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Optical microscope, Raman spectroscopy, and Photoluminescence measurement in two-dimensional (2D) materials

Youqiang

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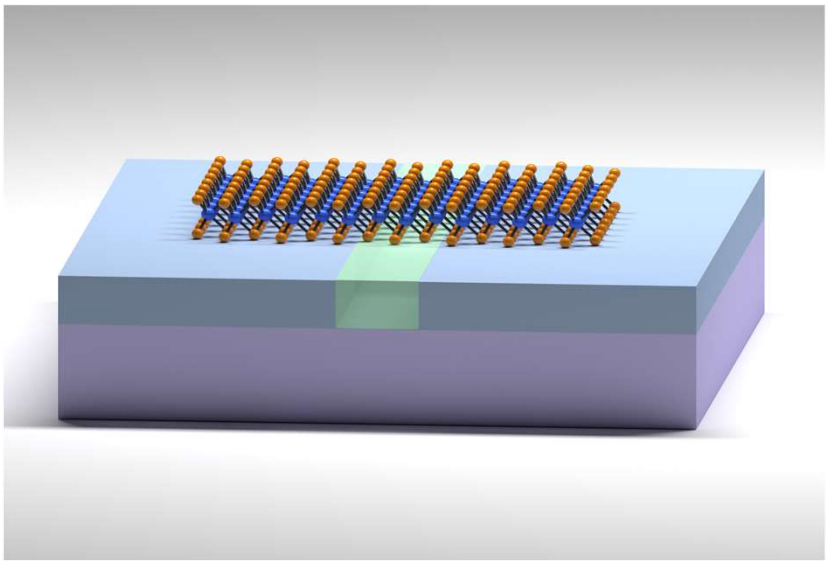
Contents

Theory
- ❑ Optical microscope
- ❑ Raman spectroscopy
- ❑ Photoluminescence measurement

Measurement setup and sources of the uncertainty

No details about principles and equations

But some useful information on how to apply them in 2d materials

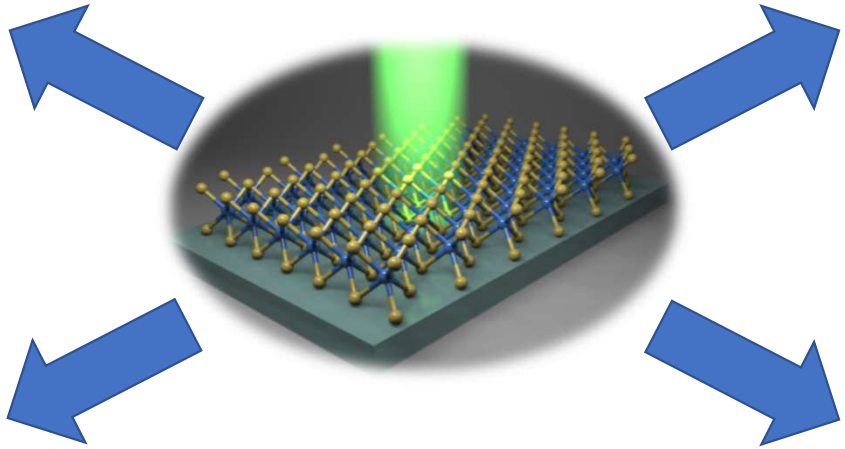


2d materials on a substrate

Background

Emission
- ☆ Photoluminescence
- ☆ Raman spectroscopy
- UV photoelectron spectroscopy

Reflection
- ☆ Optical microscope
- Reflection spectroscopy



Absorption
- Photoconductance
- Photoelectron spectroscopy

Transmission
- Absorption coefficient
- Infrared spectroscopy

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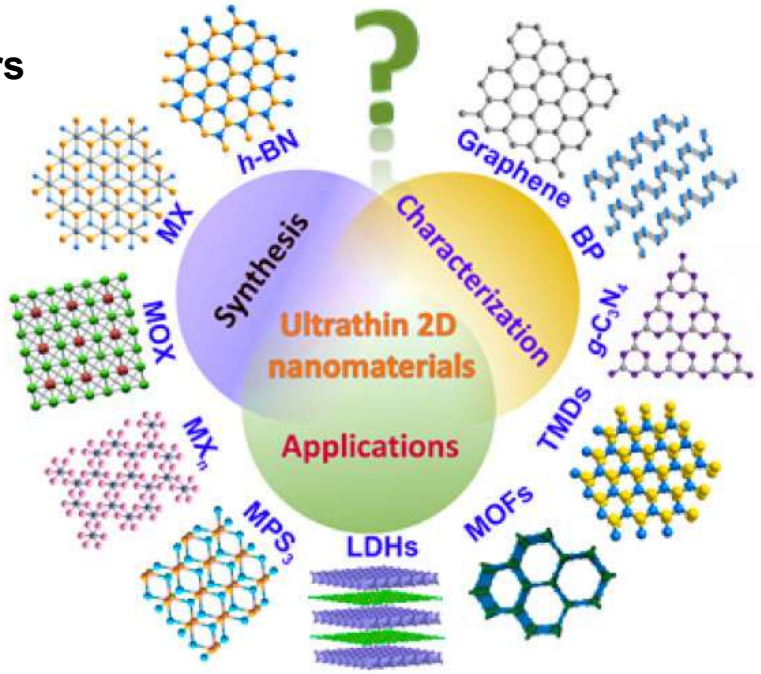
The emerging of the graphene open a new world in materials science

Thickness is only few nanometers

Important!!!

Layer number



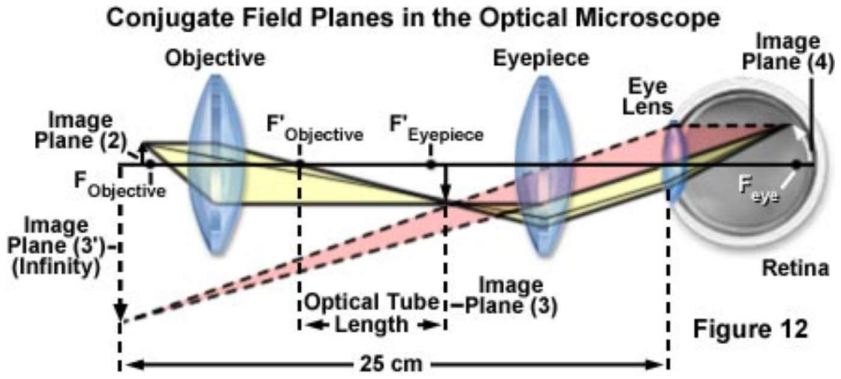
The role of the optical microscope, Raman spectroscopy, and photoluminescence

Lots of examples

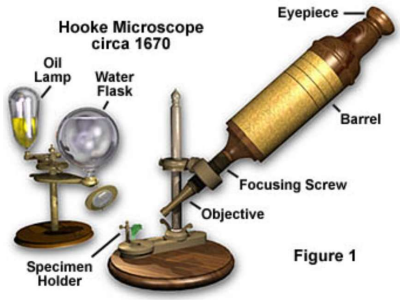
Various groups of 2D materials

Optical microscope

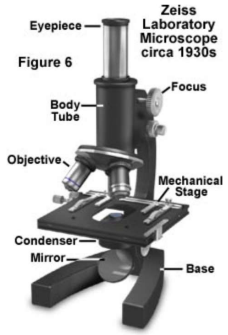
Background-optical microscope



Optical paths



1670



20th century

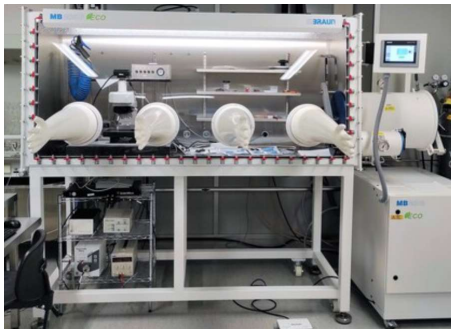
modern

More sophisticated

Background-optical microscope

4th floor

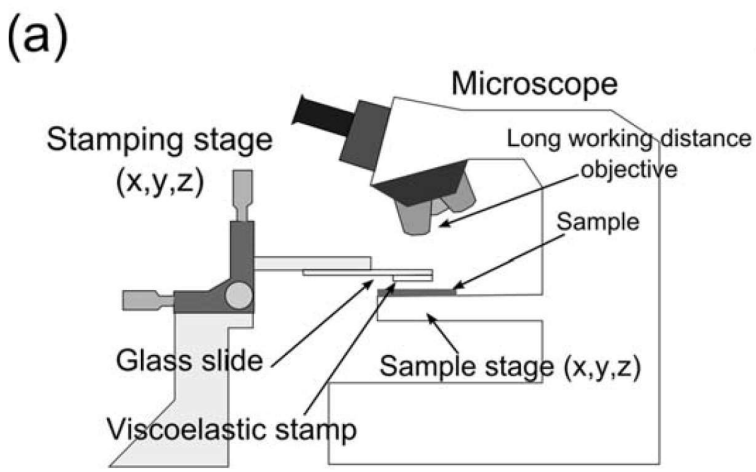
There are several microscopes our group member used



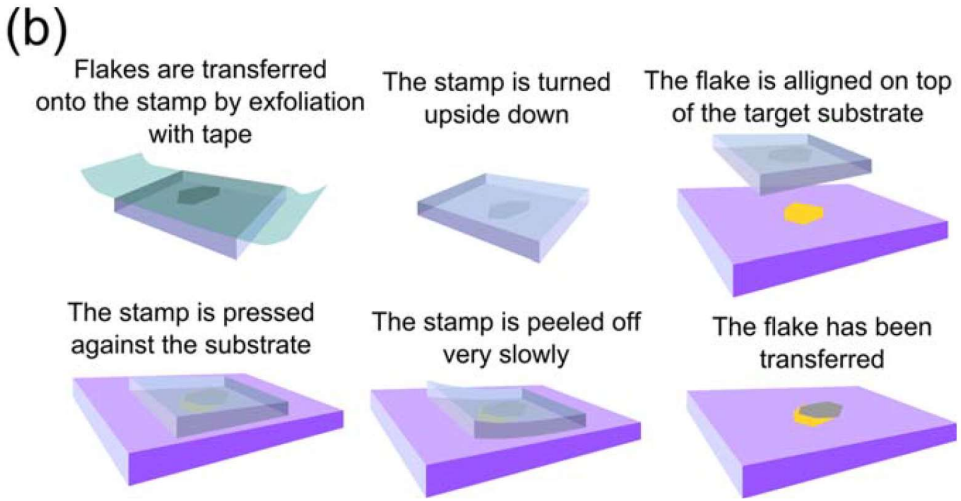
Nanotalo

F13 in the cleanroom

Optical microscope on 2d materials



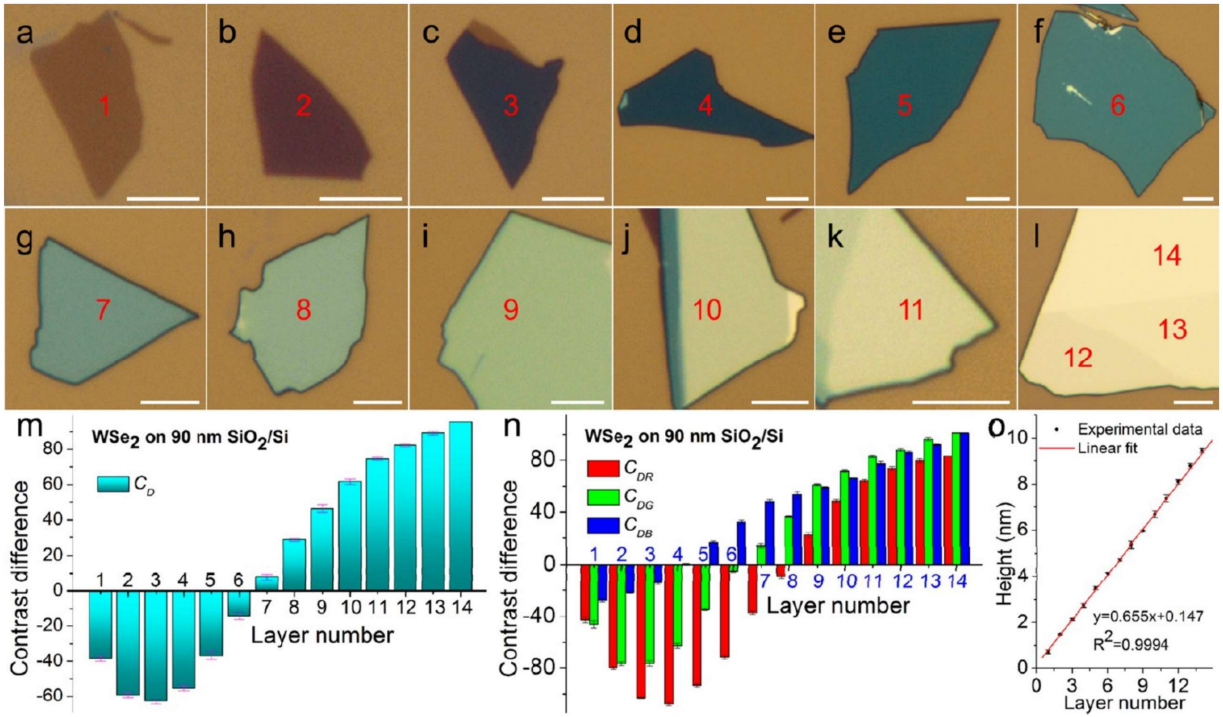
The diagram of the transferring system



The schematic view of exfoliating 2d materials and stacking them

Optical microscope on 2d materials

$$C(\lambda) = \frac{I_{flake} - I_{substrate}}{I_{flake} + I_{substrate}}$$

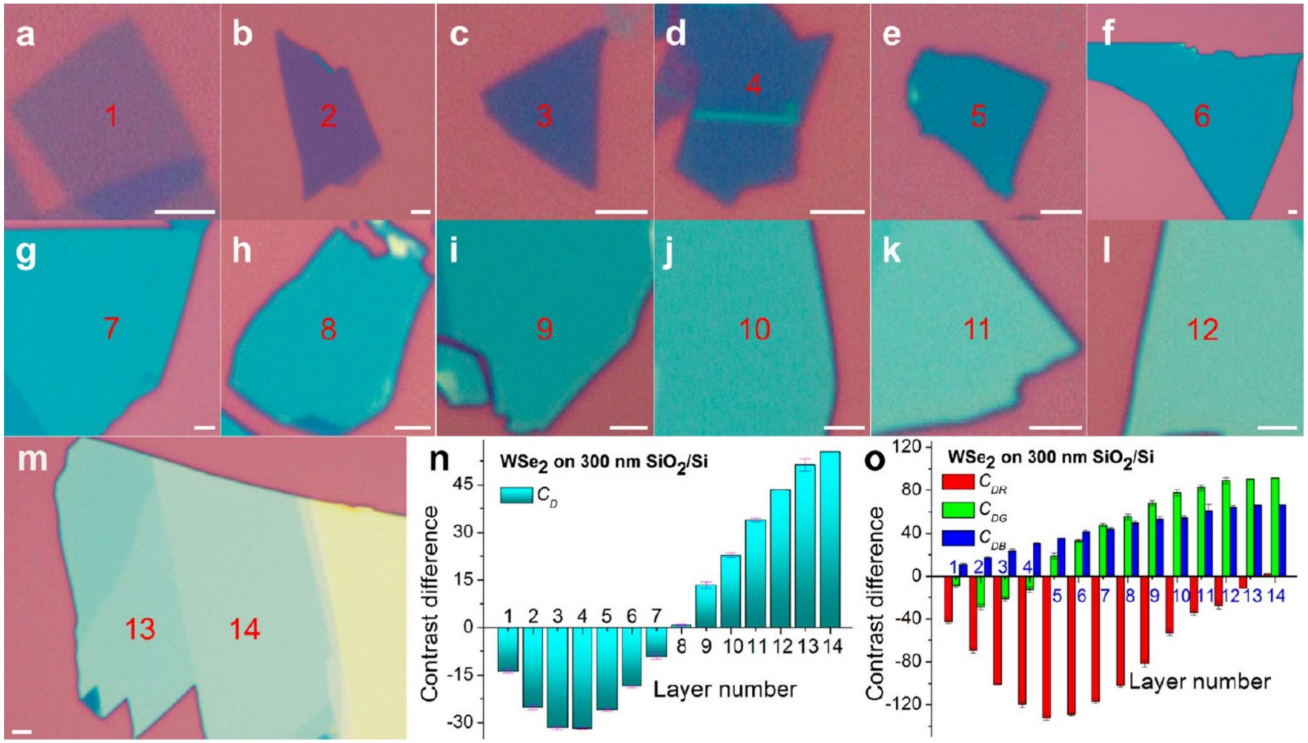


Combining with AFM

A library for quickly identifying the layer number

ACS Nano 2013, 7, 11, 10344−10353

Optical microscope on 2d materials



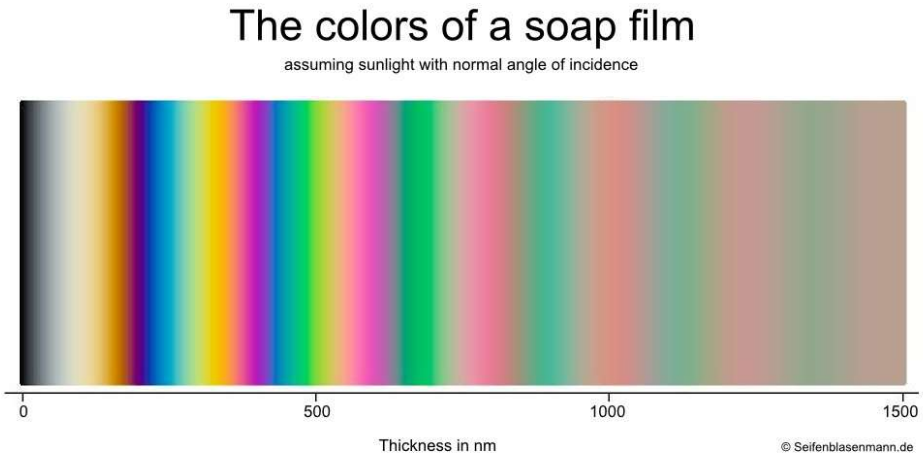
Different substrate
300 nm SiO_2/Si

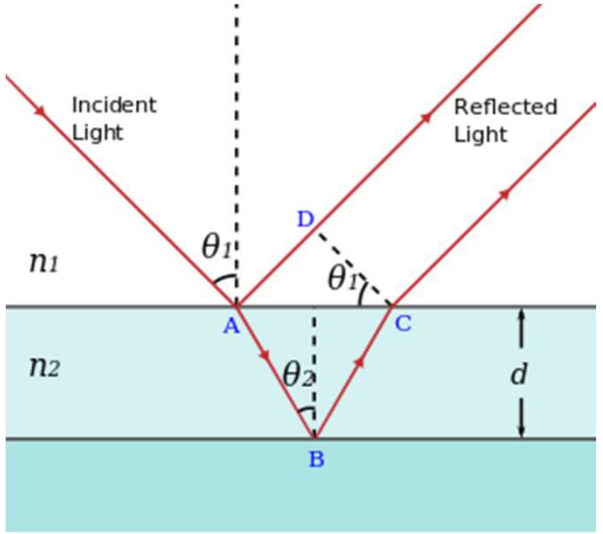
ACS Nano 2013, 7, 11, 10344−10353

Optical microscope on 2d materials

Different thickness with different color

Why?

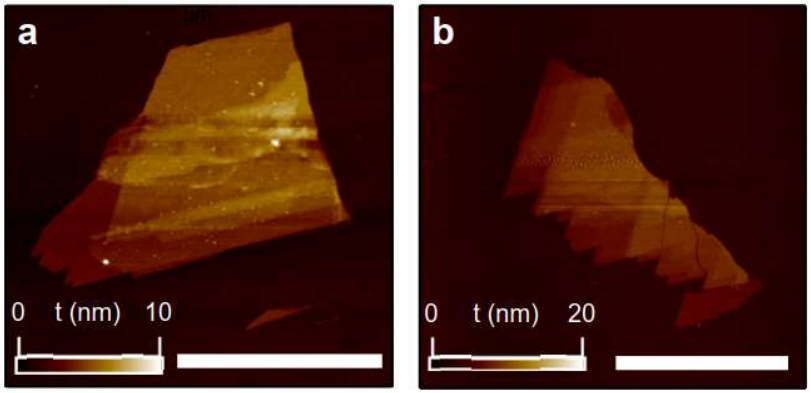


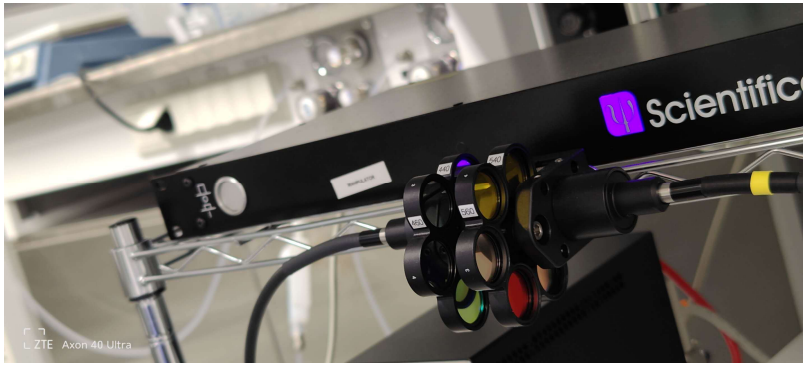


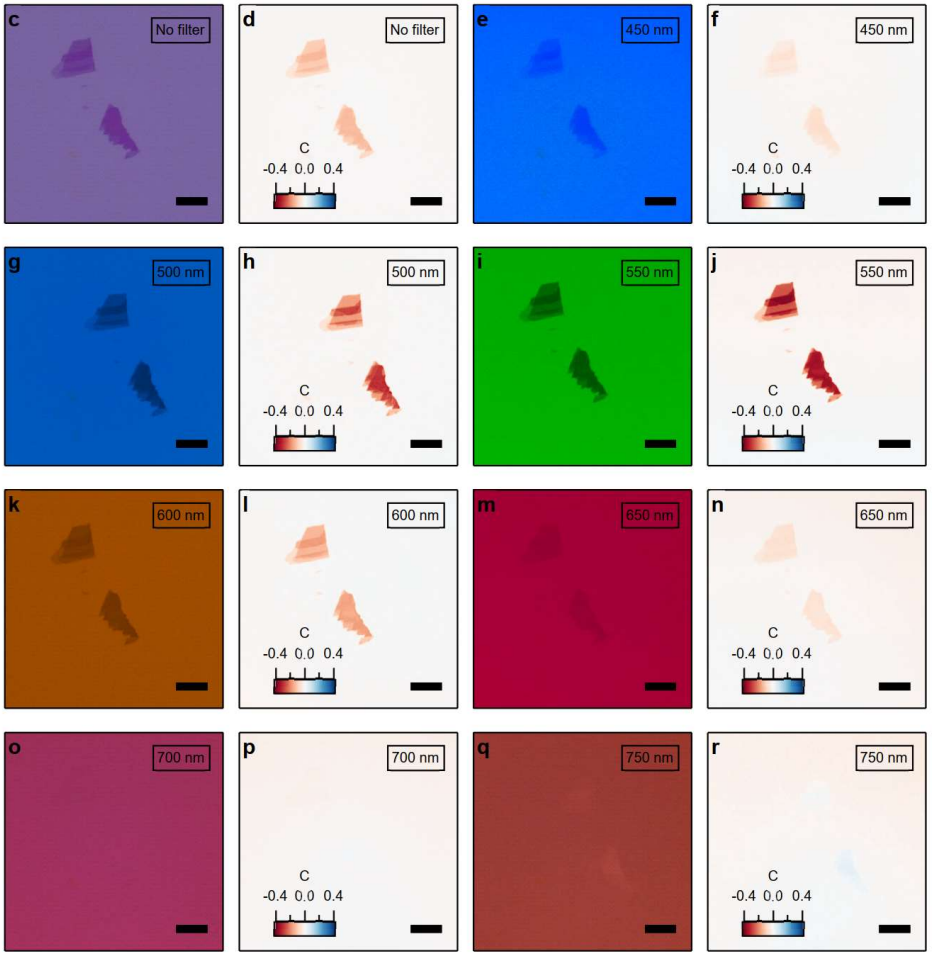
$$2n_2 d\cos\left(\theta_2\right) = m\lambda$$

Thin-film interference

Optical microscope on 2d materials



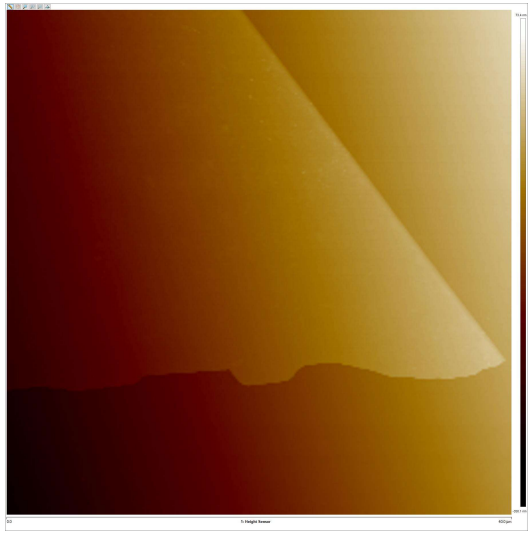




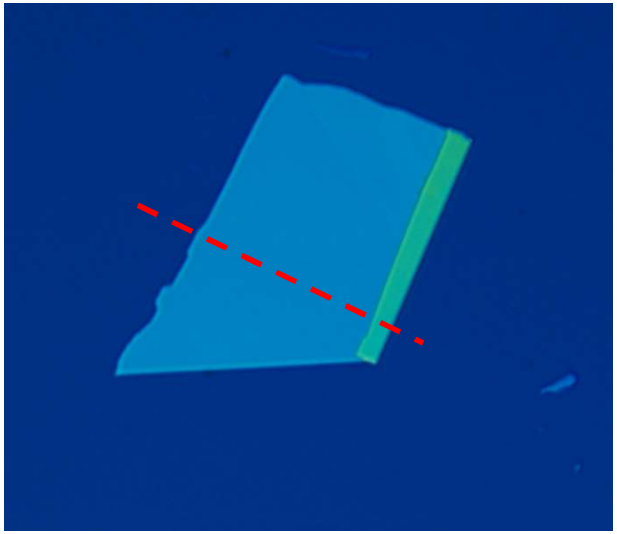
ACS Nano 2021, 15, 7, 11898−11907

TaS_2

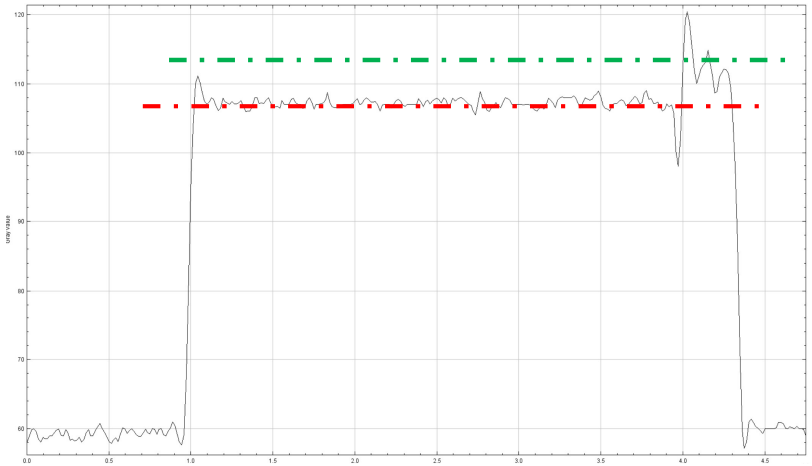
Optical microscope on 2d materials



AFM



Optical images



Optical contrast generated by ImageJ software

Optical microscope on 2d materials

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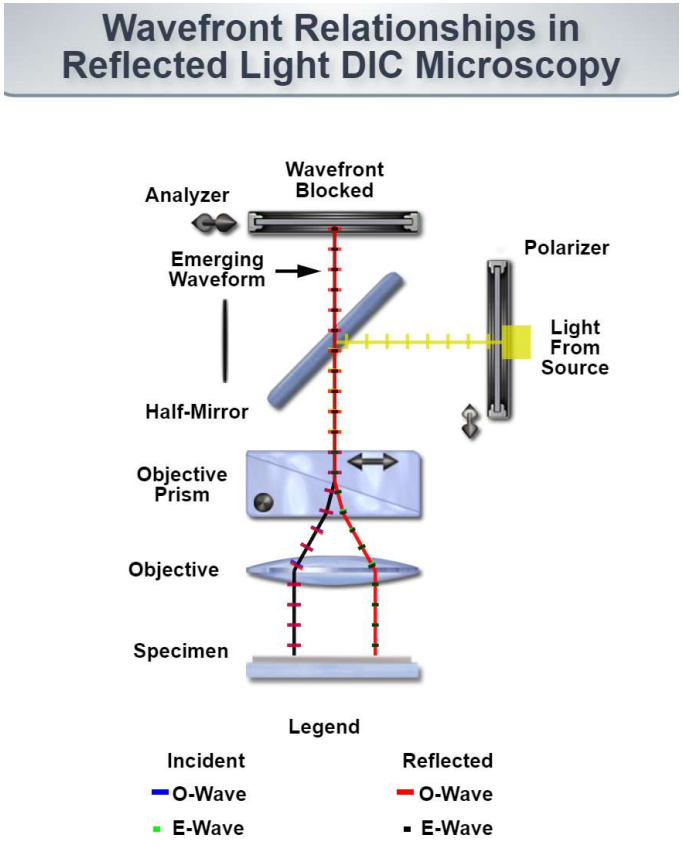
Bubble， cracks can appear during exfoliation.

Bad for the performance of devices

Some can not be found by using a bright field mode optical microscope

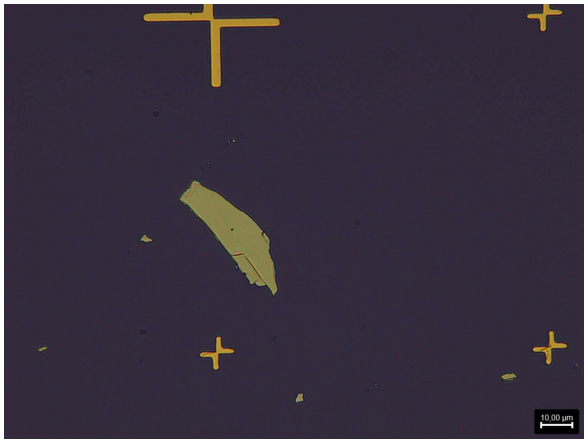
?

Can give the information of hole, bubble, crack…….

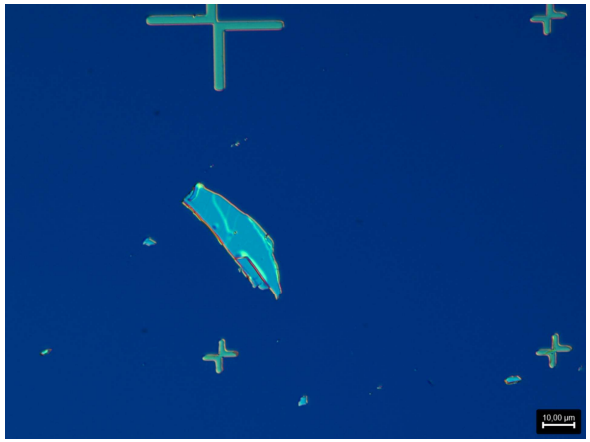


Differential Interference Contrast

Optical microscope on 2d materials



Bright field mode



DIC mode

https://www.microscopyu.com/tutorials/wavefront-relationships-in-reflected-light-dic-microscopy

Raman spectroscopy

Raman spectroscopy on 2d materials

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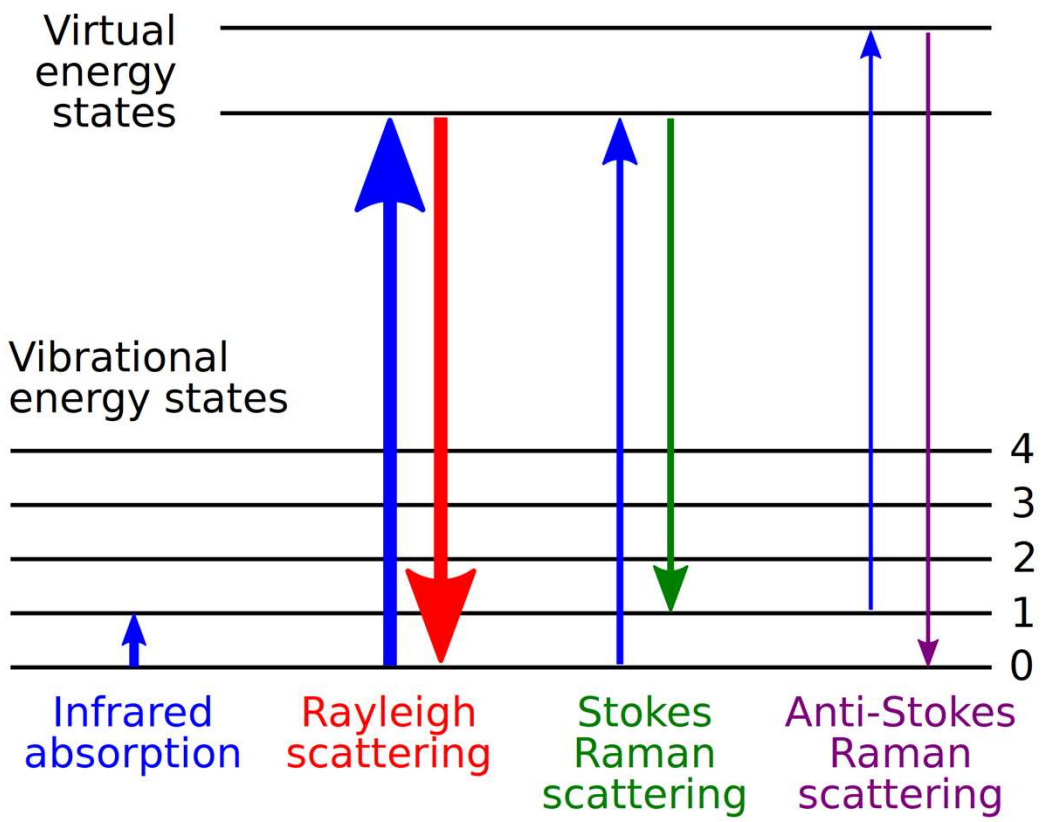
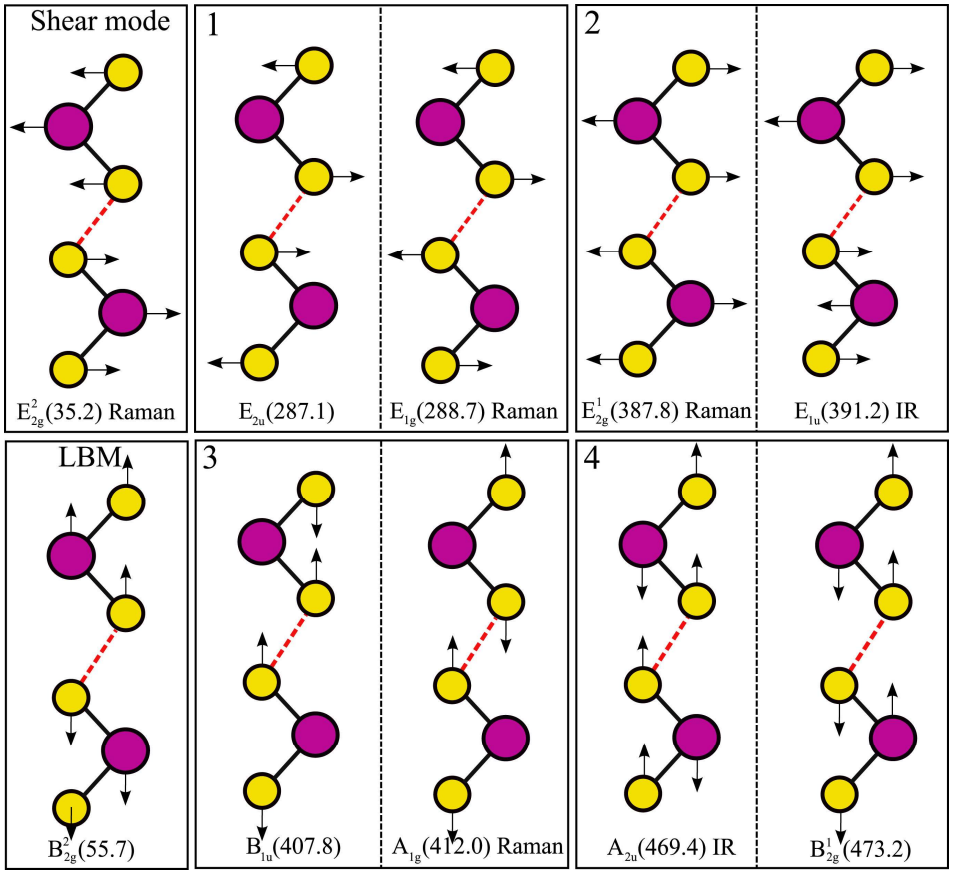
Interaction between light and phonons

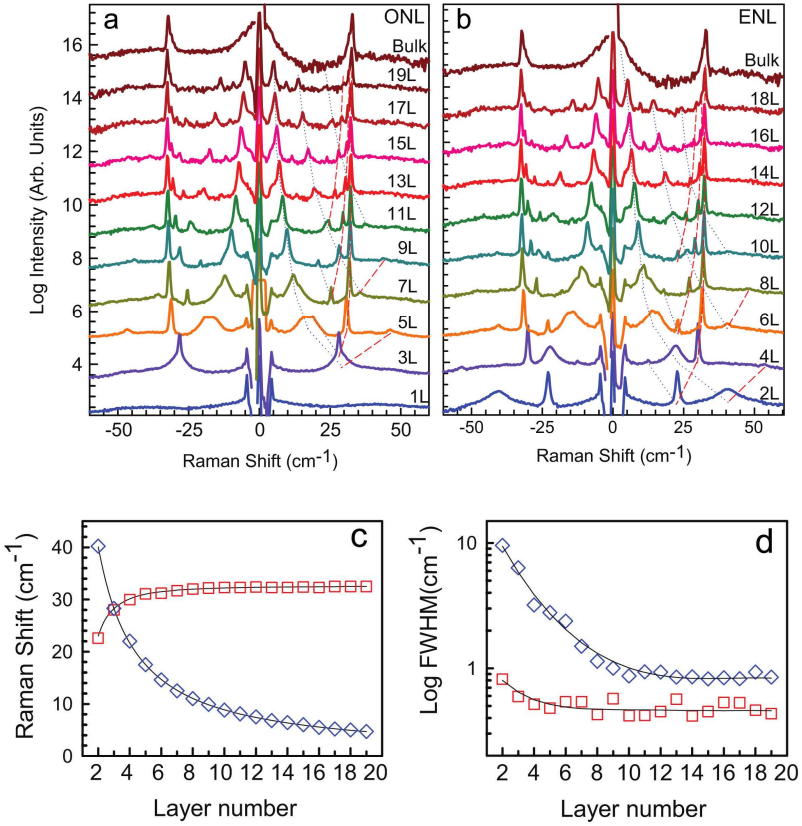


Brief overview of Raman signal

Raman spectroscopy on 2d materials

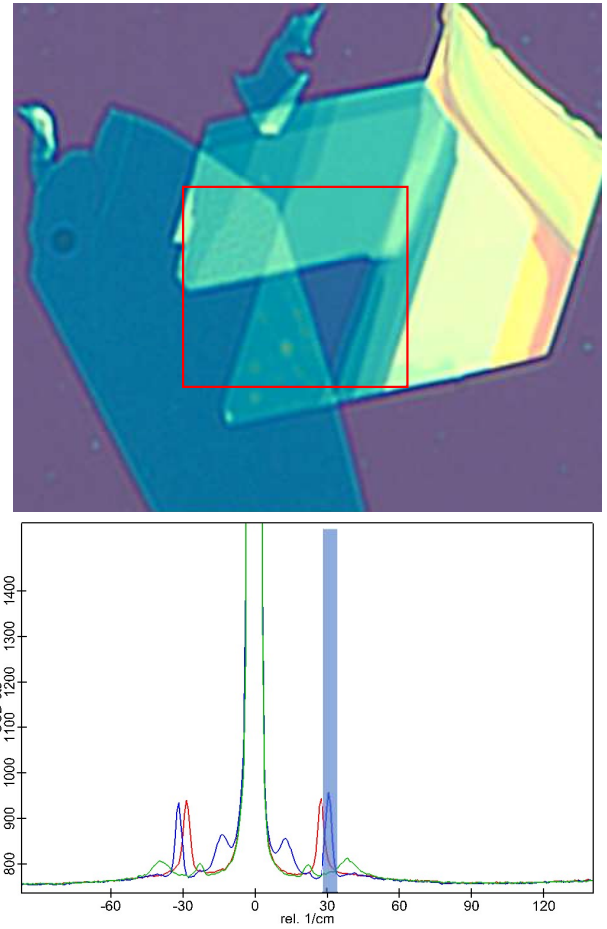


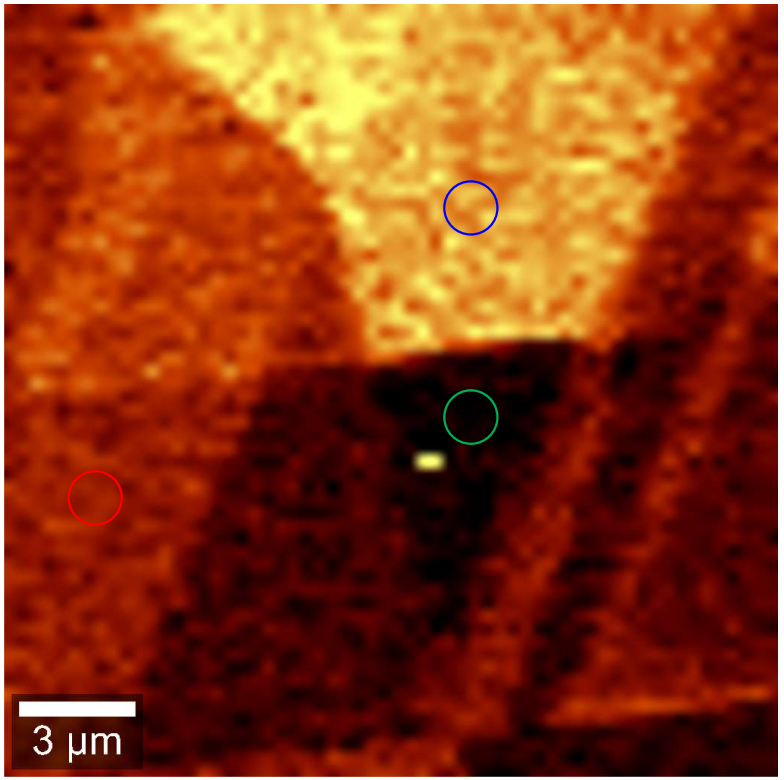
Different phonon modes



https://doi.org/10.1016/j.surfrep.2015.10.001

Raman spectroscopy on 2d materials



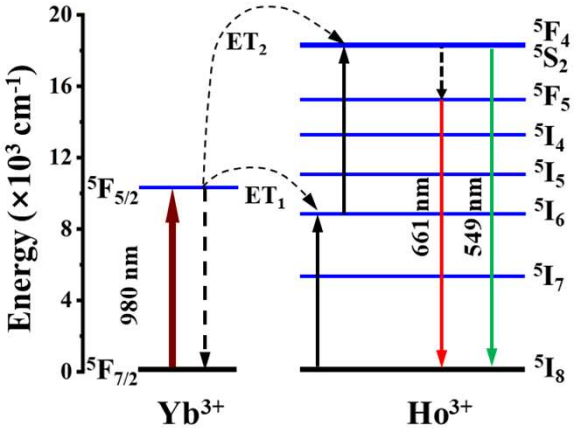


Photoluminescence (PL)

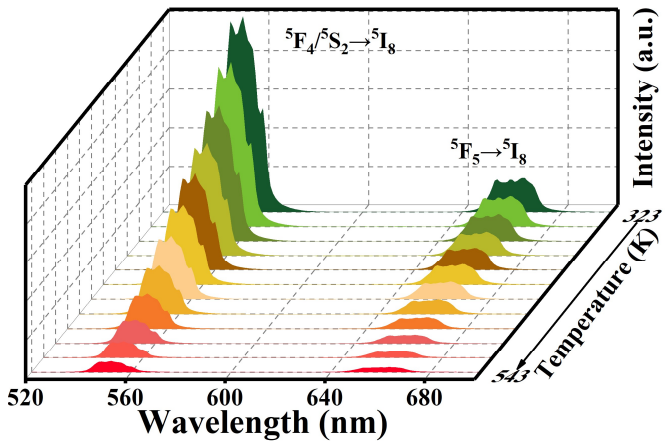
PL measurement

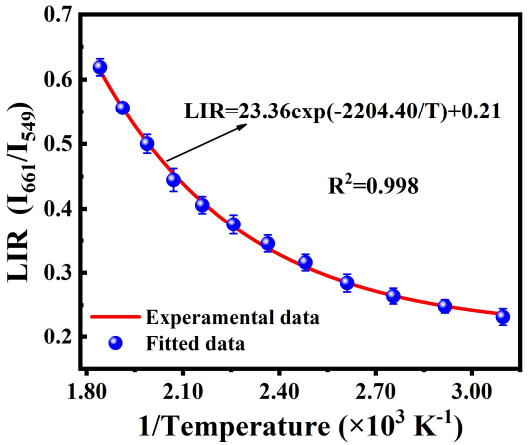
Light excite electrons to a higher energy level in an atom and then go to lower energy and release the energy by emitting photons

Rare earth ions



The pathway of upconversion luminescence
ET—energy transfer

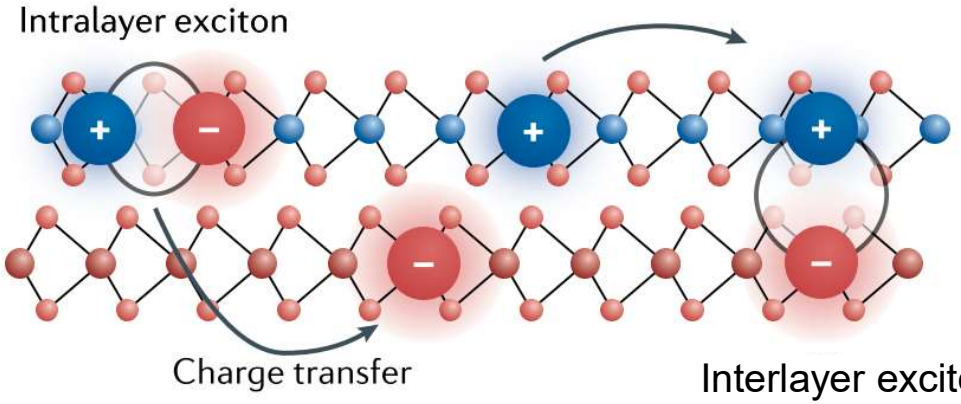


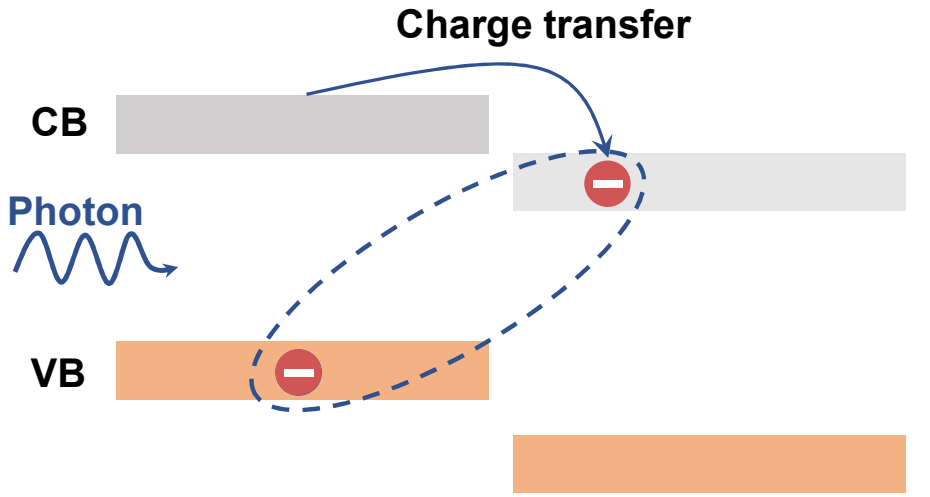


Temperature dependence

PL measurement

An **exciton** is a bound state of an electron and an electron hole which are attracted to each other by the electrostatic Coulomb force. (From Wikipedia)



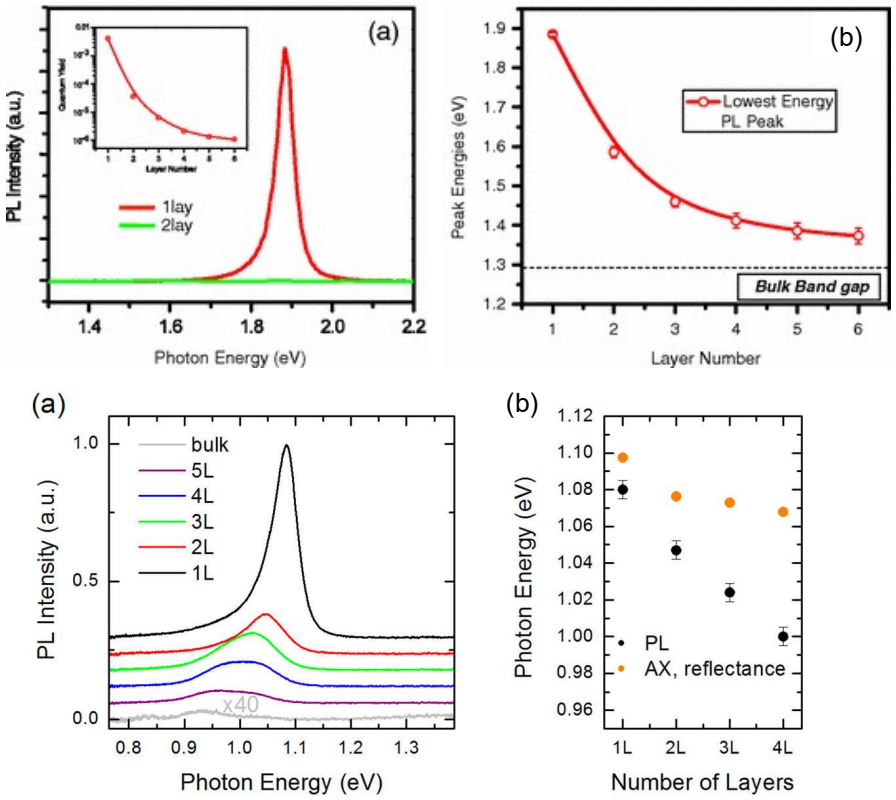


CB——conductive band; VB ——valence band

REF. *Nature Reviews Materials* **volume 7**, pages449–464 (2022)

PL measurement

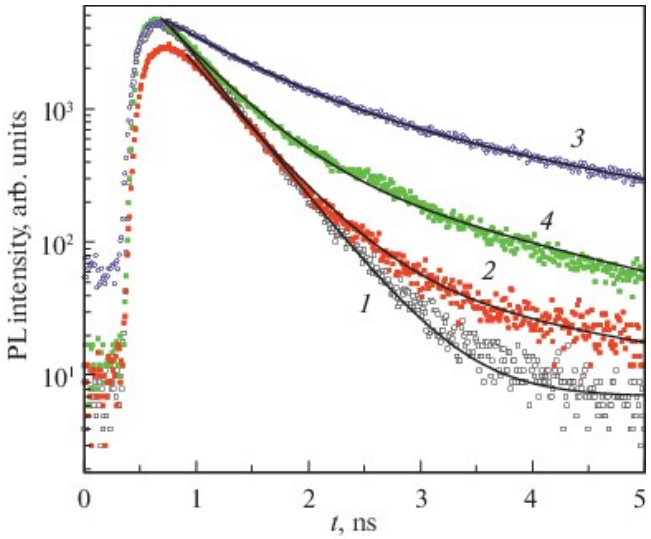
PL identify the layer number



PL measurement

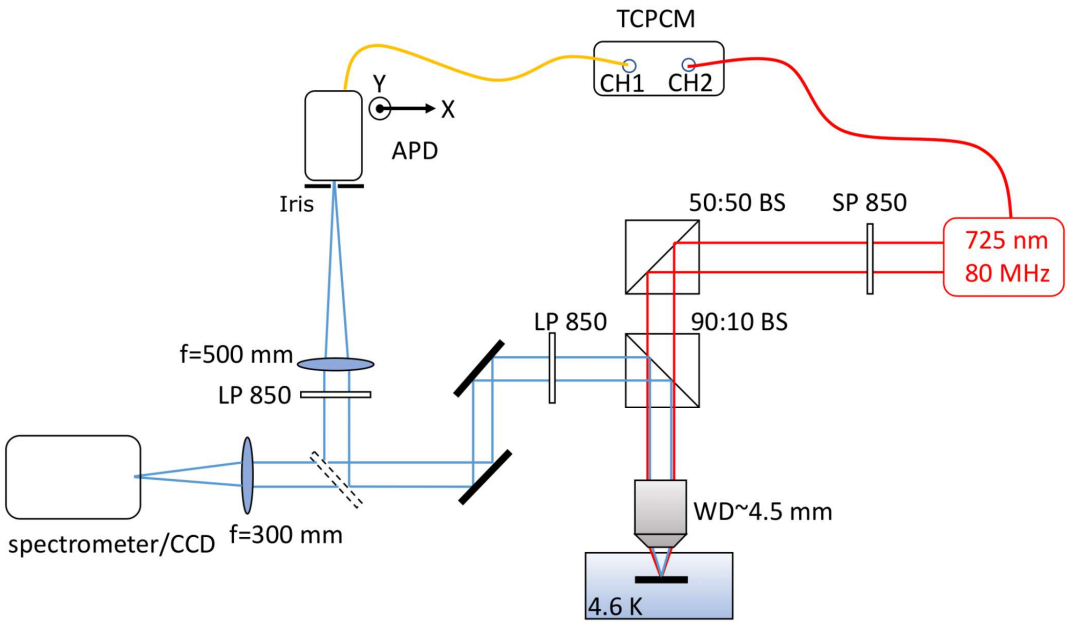
Excitons are demonstrated as a bridge between photons and electrons

How to monitor their behavior like electrons (A, V……)



Time resolved photoluminescence

PL measurement



Sketch of the experimental setup. Red lines: excitation laser; blue lines: reflected laser and emitted photons.

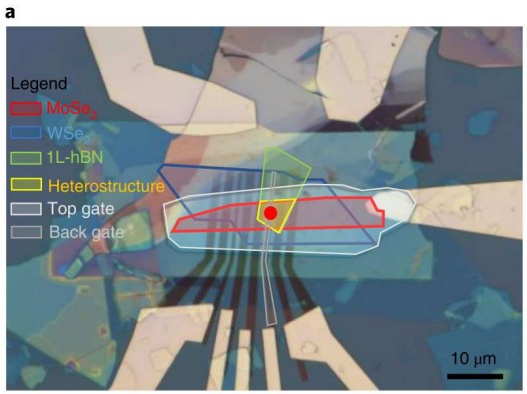
TCPCM-Time correlated photon counting module

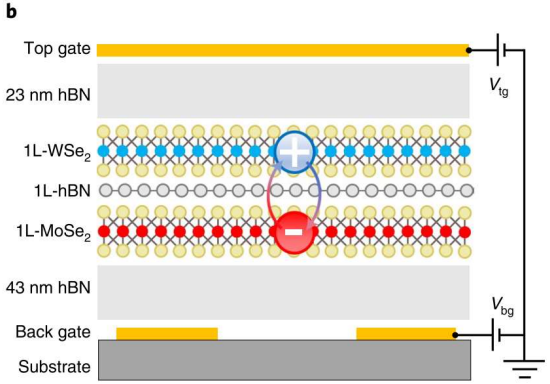
APD-Avalanche photodiode

Nature photonics, 2022, 16(1): 79-85

PL measurement

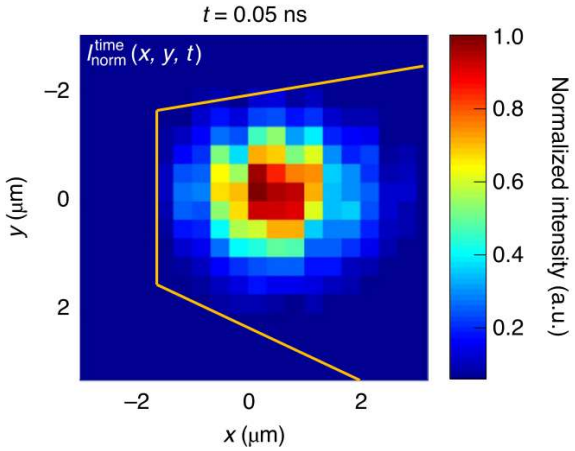
Device structure



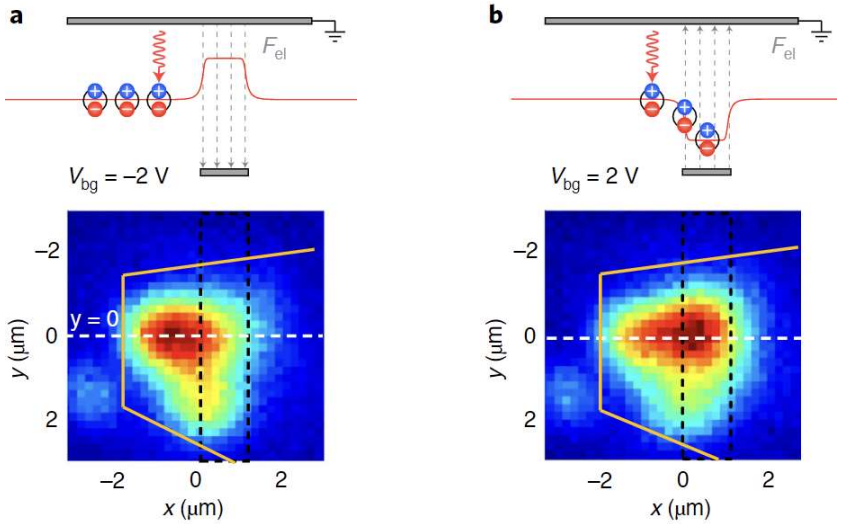


Electron-hole pair recombination

Photoluminescence (PL)



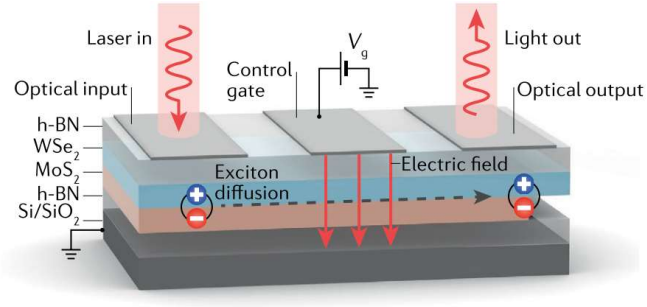
Expansion of an exciton cloud



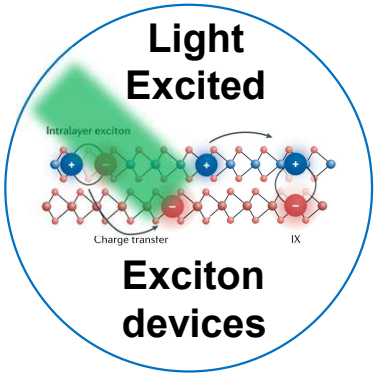
Control of the exciton flux by applying an electric field

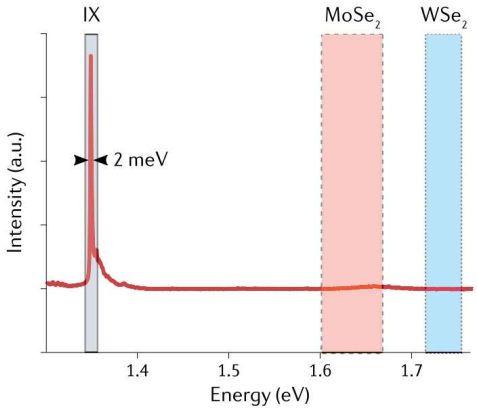
Nature photonics, 2022, 16(1): 79-85

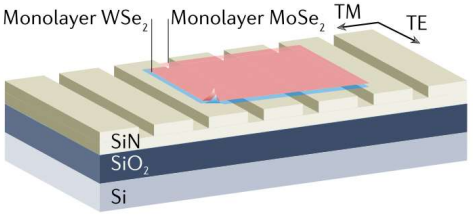
PL measurement



Excitonic Switch and Transistor





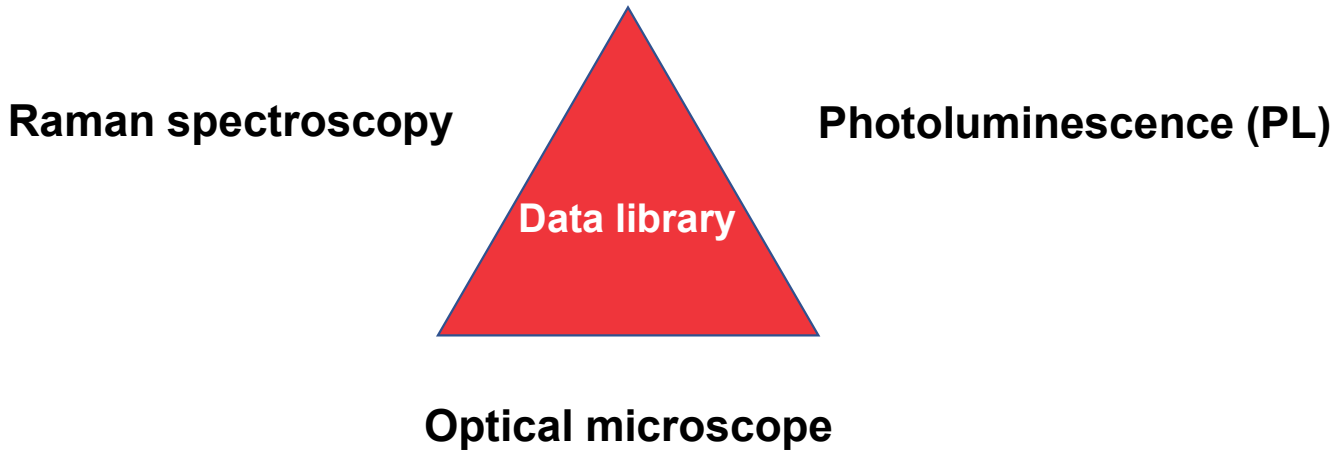


Nanolaser

?

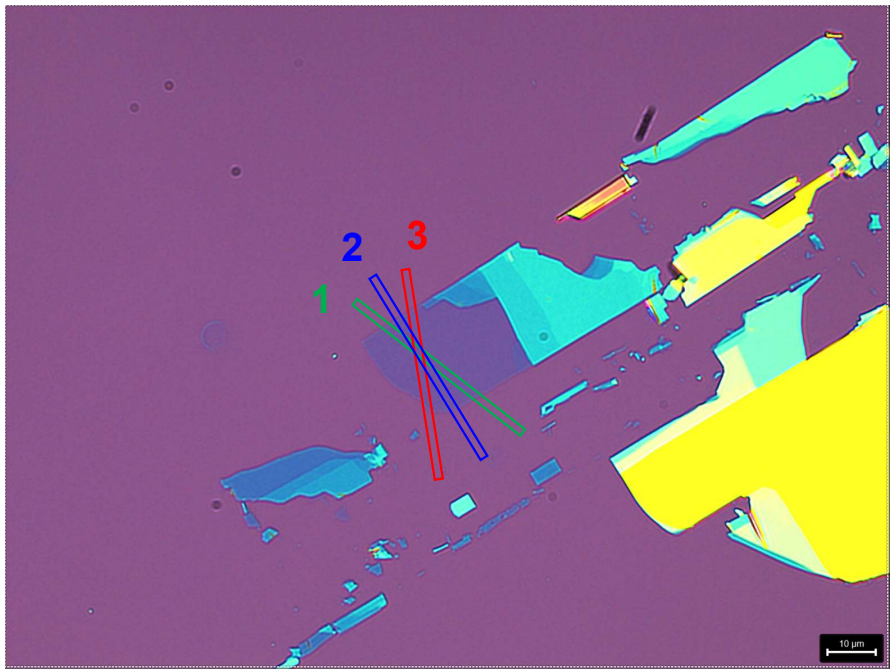
Summary

The layer number of the 2D materials can be characterized by several methods

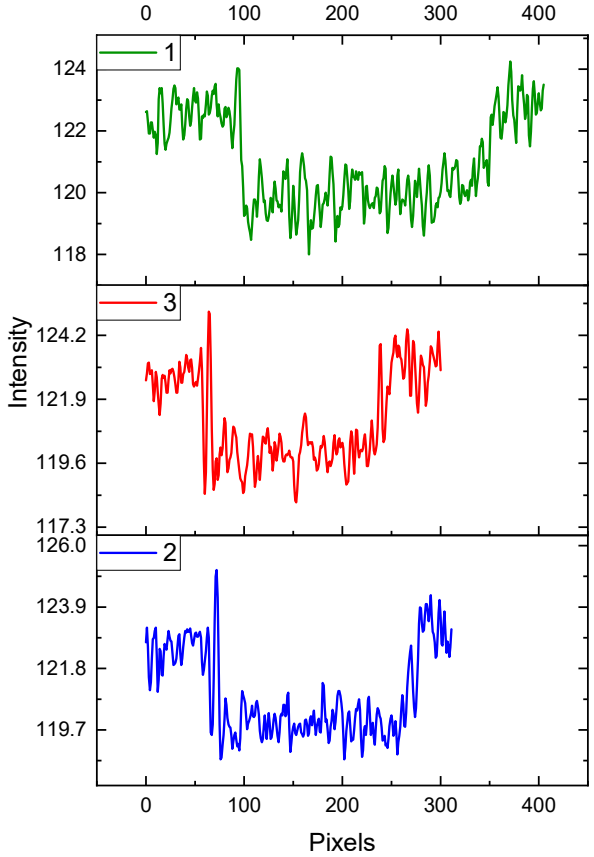


Measurement setup and sources of uncertainty

Optical contrast



VOCI

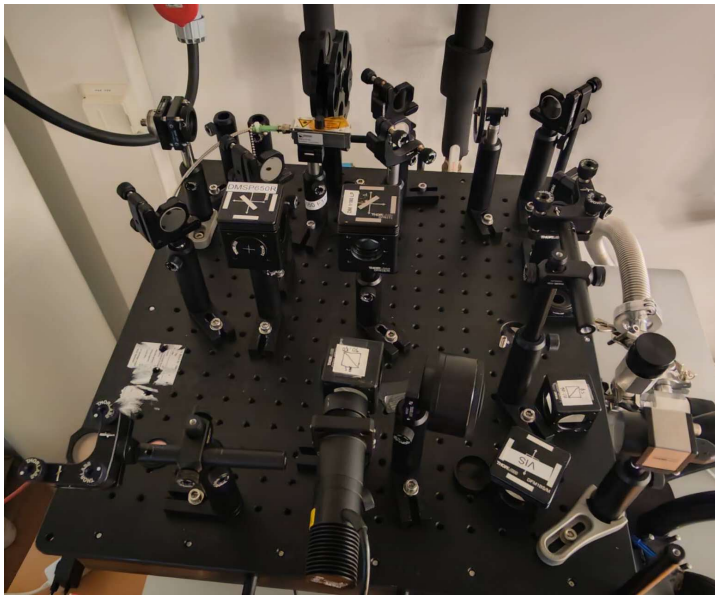


$$C(\lambda) = \frac{I_{flake} - I_{substrate}}{I_{flake} + I_{substrate}}$$

Optical contrast difference

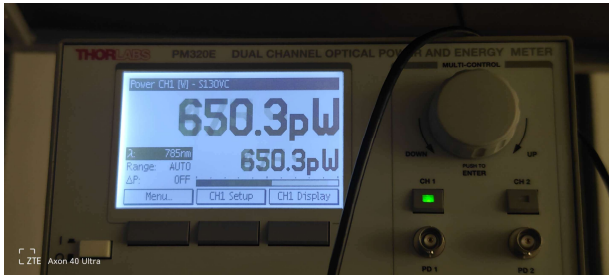
1	-1,5%
3	-4%
2	-2,62988%

PL measurement



PL measurement setup

Temperature sensor



Powermeter

Alignment

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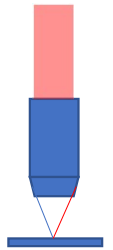
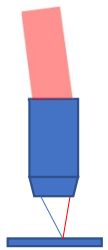
Using a CMOS imaging camera for the quality of the alignment

1

2



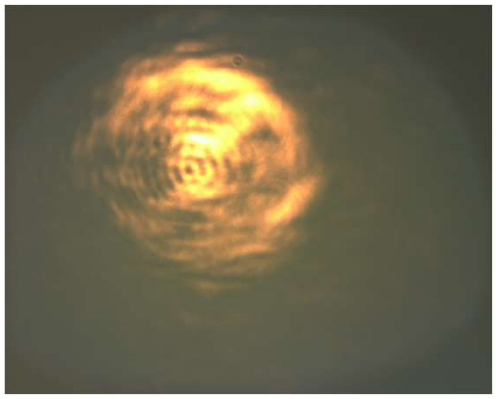
1



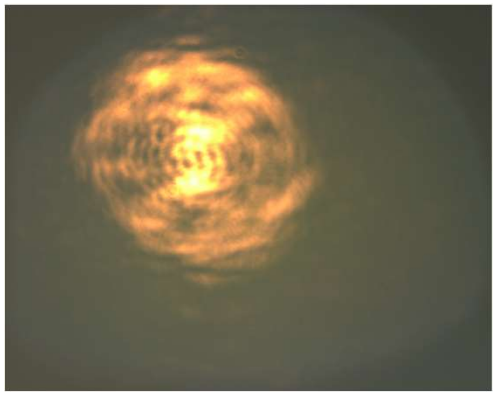
2

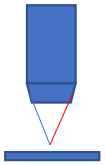
We do manually

Good alignment

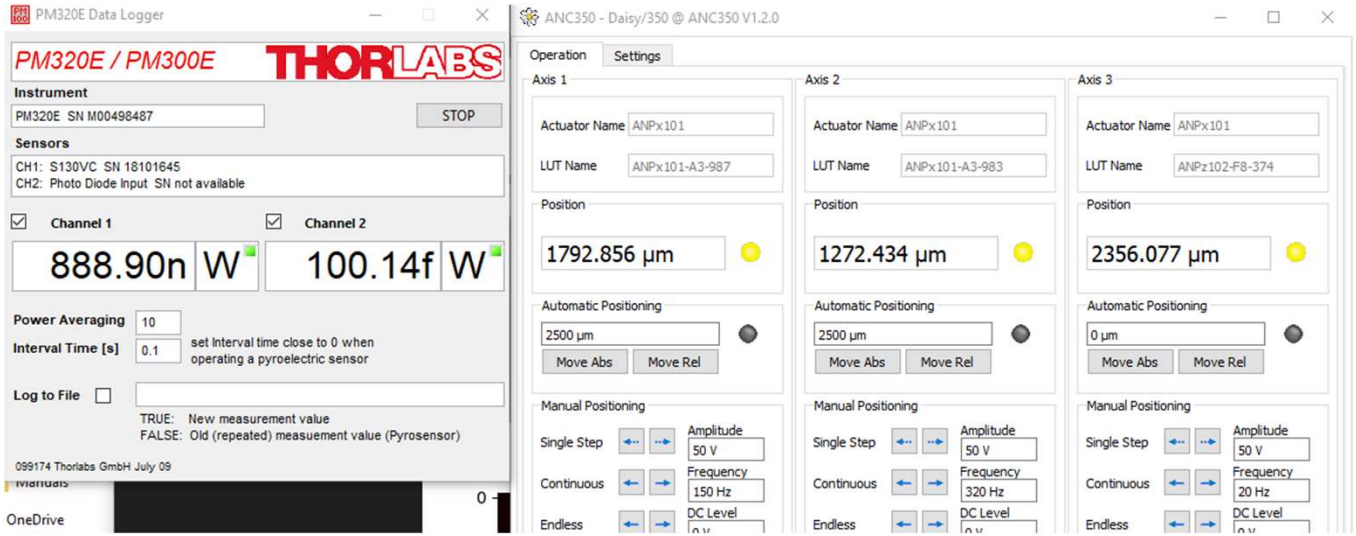


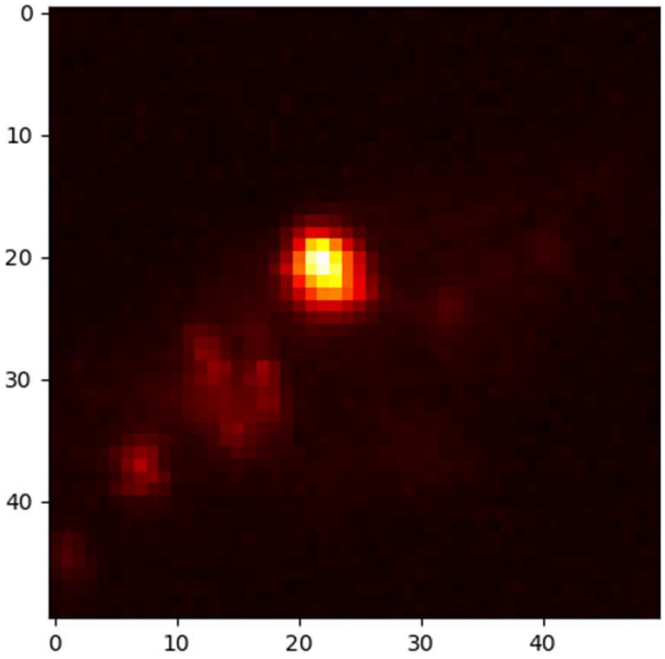
Out of focus





PL Mapping





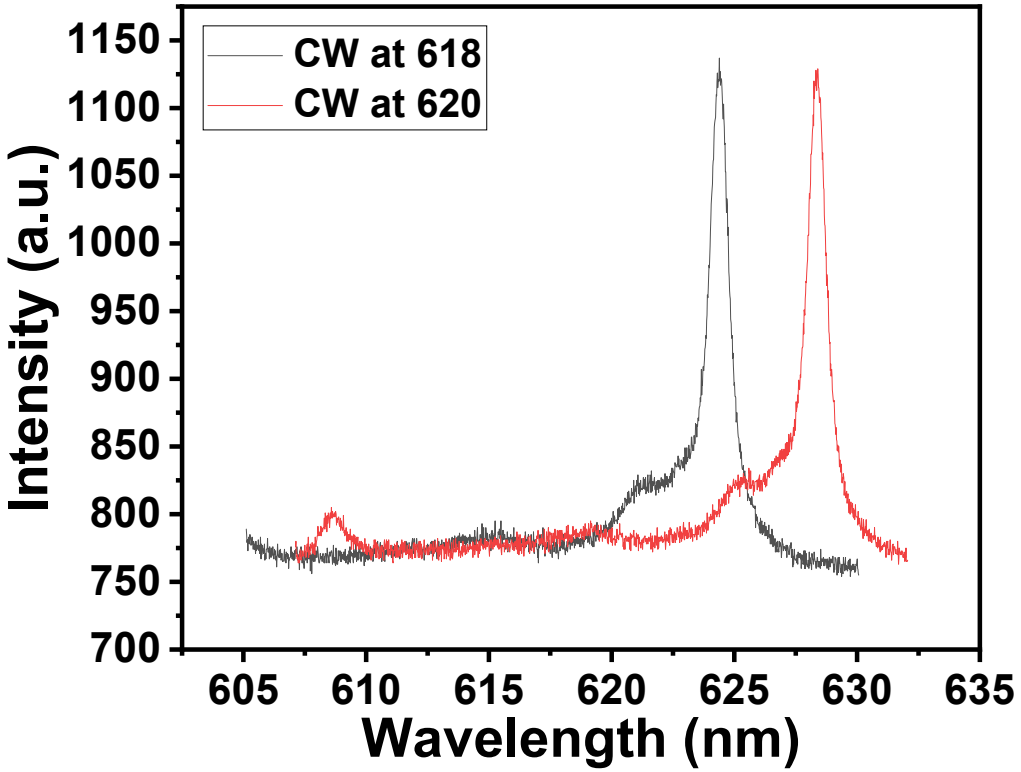
Power (nW)	894.33	894.89	893.59	
X (um)	1792.686	1792.193	1791.838	
Y (um)	1272.503	1272.458	1272.652	
Z (um)	2355.908	2356.098	2355.888	

Spectrograph without proper calibration

Not proper calibration

CW: Center wavelength

Spectrograph moved

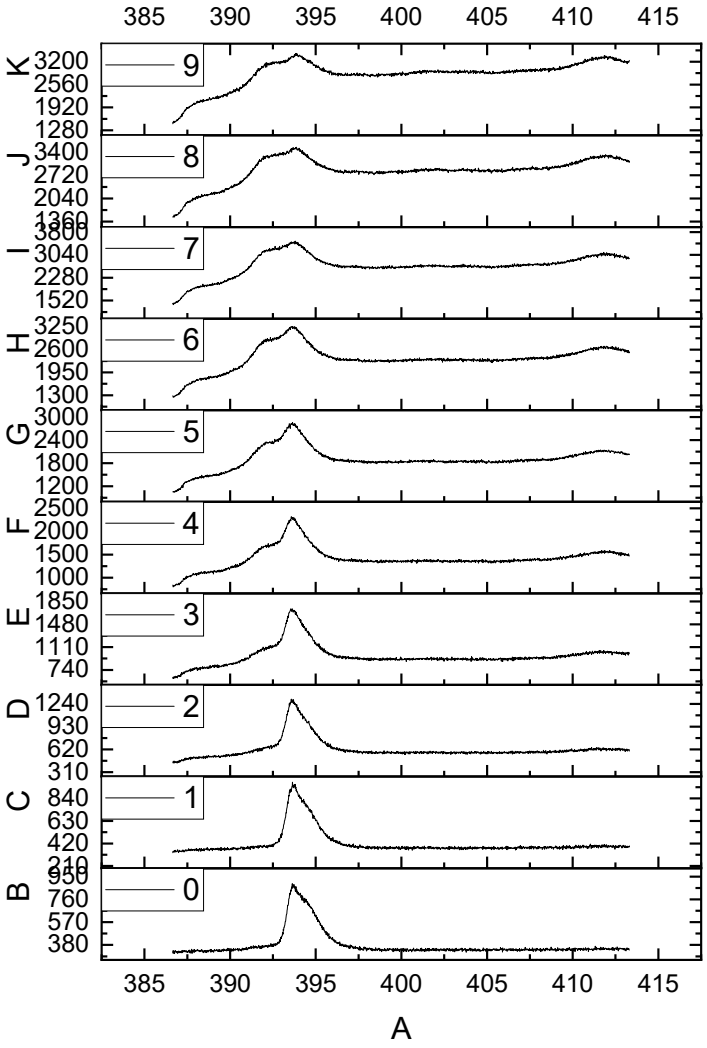


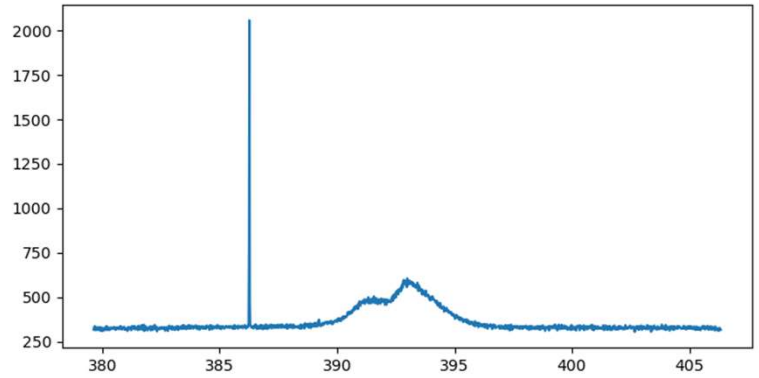
Background

B ⊥ (T)

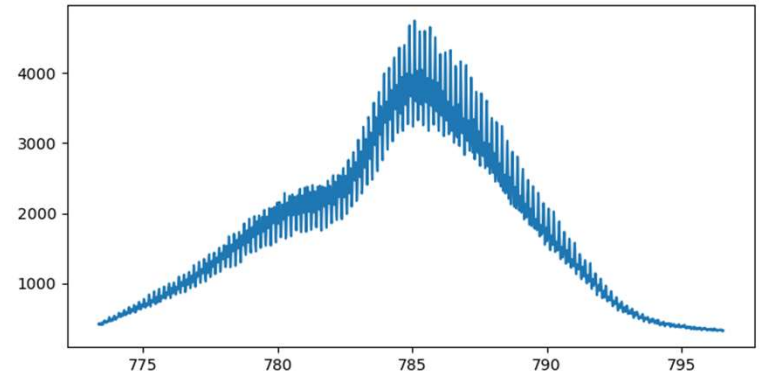
GaSe

Background



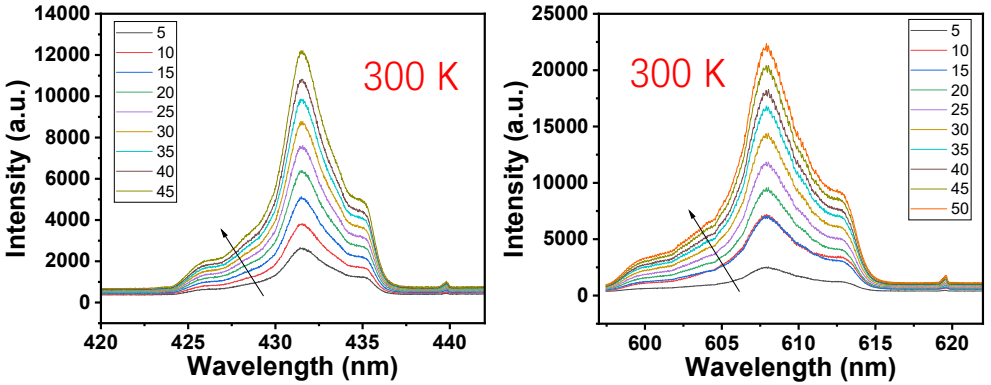


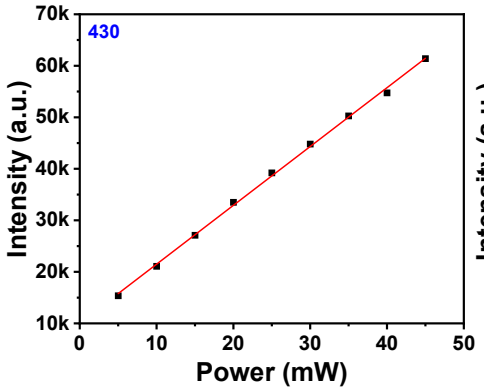
Cosmic radiation

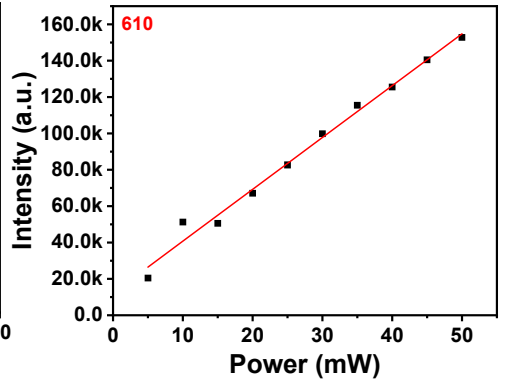


Spectrum of 785 Laser

Power dependent emission







Equation	y = a + b*x
Plot	A78550mw1s300_U
Weight	No Weighting
Intercept	10058.78411 ± 425.11605
Slope	1142.36166 ± 15.10902
Residual Sum of Squares	2396966.37717
Pearson's r	0.99939
R-Square (COD)	0.99878
Adj. R-Square	0.9986

Equation	y = a + b*x
Plot	A78550mw1s300_W@2
Weight	No Weighting
Intercept	12225.69148 ± 3355.03229
Slope	2851.12344 ± 108.14248
Residual Sum of Squares	1.92964E8
Pearson's r	0.99429
R-Square (COD)	0.98862
Adj. R-Square	0.9872

Learning source

Anatomy of a Microscope | Microscopy Primer | Olympus LS (olympus-lifescience.com)

https://wiki.aalto.fi/display/SSC/Raman+Spectroscopy

https://www.microscopyu.com/tutorials/wavefront-relationships-in-reflected-light-dic-microscopy