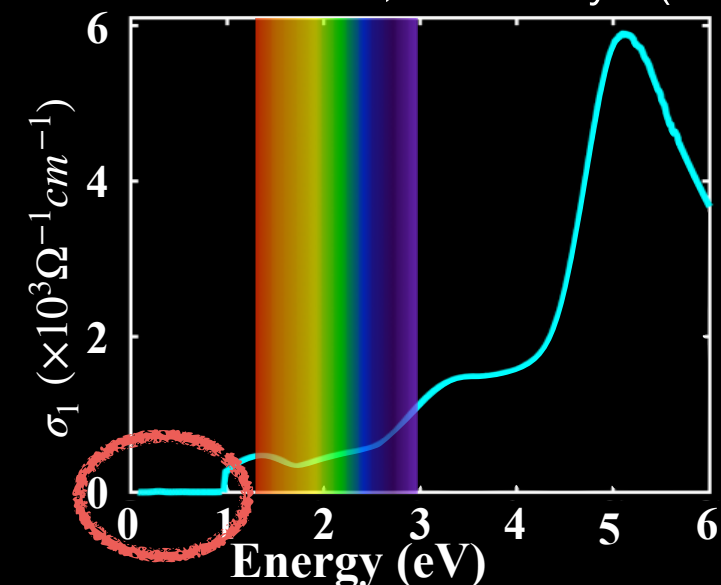
J. Sears et. al, Nat. Phys (2020)

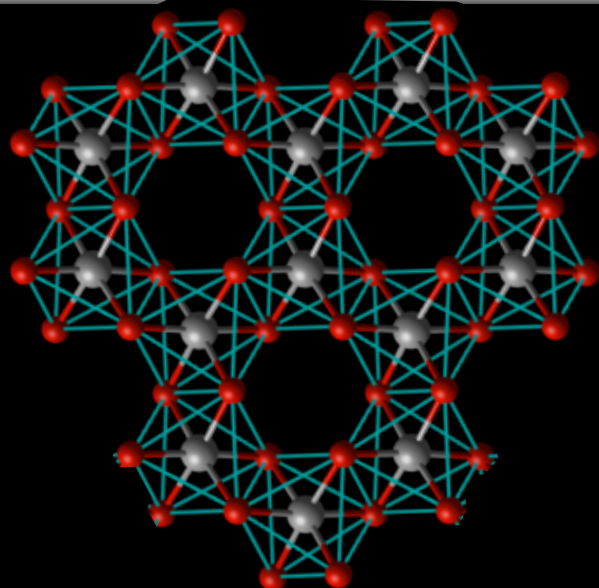




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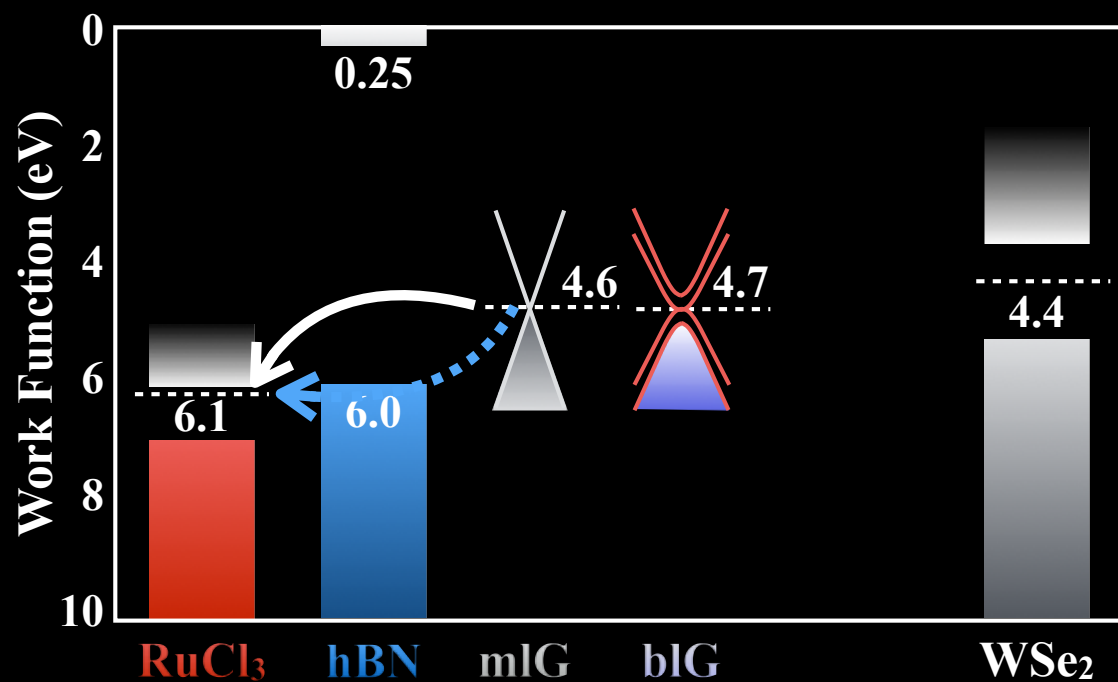
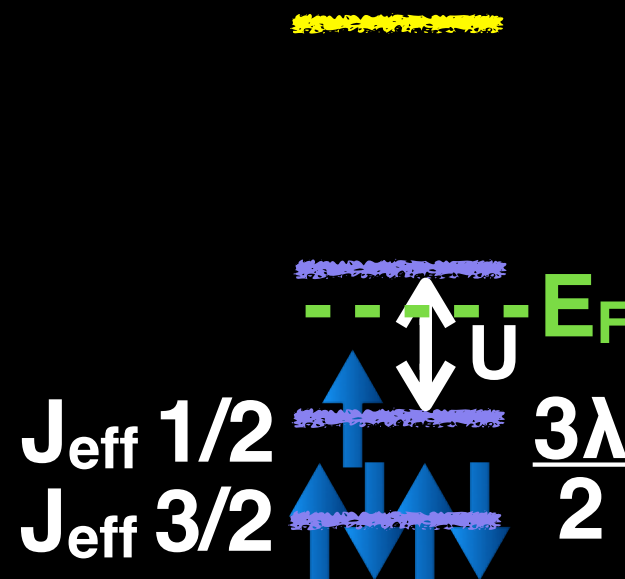
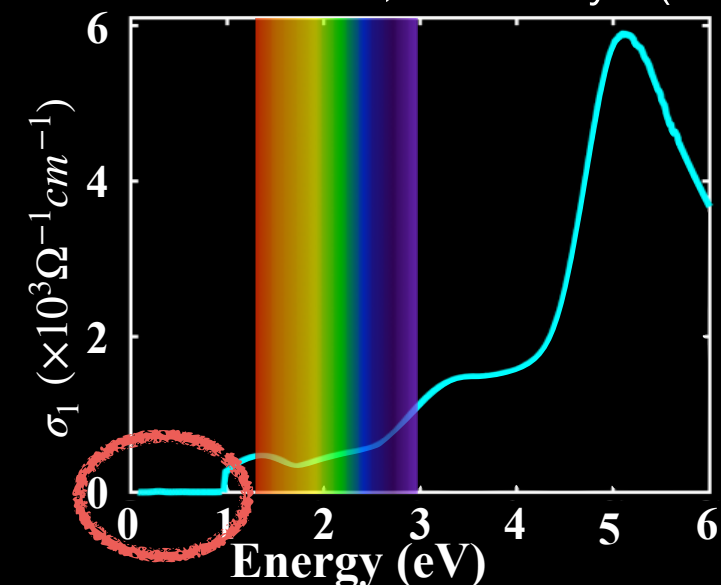
J. Sears et. al, Nat. Phys (2020)

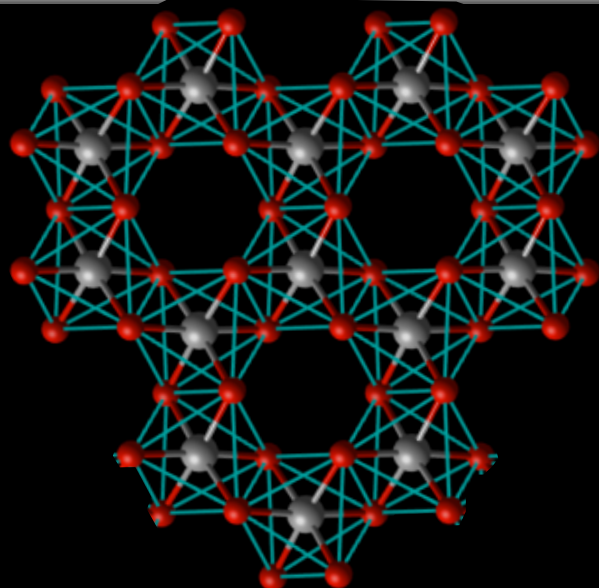




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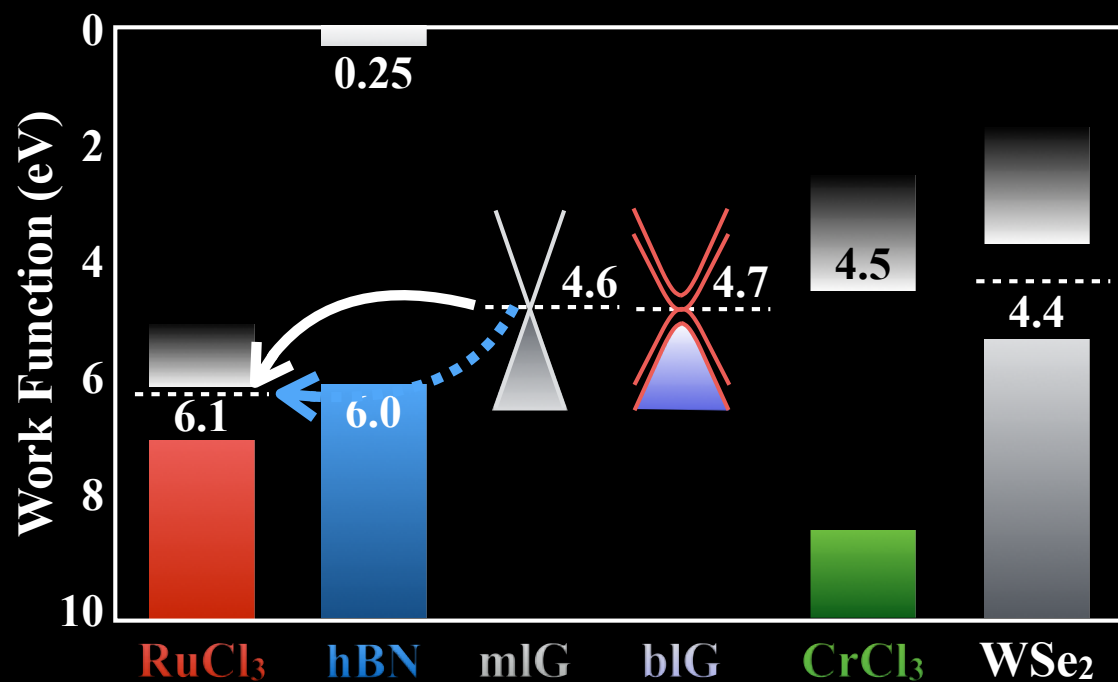
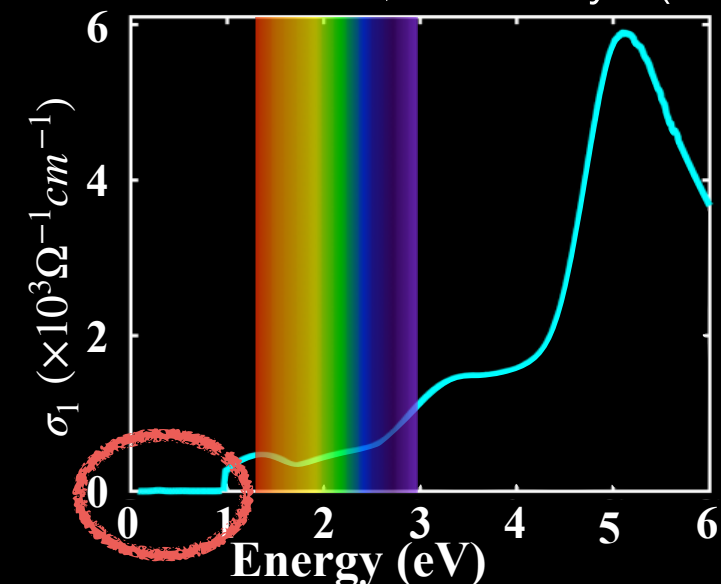
J. Sears et. al, Nat. Phys (2020)

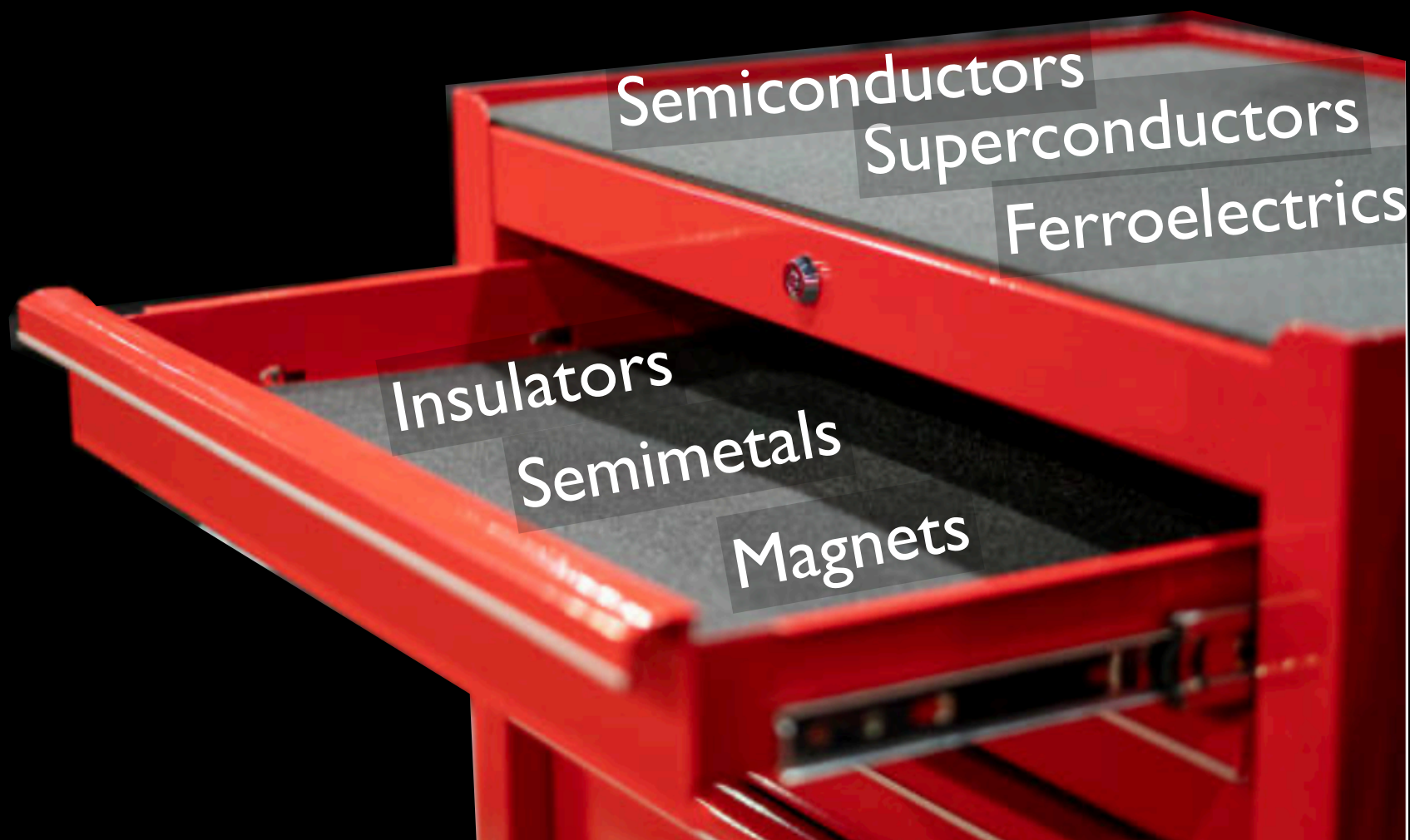


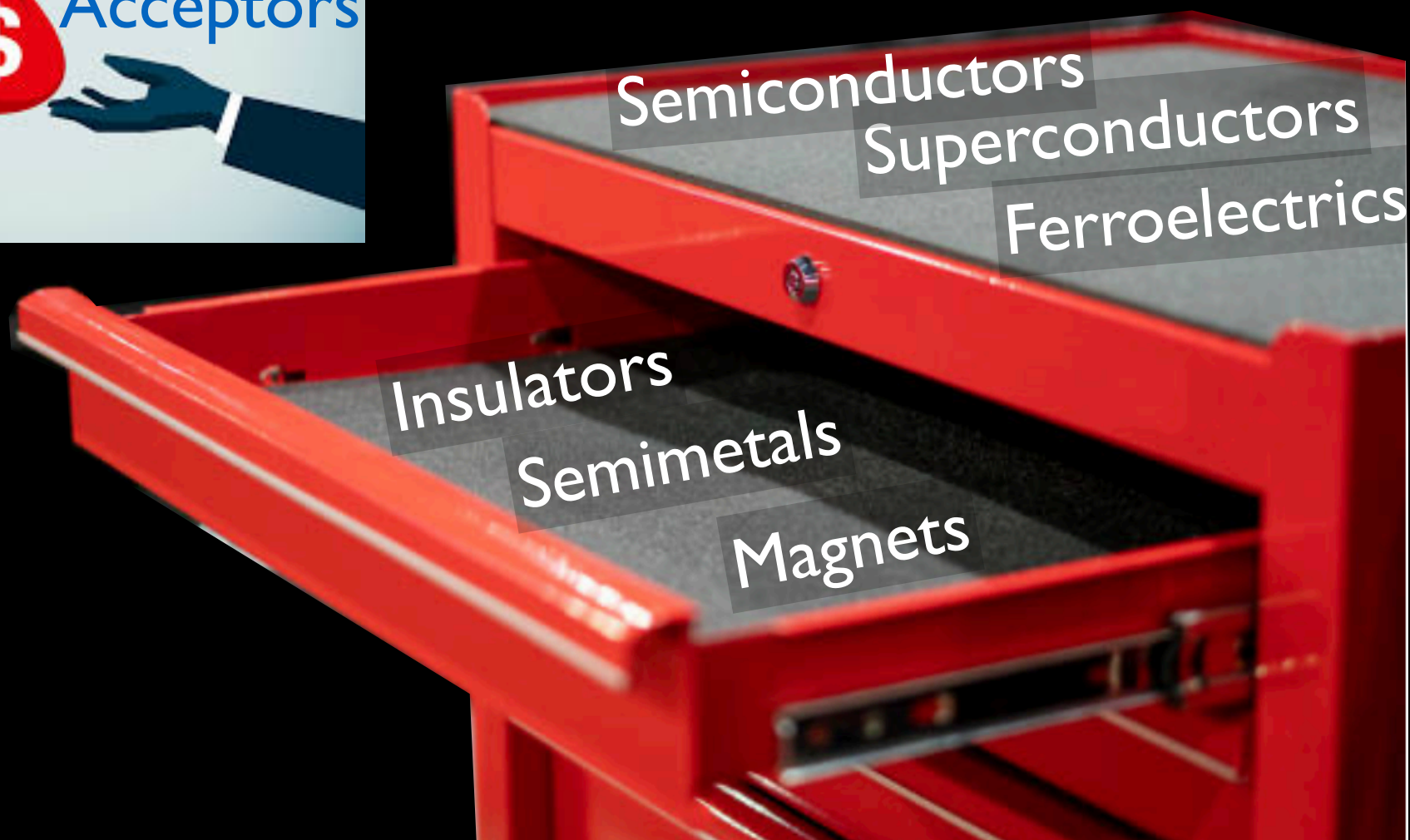


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J. Sears et. al, Nat. Phys (2020)



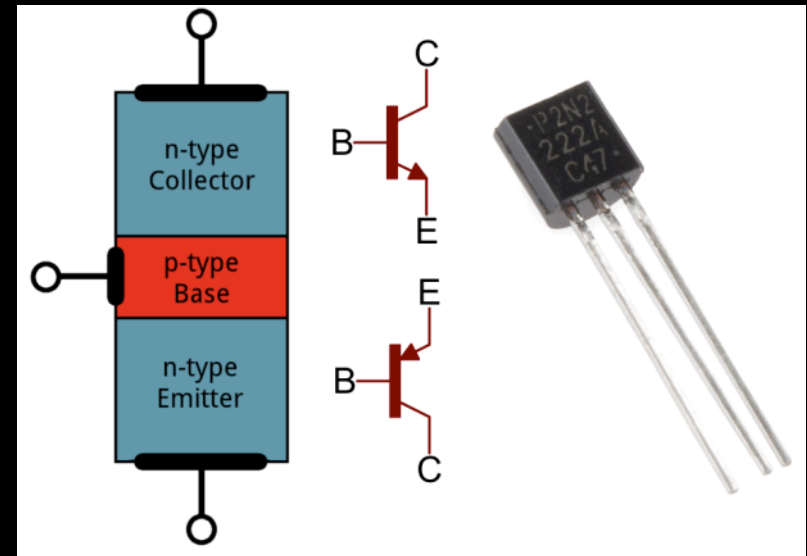




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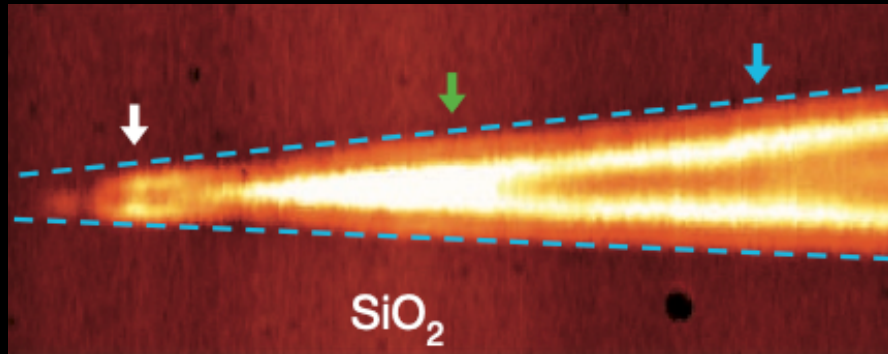
Donors & Acceptors

Electronics



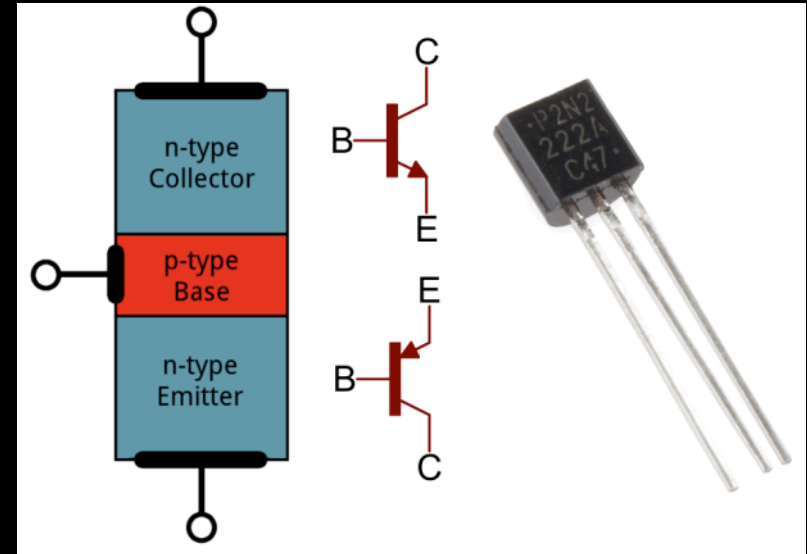
Donors & Acceptors

Plasmonics



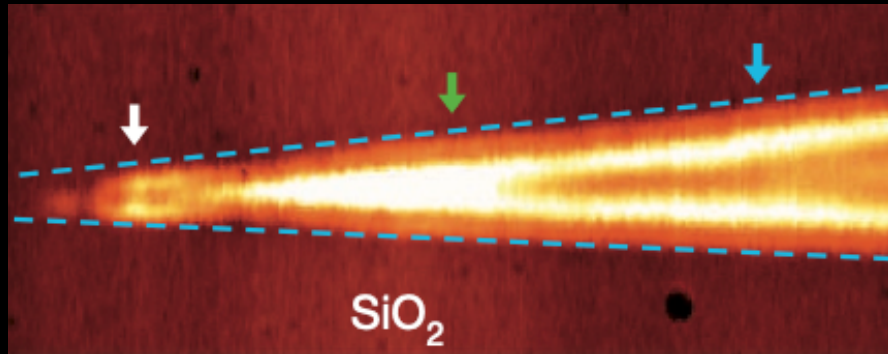
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Koppens: Nature 487, 77 (2012)

Electronics



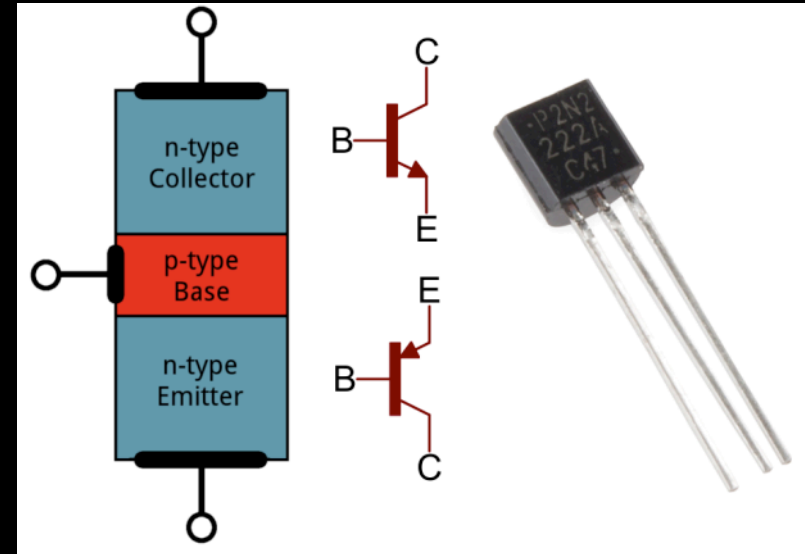
Donors & Acceptors

Plasmonics

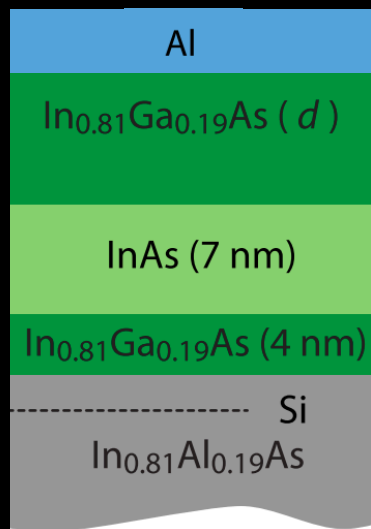


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Electronics



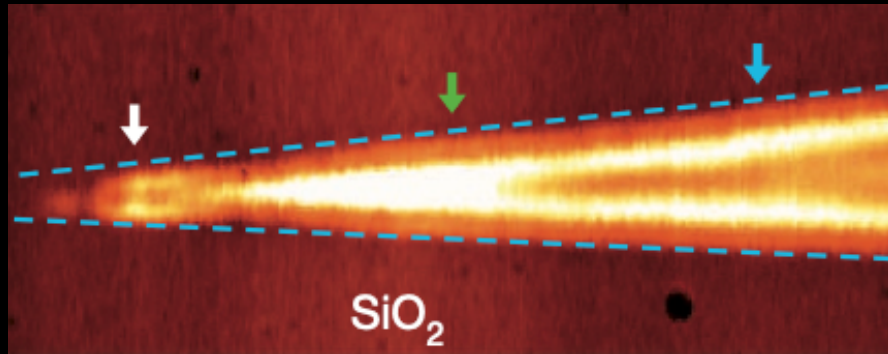
New Phases



J. Shabani et. al,
PRB 93 155402
(2016)

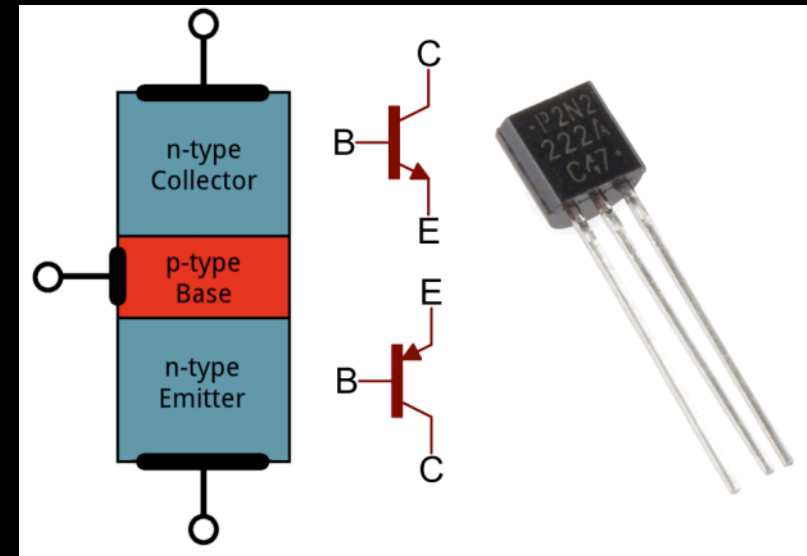
Donors & Acceptors

Plasmonics

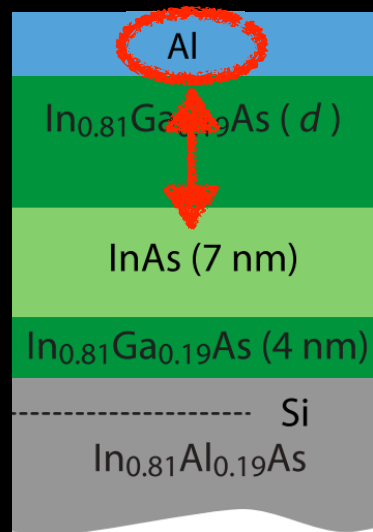


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Electronics



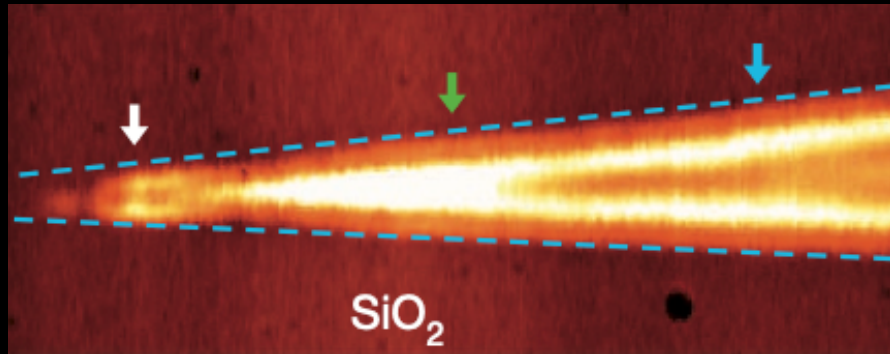
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J. Shabani et. al,
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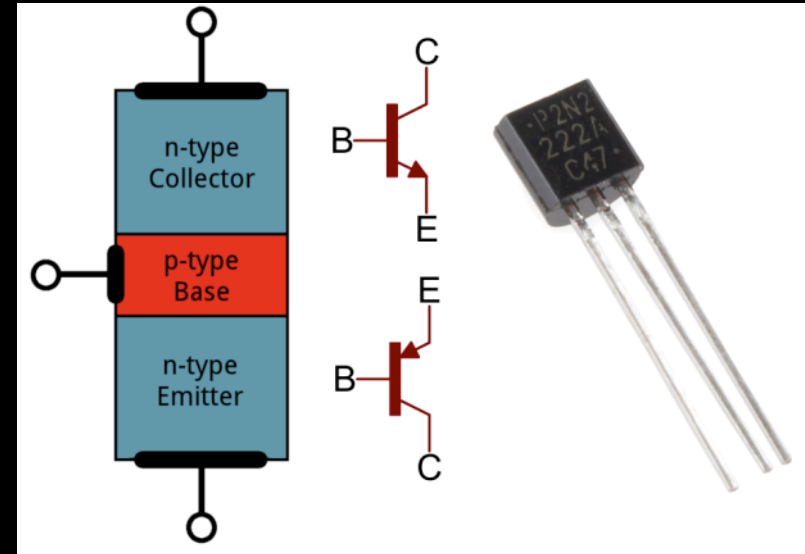
Donors & Acceptors

Plasmonics



Basov: Nature 487, 82 (2012)
Koppens: Nature 487, 77 (2012)

Electronics



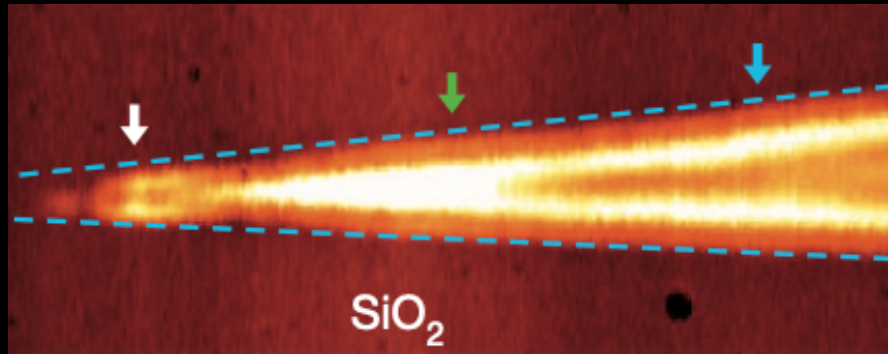
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J. Shabani et. al,
PRB 93 155402
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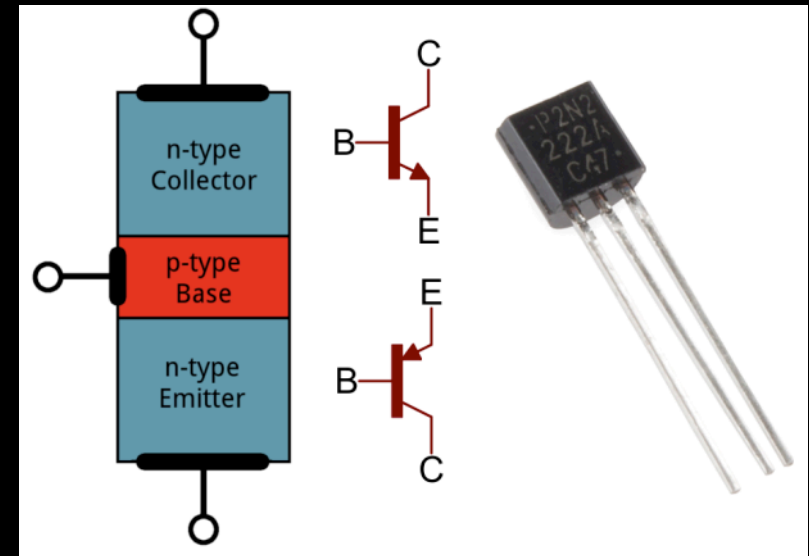
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Plasmonics

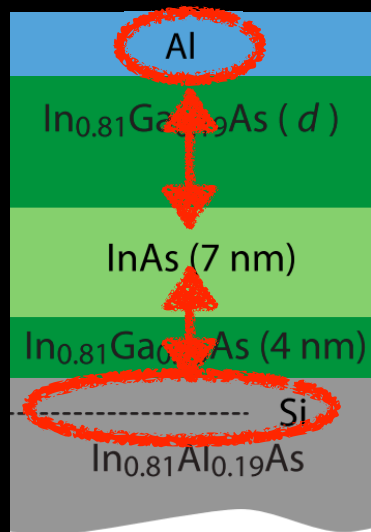


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Electronics

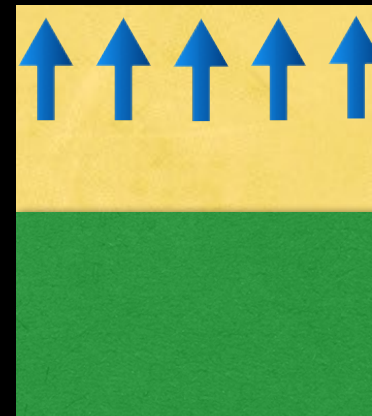


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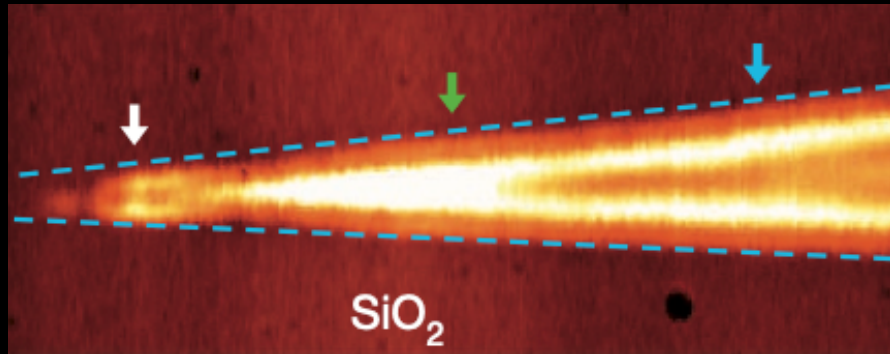
J. Shabani et. al,
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Magnets



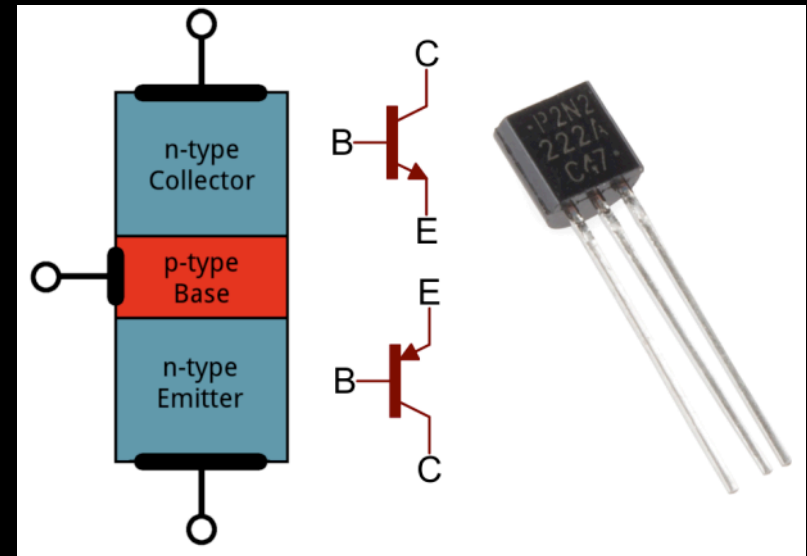
Donors & Acceptors

Plasmonics



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Koppens: Nature 487, 77 (2012)

Electronics

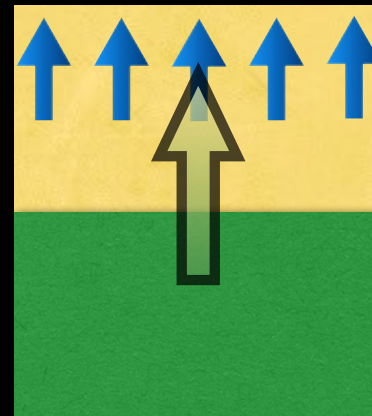


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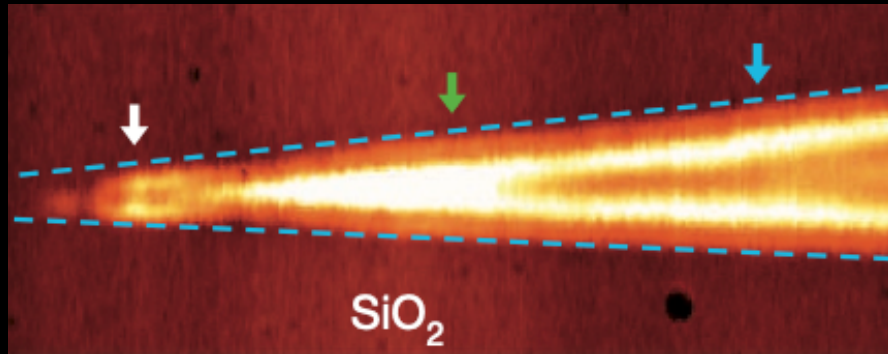
J. Shabani et. al,
PRB 93 155402
(2016)

Magnets



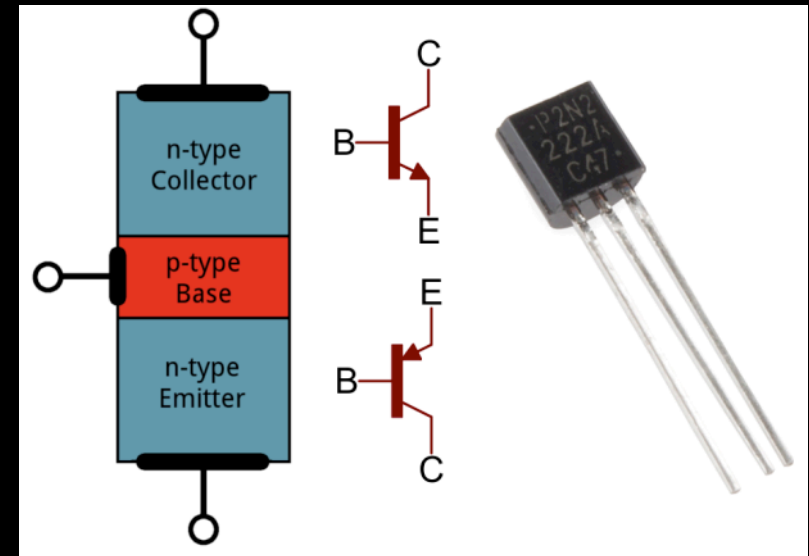
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Plasmonics

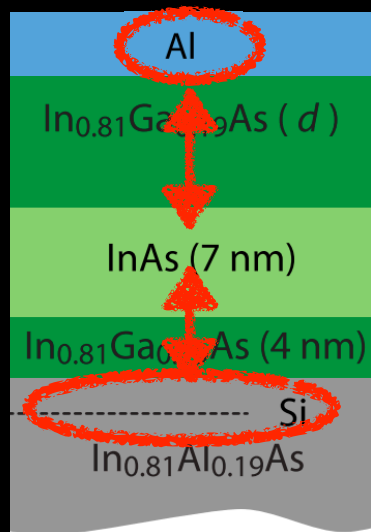


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Electronics

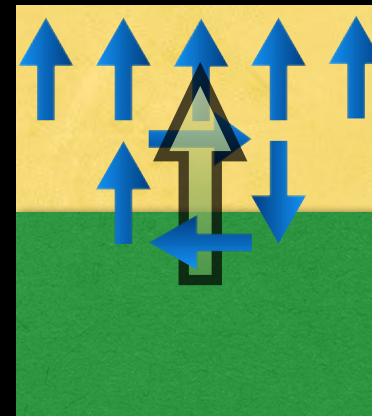


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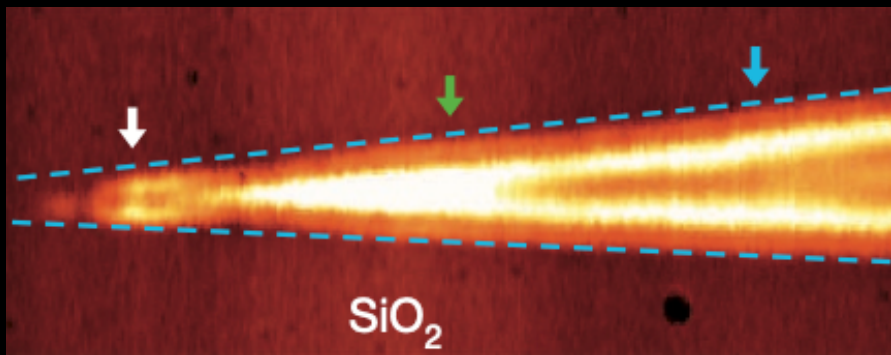
J. Shabani et. al,
PRB 93 155402
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Magnets



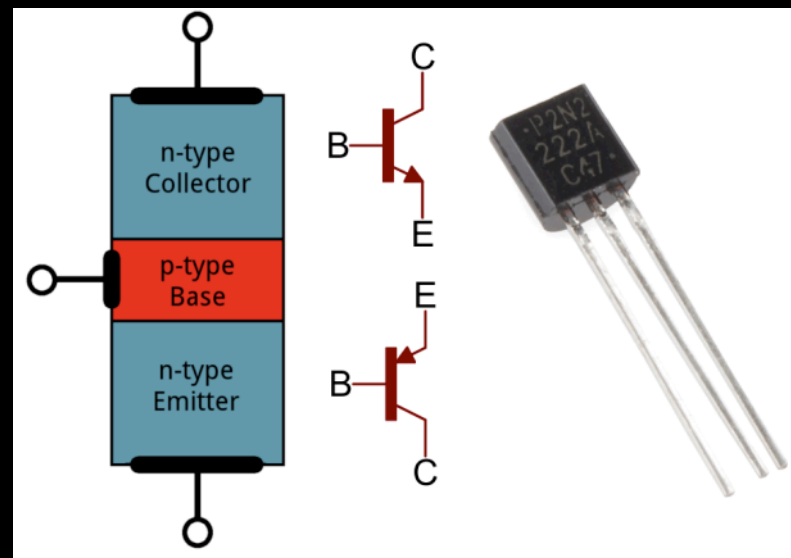
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Plasmonics

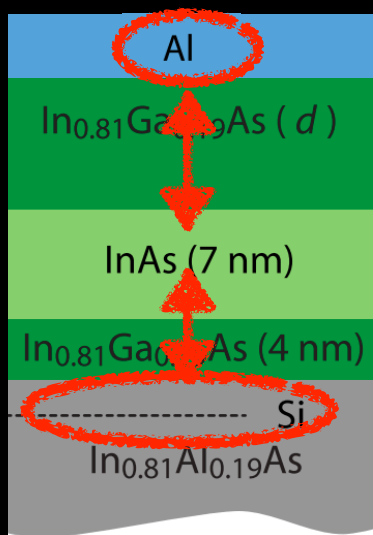


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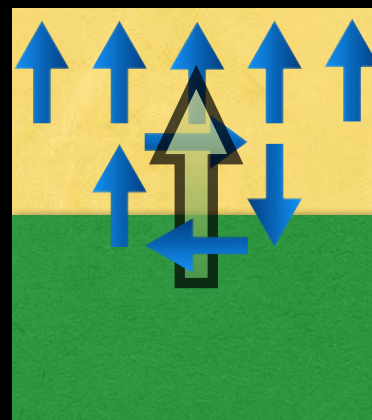


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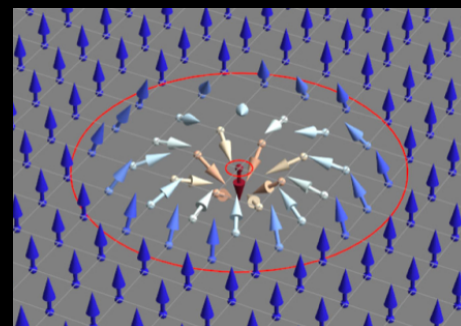


J. Shabani et. al,
PRB 93 155402
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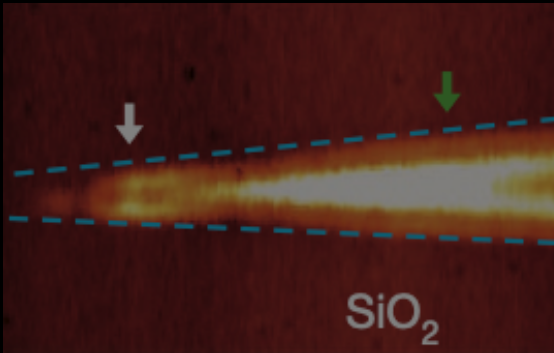


S. Banerjee et. al,
PRX 4 031045
(2014)



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Plasmonics



Basov: Nature 487,
Koppens: Nature 487

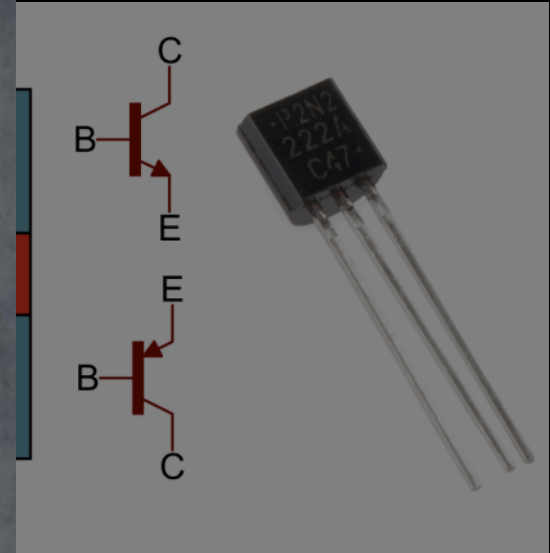
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PRB 93 155402
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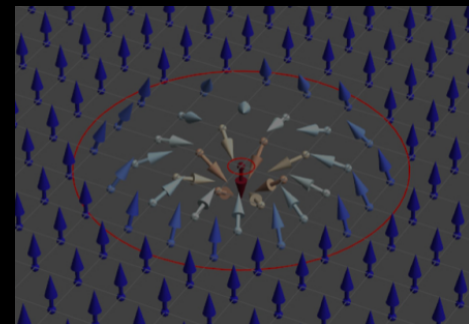


Electronics



S

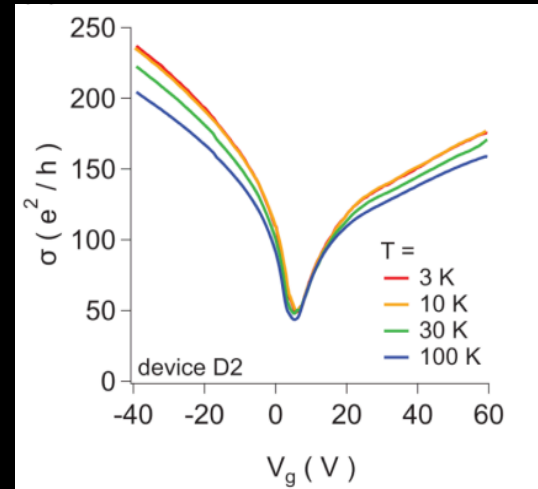
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Initial Results

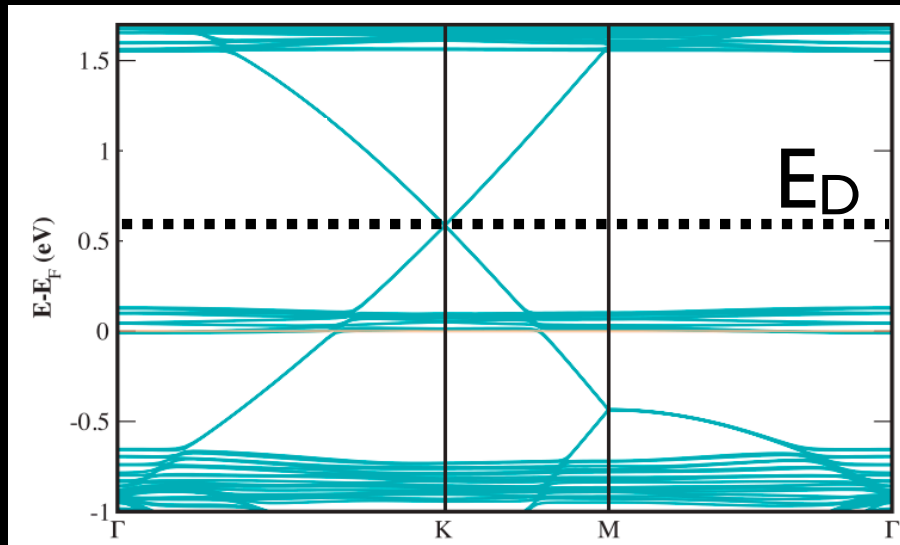
Initial Results

B. Zhou, et al., PRB 100, 165426 (2019)

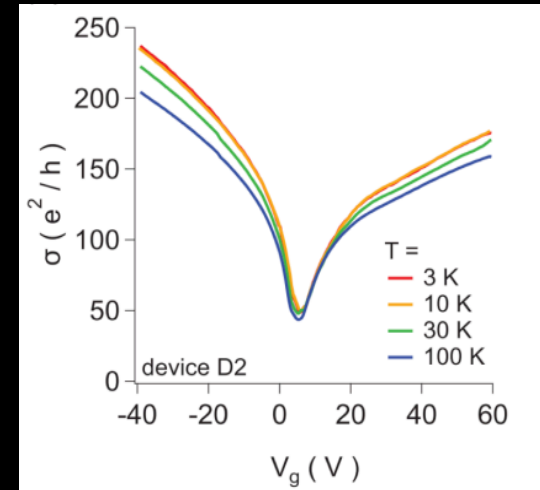


Initial Results

S. Biswas, et al., PRL 123, 237201 (2019)
E. Gerber, et al., PRL 124, 106804 (2020)

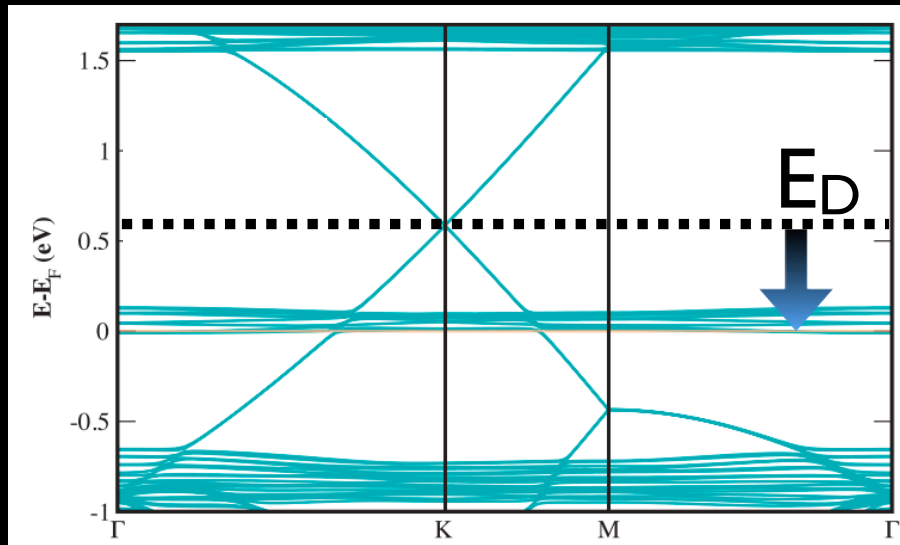


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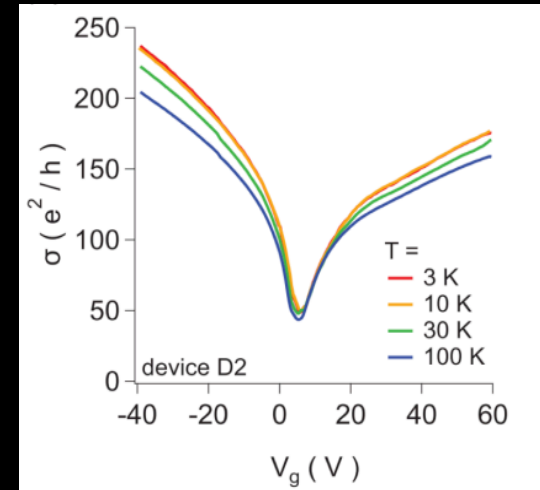


Initial Results

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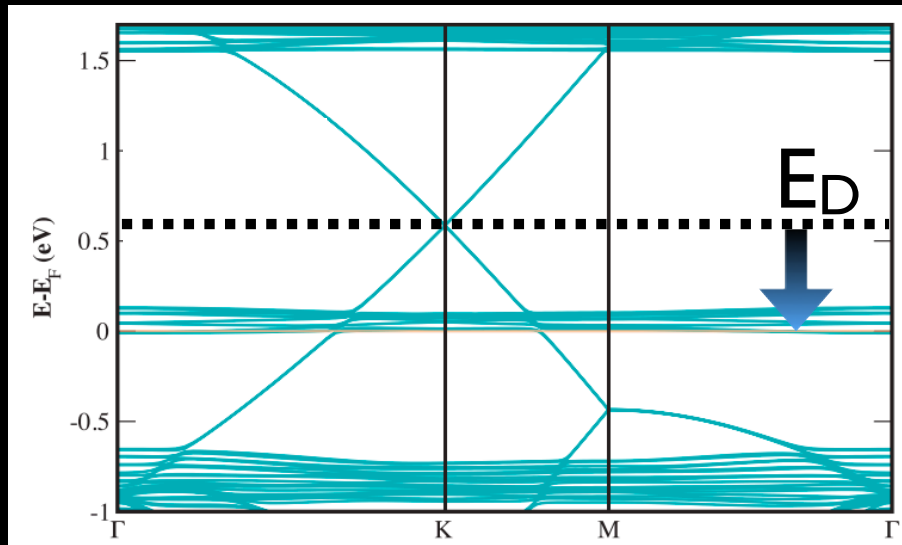


B. Zhou, et al., PRB 100, 165426 (2019)

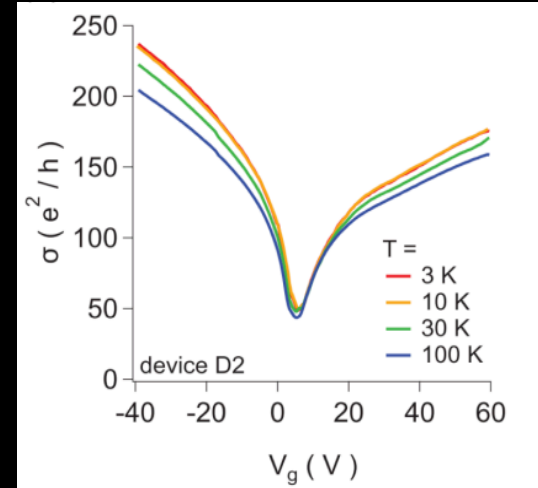


Initial Results

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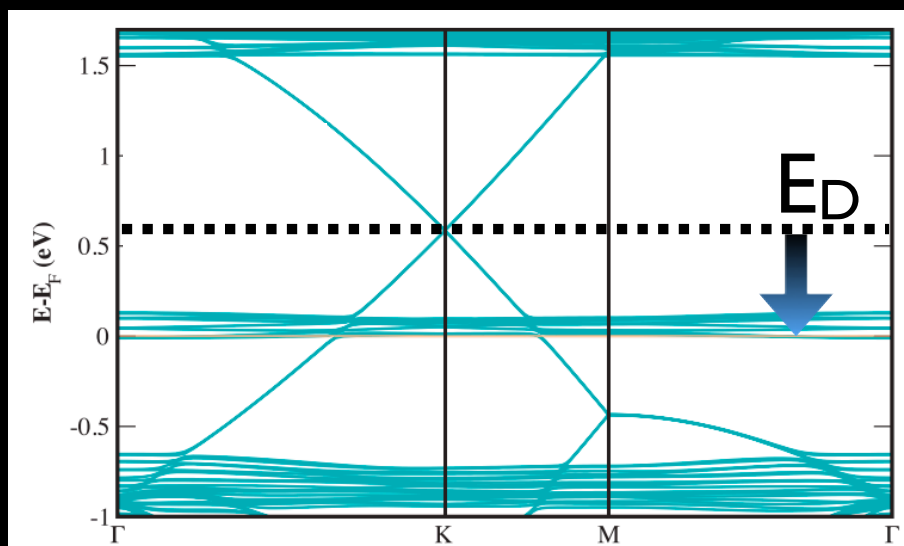
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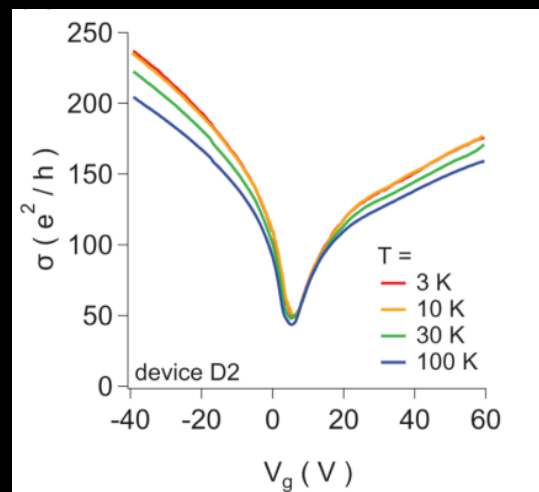
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Initial Results

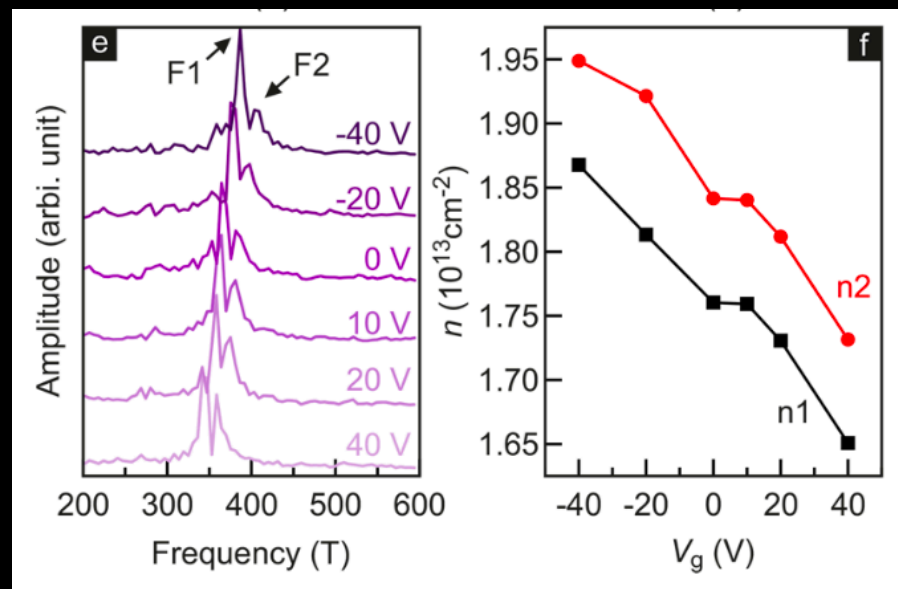
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B. Zhou, et al., PRB 100, 165426 (2019)



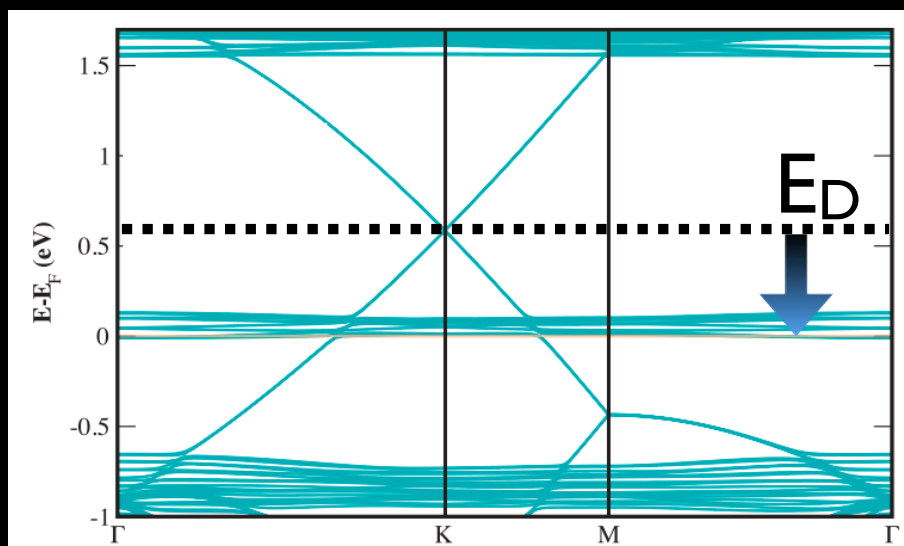
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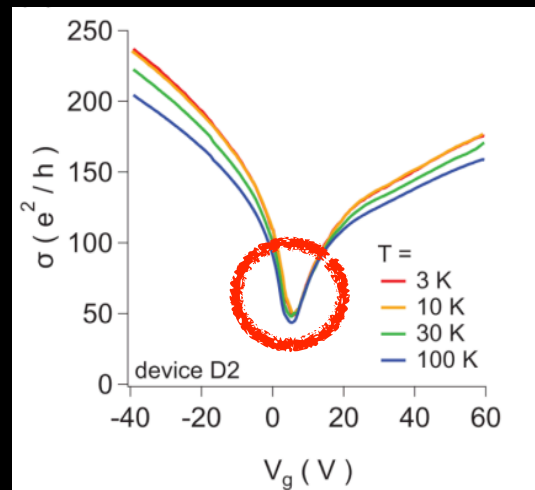
S. Mashhadi, et al., Nanoletters 19, 4659 (2019)

Initial Results

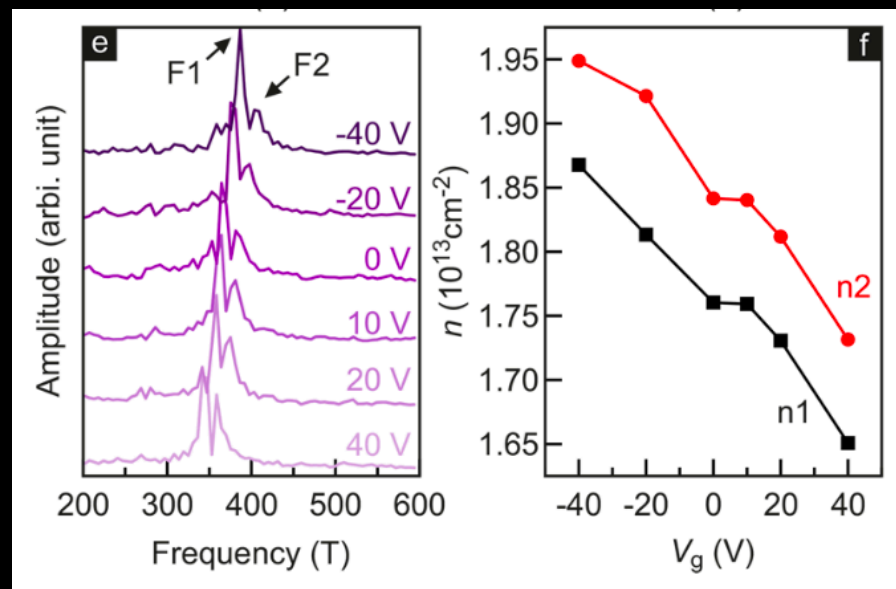
S. Biswas, et al., PRL 123, 237201 (2019)
E. Gerber, et al., PRL 124, 106804 (2020)



B. Zhou, et al., PRB 100, 165426 (2019)



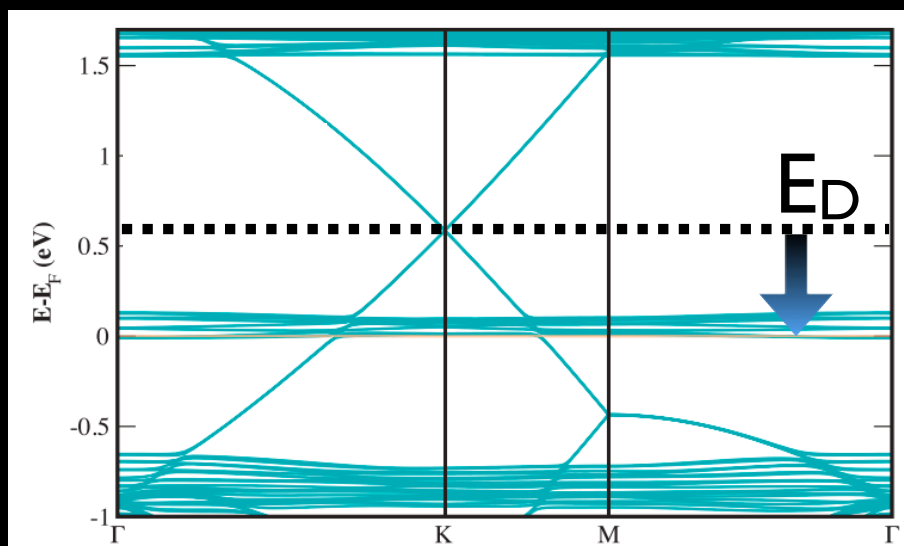
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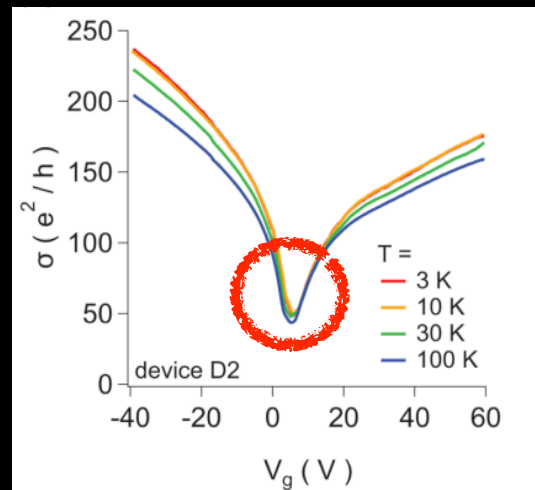
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Initial Results

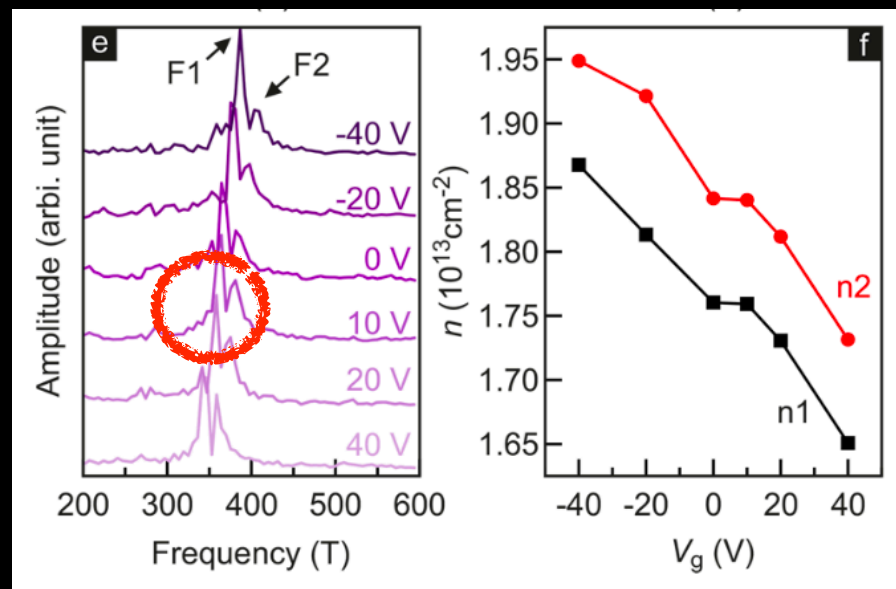
S. Biswas, et al., PRL 123, 237201 (2019)
E. Gerber, et al., PRL 124, 106804 (2020)



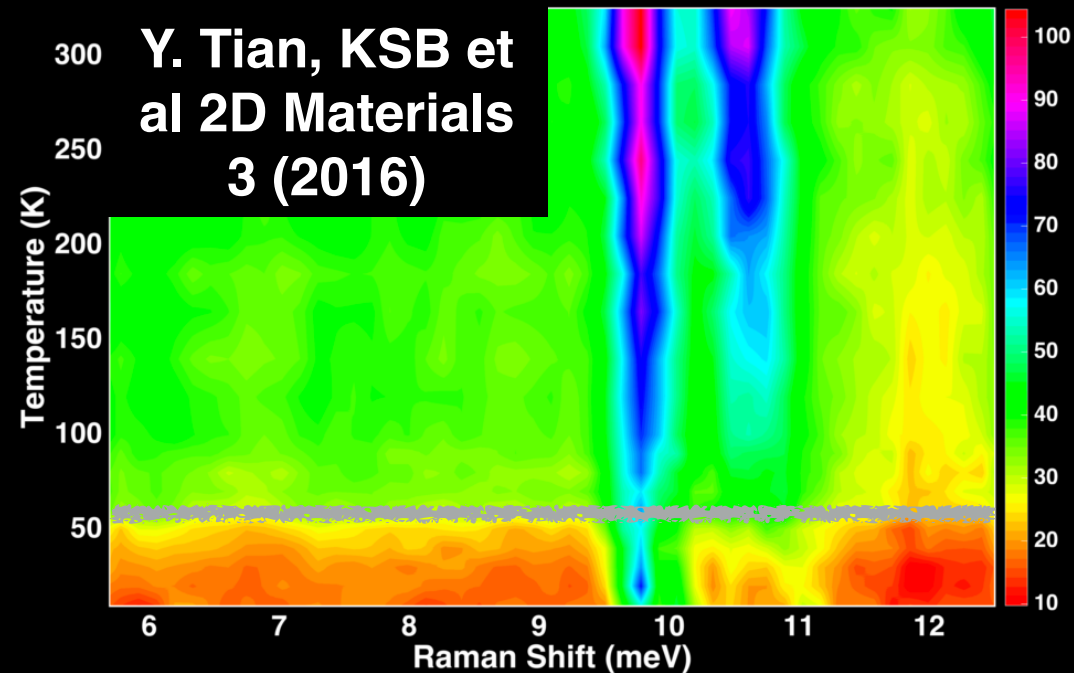
B. Zhou, et al., PRB 100, 165426 (2019)



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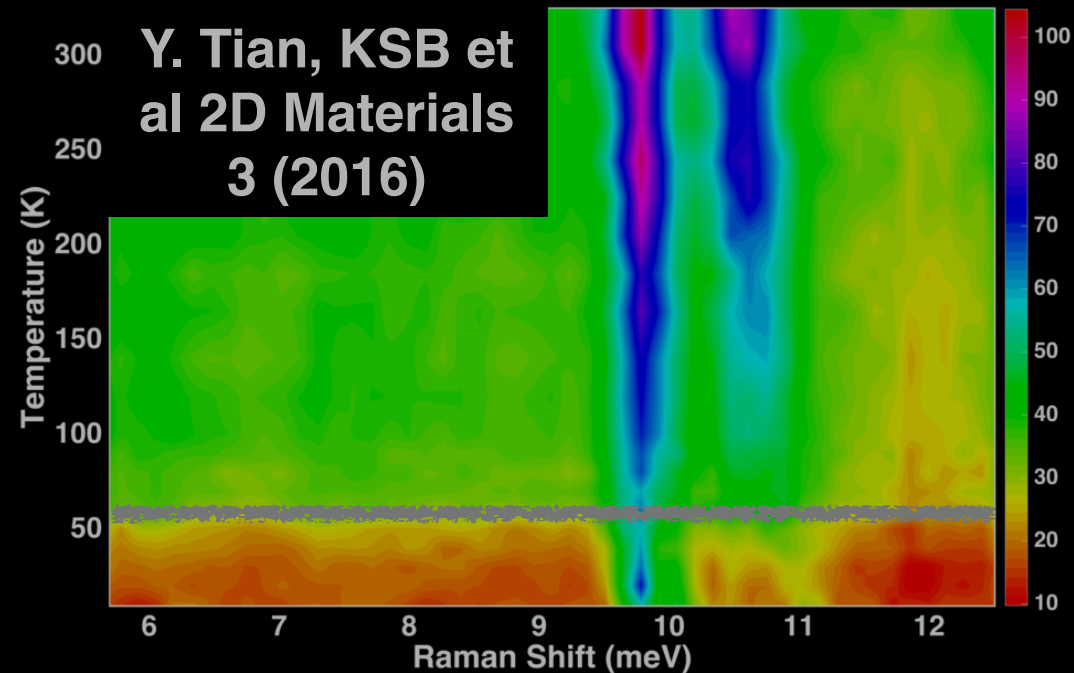
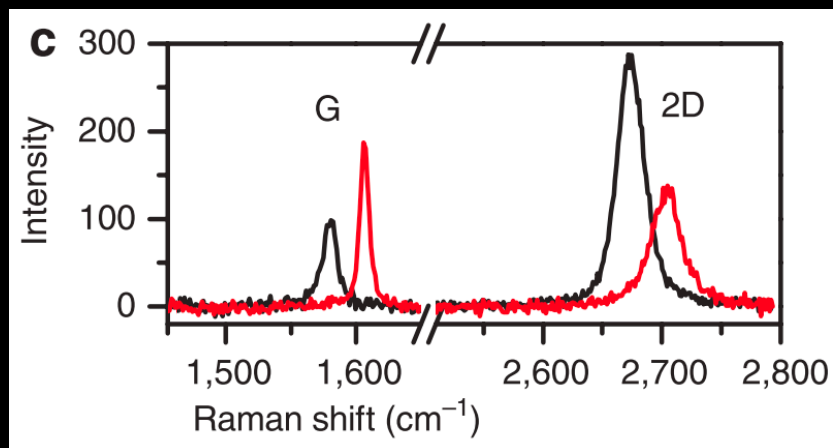


S. Mashhadi, et al., Nanoletters 19, 4659 (2019)



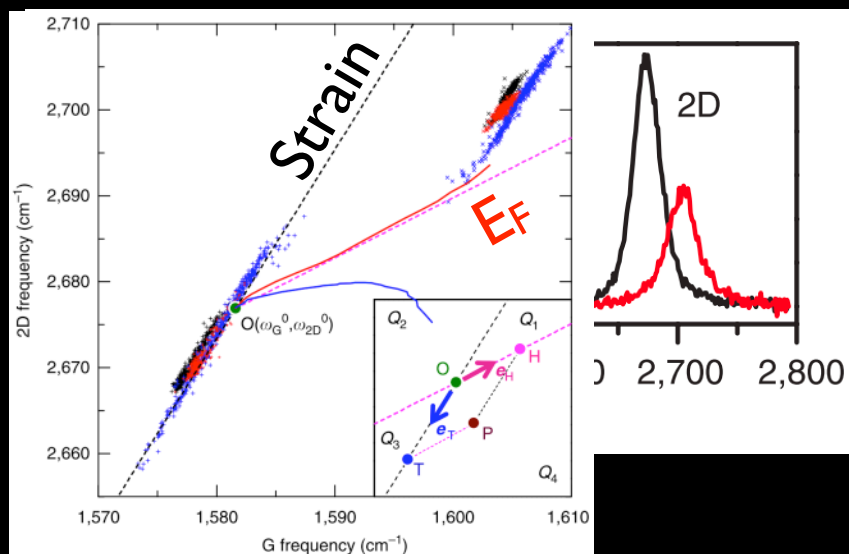
Y. Wang, KSB et al, arXiv:2007.06603

Nat. Comm. 3,1024 (2012)

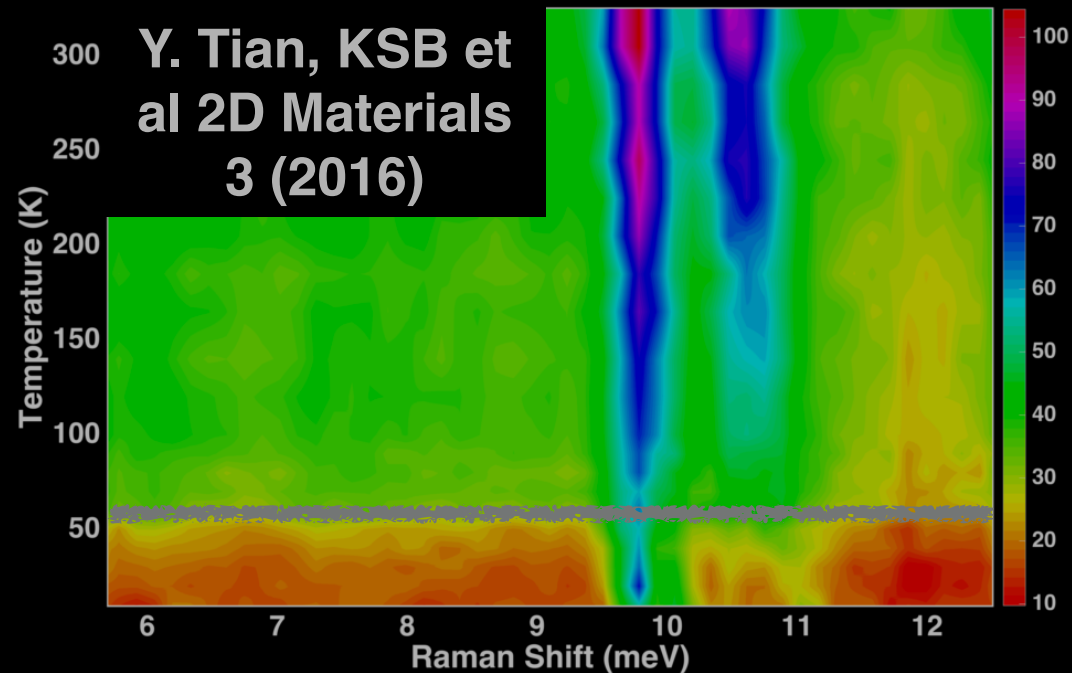


Y. Wang, KSB et al, arXiv:2007.06603

Nat. Comm. 3,1024 (2012)

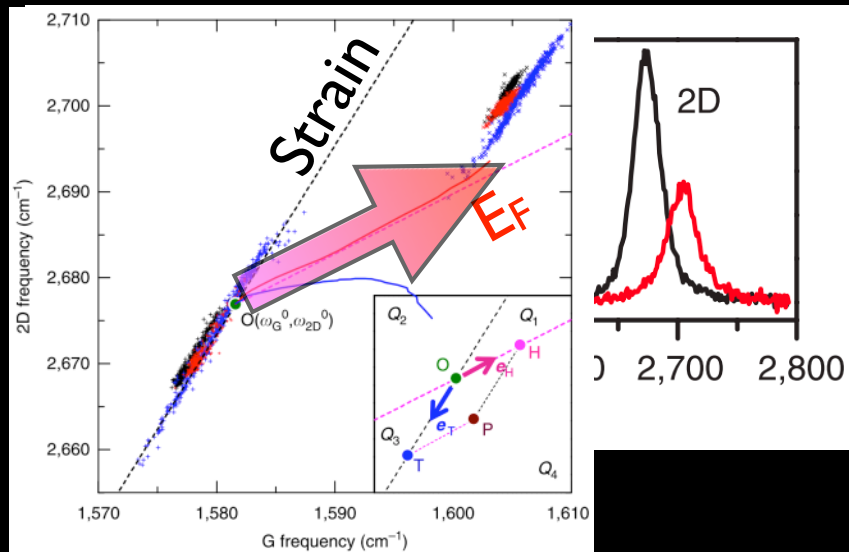


Y. Tian, KSB et al 2D Materials 3 (2016)

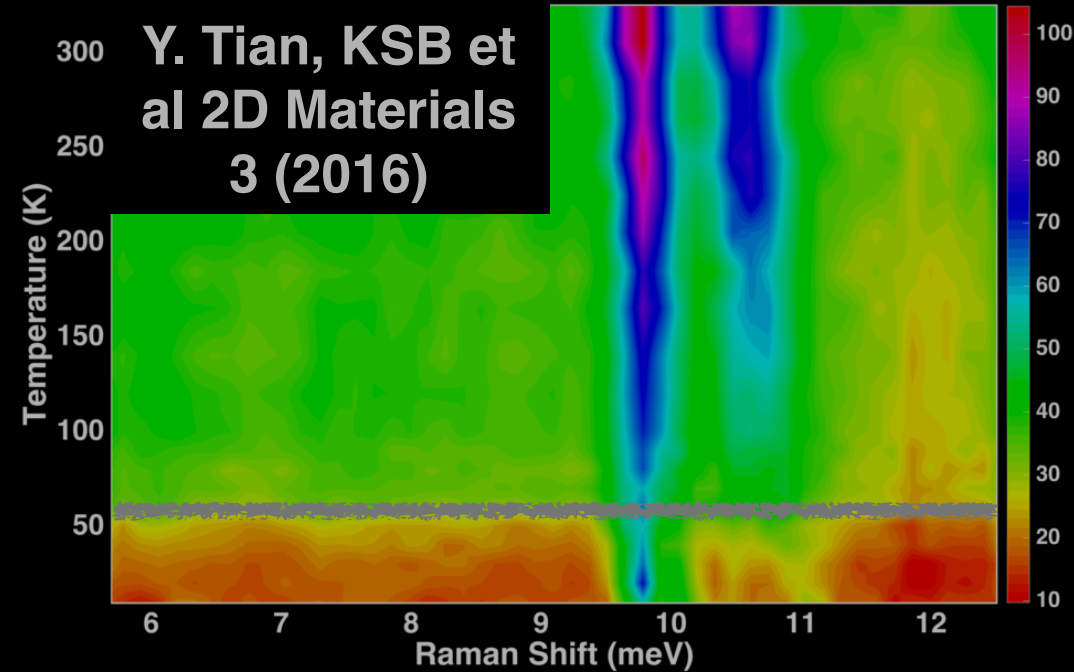


Y. Wang, KSB et al, arXiv:2007.06603

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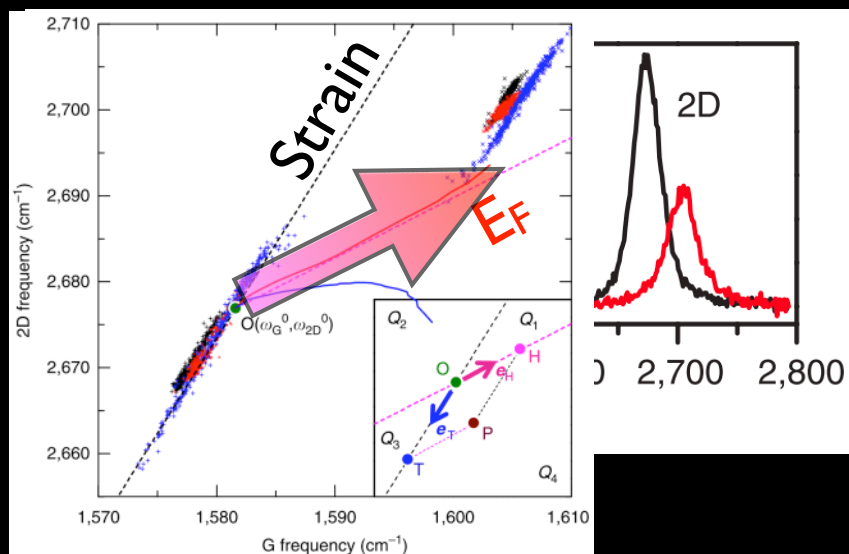


Y. Tian, KSB et al 2D Materials 3 (2016)

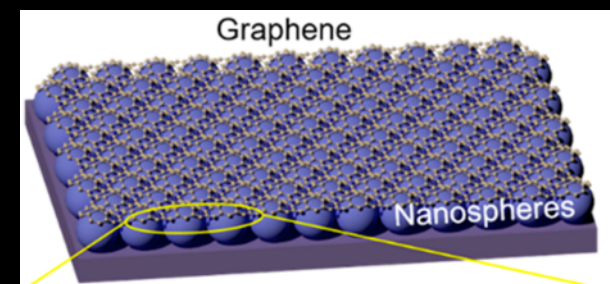
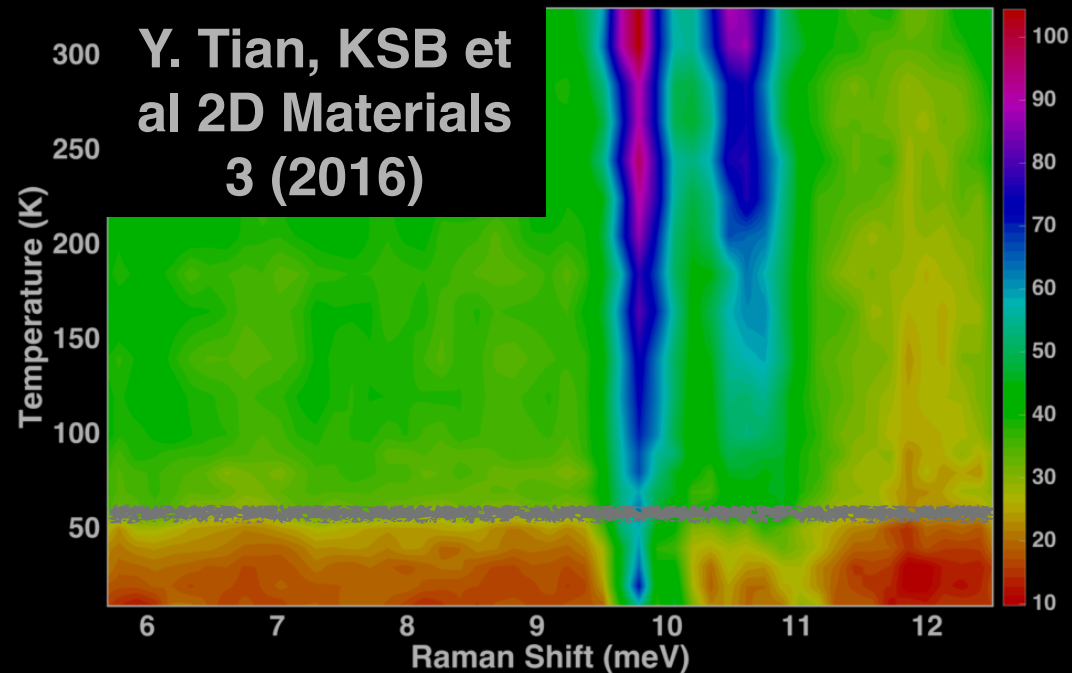


Y. Wang, KSB et al, arXiv:2007.06603

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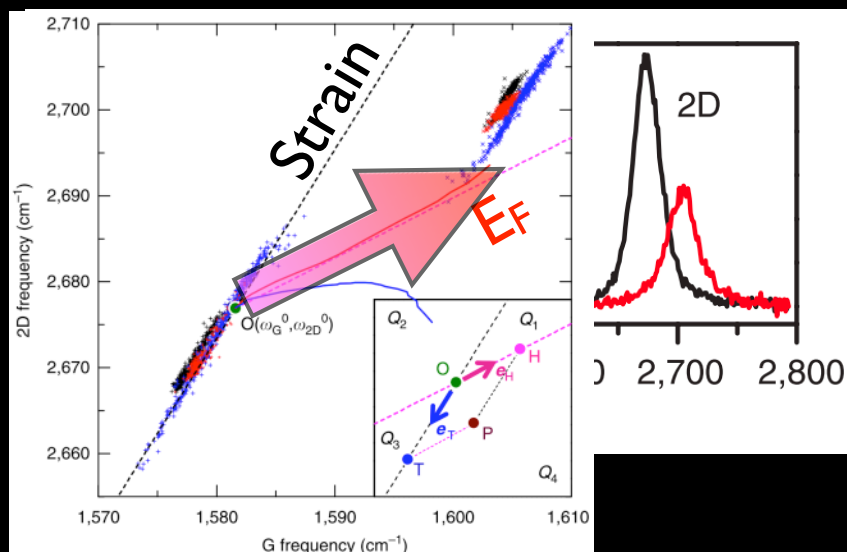
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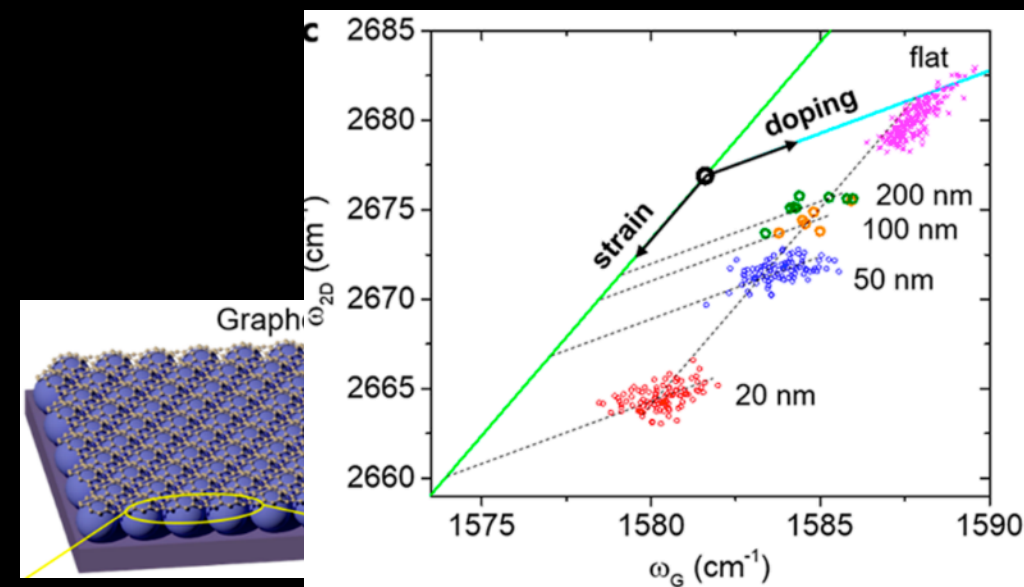
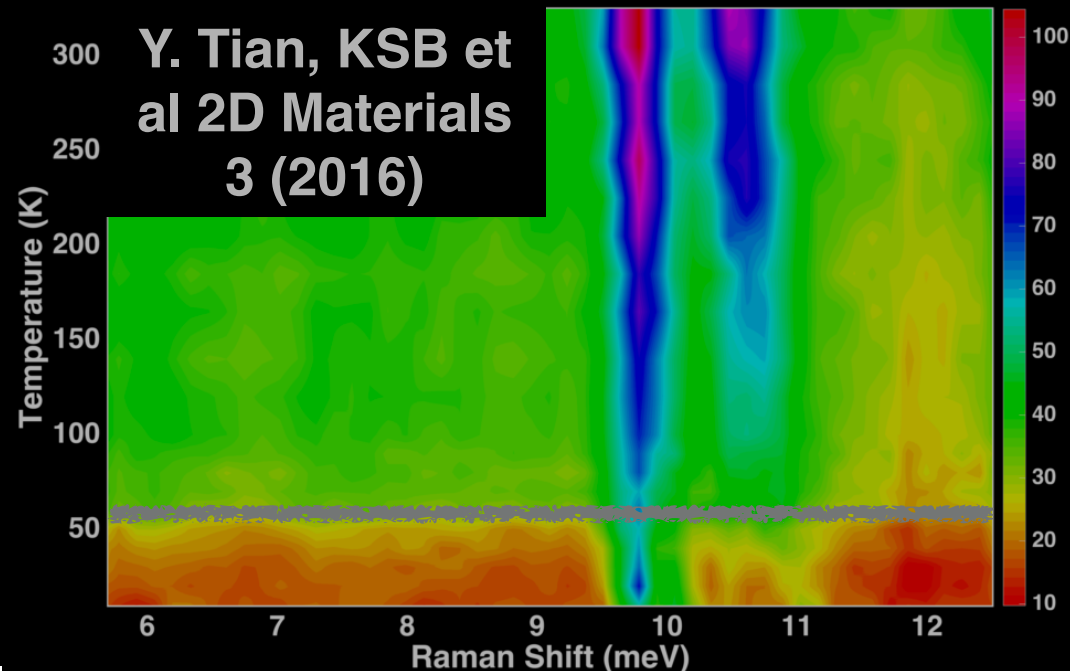
Y. Zhang et. al, Nano Lett. 18, 2098 (2018)

Y. Wang, KSB et al, arXiv:2007.06603

Nat. Comm. 3,1024 (2012)



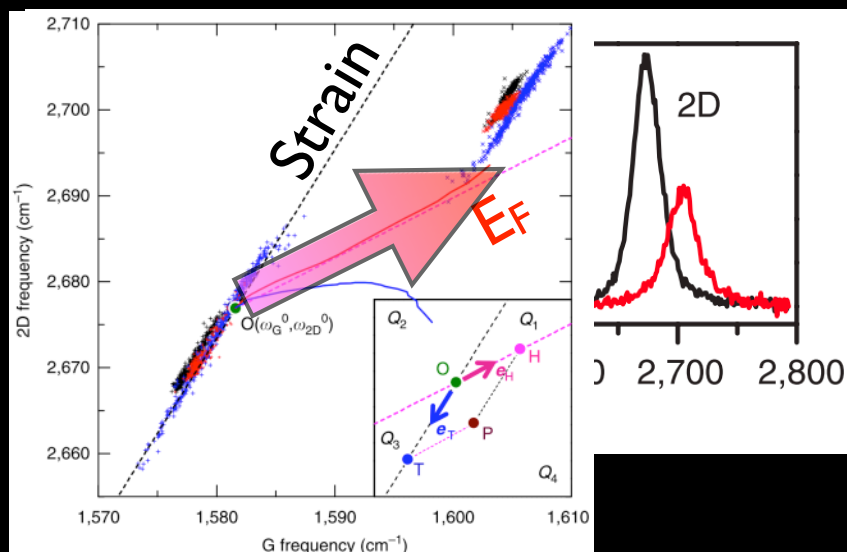
Y. Tian, KSB et al 2D Materials 3 (2016)



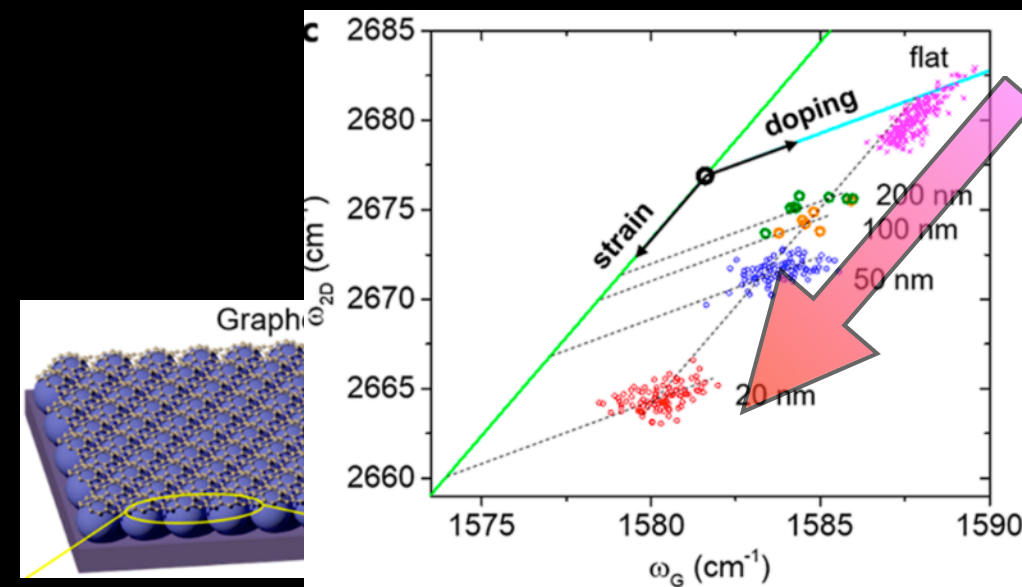
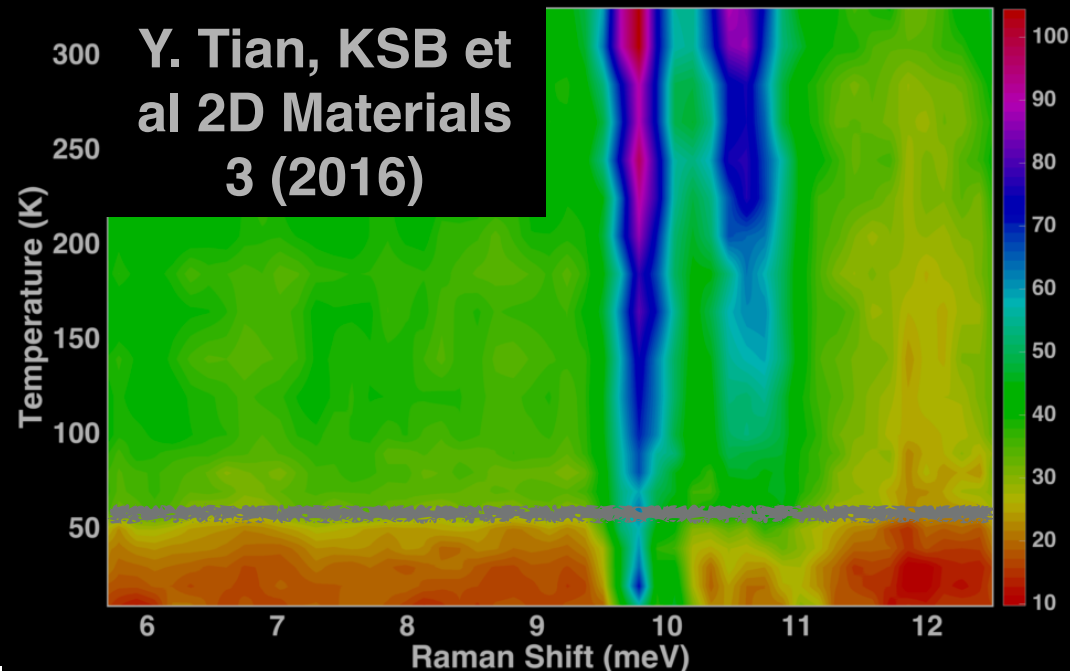
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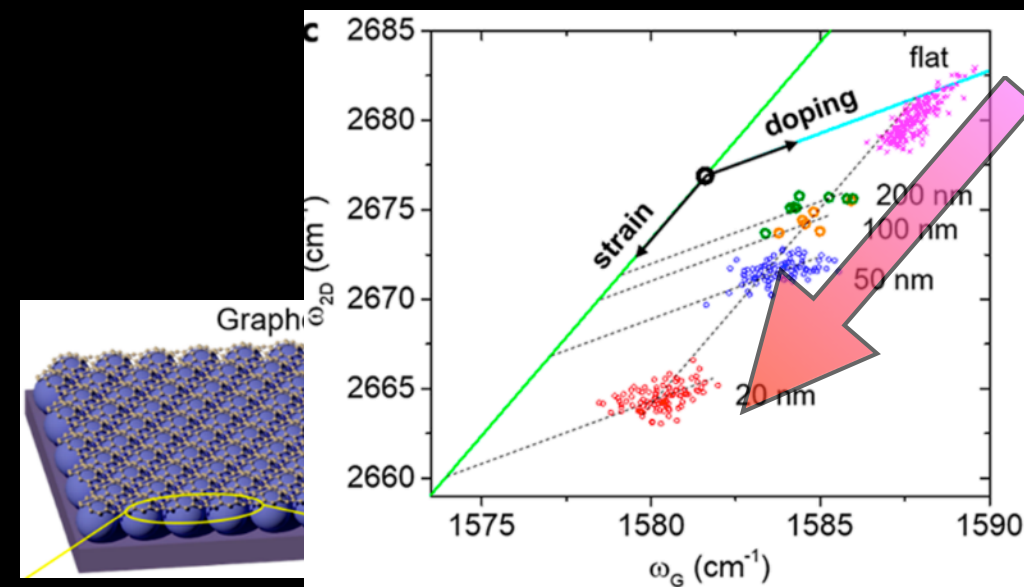
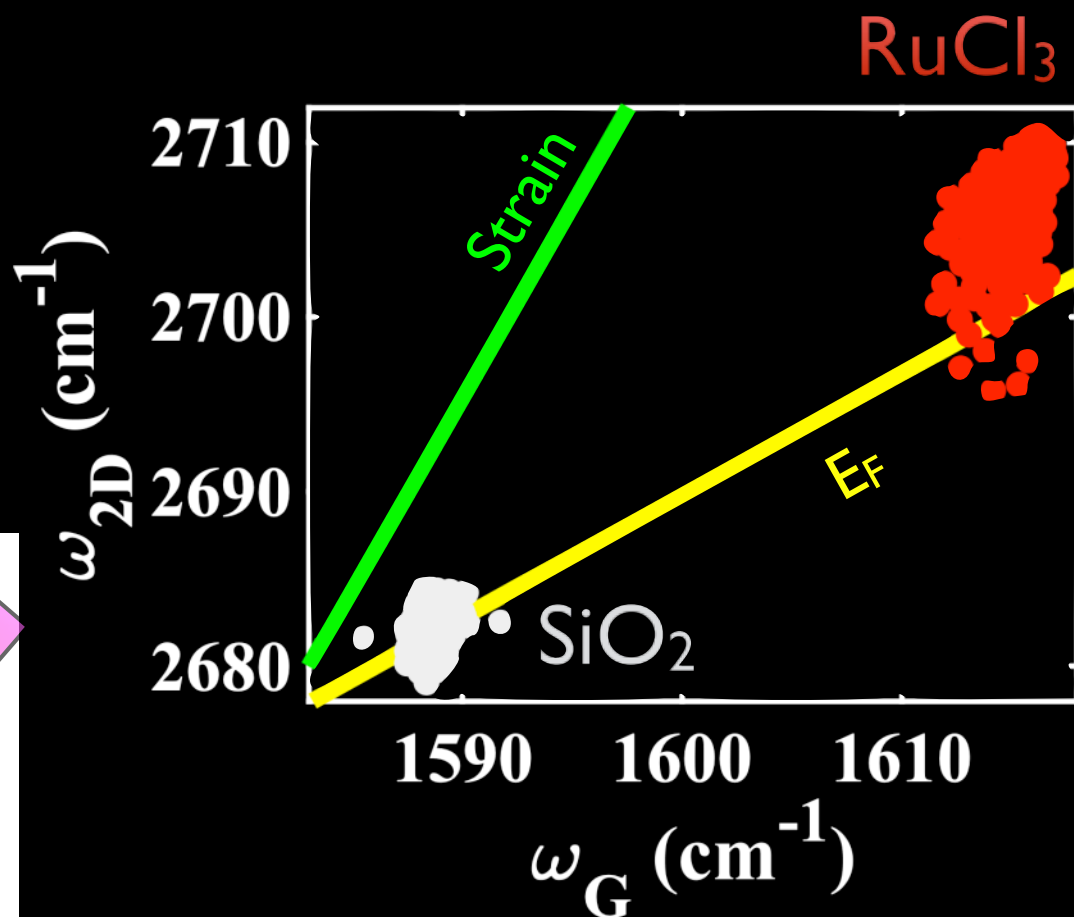
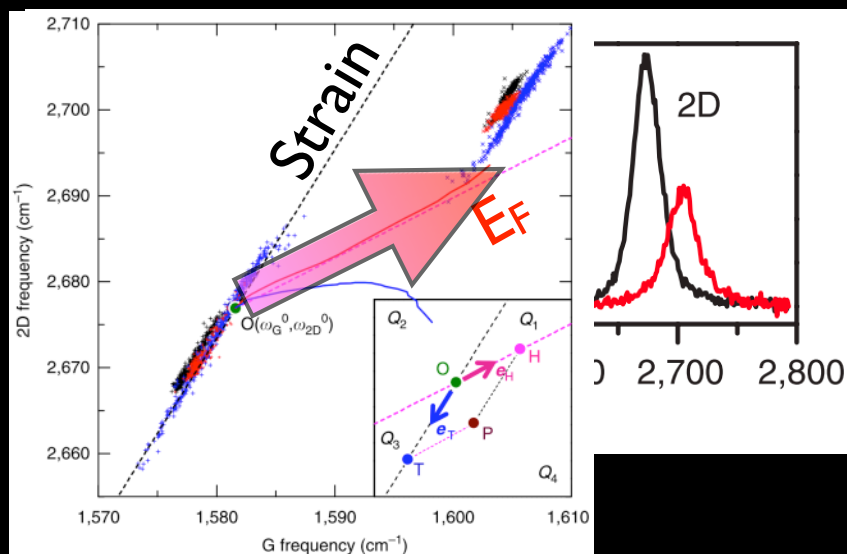
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Y. Zhang et. al, Nano Lett. 18, 2098 (2018)

Y. Wang, KSB et al, arXiv:2007.06603

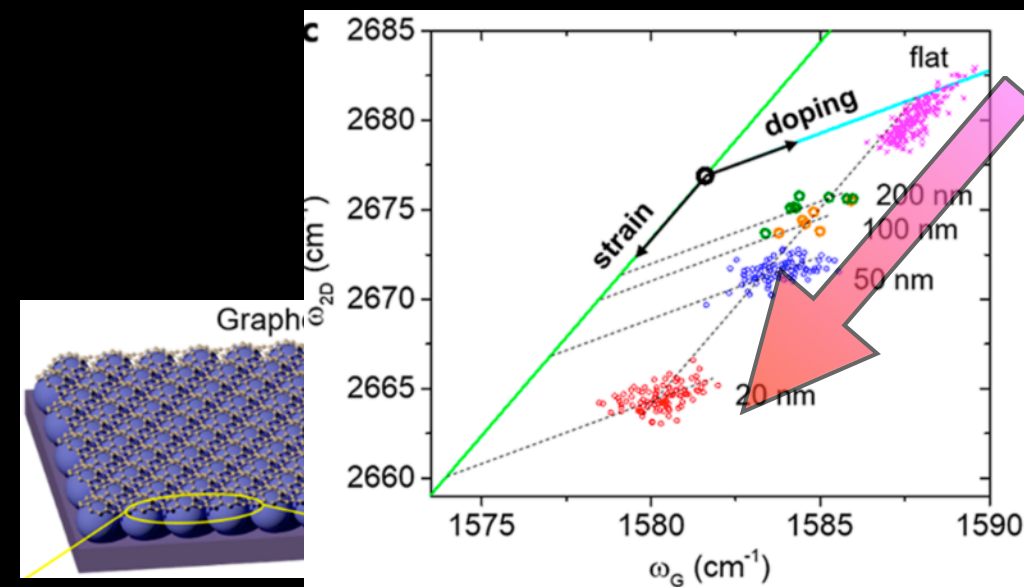
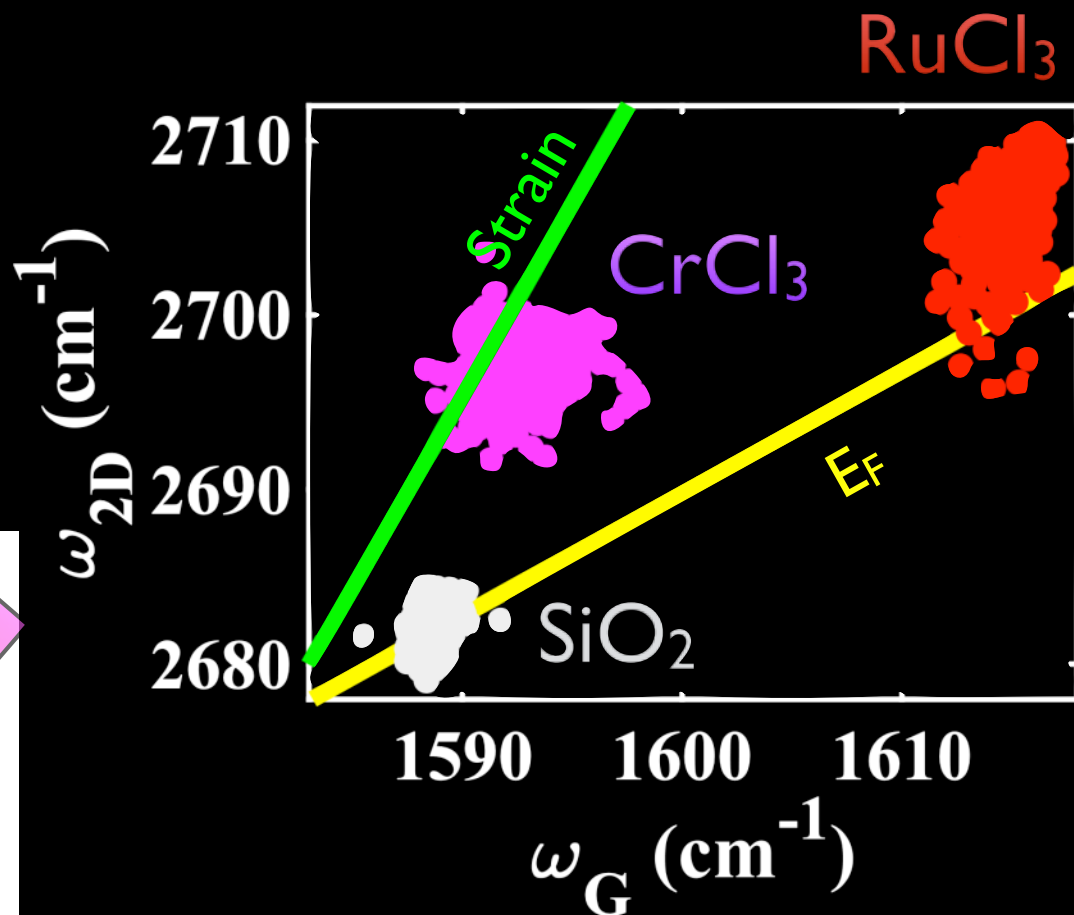
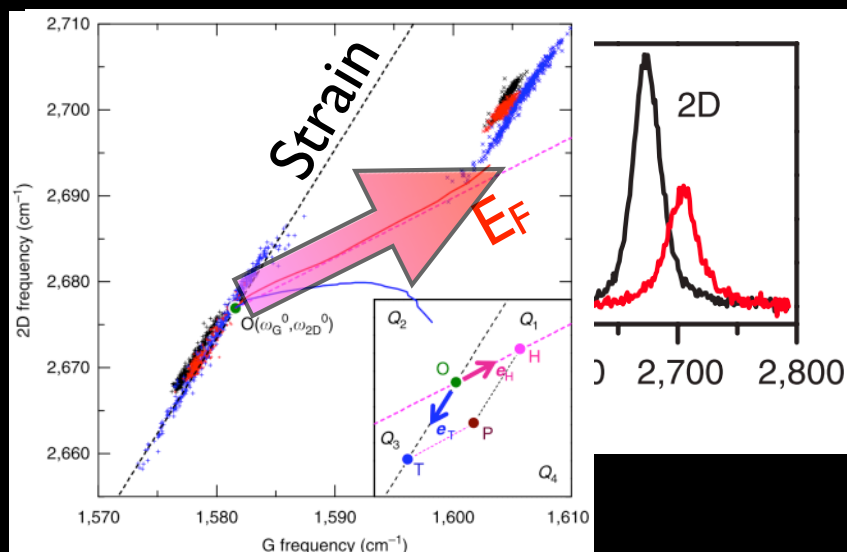
Nat. Comm. 3,1024 (2012)



Y. Zhang et. al, Nano Lett. 18, 2098 (2018)

Y. Wang, KSB et al, arXiv:2007.06603

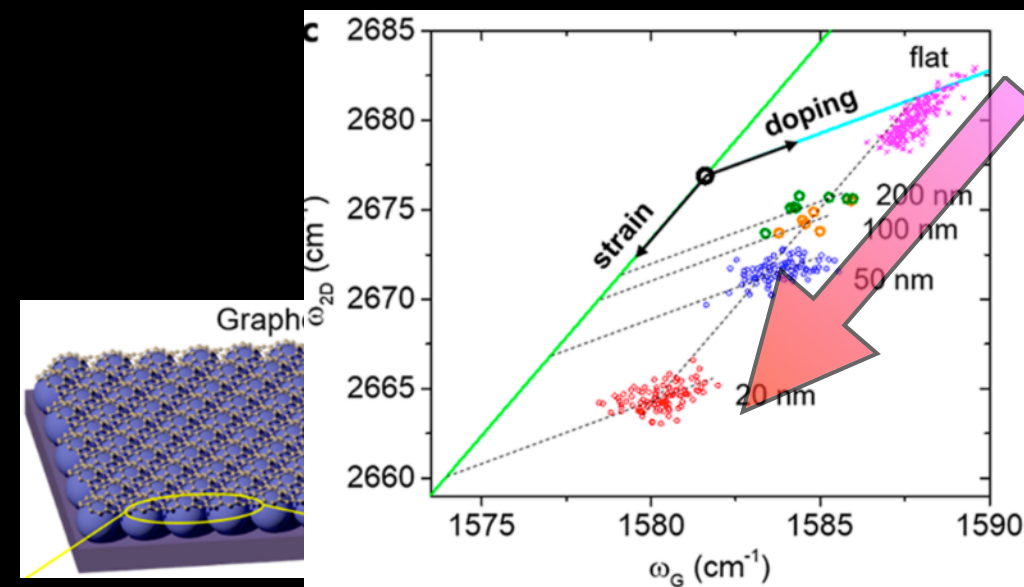
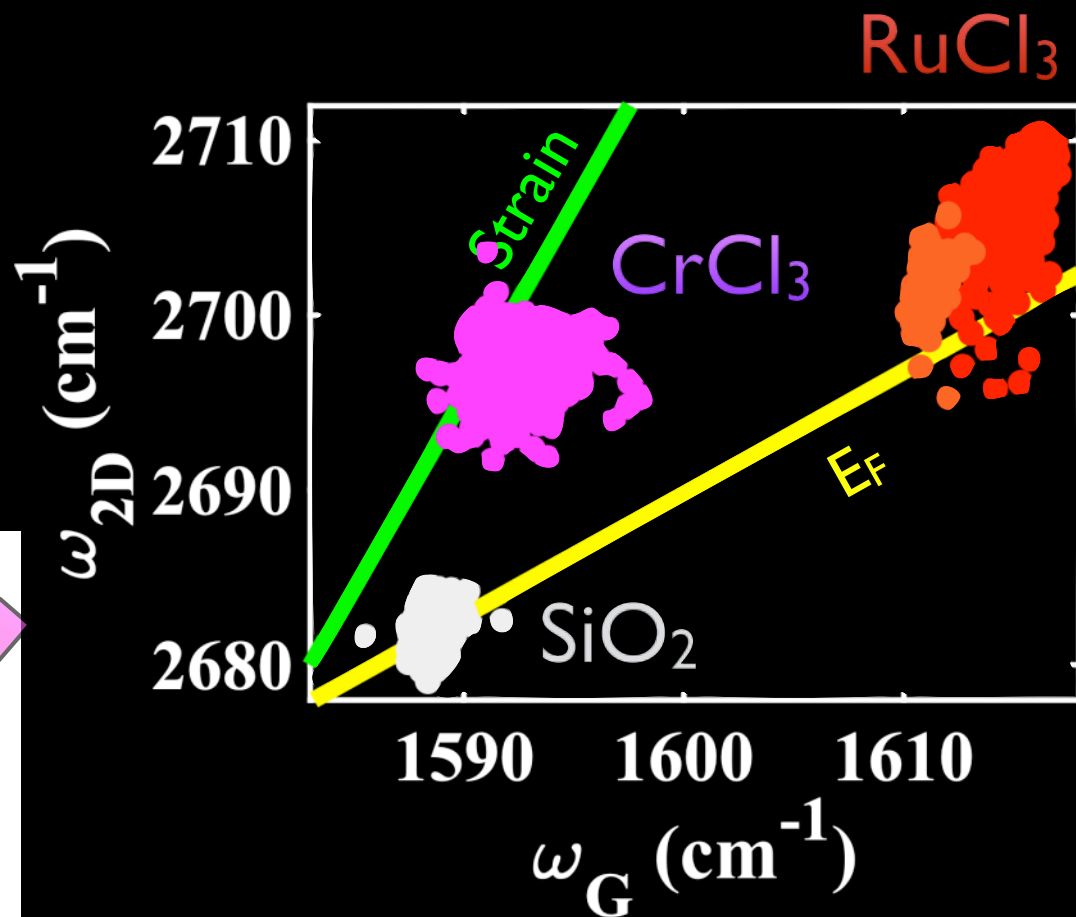
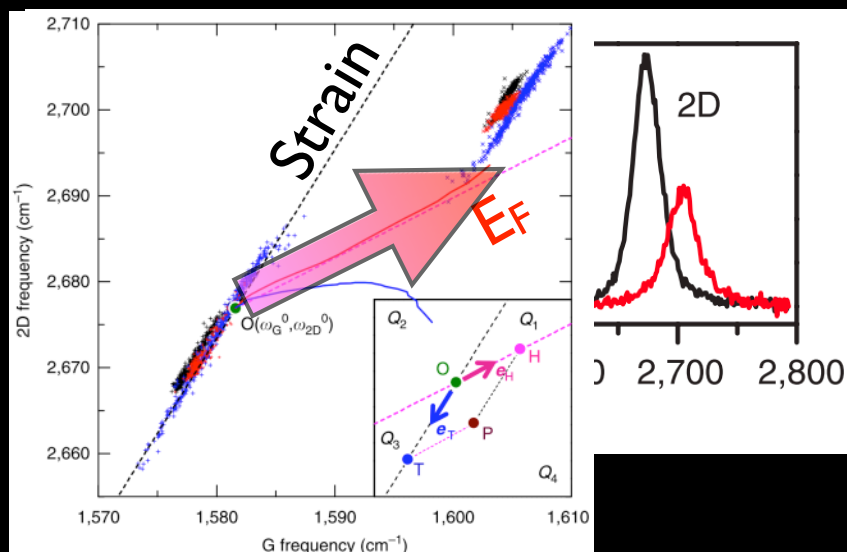
Nat. Comm. 3,1024 (2012)



Y. Zhang et. al, Nano Lett. 18, 2098 (2018)

Y. Wang, KSB et al, arXiv:2007.06603

Nat. Comm. 3,1024 (2012)



Y. Zhang et. al, Nano Lett. 18, 2098 (2018)

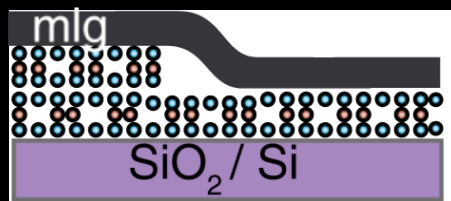
Y. Wang, KSB et al, arXiv:2007.06603

Sharp

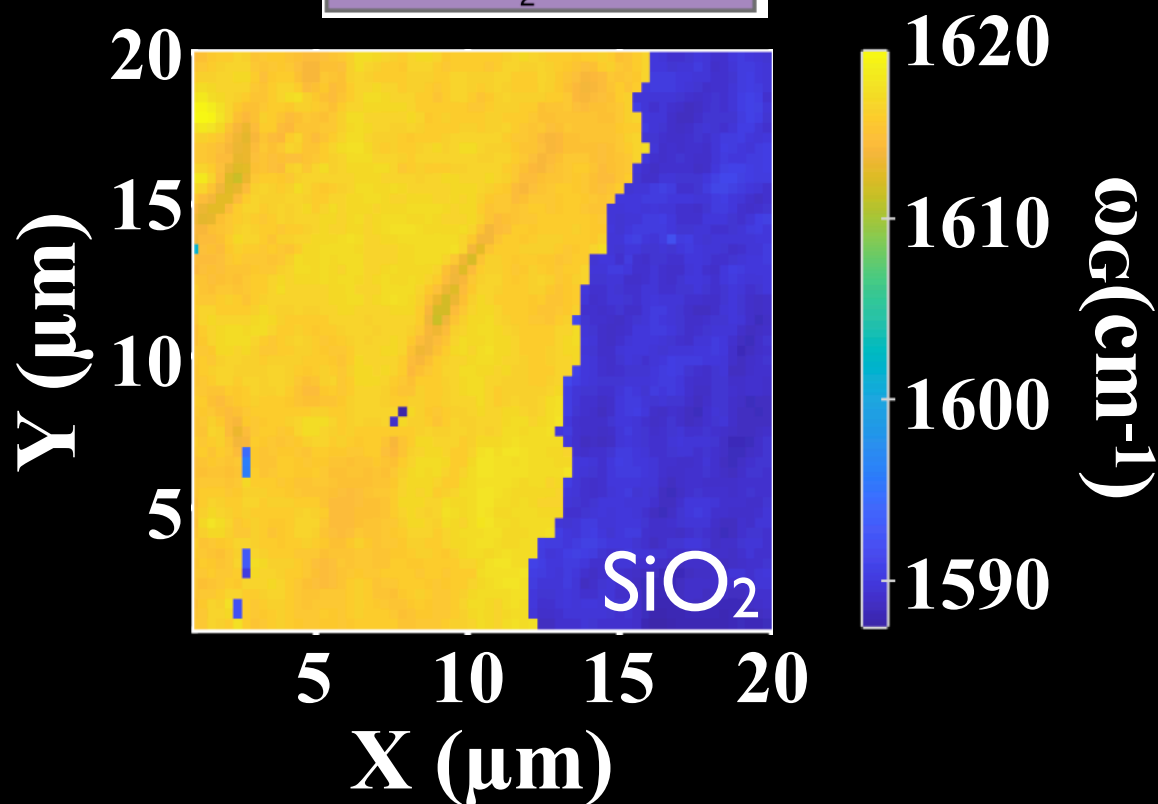
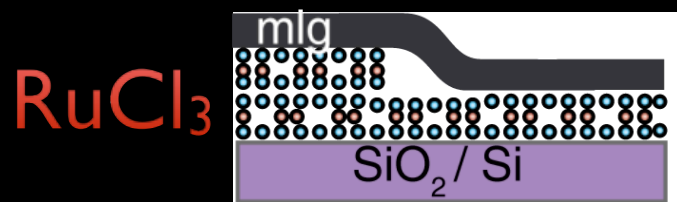
Vertical Transfer

Graphene

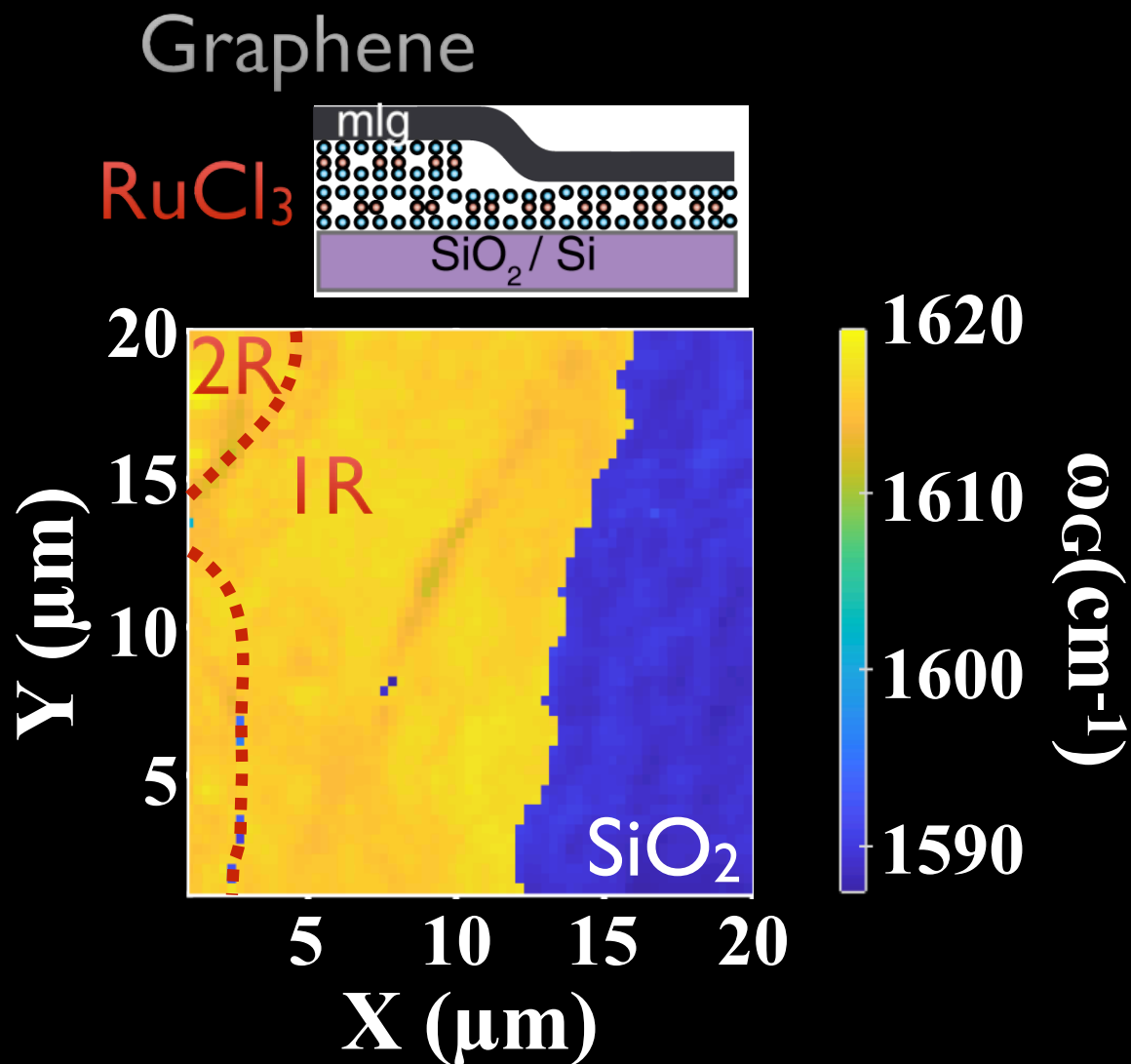
RuCl_3



Graphene

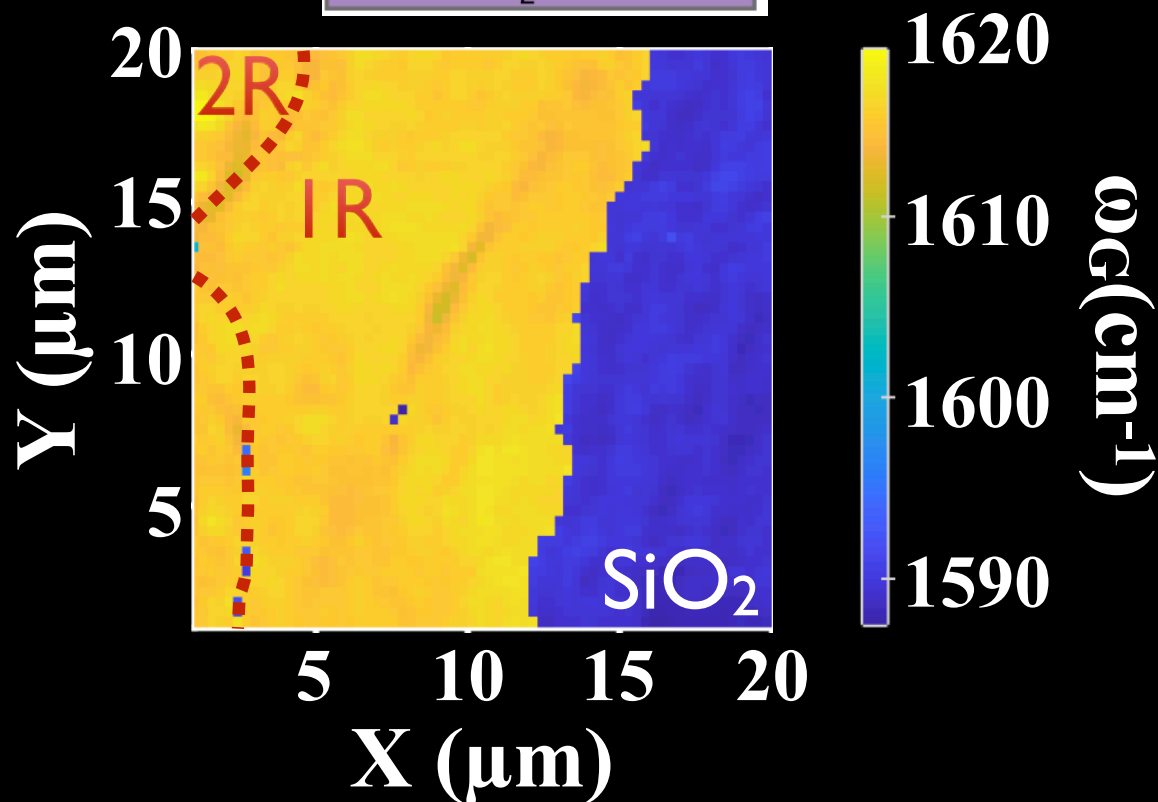
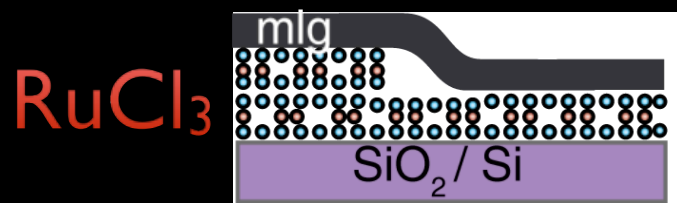


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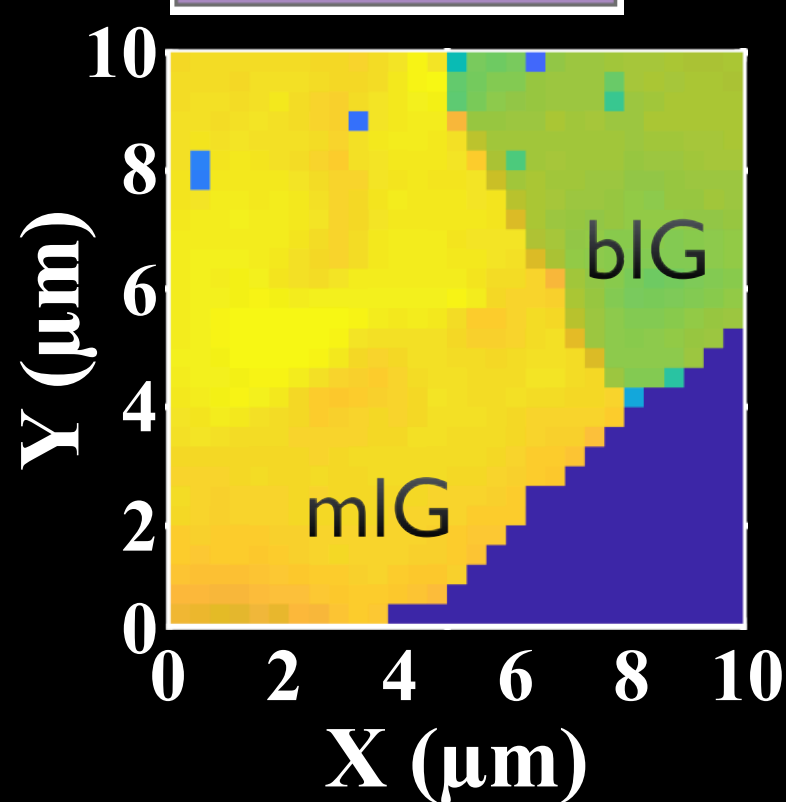
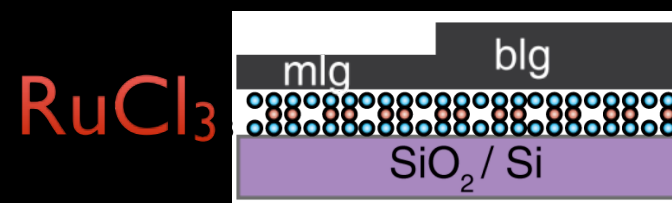


Vertical Transfer

Graphene

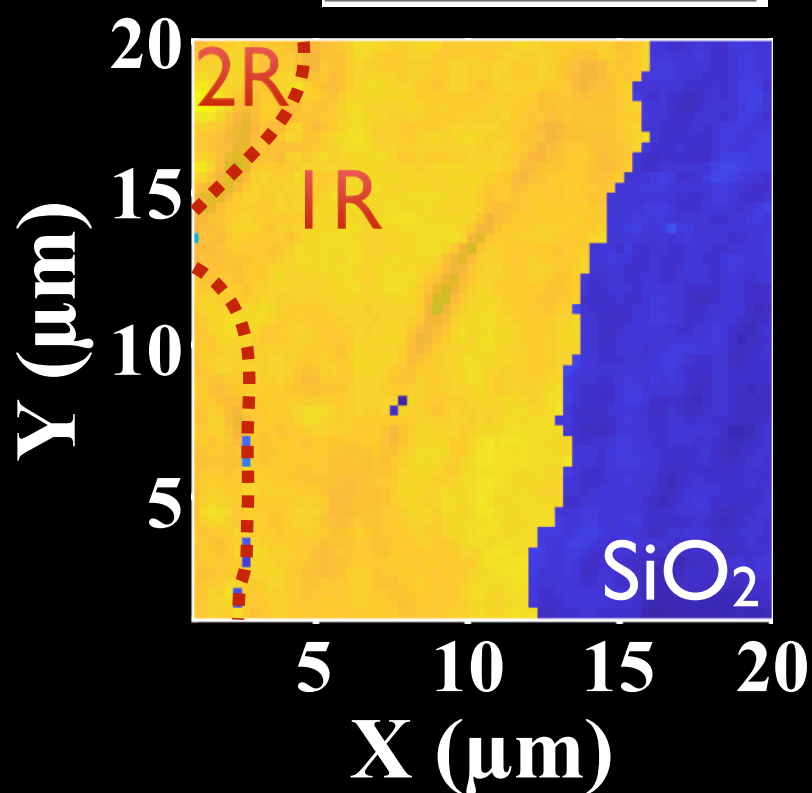
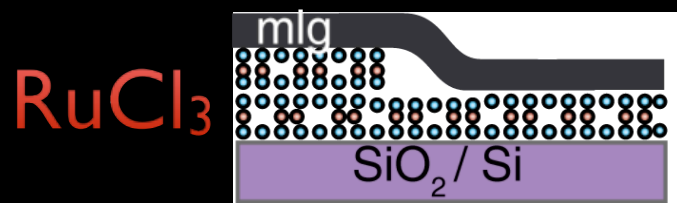


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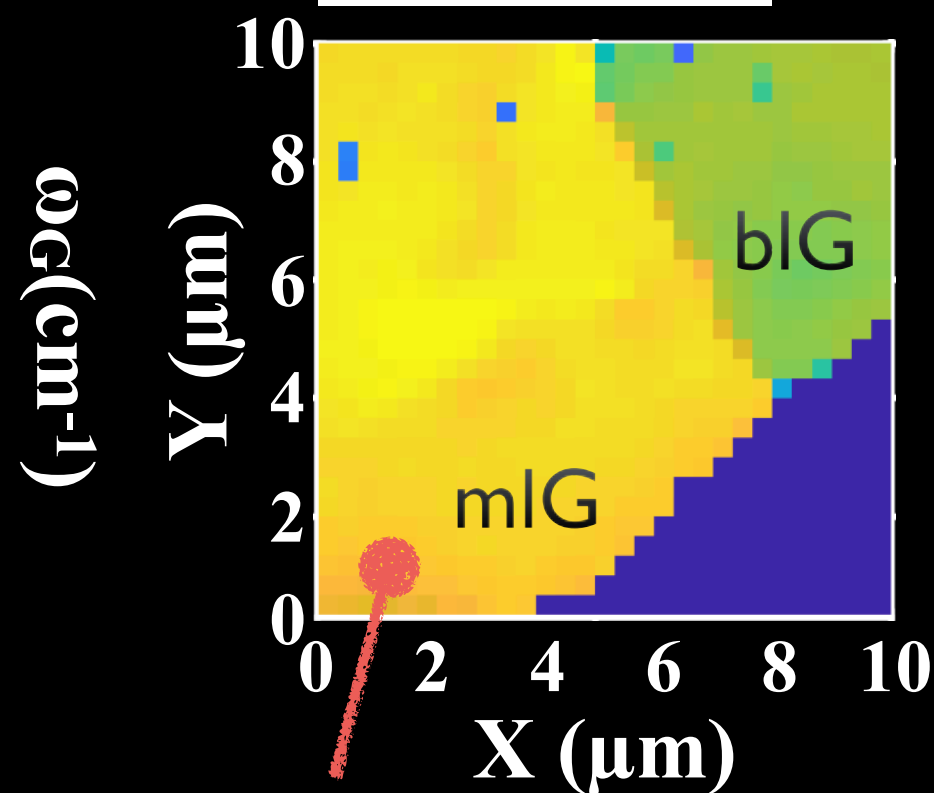
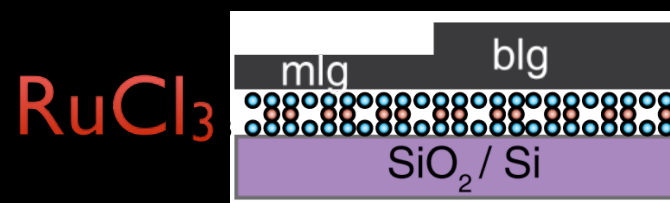


Vertical Transfer

Graphene



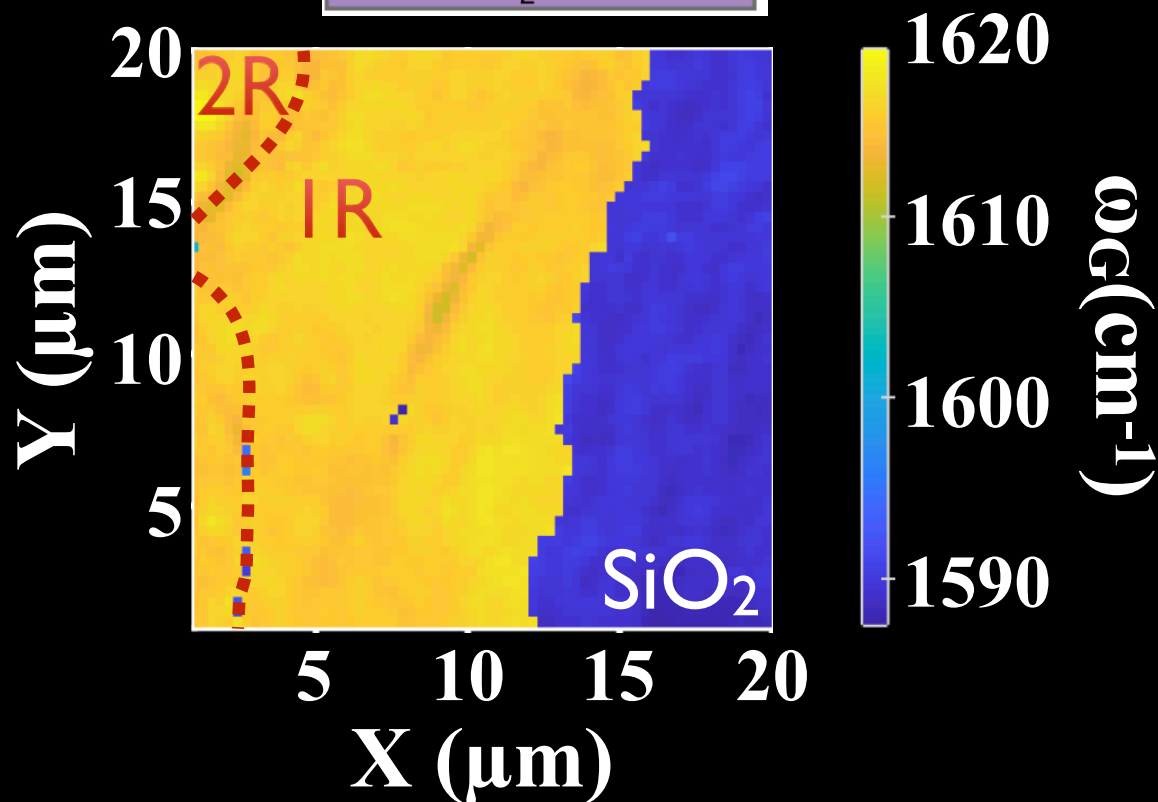
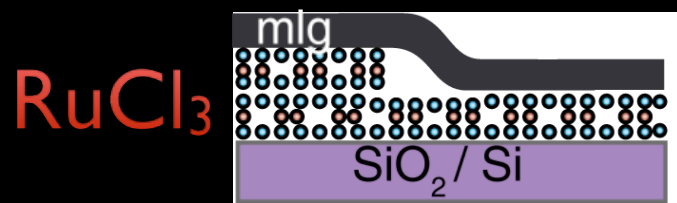
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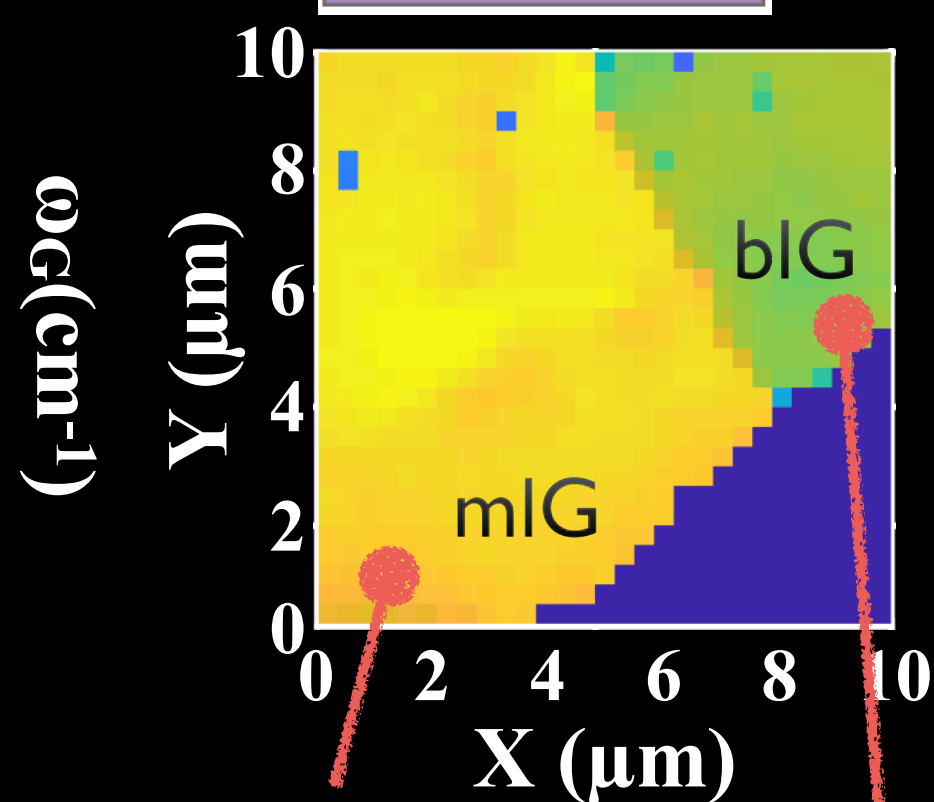
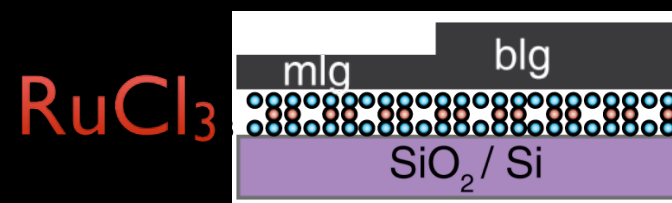
$\sim 3 \times 10^{13} \text{ cm}^{-2}$
 $E_F \sim 600 \text{ meV}$

Vertical Transfer

Graphene



mlG blG



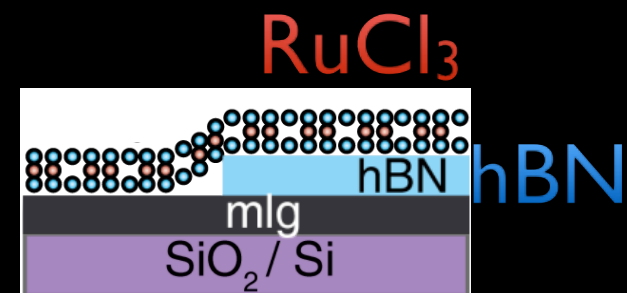
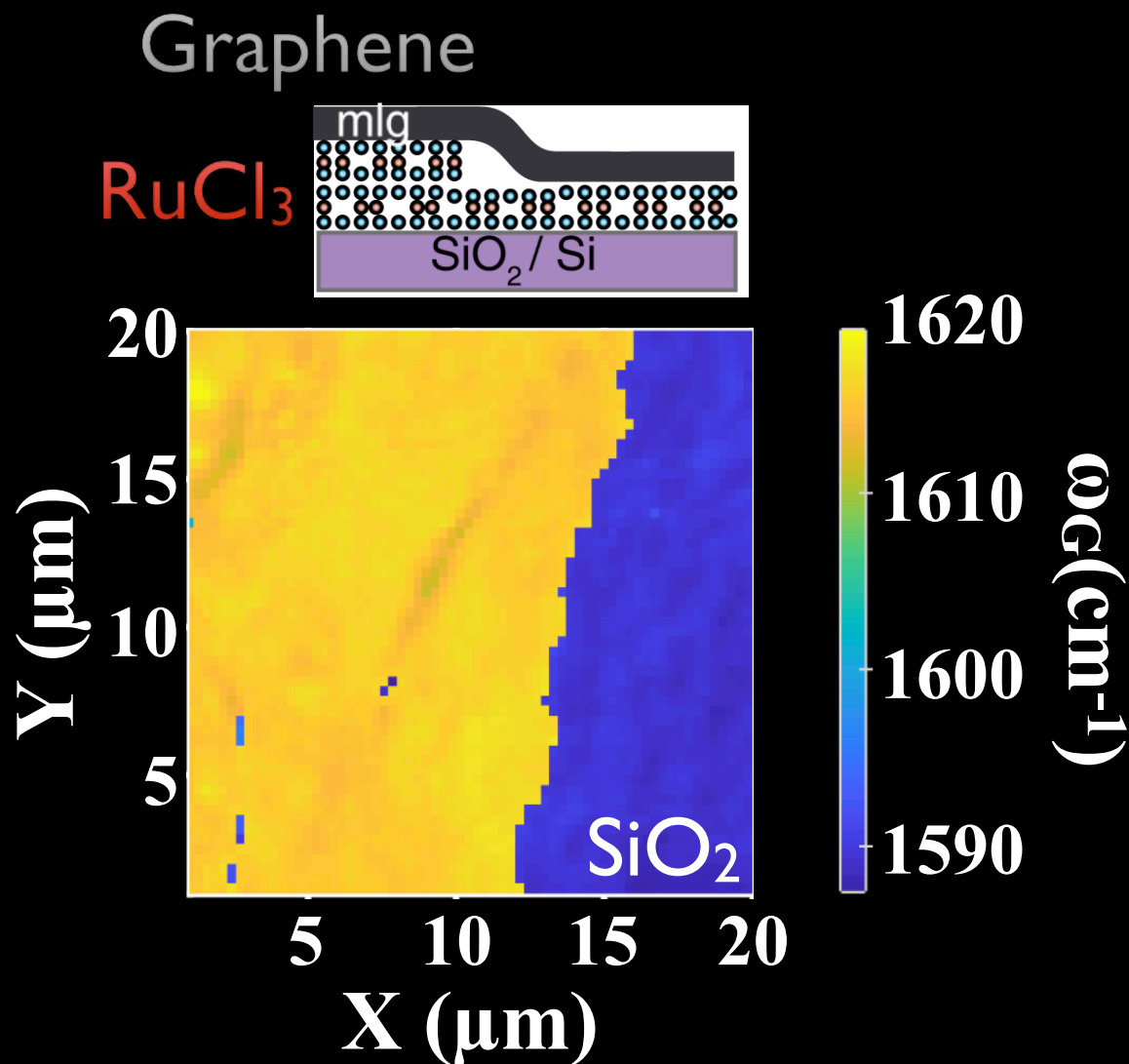
$\sim 3 \times 10^{13} \text{ cm}^{-2}$

$E_F \sim 600 \text{ meV}$

$\sim 6 \times 10^{13} \text{ cm}^{-2}$

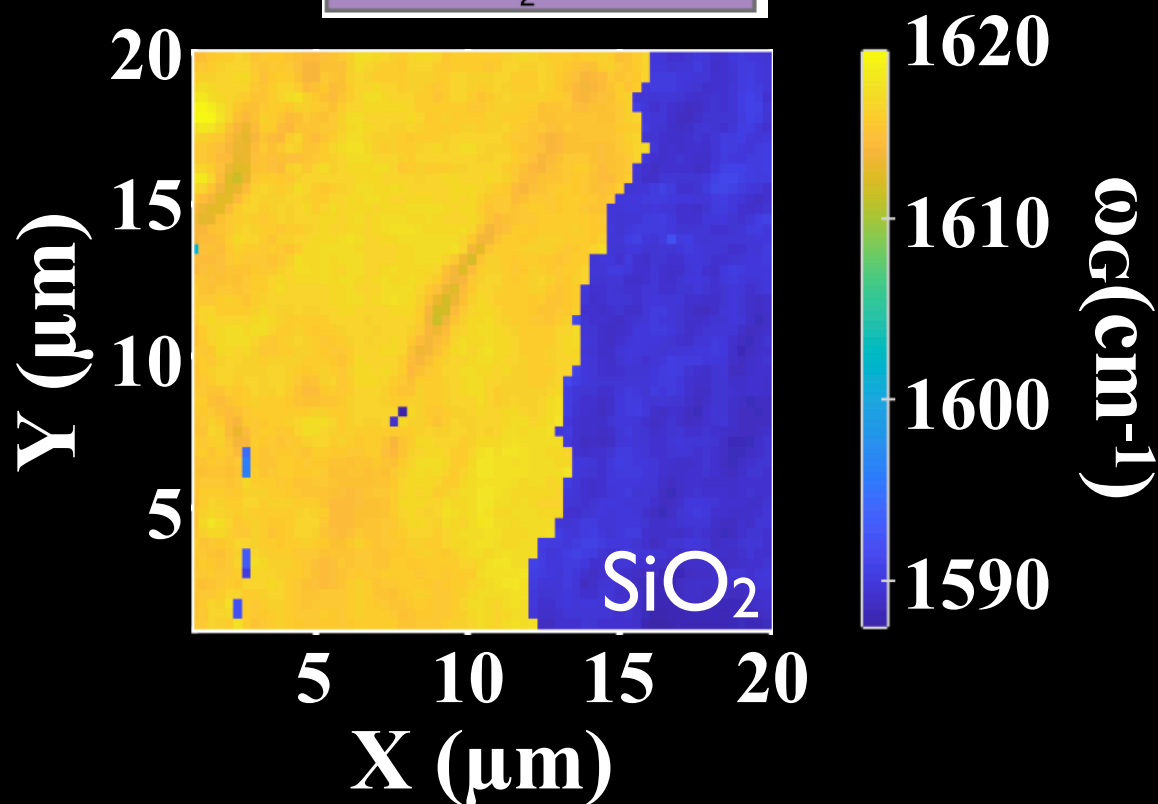
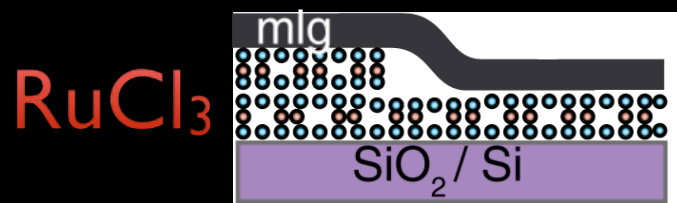
Y. Wang, KSB et al, arXiv:2007.06603

Modulation Doping

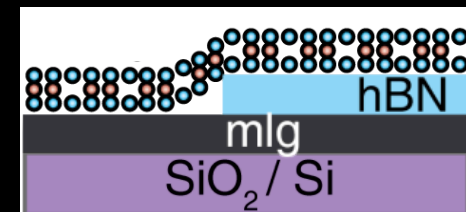


Y. Wang, KSB et al, arXiv:2007.06603

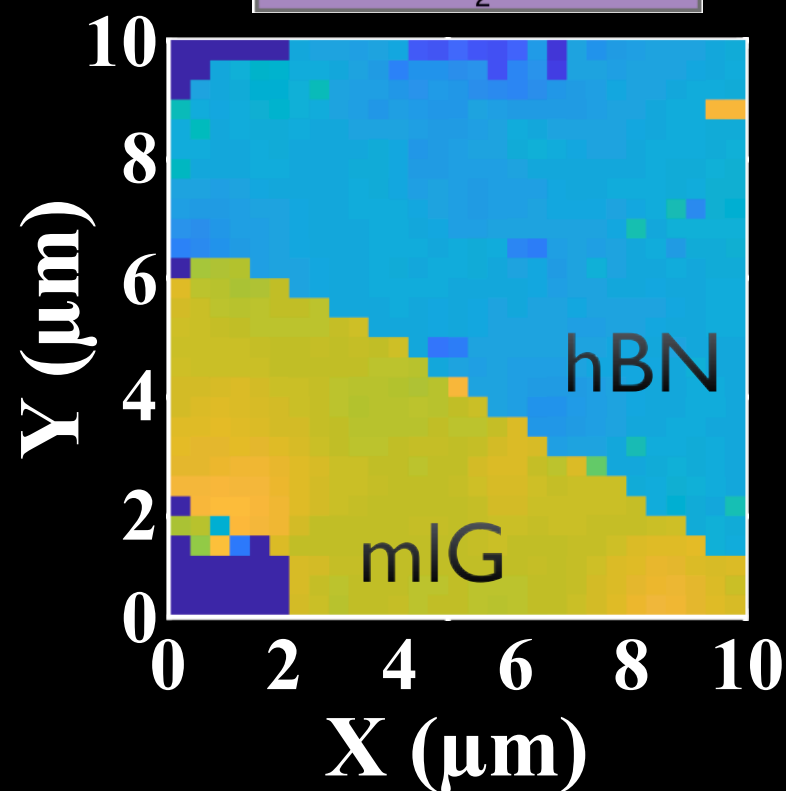
Graphene



RuCl_3



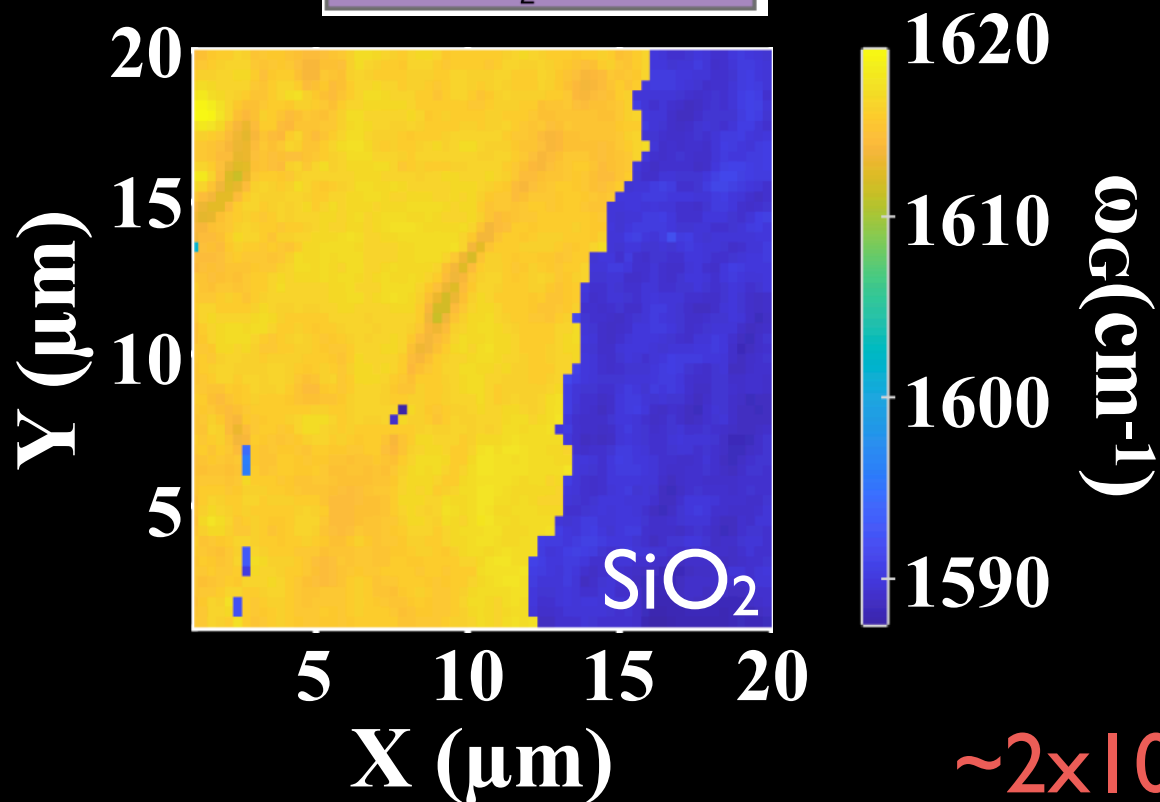
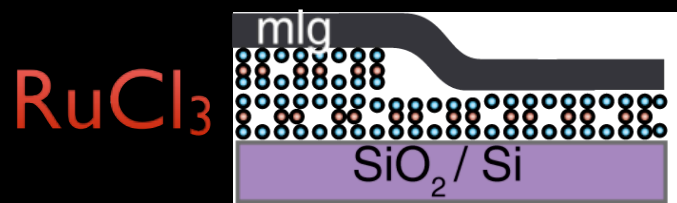
hBN



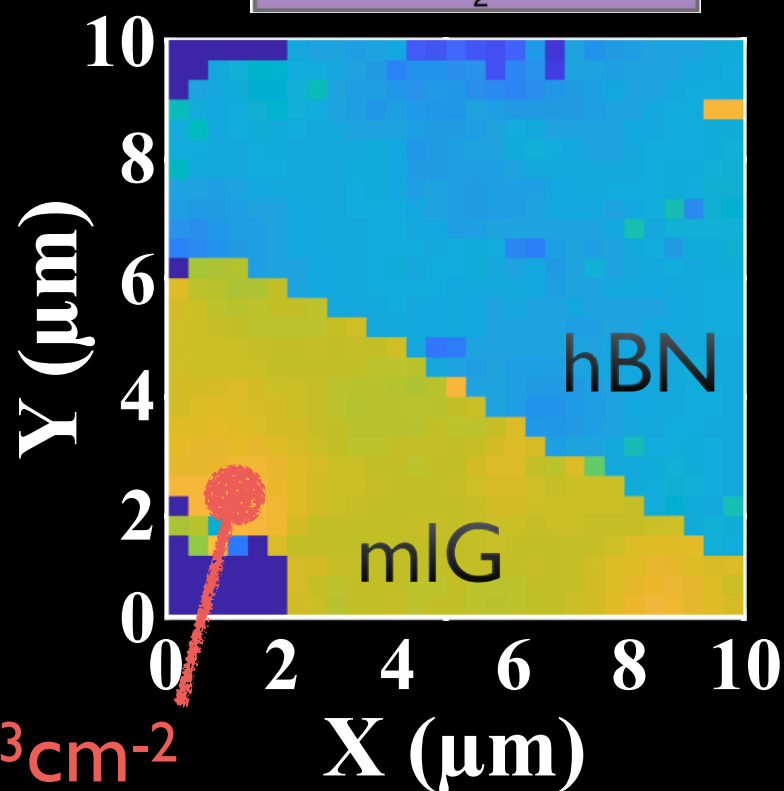
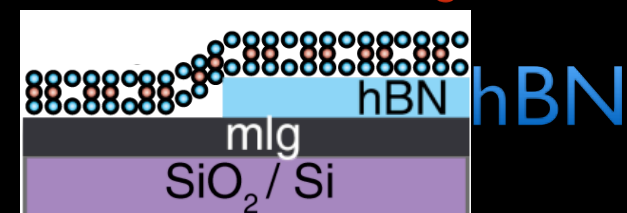
Y. Wang, KSB et al, arXiv:2007.06603

Modulation Doping

Graphene



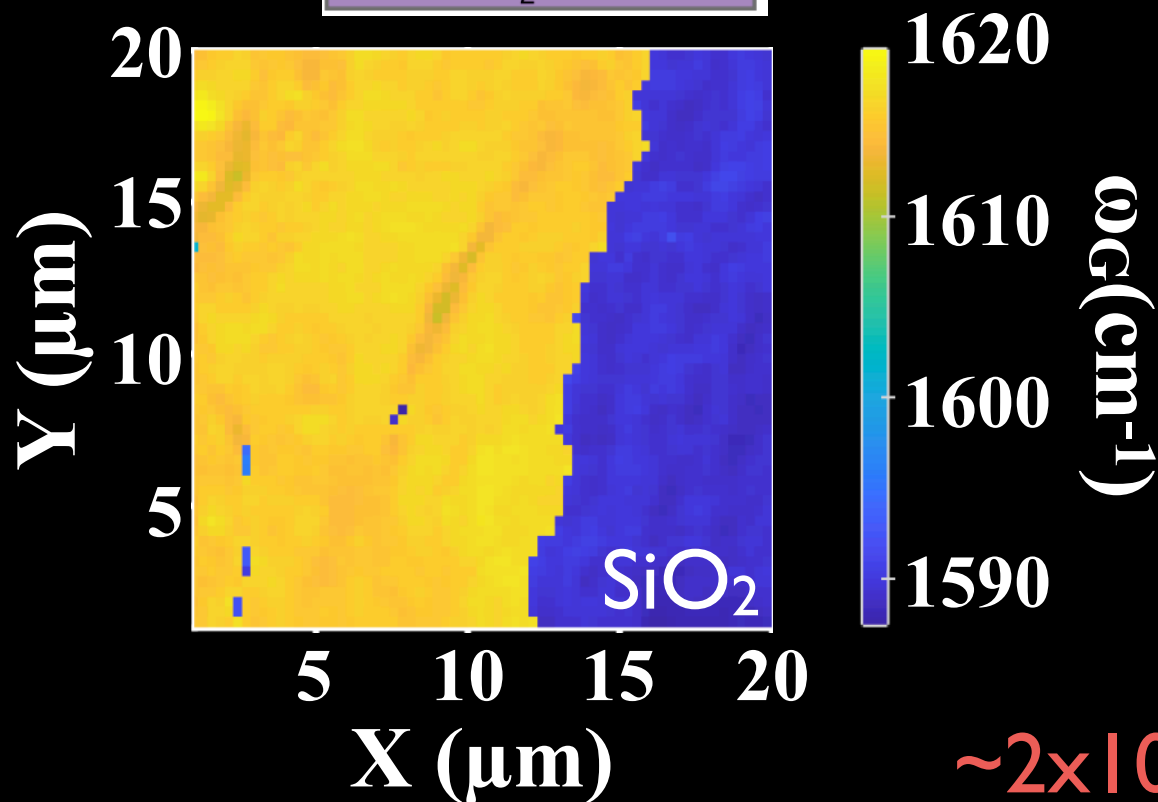
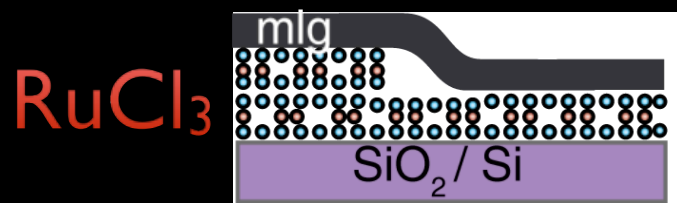
RuCl_3



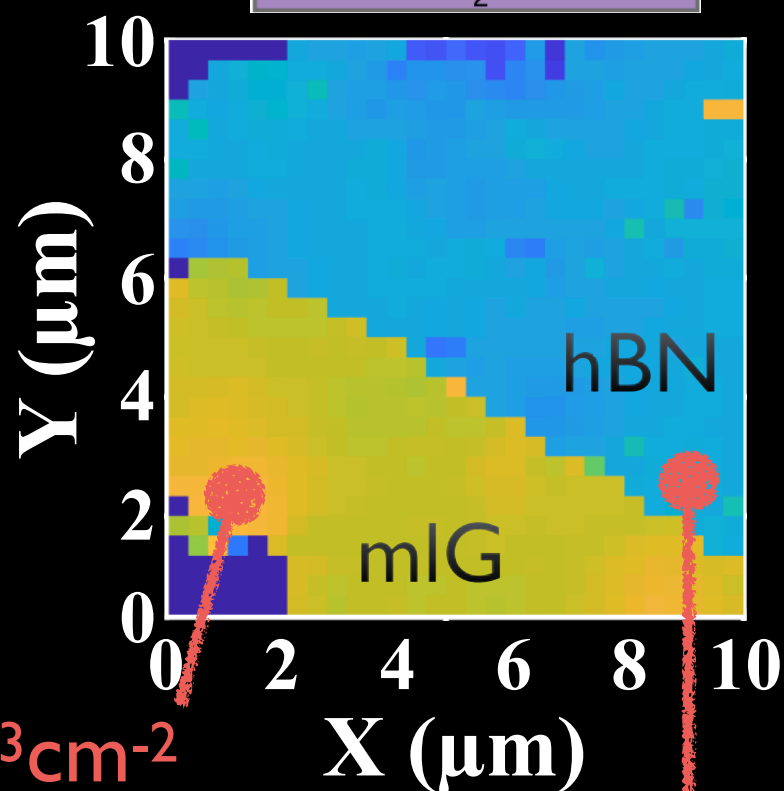
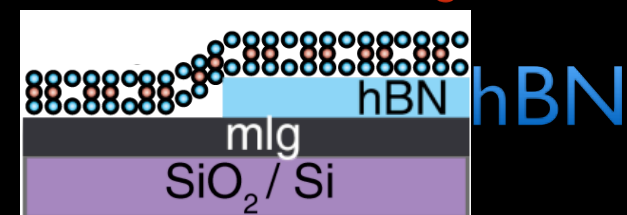
Y. Wang, KSB et al, arXiv:2007.06603

Modulation Doping

Graphene

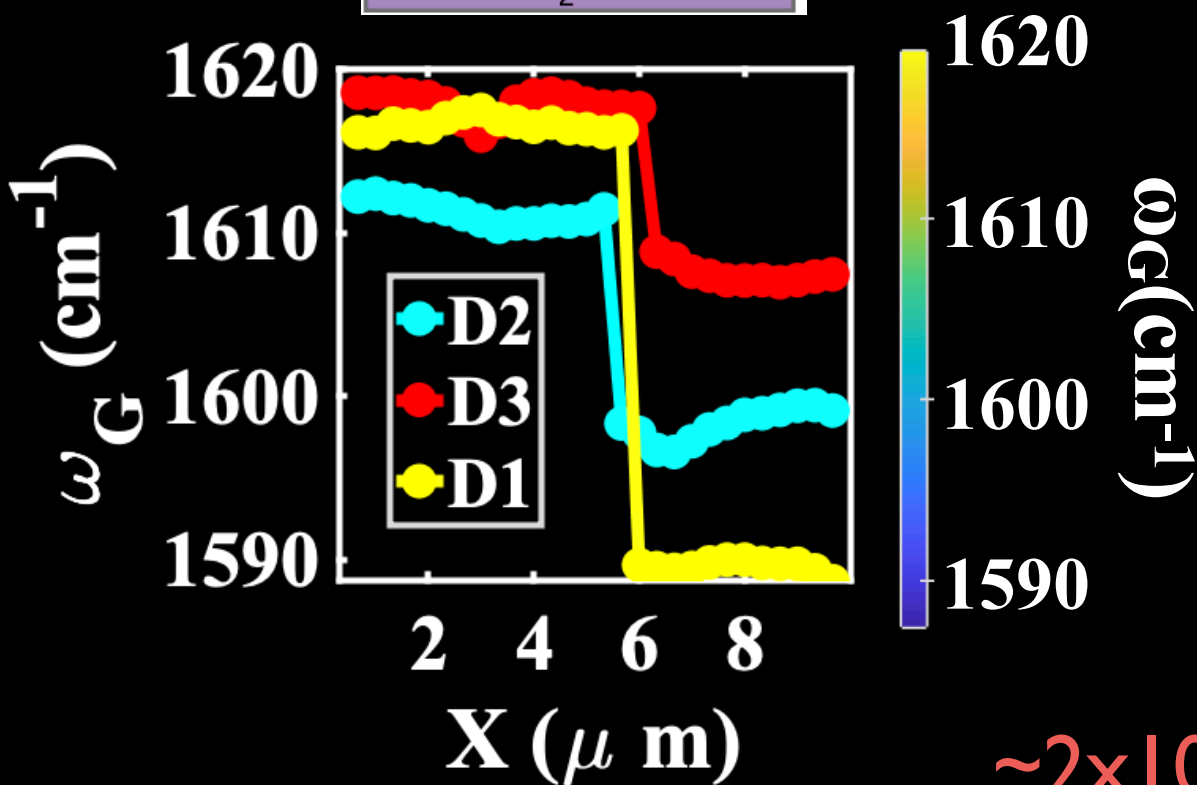


RuCl_3

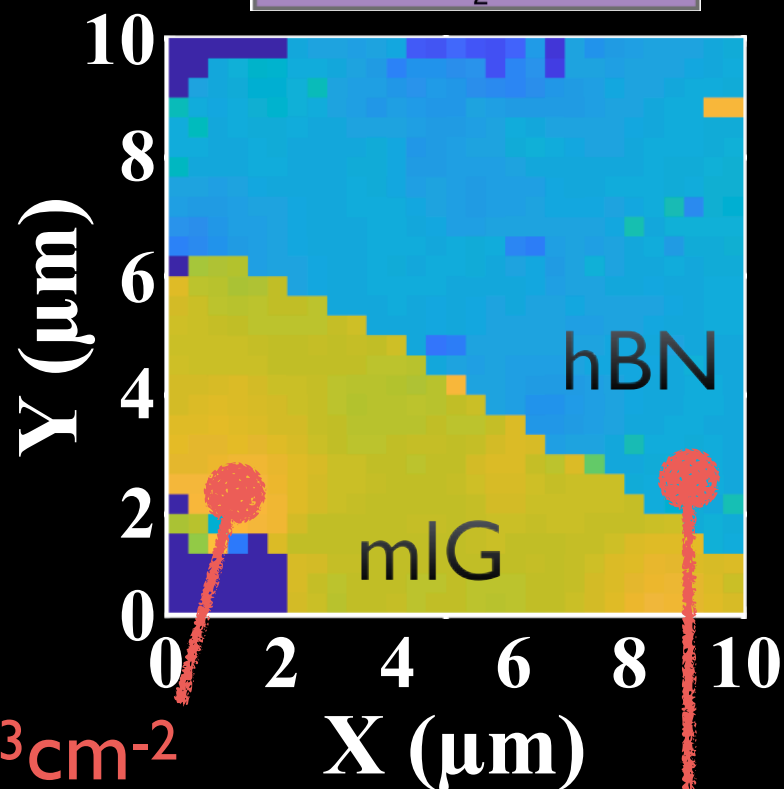
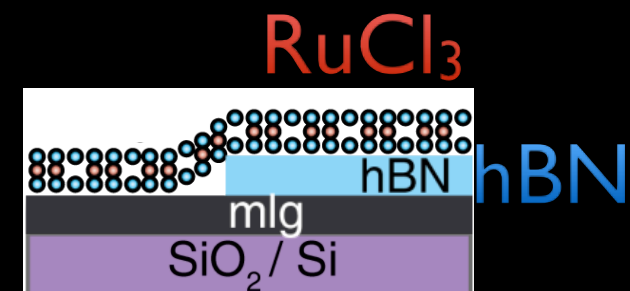


Y. Wang, KSB et al, arXiv:2007.06603

Graphene

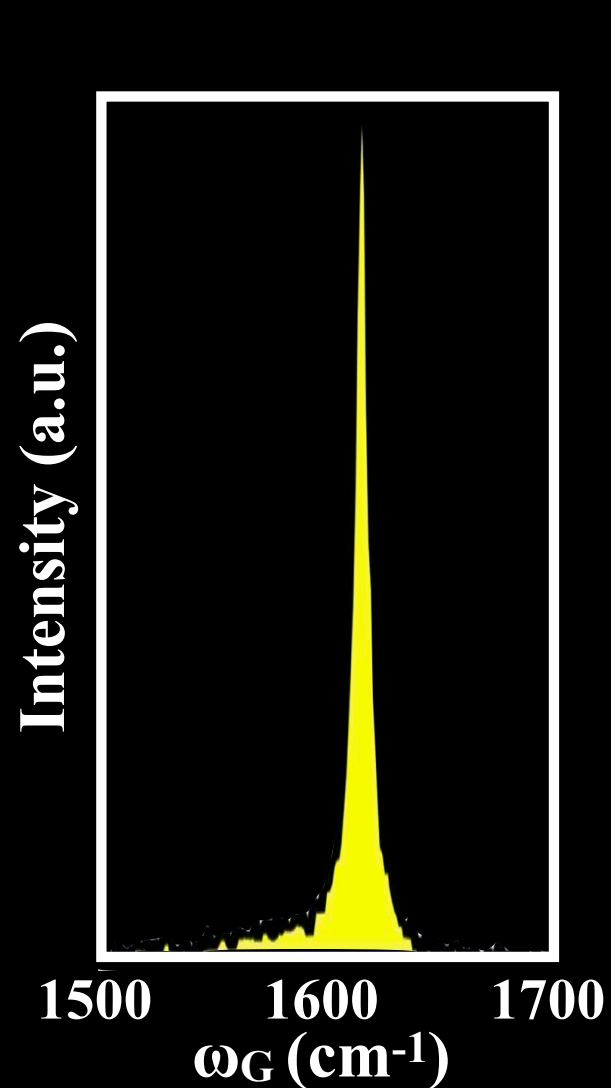


$\sim 2 \times 10^{13} \text{cm}^{-2}$



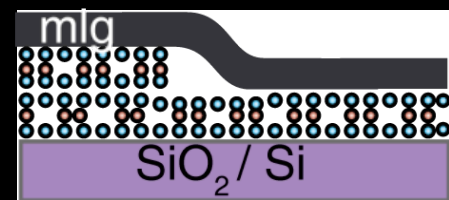
$\sim 0.6 \times 10^{13} \text{cm}^{-2}$

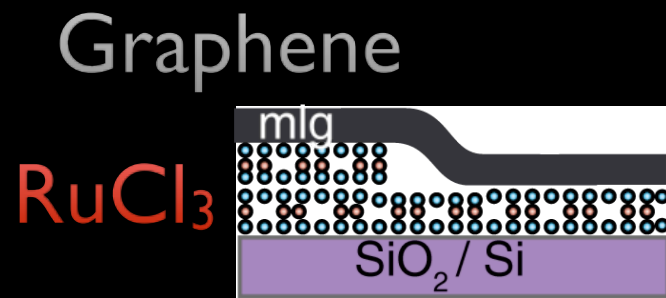
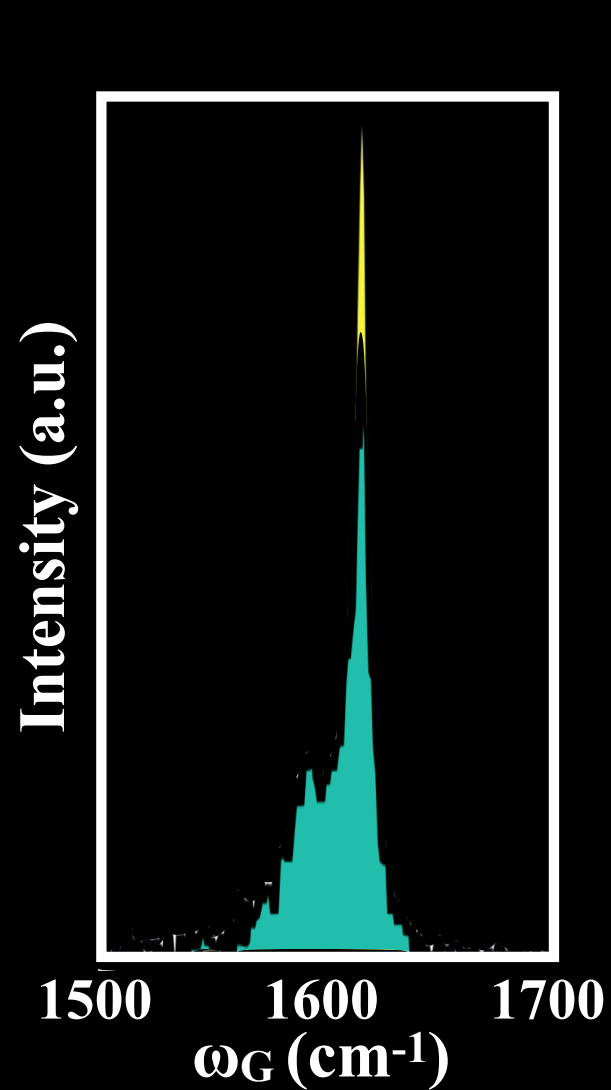
Y. Wang, KSB et al, arXiv:2007.06603

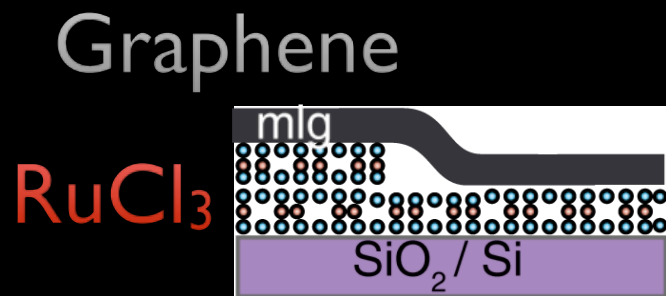
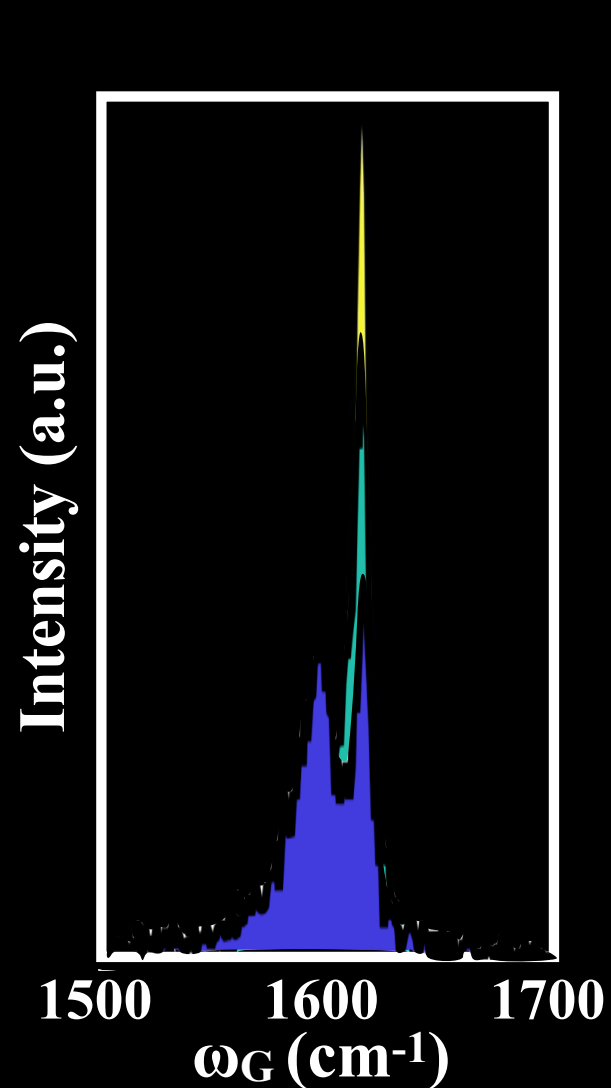


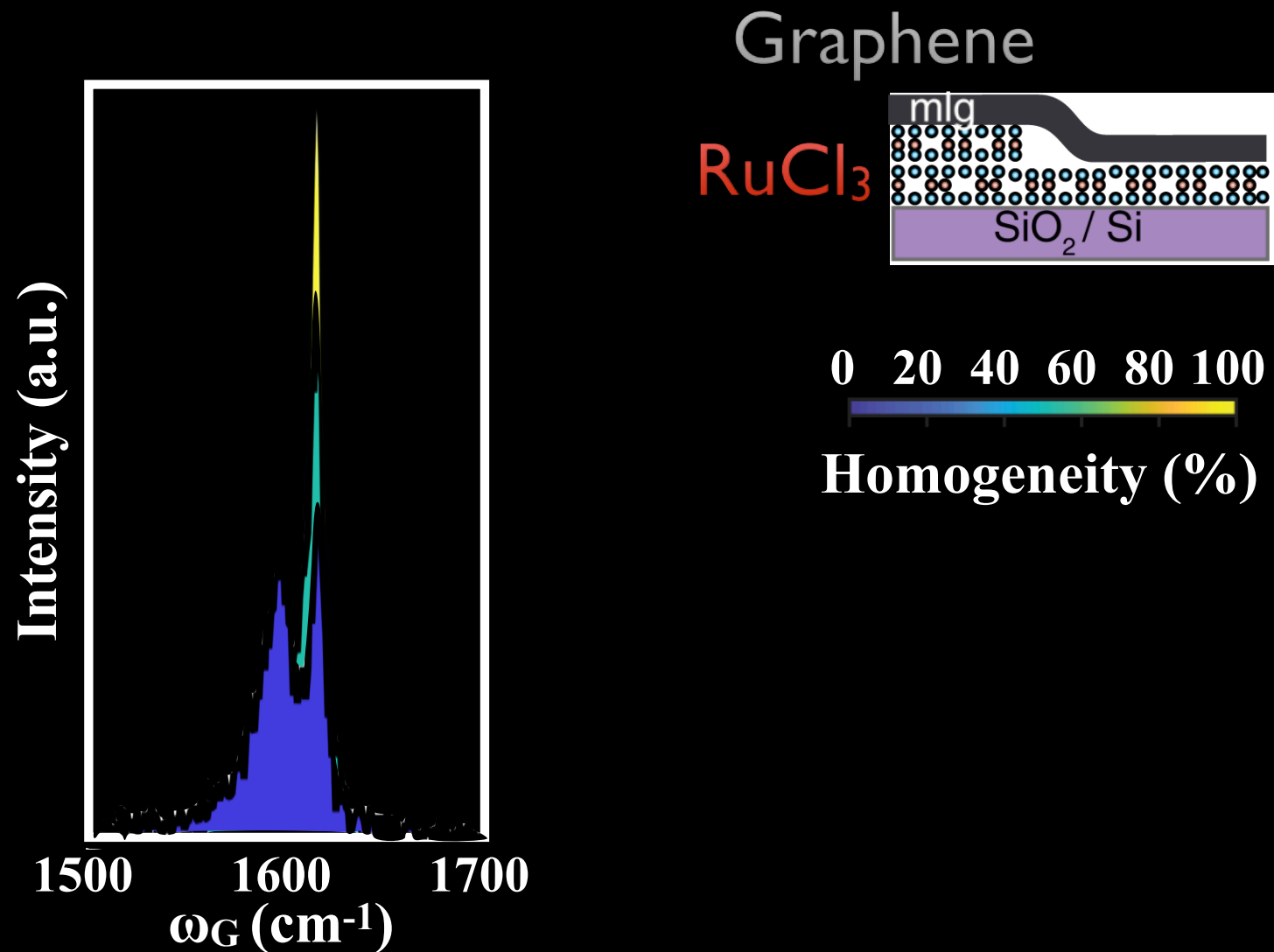
Graphene

RuCl_3

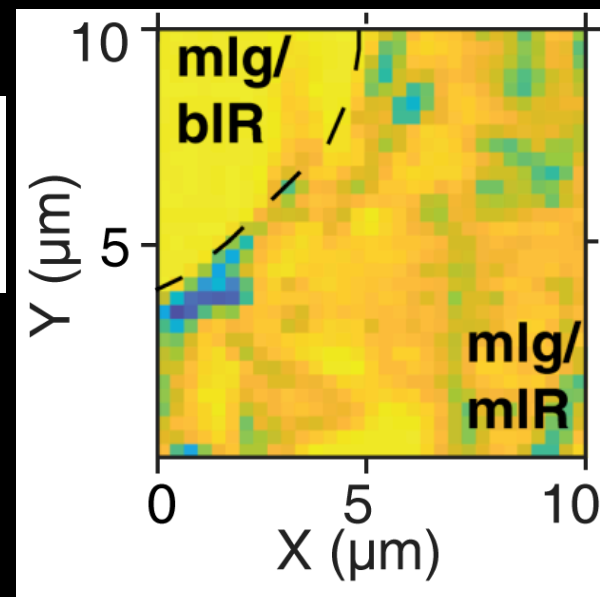
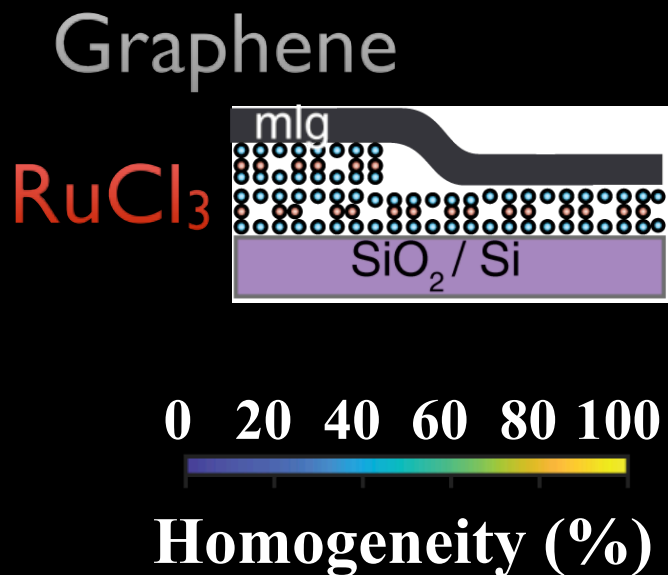
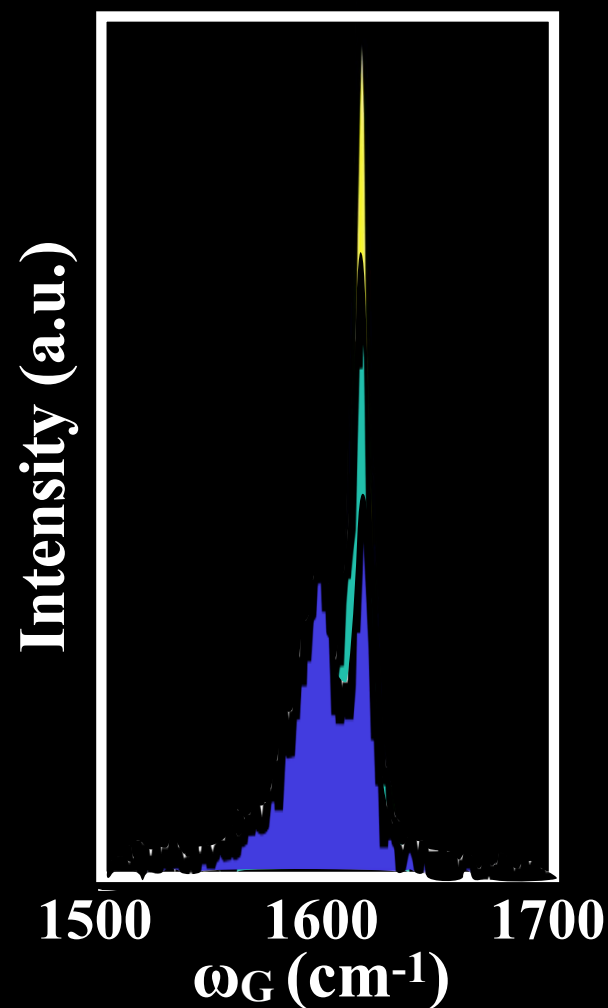




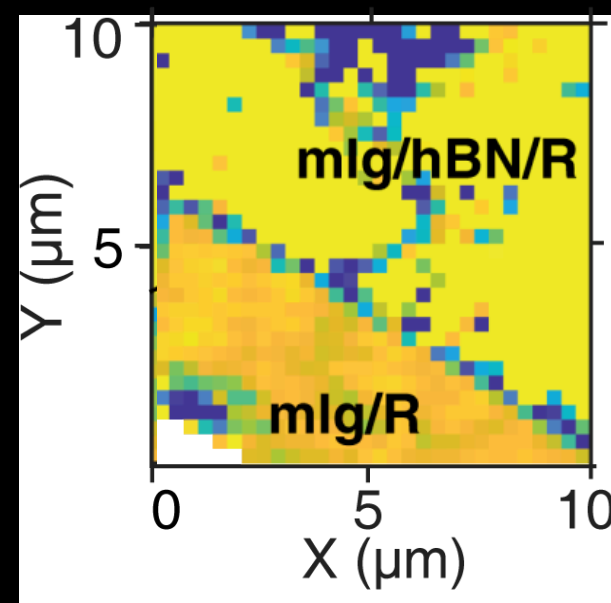
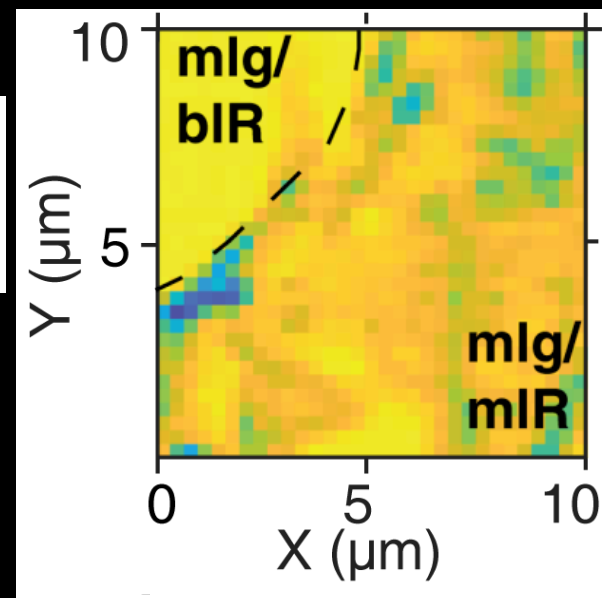
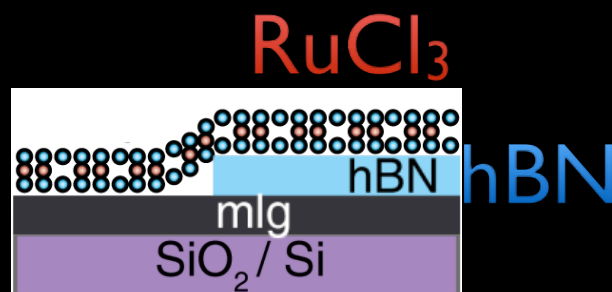
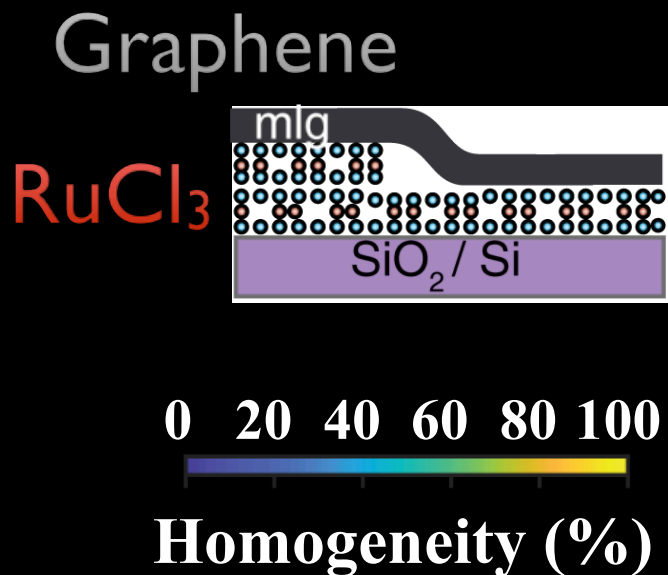
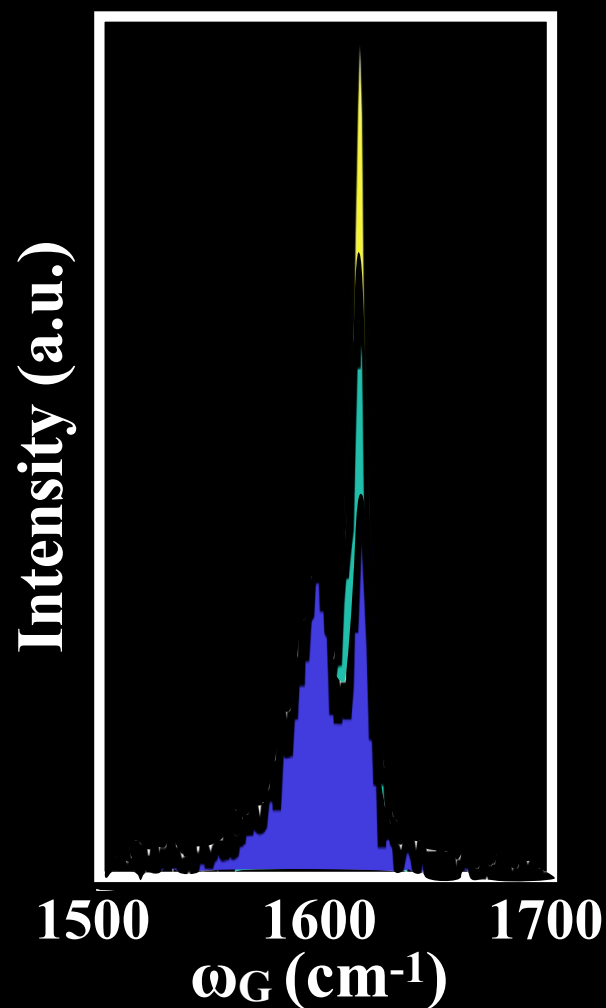




Homogeneity

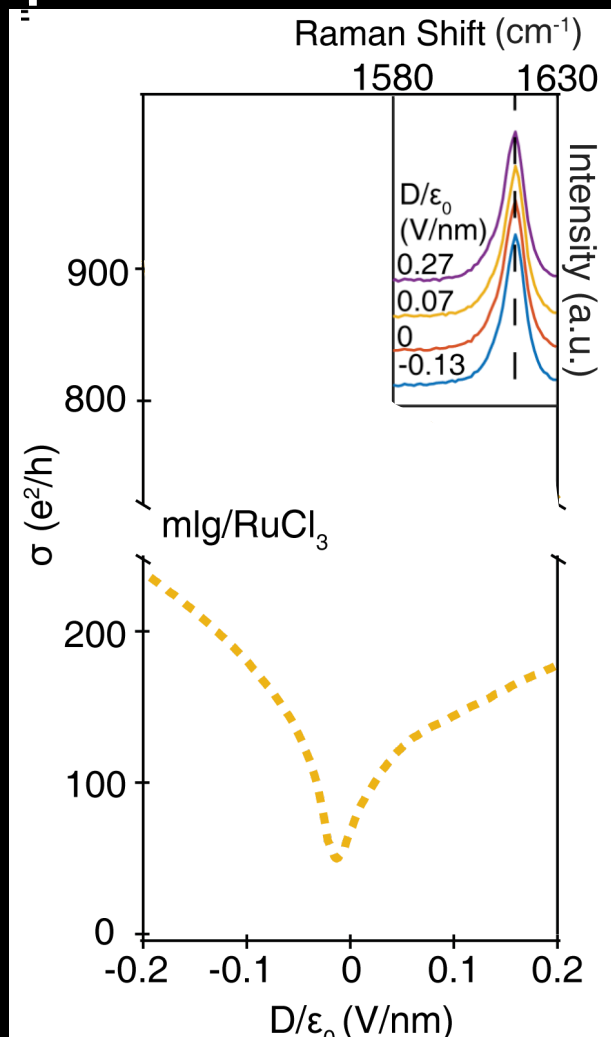


Homogeneity



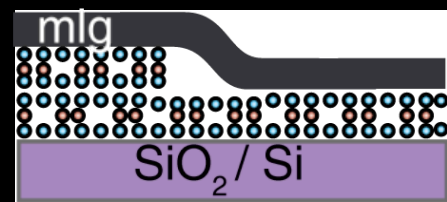
Y. Wang, KSB et al, arXiv:2007.06603

Spectra



Graphene

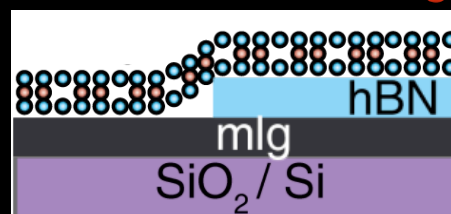
RuCl_3



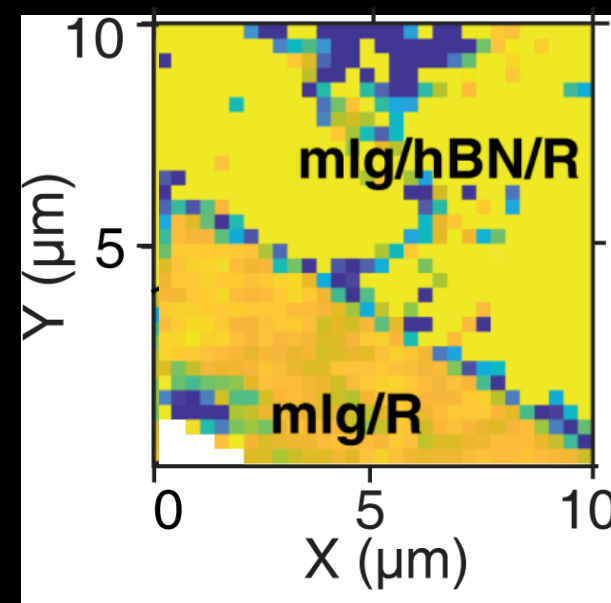
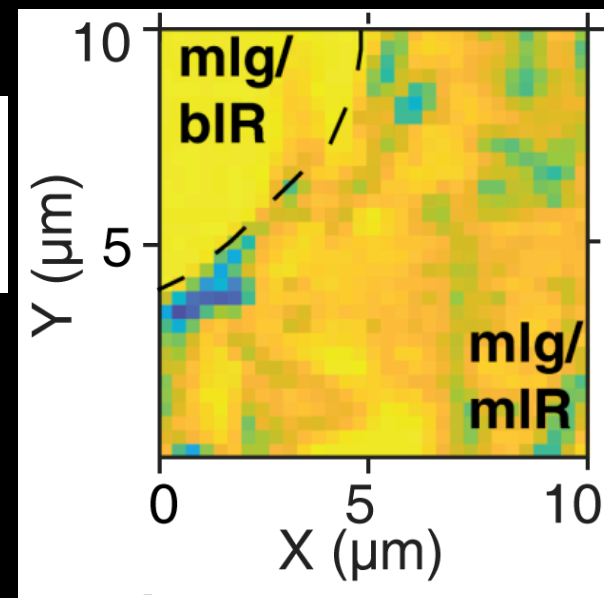
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Homogeneity (%)

RuCl_3



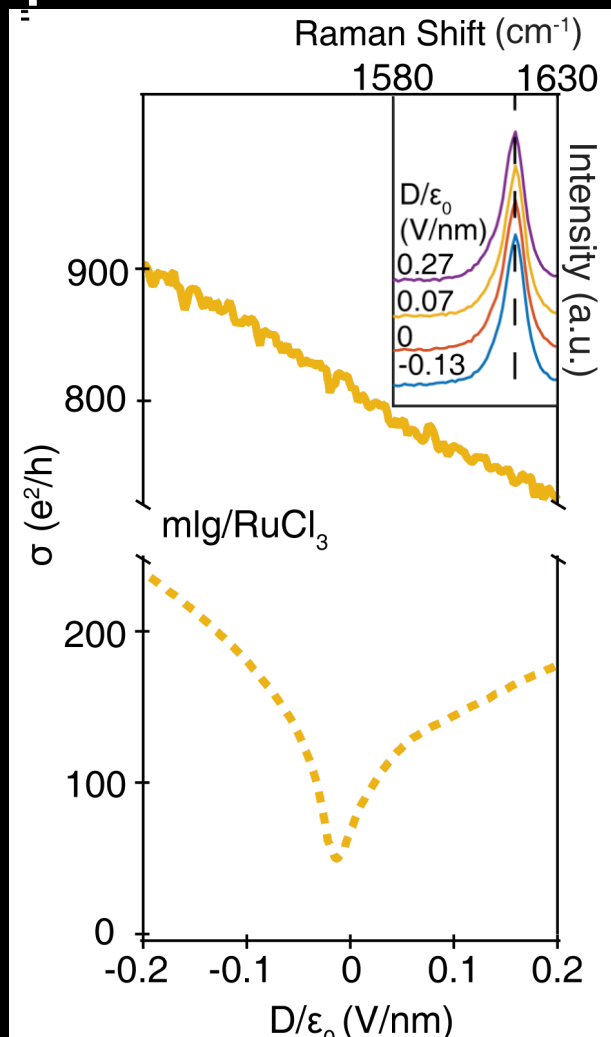
hBN



Transport

Y. Wang, KSB et al, arXiv:2007.06603

Spectra

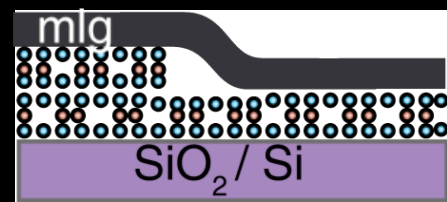


Transport

Y. Wang, KSB et al, arXiv:2007.06603

Graphene

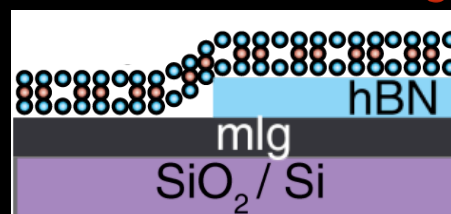
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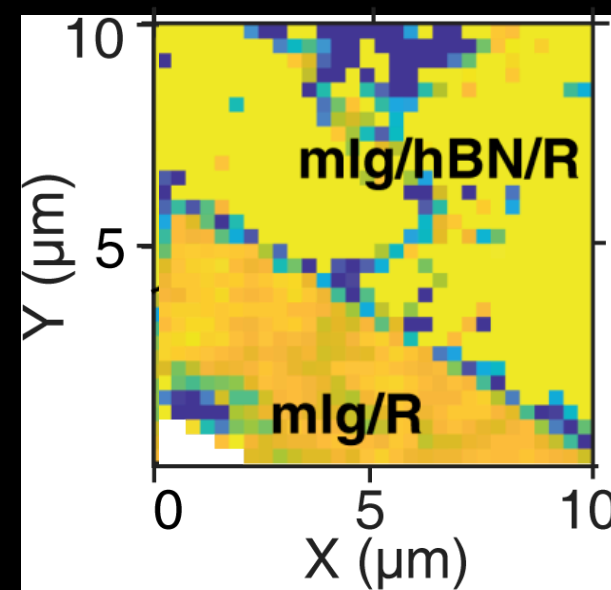
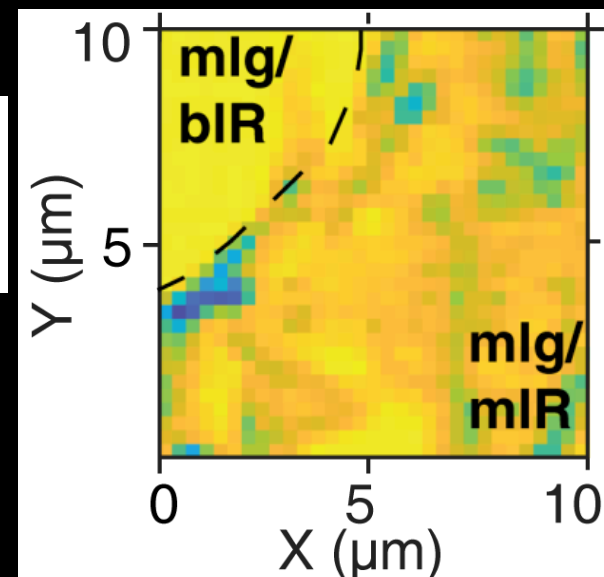
0 20 40 60 80 100

Homogeneity (%)

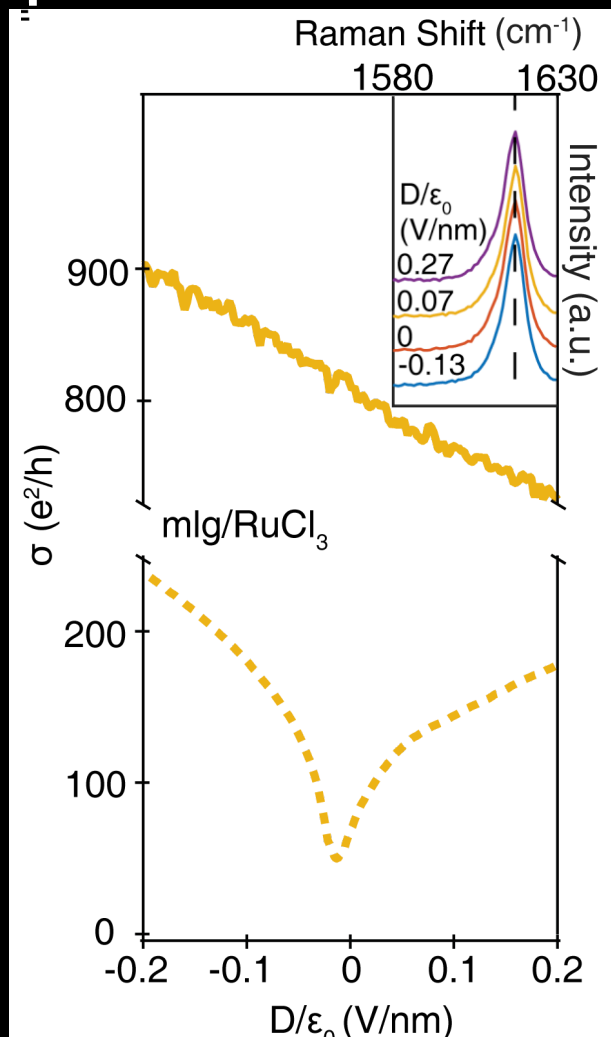
RuCl_3



hBN



Spectra

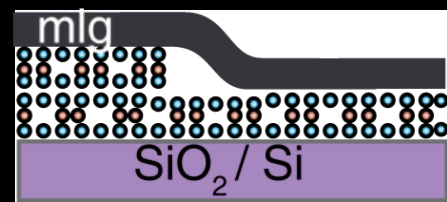


Transport

Y. Wang, KSB et al, arXiv:2007.06603

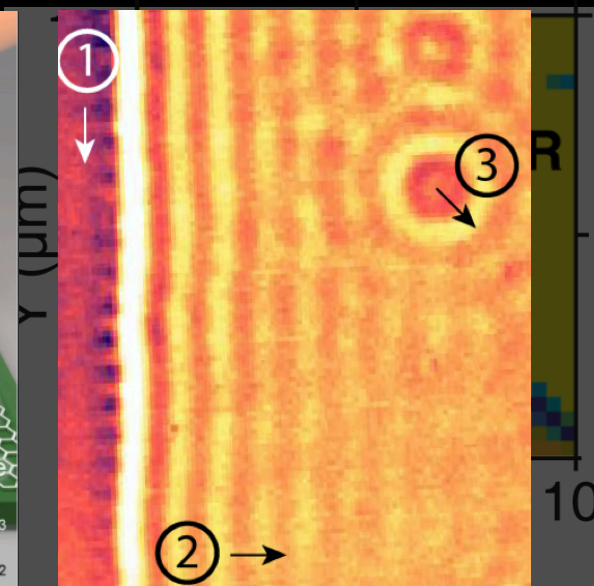
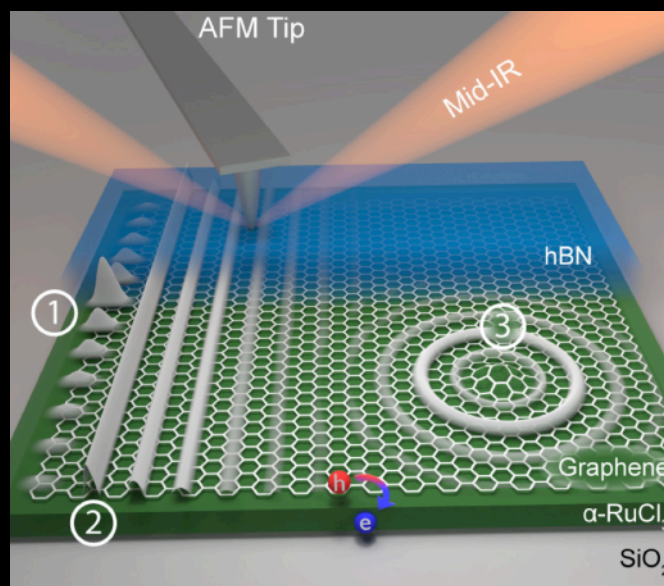
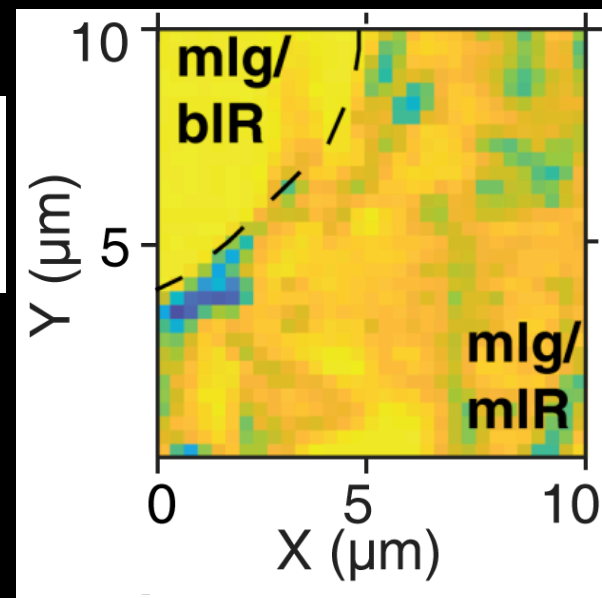
Graphene

RuCl_3



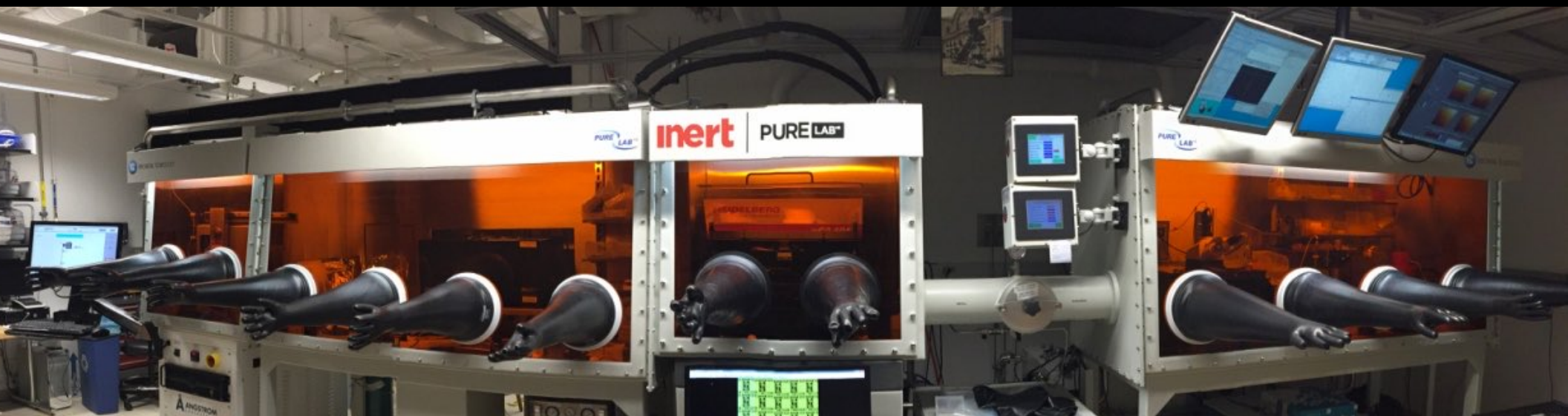
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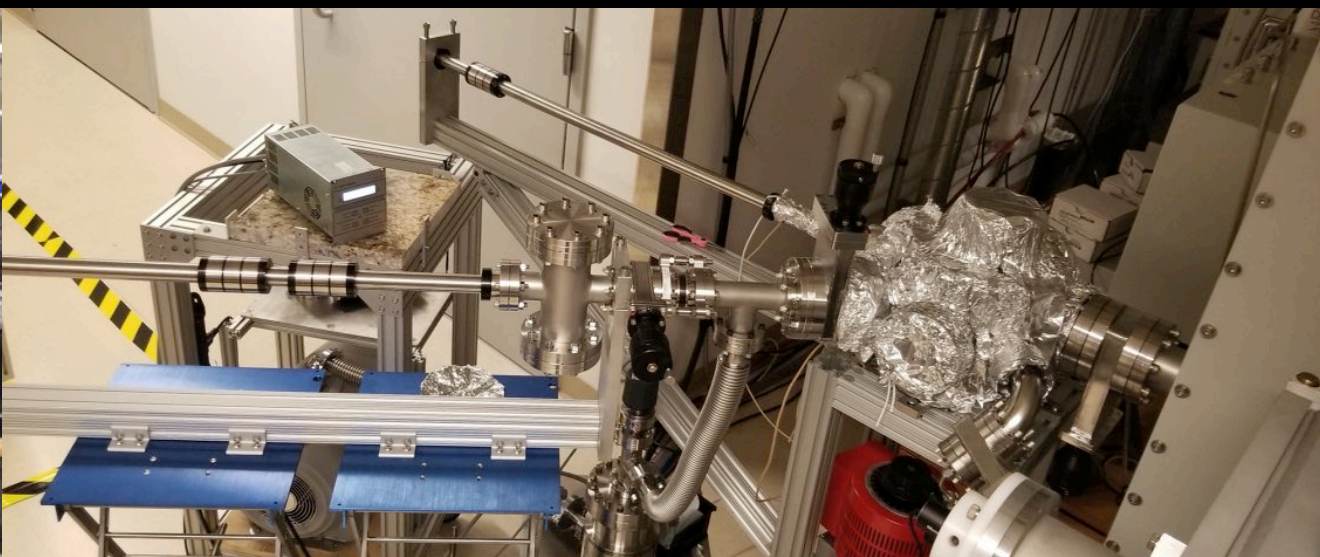
Homogeneity (%)

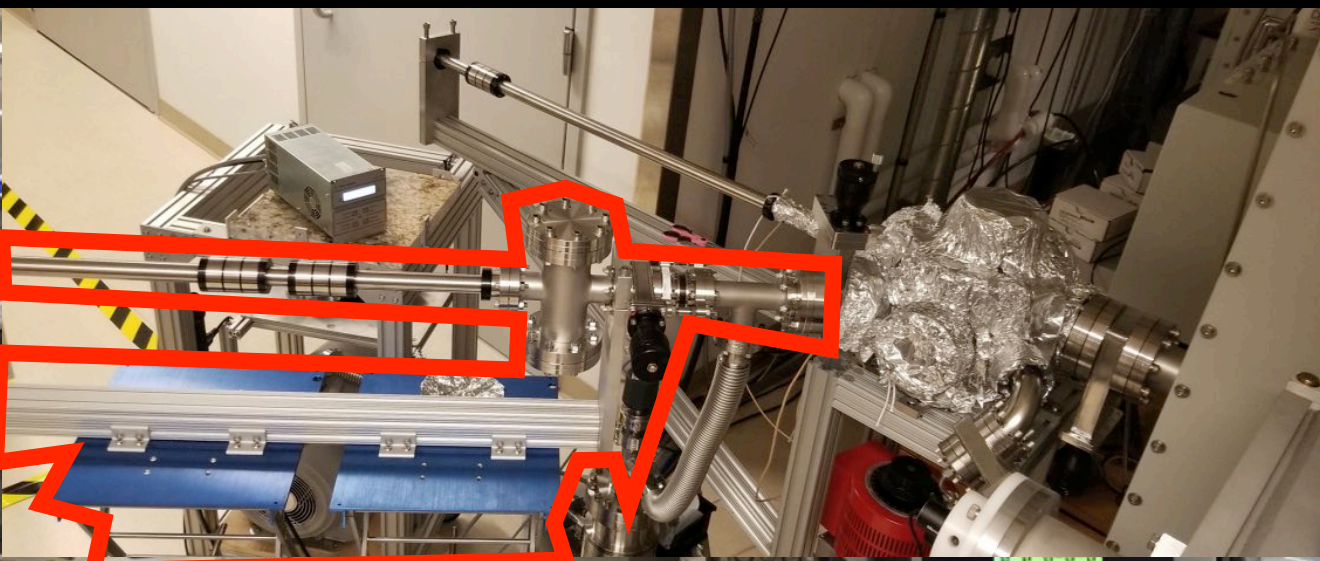


D. Rizzo, DN Basov et al, arXiv:2007.07147

Highlights







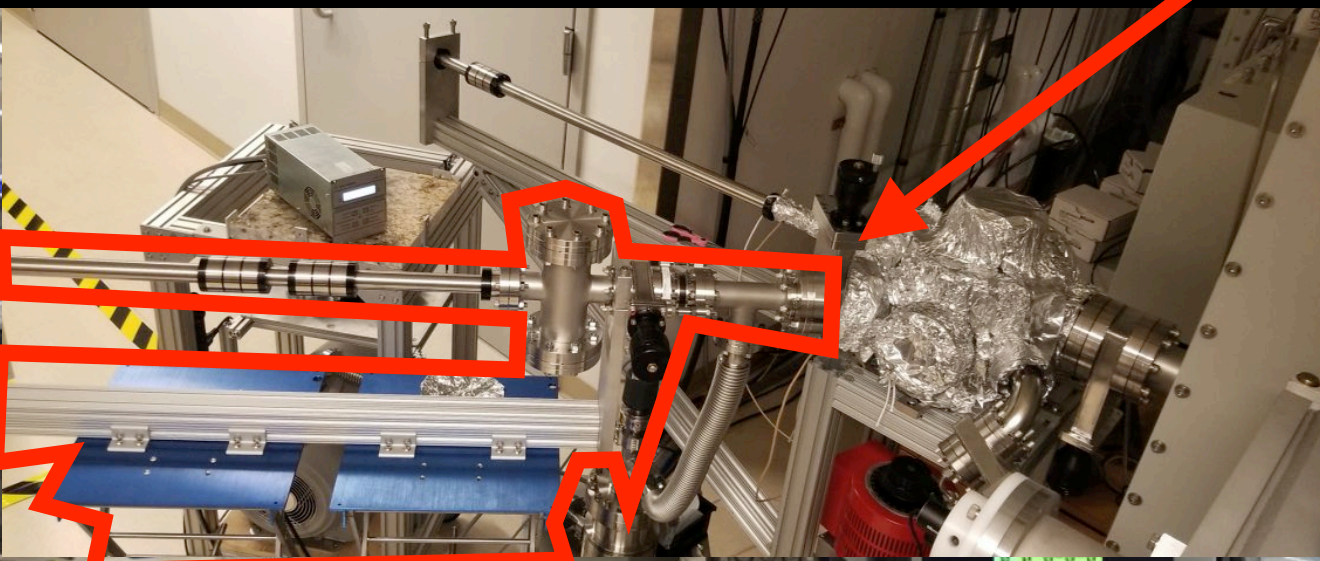
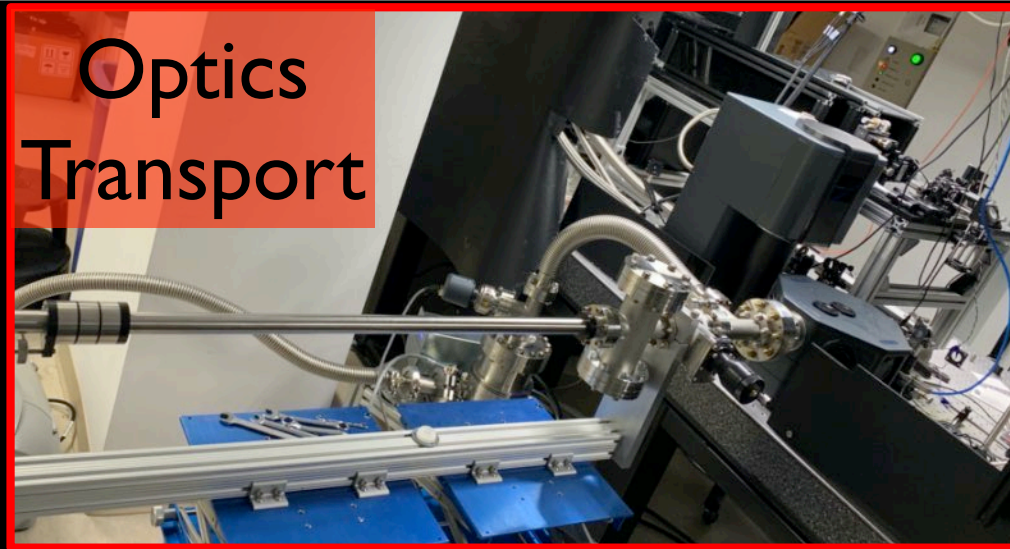
● Charge

● Sharp

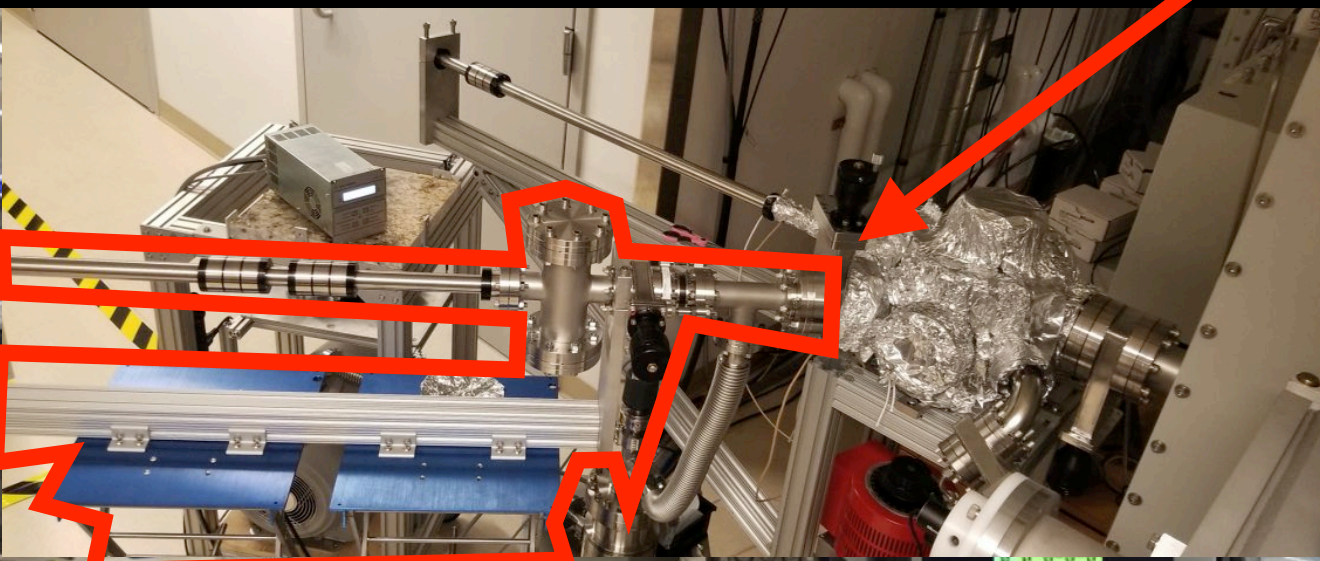
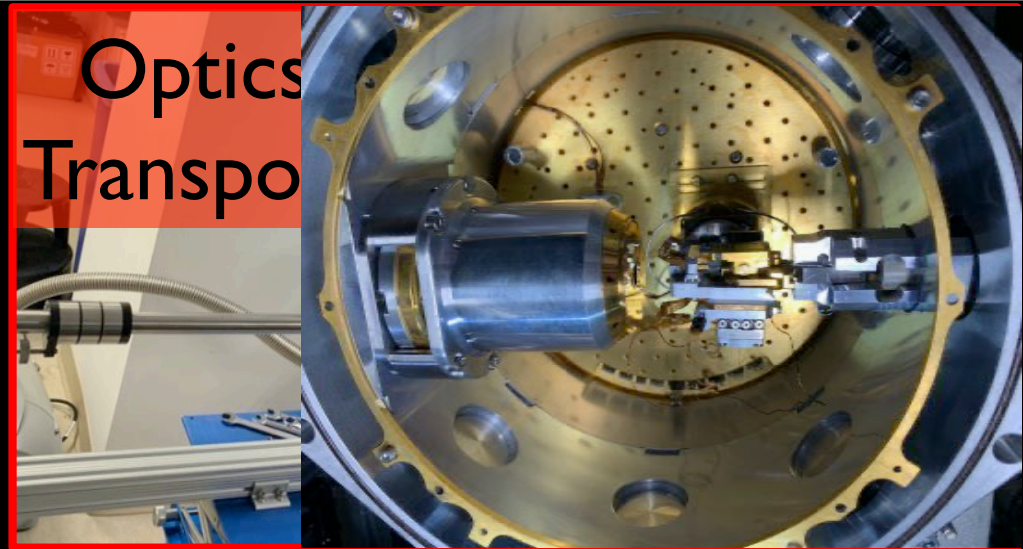


● Highlights

Other Materials



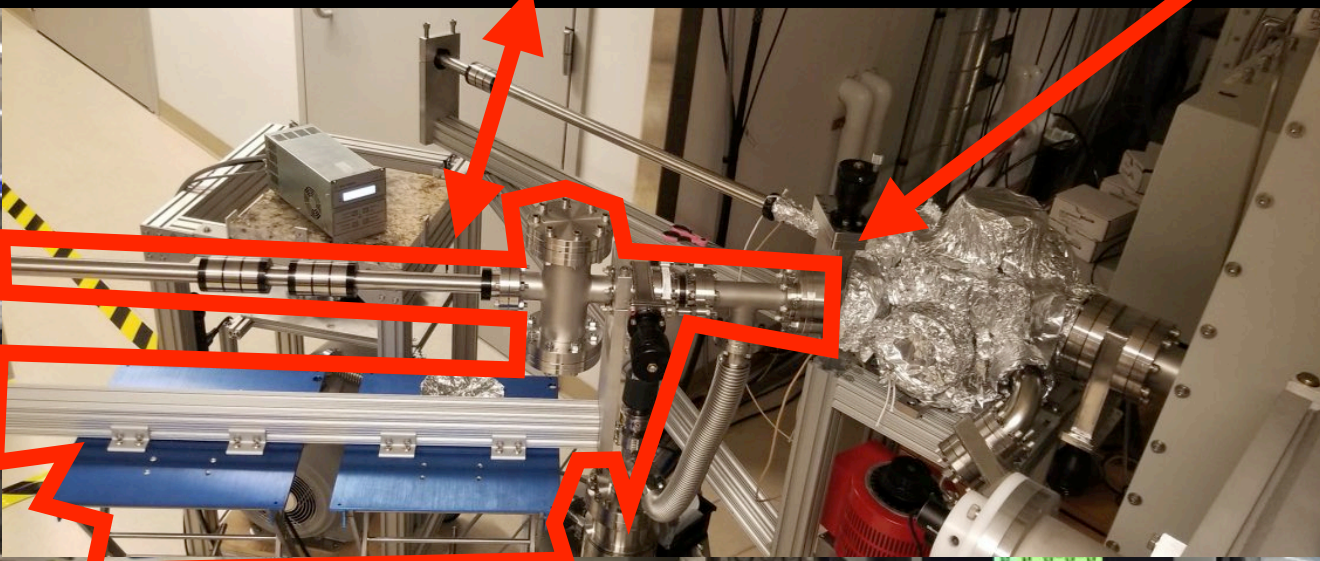
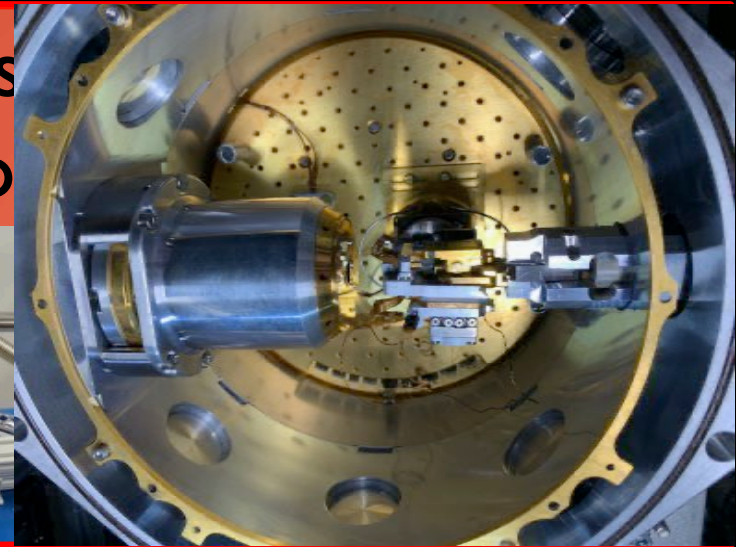
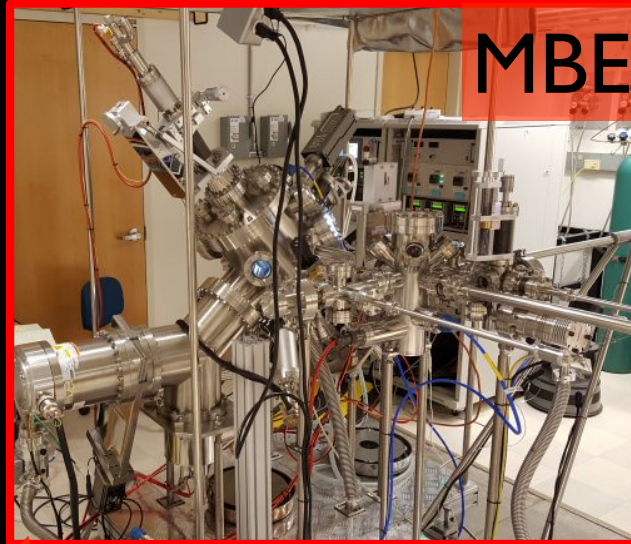
Other Materials



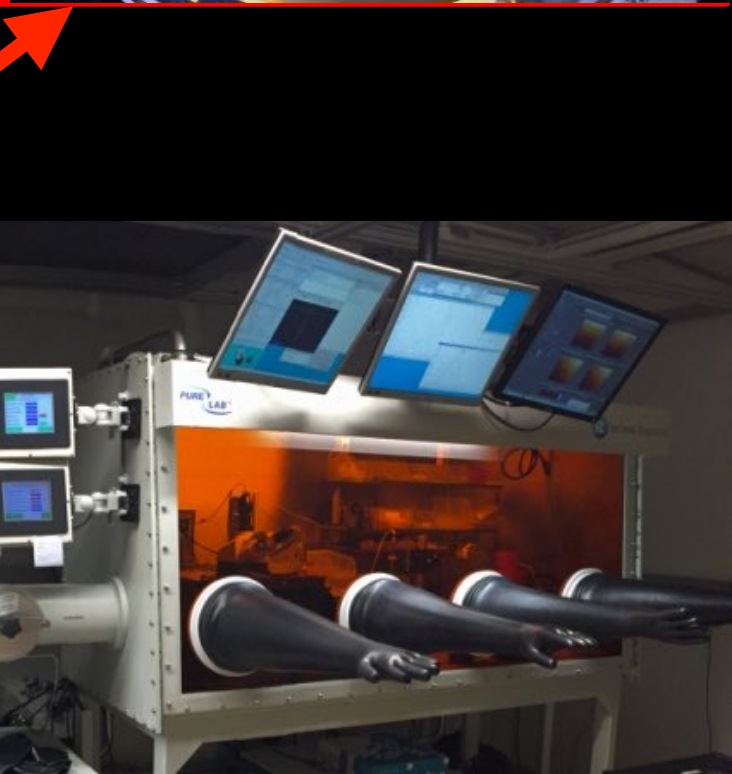
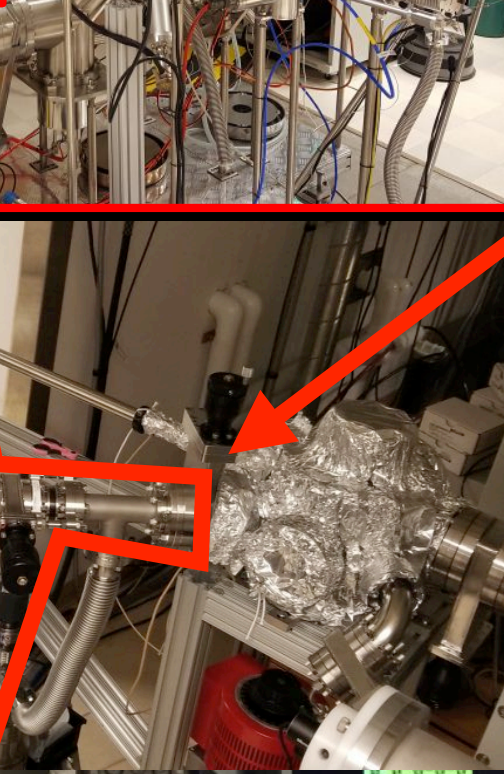
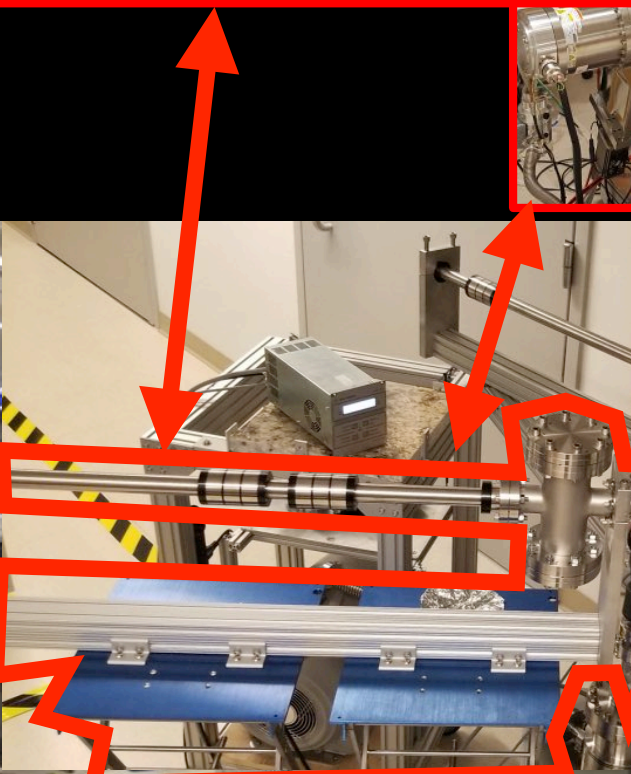
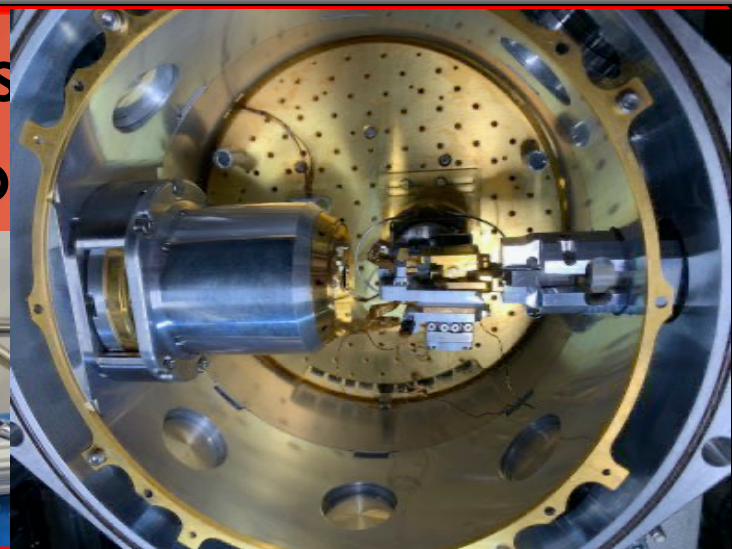
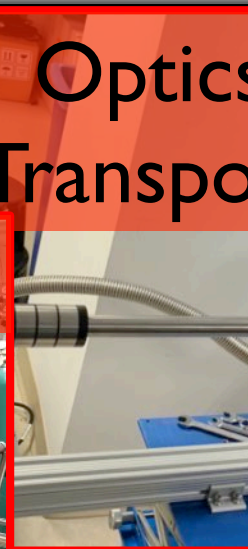
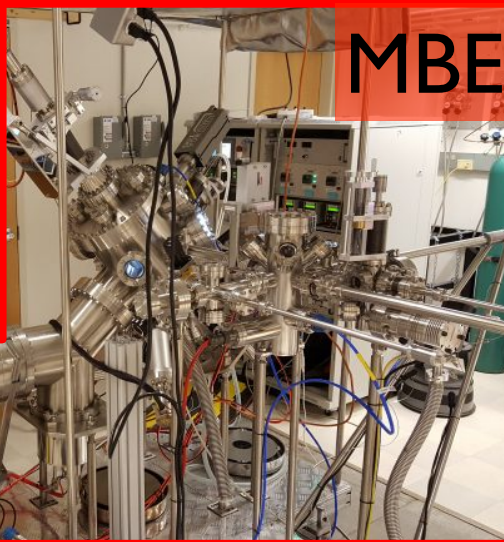
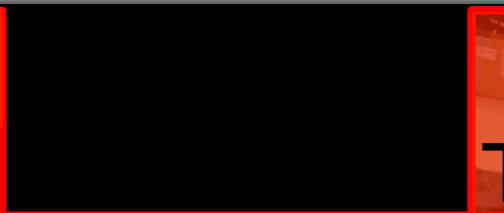
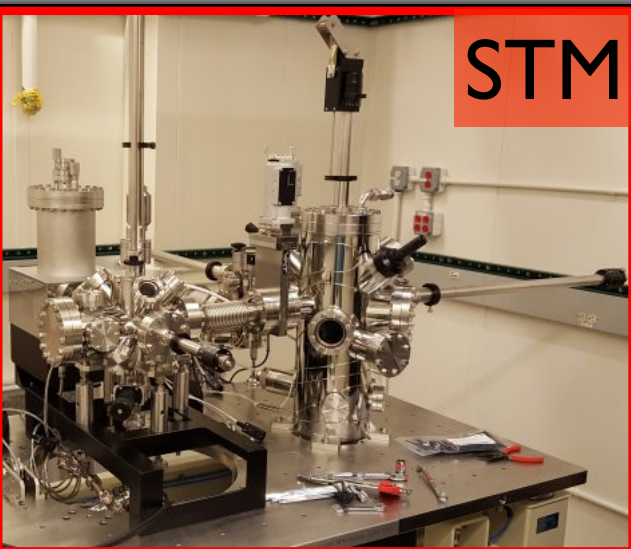
Other Materials

Optics
Transpo

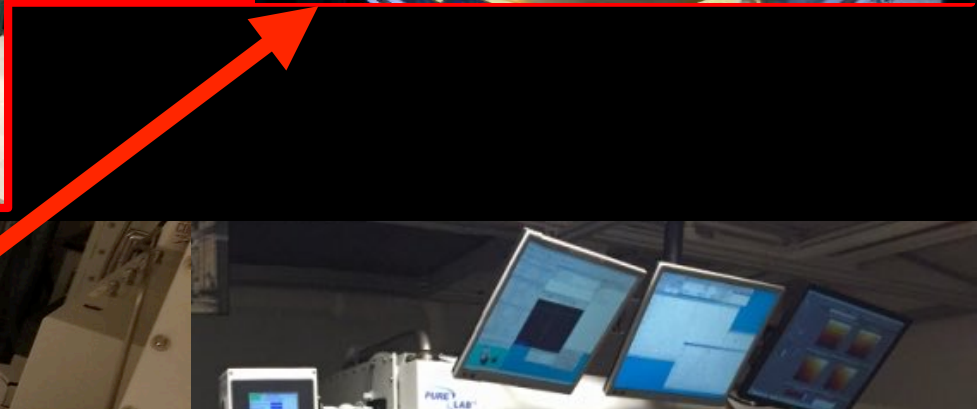
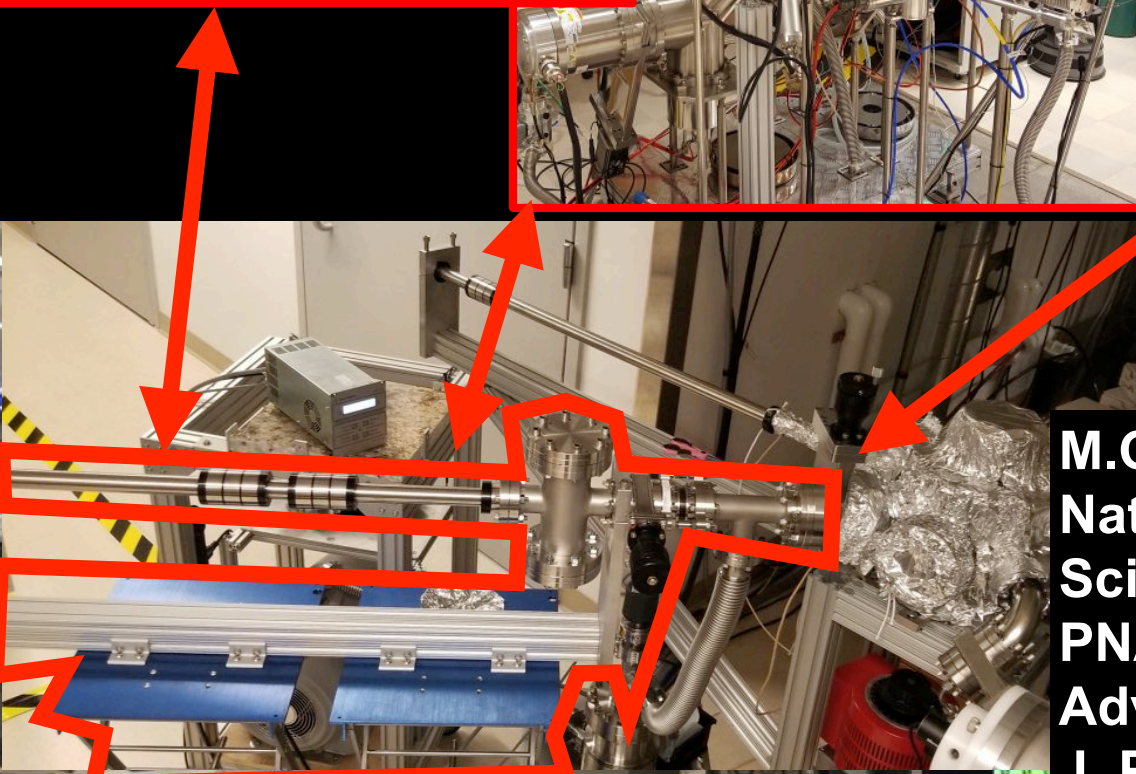
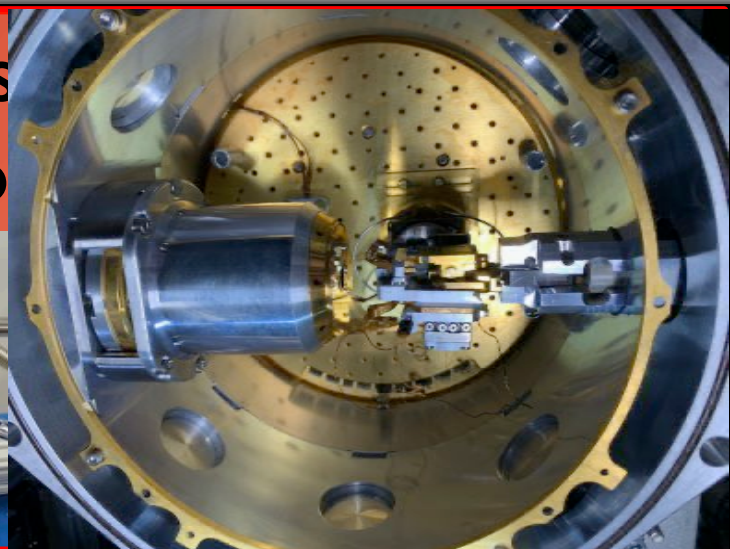
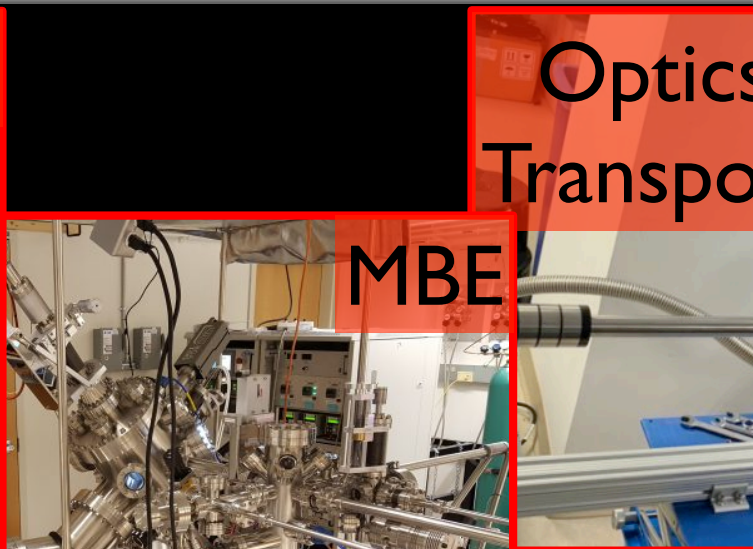
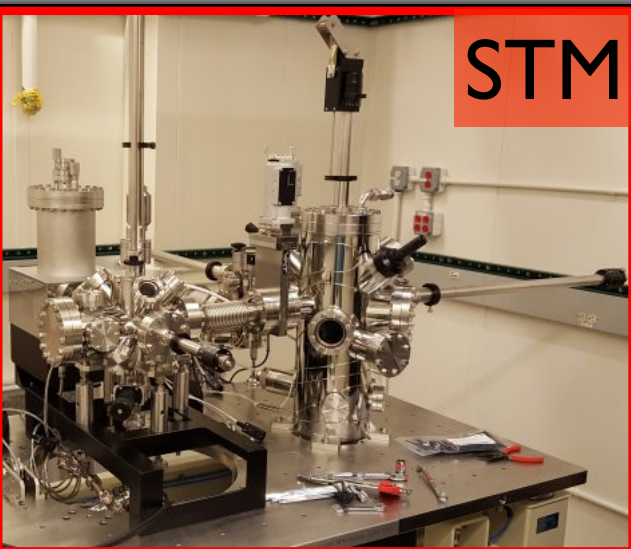
MBE



Other Materials

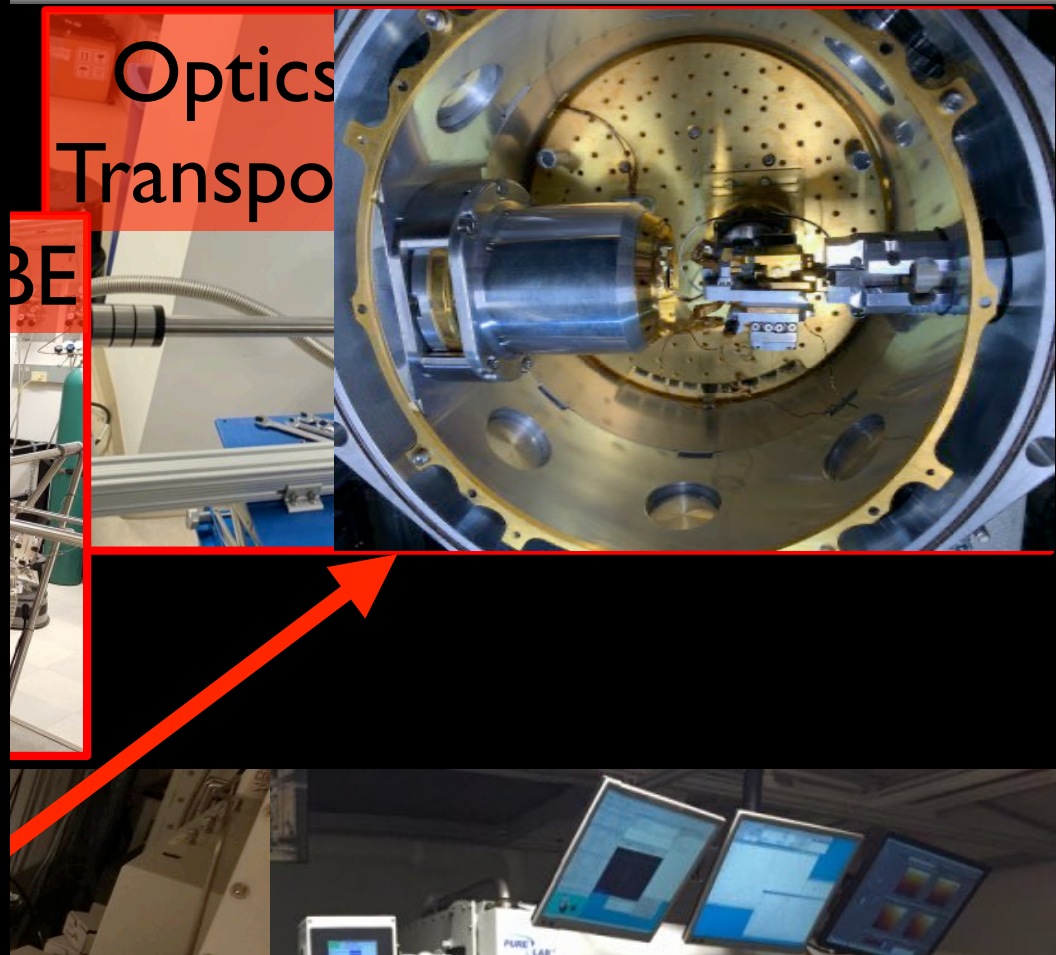
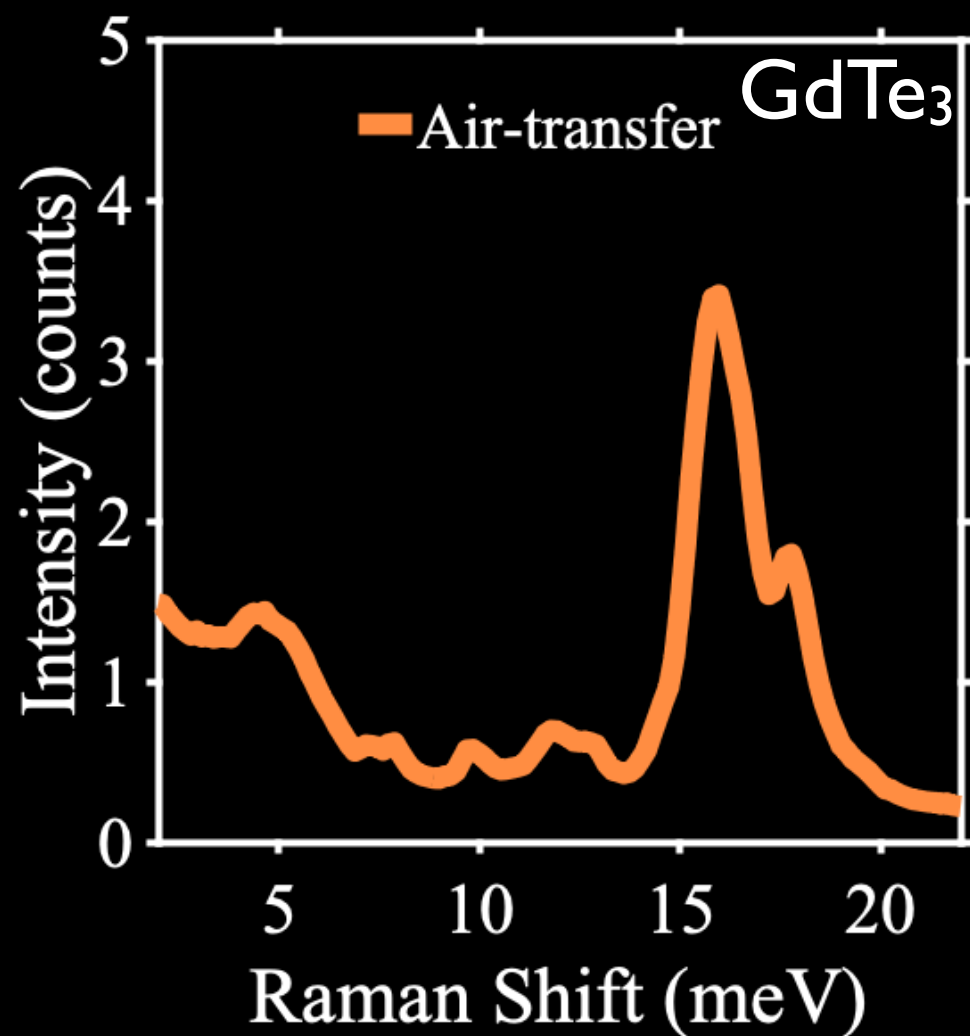


Other Materials

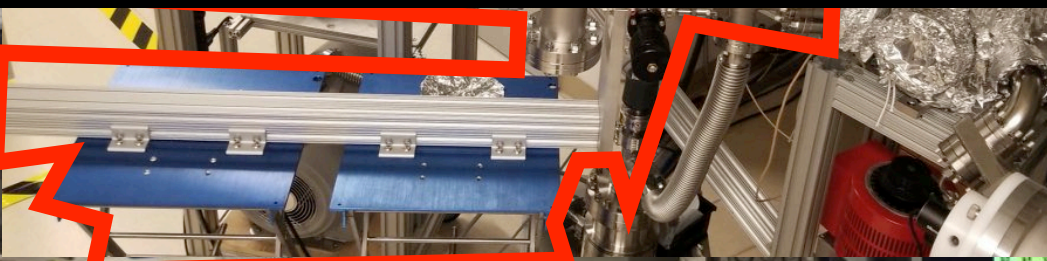


M.Gray, KSB et al, RSI (2020)
Nature Nano 14, 442 (2019)
Science Advances (2020)
PNAS 115, 6986 (2018)
Advanced Materials 1404, 1801325 (2018)
J. Phys. & Chem. Solids (2018)

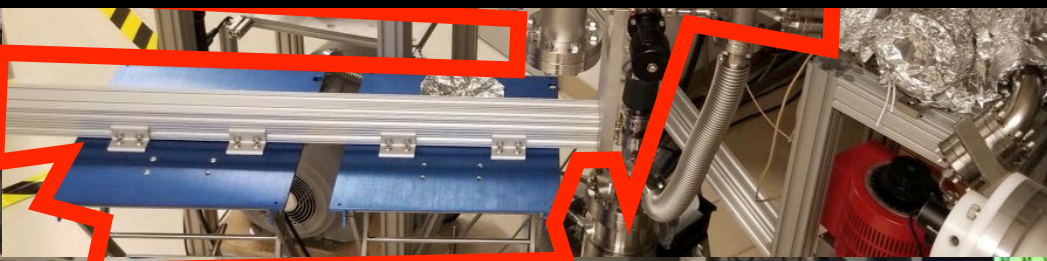
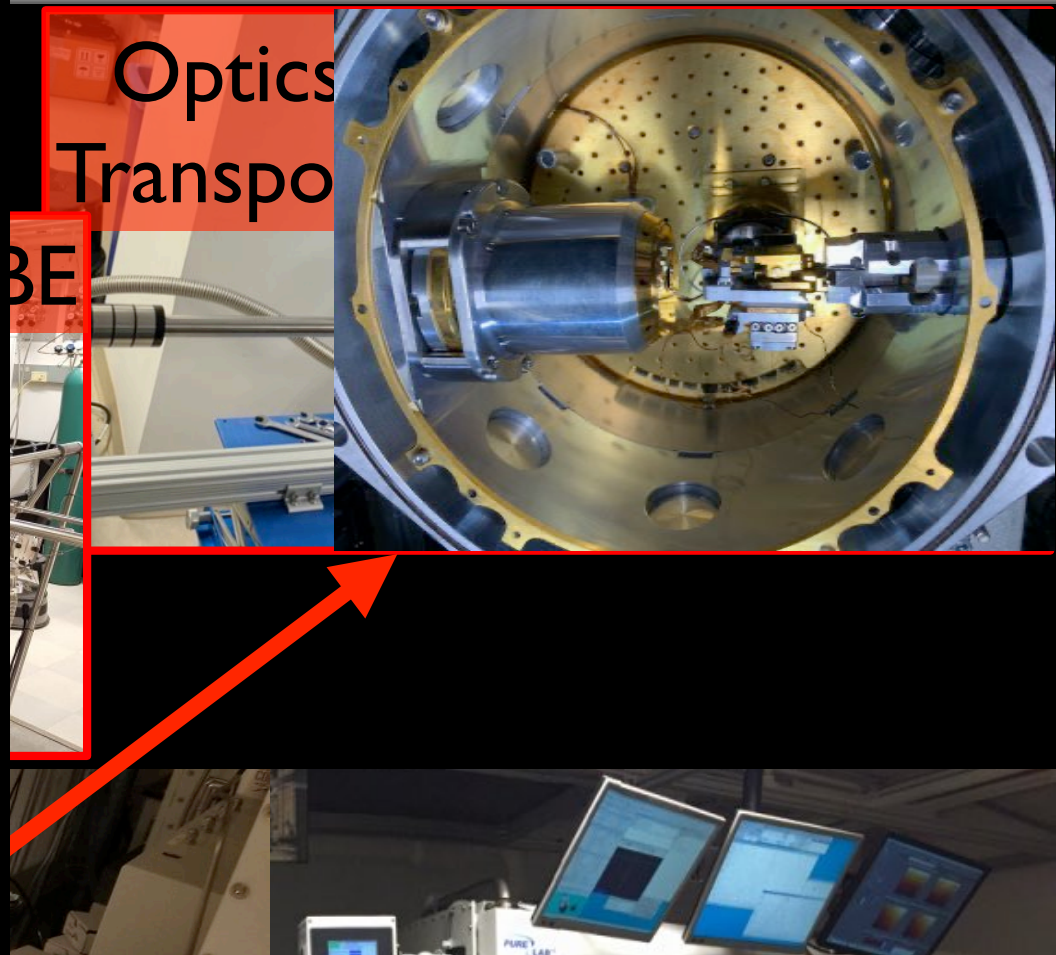
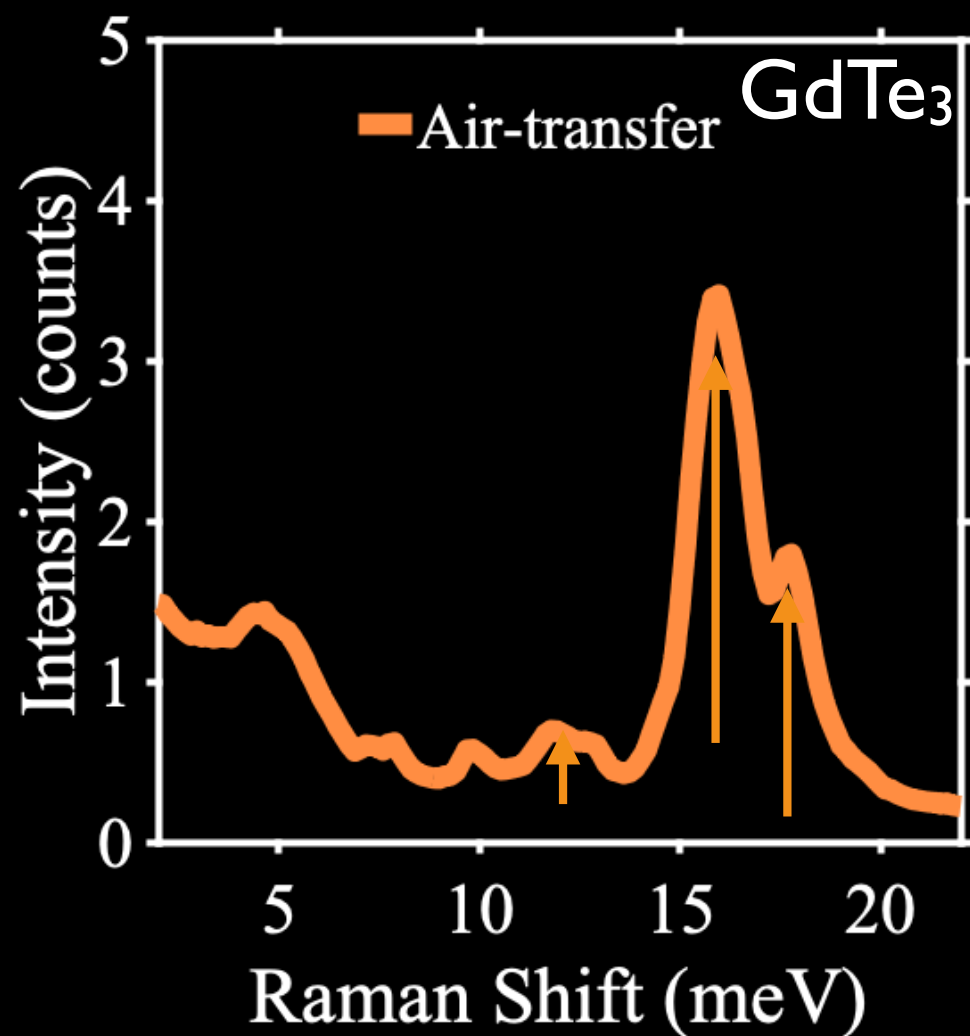
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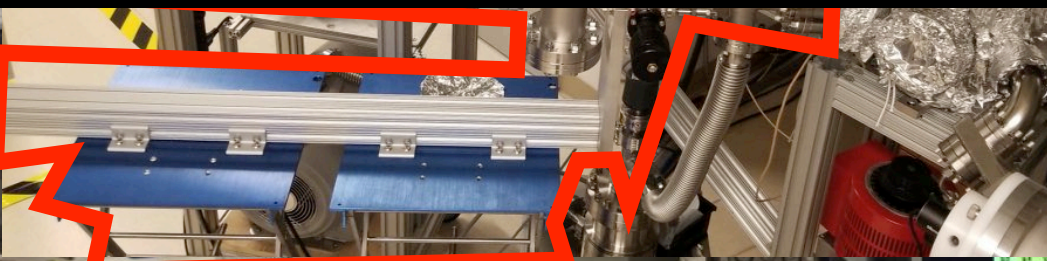
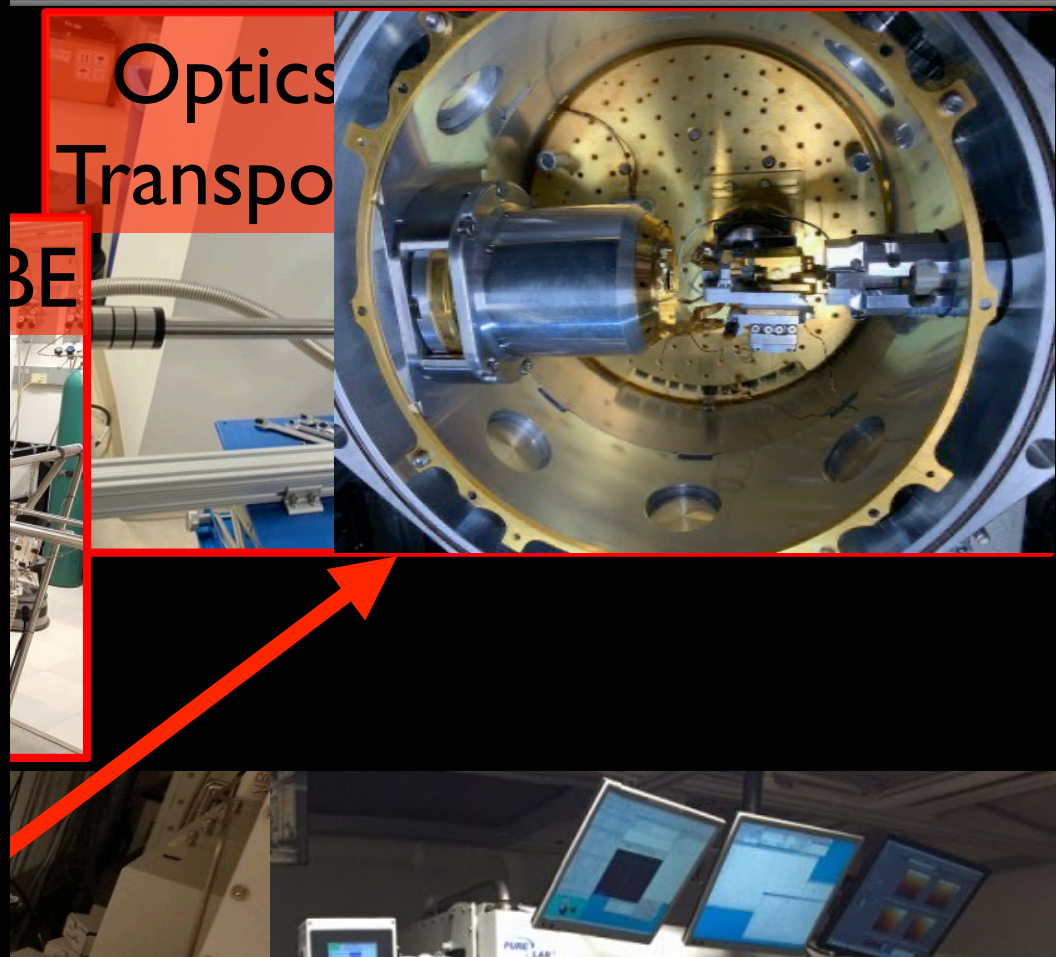
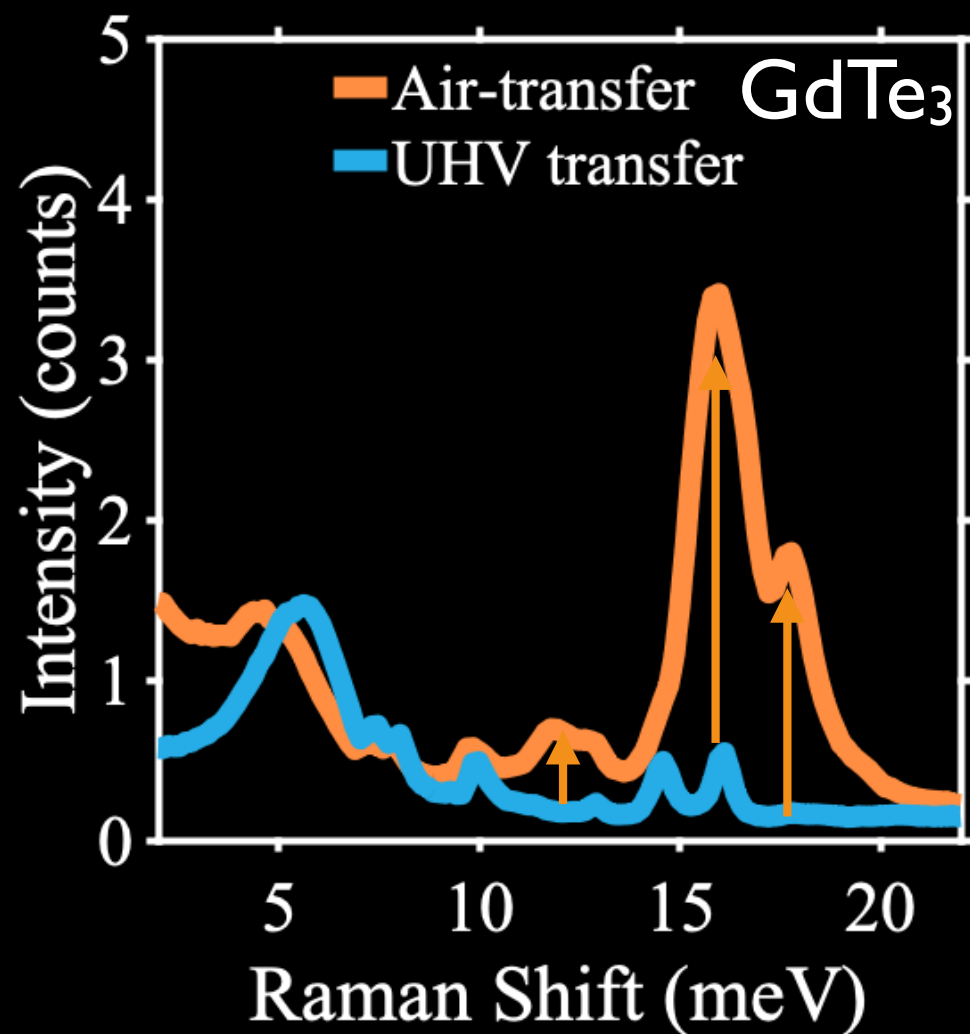


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Other Materials

EuS/RuCl₃

3.3eV/6.1eV

EuS/RuCl₃

3.3eV/6.1eV

$$\rho_{EuS} = 1.9 \times 10^{-2} \Omega \text{ cm}$$

EuS/RuCl₃

3.3eV/6.1eV

$$\rho_{EuS} = 1.9 \times 10^{-2} \, \Omega \, cm$$

$$\rho_{EuS/R} = 4.5 \times 10^{-6} \, \Omega \, cm$$

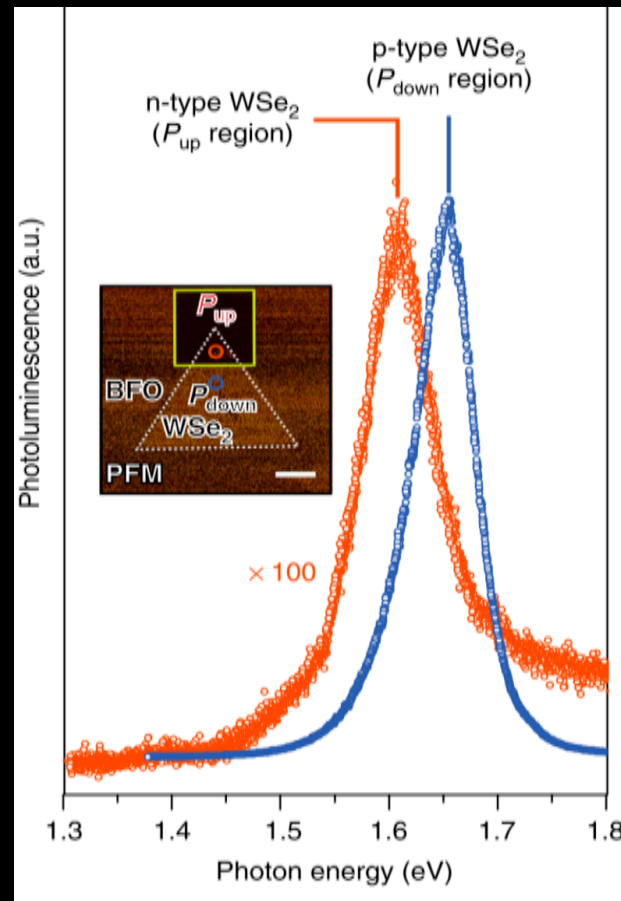
EuS/RuCl₃

3.3 eV/6.1 eV

WSe₂/RuCl₃

$$\rho_{EuS} = 1.9 \times 10^{-2} \Omega \text{ cm}$$

$$\rho_{EuS/R} = 4.5 \times 10^{-6} \Omega \text{ cm}$$



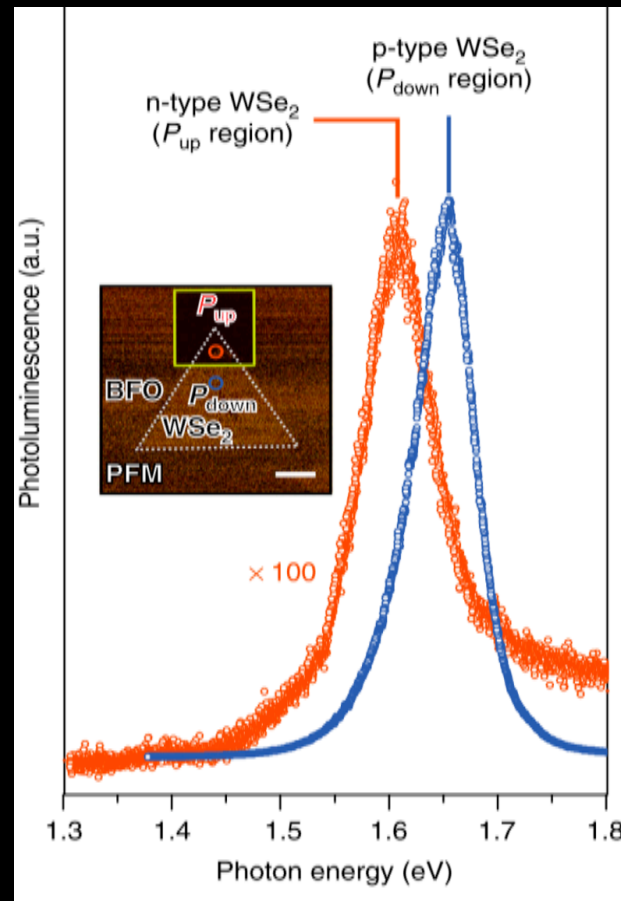
Nat. Comm. 9, 3143 (2018)

EuS/RuCl₃
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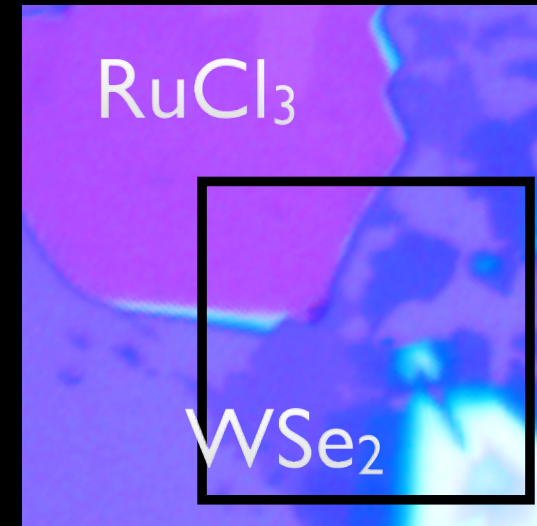
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WSe₂/RuCl₃



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Other Materials

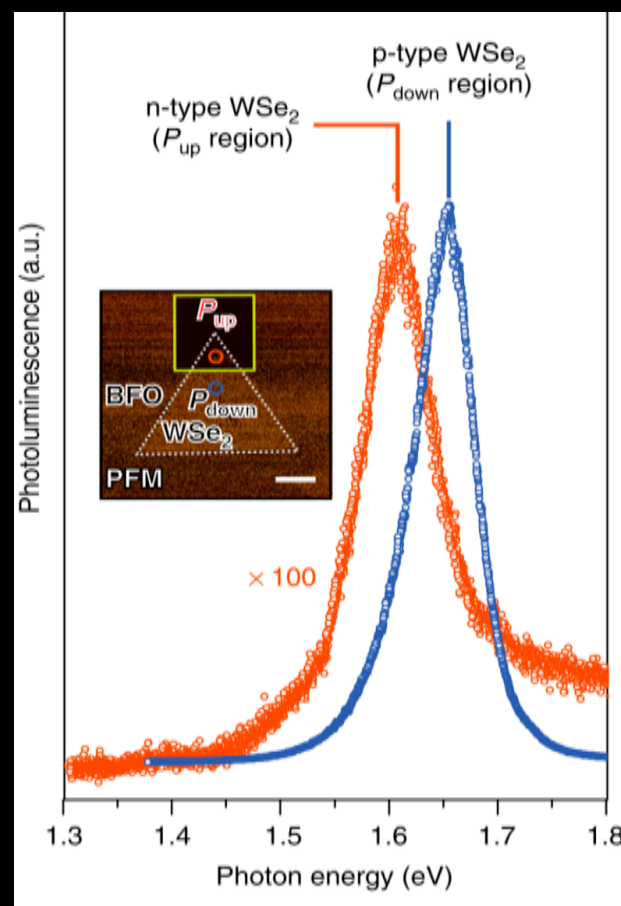
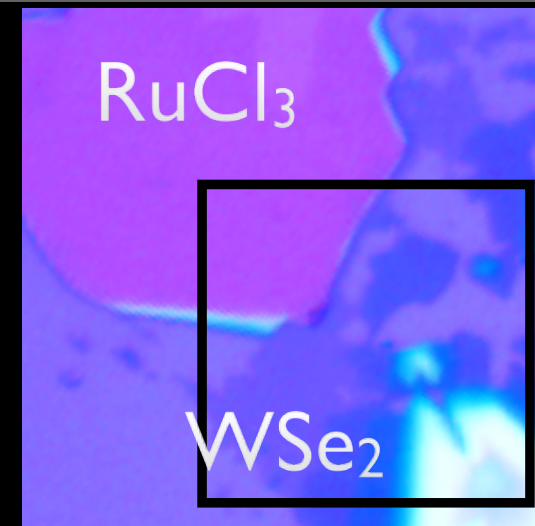
EuS/RuCl₃

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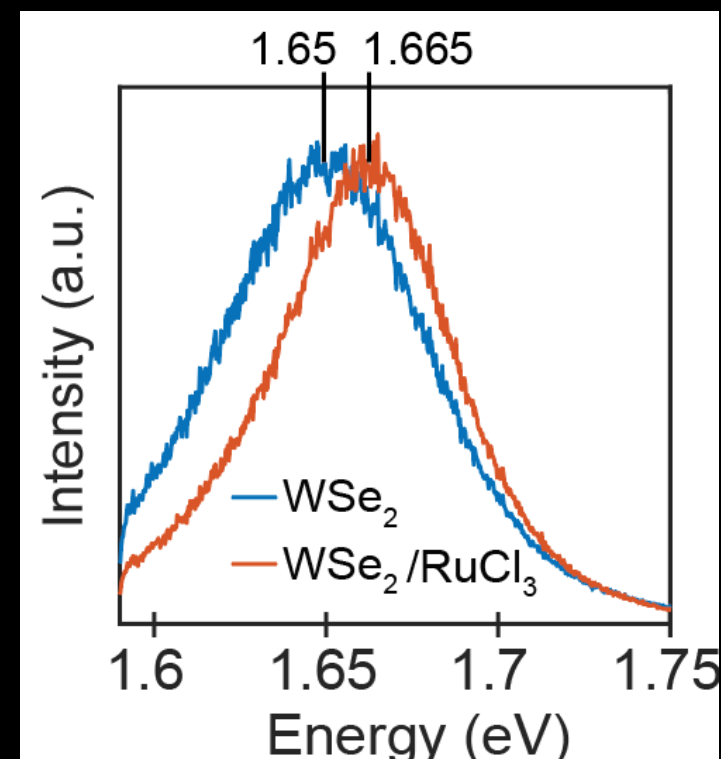
$$\rho_{EuS} = 1.9 \times 10^{-2} \Omega \text{ cm}$$

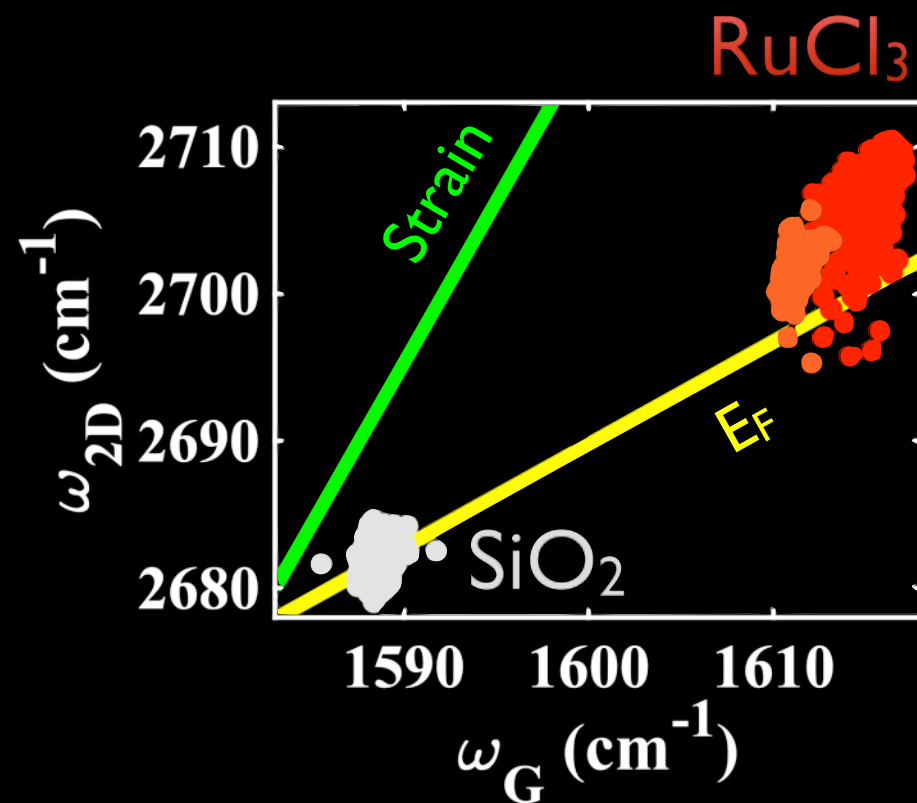
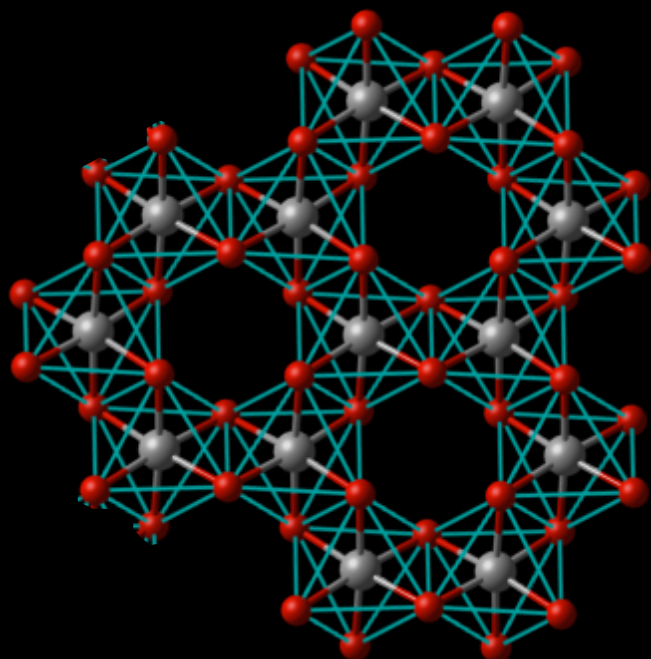
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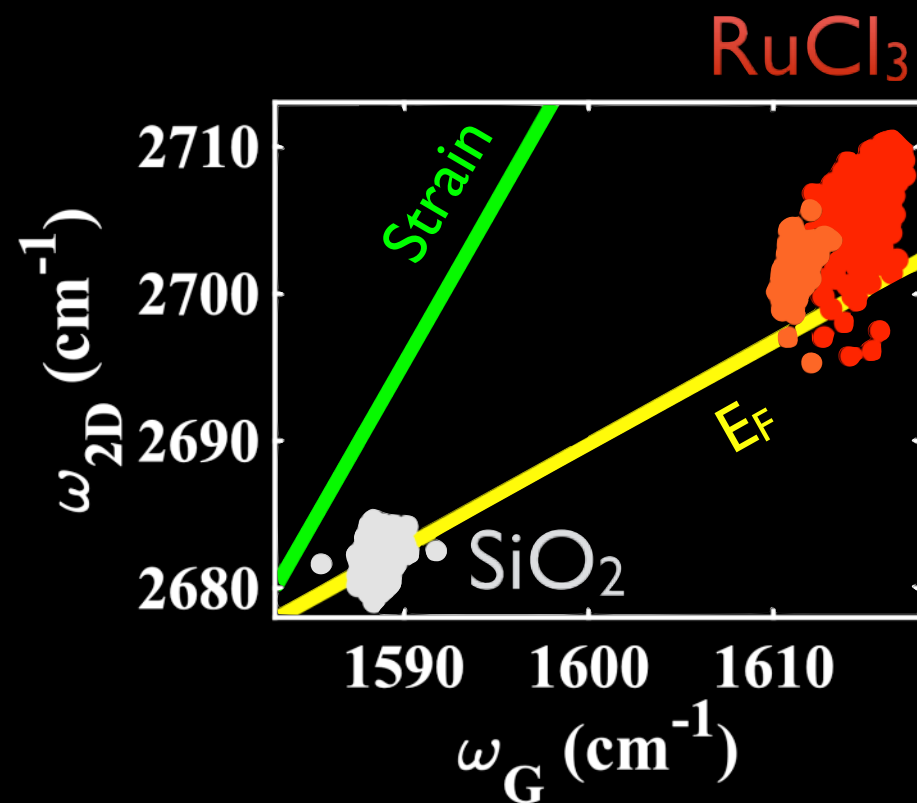
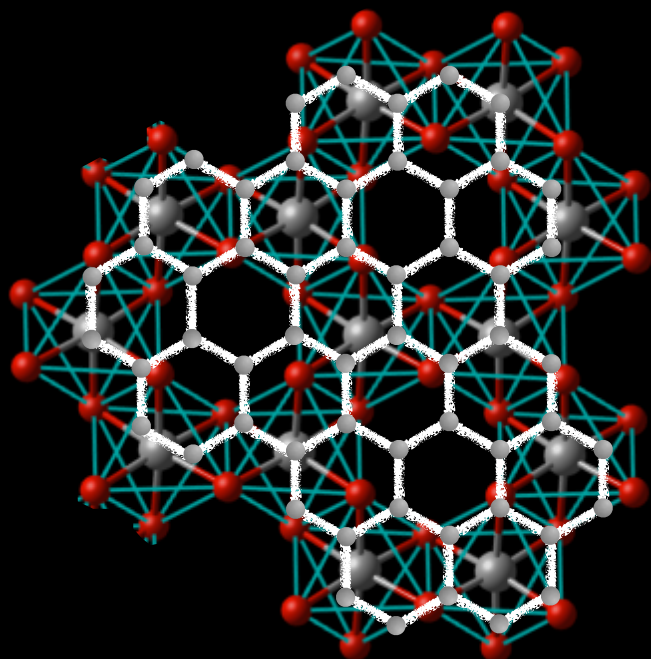
WSe₂/RuCl₃

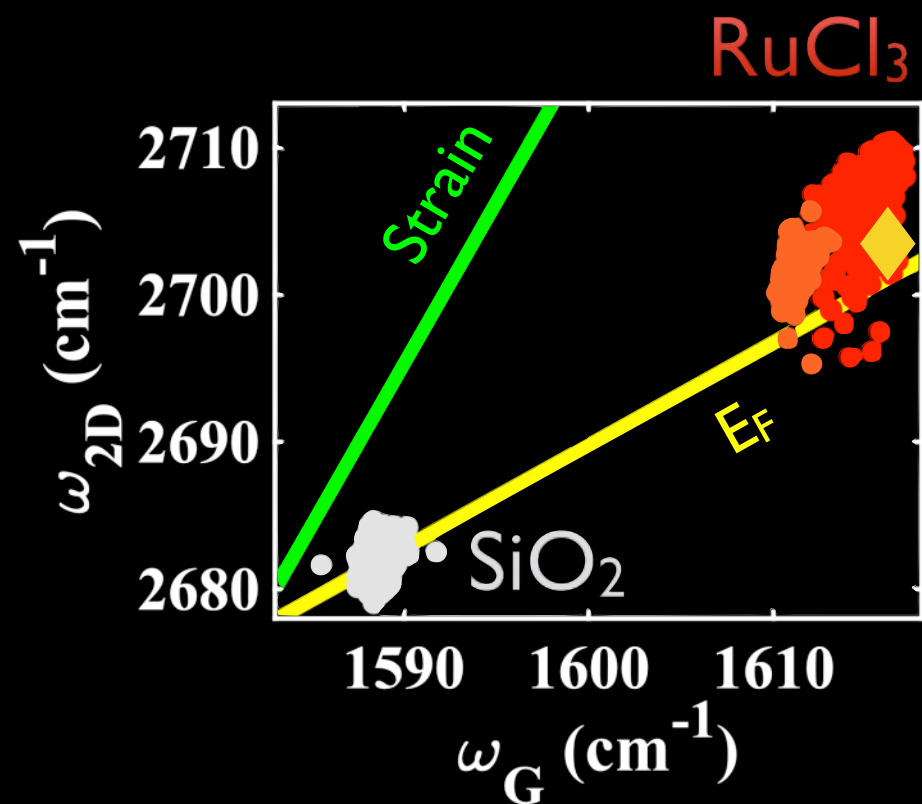
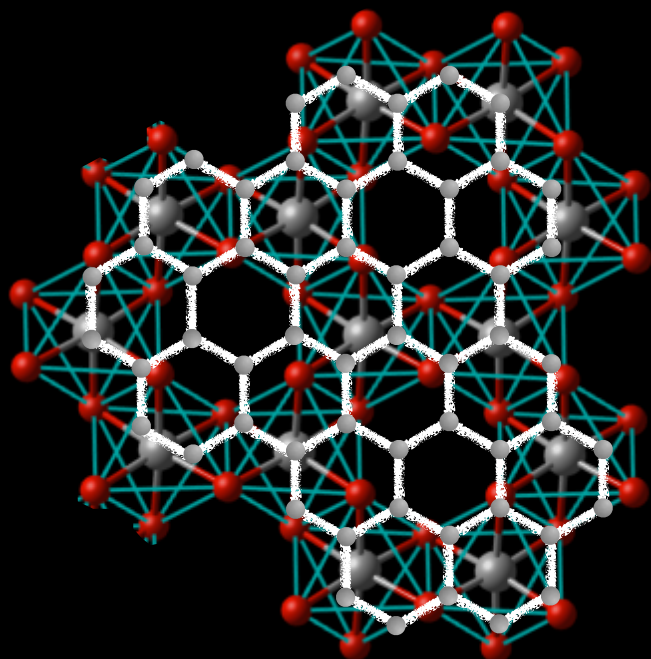


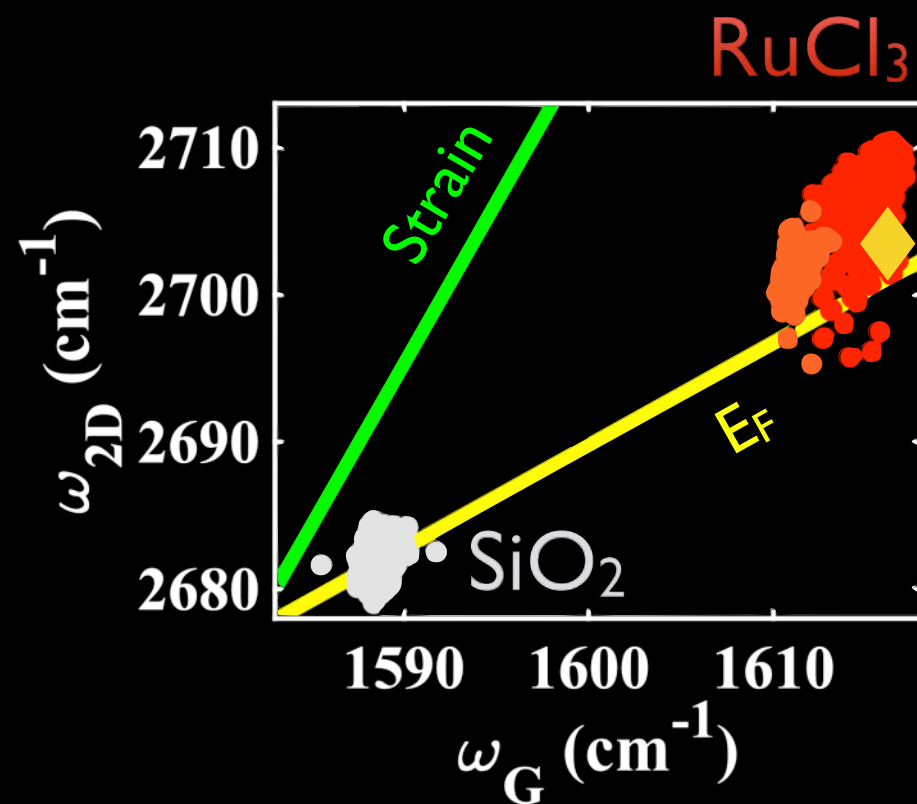
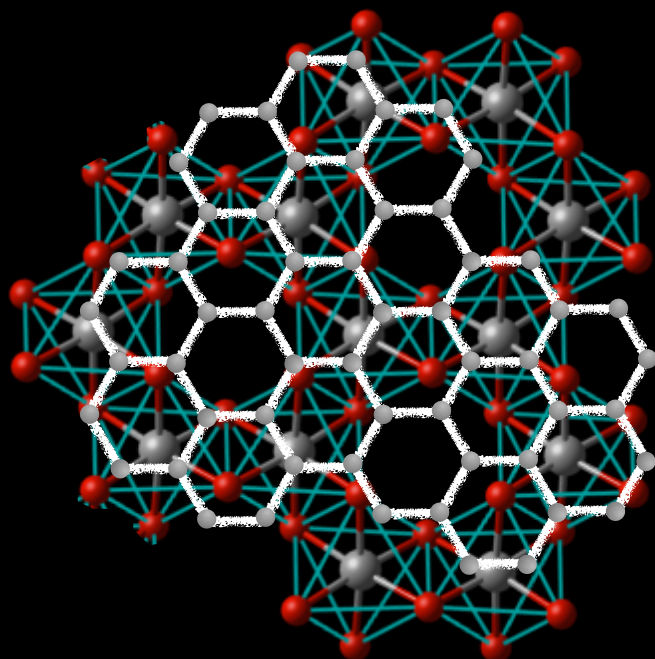
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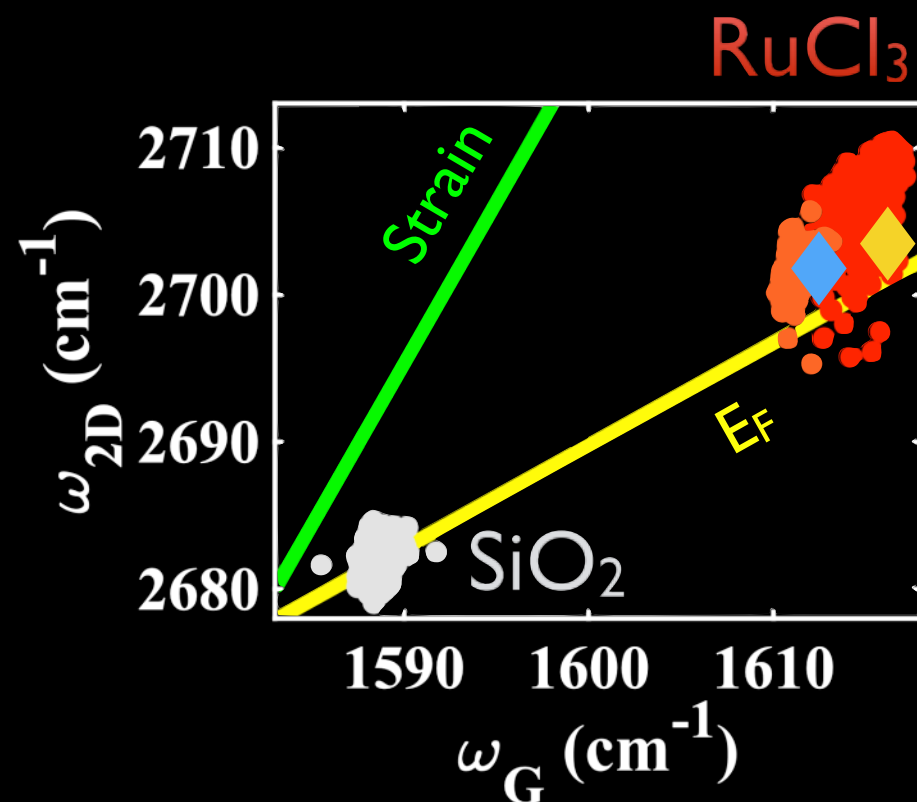
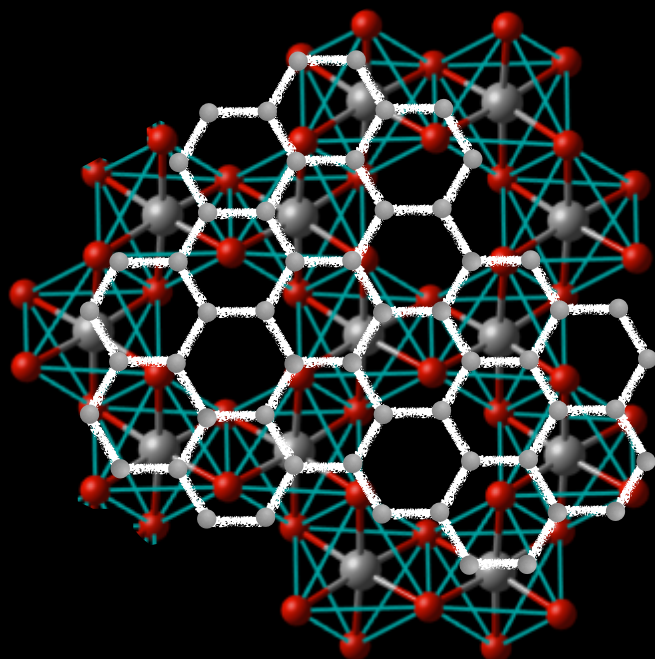












Y. Wang, KSB et al, arXiv:2007.06603



Collaborations?

POSTDOC

OPENING

Acknowledgements

Raman
Y. Wang

Devices:

J. Balgley

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(WUSL)

RuCl₃ Samples

J.-Q. Yan

D. Mandrus
(U.T./ORNL)

hBN (NIMS)

K. Watanabe
T. Taniguchi

Theory:

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X. Lu (WUSL)

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Glovebox

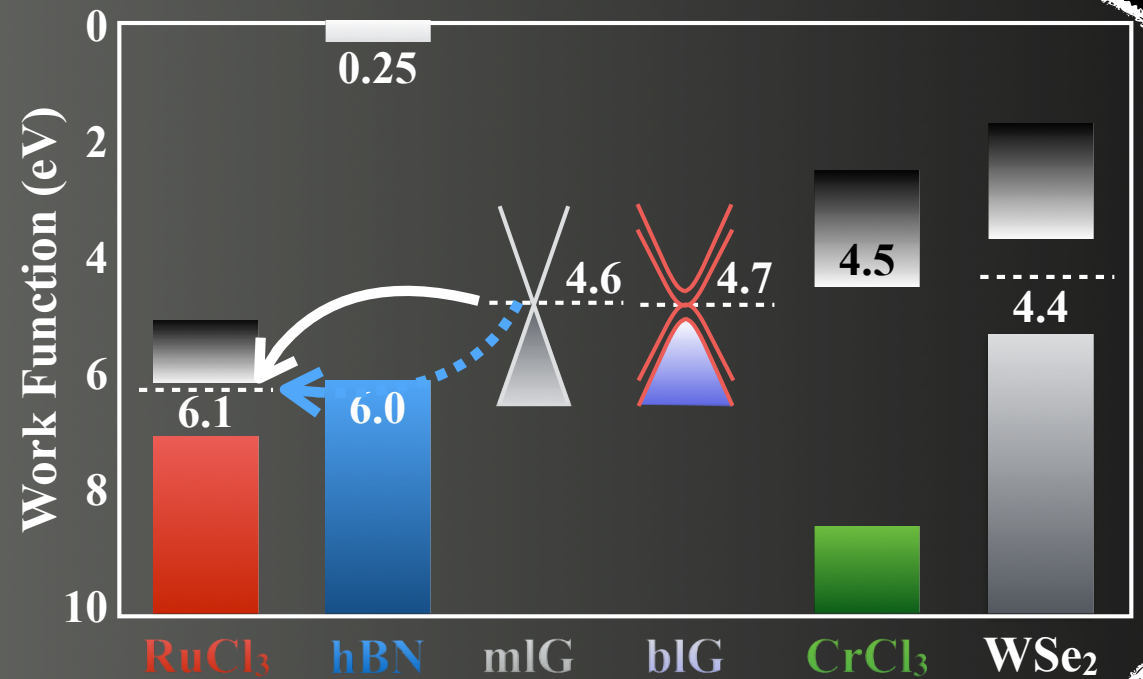
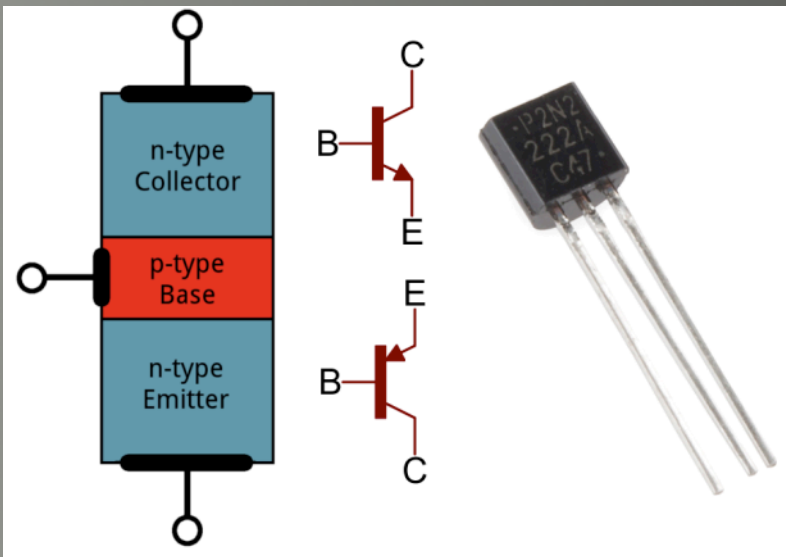
Mason Gray

Narendra Kumar

Erin Sutton (U. Pitt)

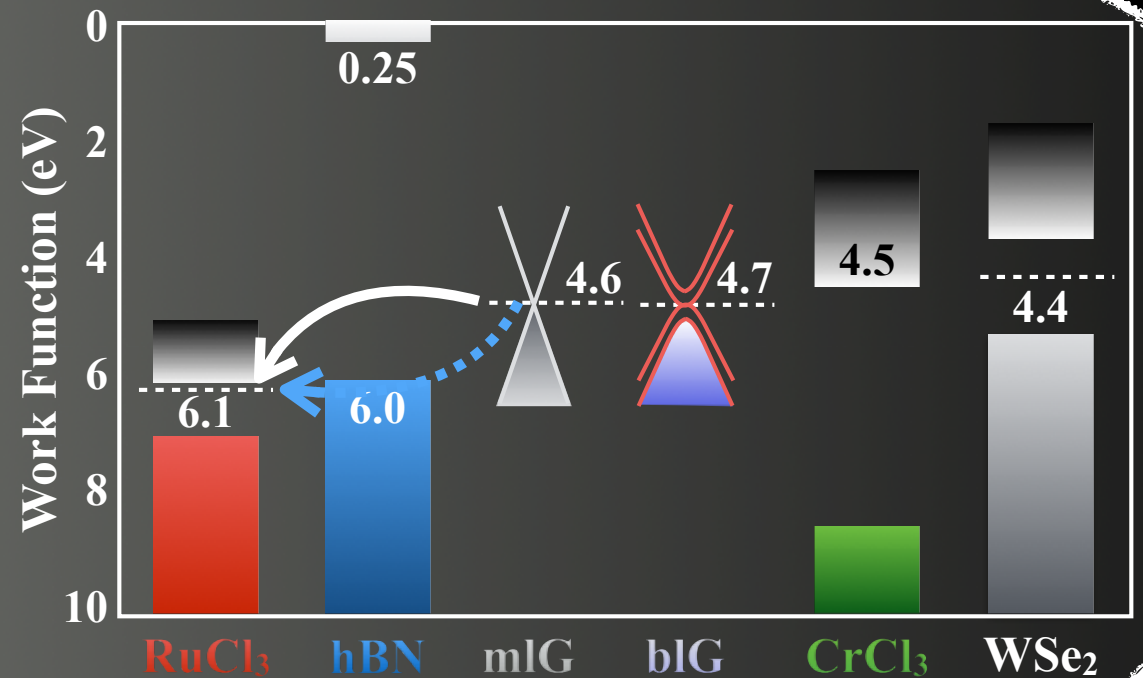
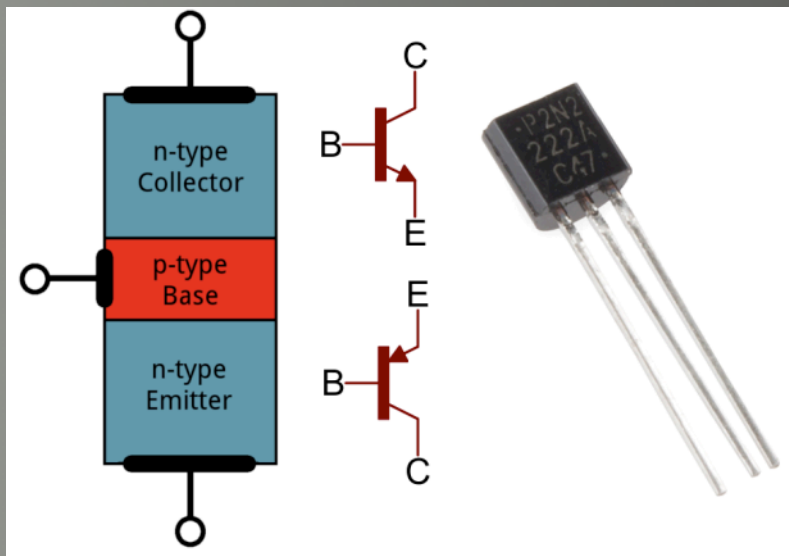
Acknowledgements

Charge

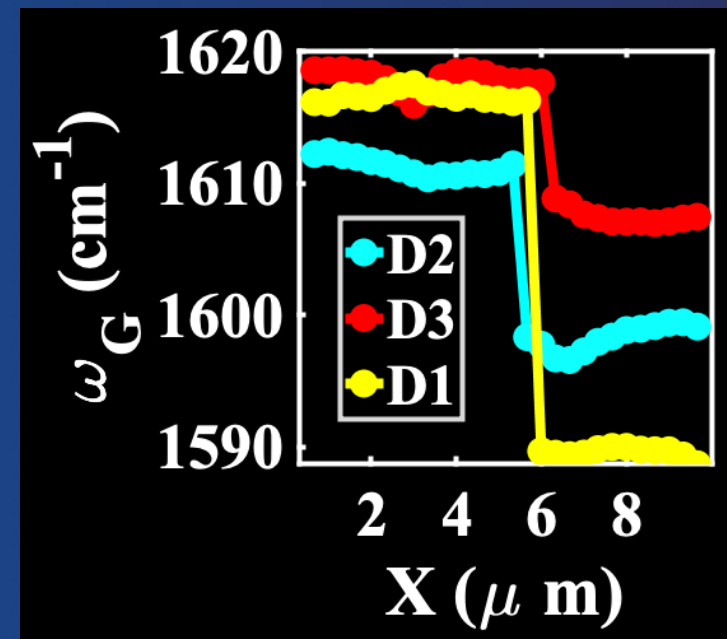
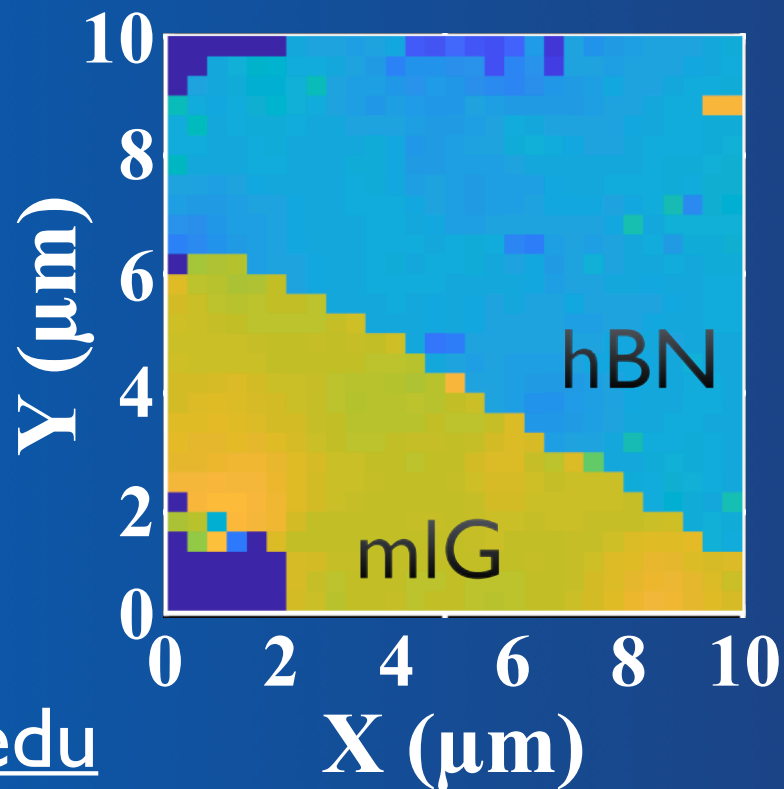
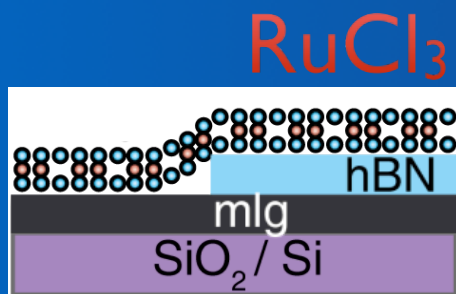


Summary

Charge



Sharp



arXiv:2007.06603

ks.burch@bc.edu