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RECENT PROGRESS IN GRAPHENE & 2D MATERIALS RESEARCH

# Optically Induced Transparency and Extinction in Dispersed $MoS_2$, $MoSe_2$, and Graphene Nanosheets

Ningning Dong

SIOM

n.n.dong@siom.ac.cn

中国科学院上海光学精密机械研究所
Shanghai institute of Optics and Fine Mechanics, CAS

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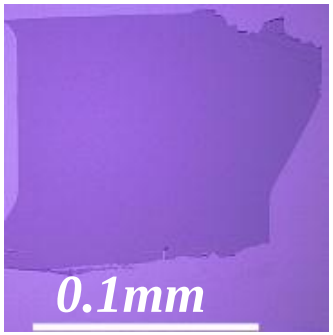
# Outline

- 2D layered nanomaterials
- Optical modulation & NLO properties in dispersed 2D nanosheets
- Summary

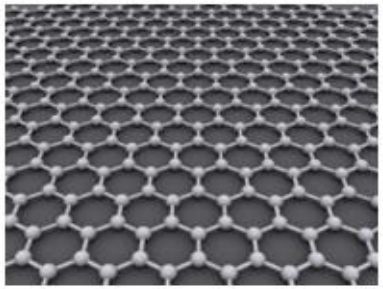
# 2D layered nanomaterials

Layered structure in life

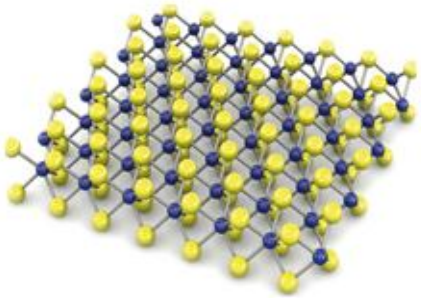




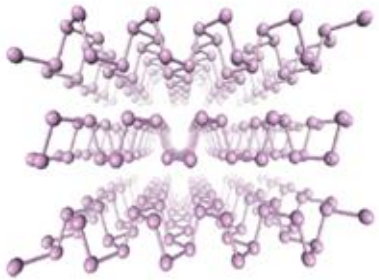

Graphene: single atomic layer



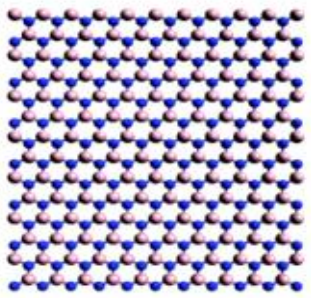
Graphene



TMDs



BP



BN

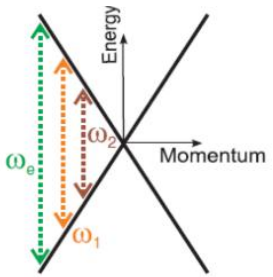
- STRONG covalent bonds in layer;
- WEAK van der Waals interaction between layers;
- SPECIFIC 2D confinement of electron motion;
- ABSENCE of interlayer perturbation;
- UNIQUE electronic, optical, mechanical and thermal properties.

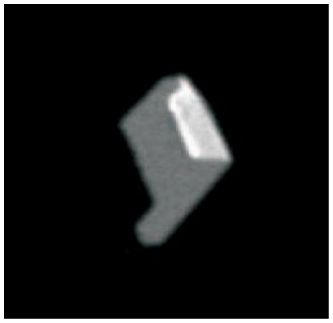
# Nanoscale nonlinear optical effects

## Nonlinear optics

$$\boldsymbol{P}=\varepsilon_0[\chi^{(1)}\boldsymbol{E}+\chi^{(2)}\boldsymbol{E}^2+\chi^{(3)}\boldsymbol{E}^3+\ldots]$$

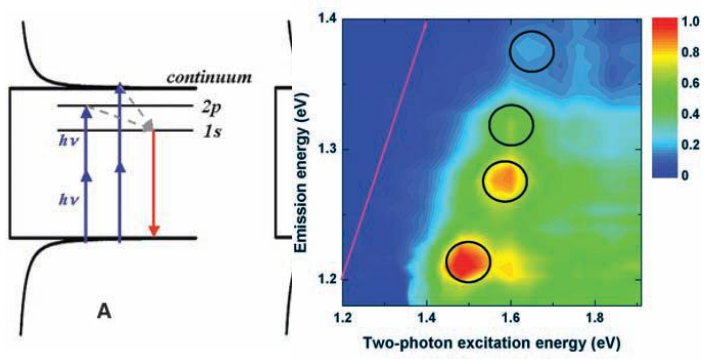
- $\chi^{(2)}$, frequency conversion
- $\chi^{(3)}$, nonlinear refractive index and absorption



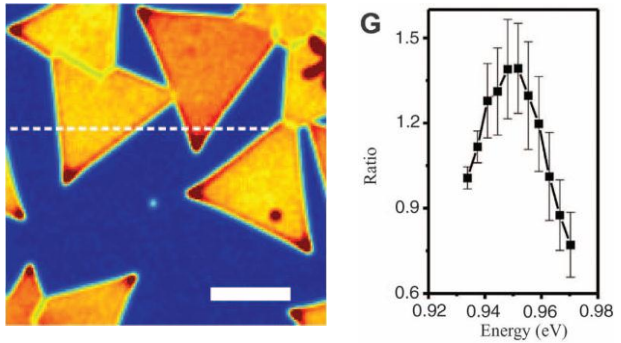
$\mathrm{Re}\chi^{(3)}$ Coherent nonlinear optical response of Graphene

E. Hendry, ***Phys. Rev. Lett.*** (2010)




$\mathrm{Im}\chi^{(3)}$ The optical resonances in carbon nanotubes

F. Wang, ***Science*** (2005)



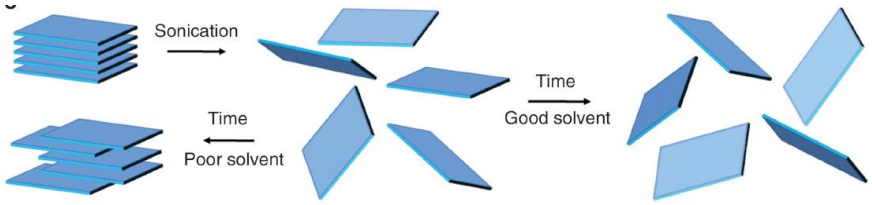

$\chi^{(2)}$ Edge nonlinear optics on a $MoS_2$ at atomic monolayer

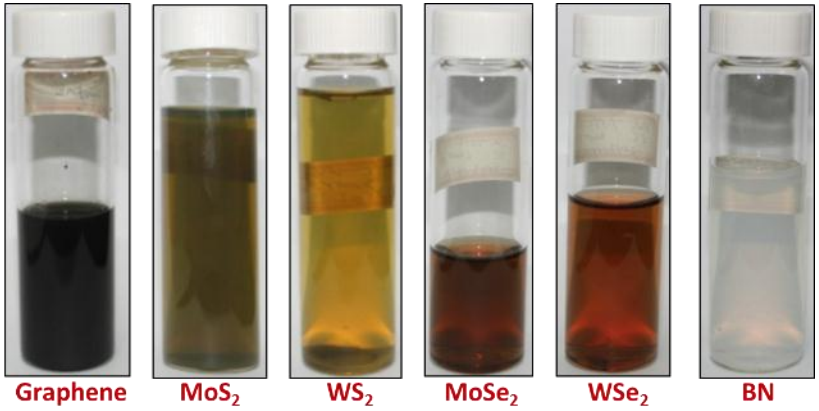
X. Yin, ***Science*** (2014)

Promising Applications: Fiber Lasers, LEDs, Solar cells, Optical switches, Displays, Optical modulators, etc.

# Nanosheets in dispersions

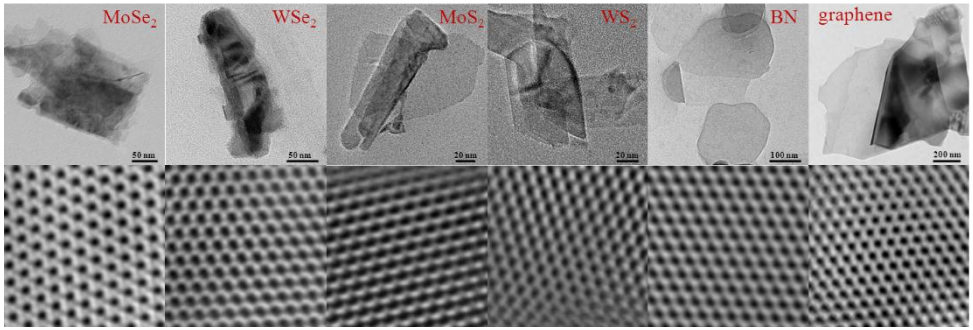
## Sonication-assisted exfoliation

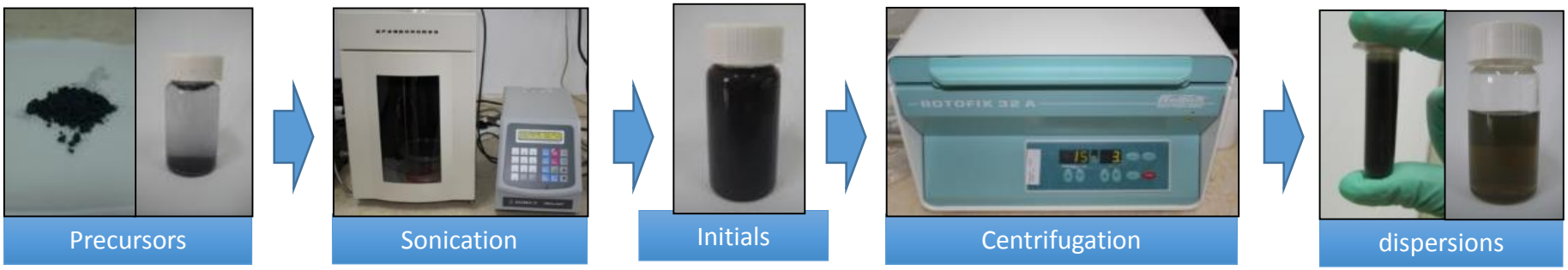



In solubility theory, a dispersion can be considered a solution when the free energy of mixing ΔGmix is negative.

$$\Delta \overline{G}_{\text{mix}} = \Delta \overline{H}_{\text{mix}} - T\Delta \overline{S}_{\text{mix}}$$




Hernandez et al. Nature Nanotech. (2008); Coleman et al. Science (2011); Nicolosi et al. Science (2013).

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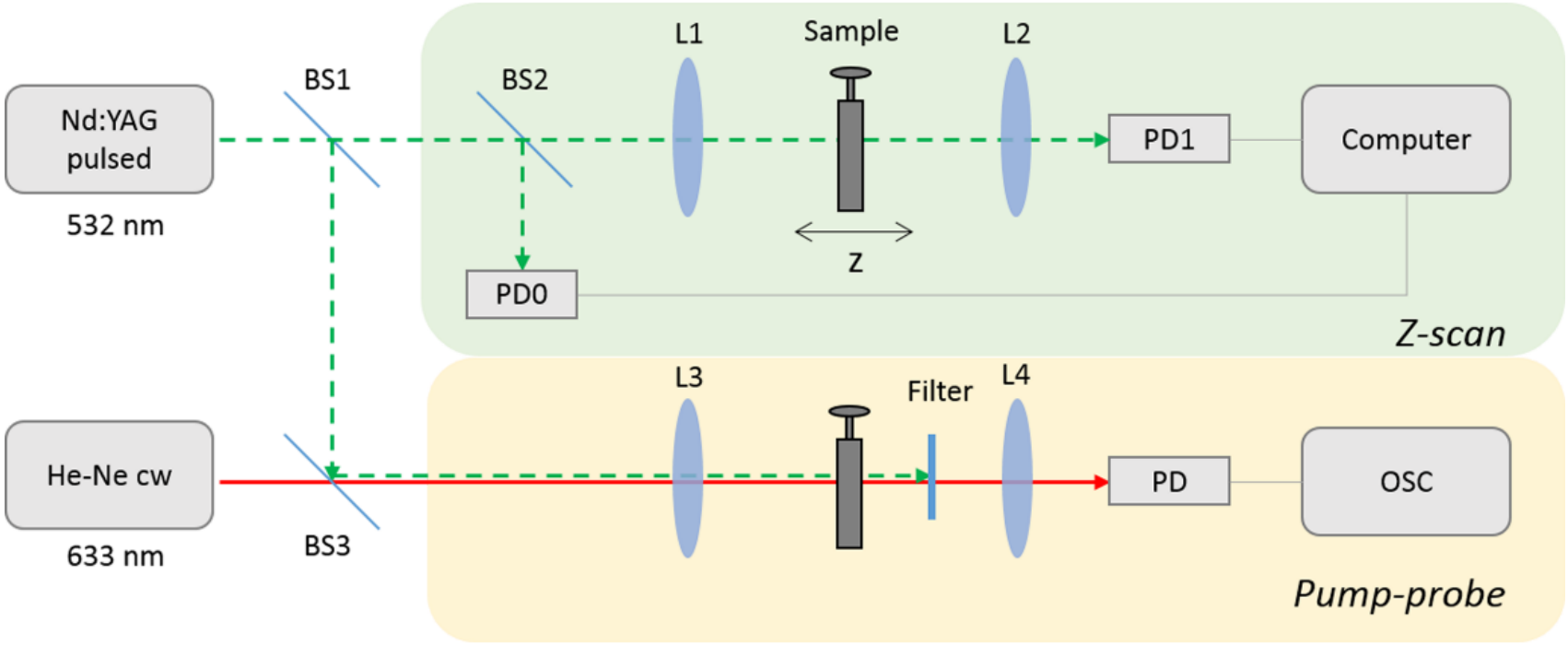
# Optical measurement system for nonlinear optical study

Pump: 532 nm, 6 ns, 10 Hz
Probe: 633 nm, cw



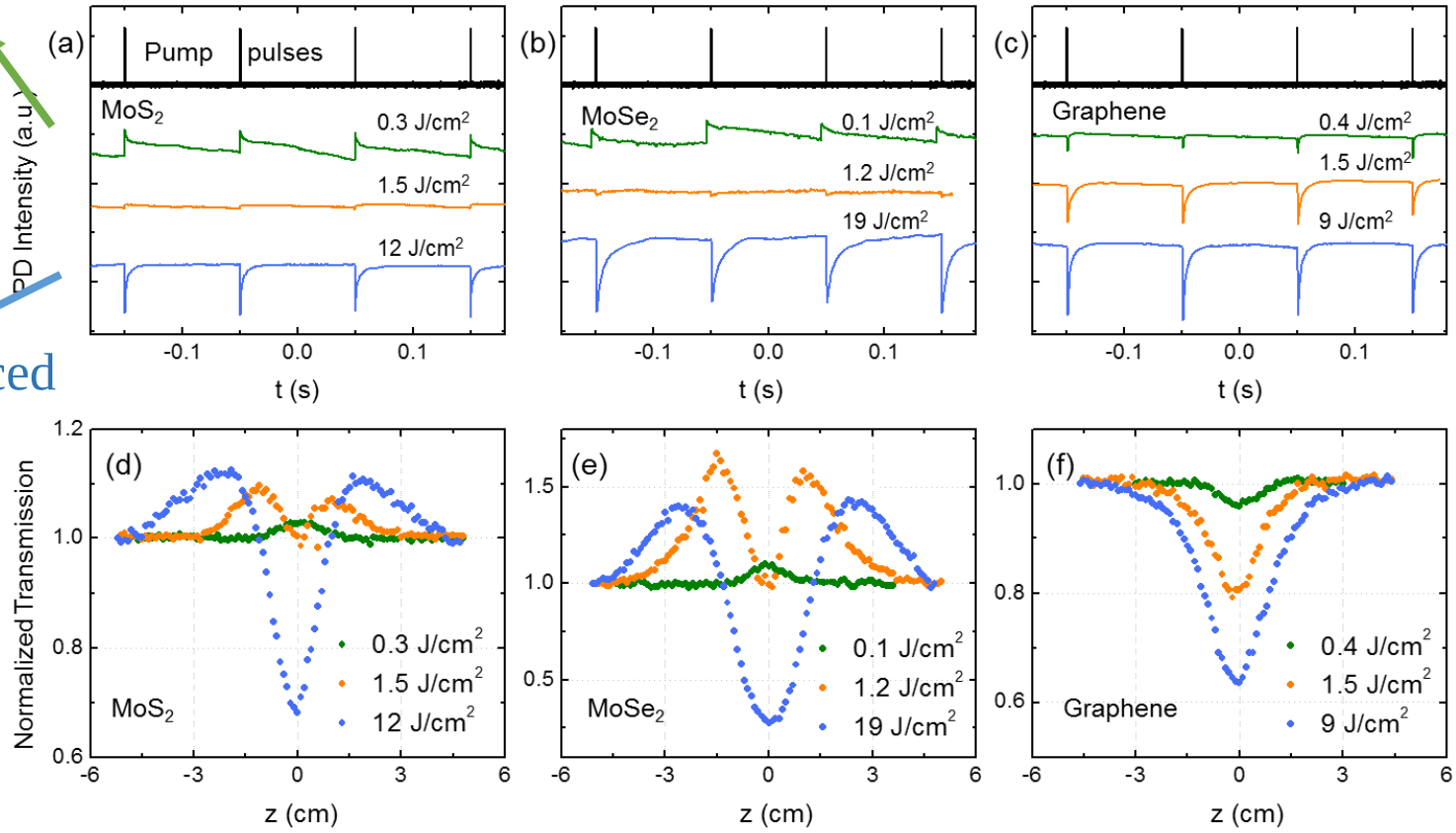

Quartz cell: 10 × 10 mm
Linear transmittance $T_0$ ~ 47% @ 532 nm

# Optical modulation induced by SA and NLS at ns

Optically induced transparency

Optically induced extinction

Probe light = 5 mW

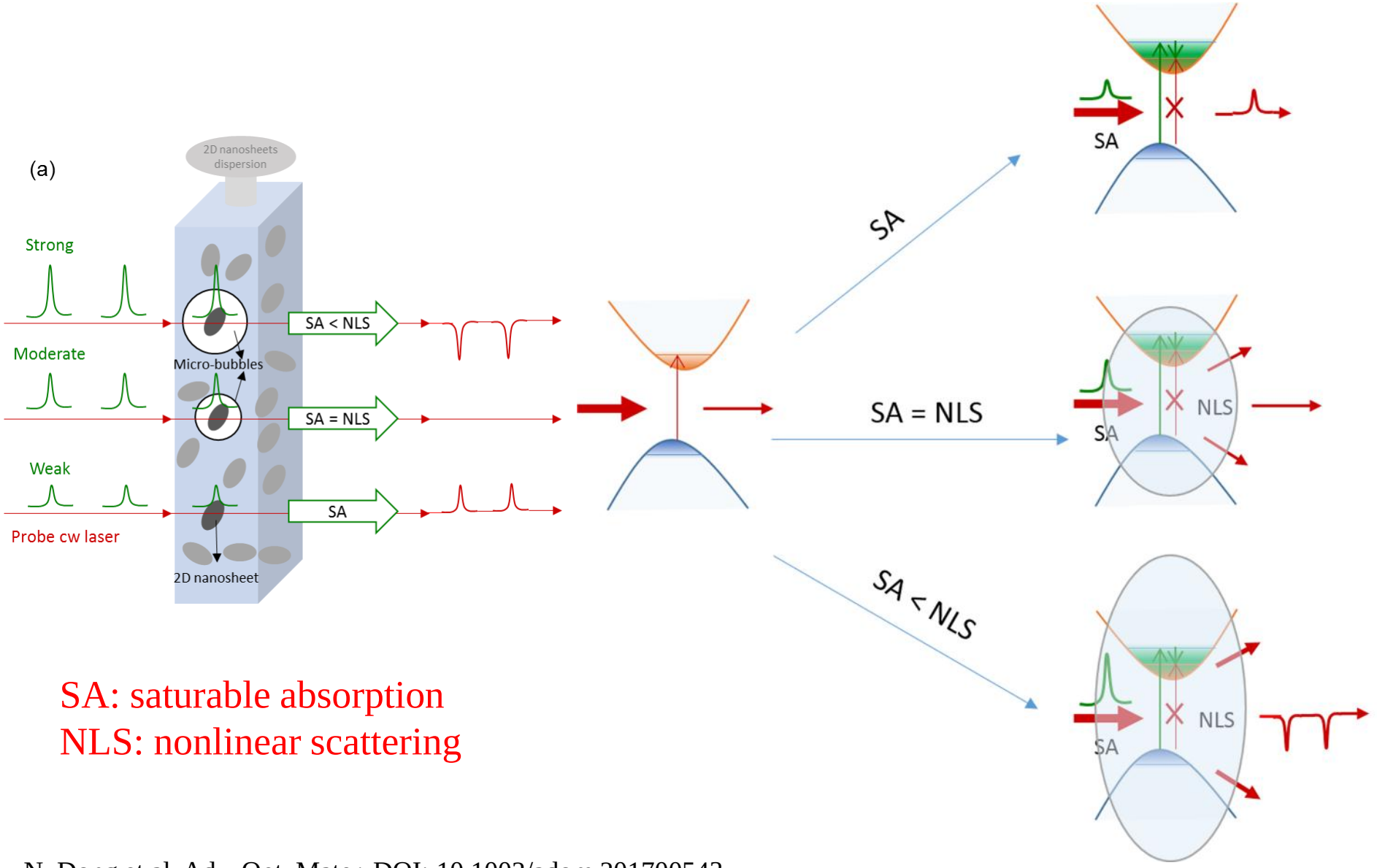



(a)-(c): Optical modulation results.

(d)-(f): Open-aperture Z-scan results.

N. Dong et al. Adv. Opt. Mater. DOI: 10.1002/adom.201700543

# Schematic representation of the optical modulation process




SA: saturable absorption
NLS: nonlinear scattering

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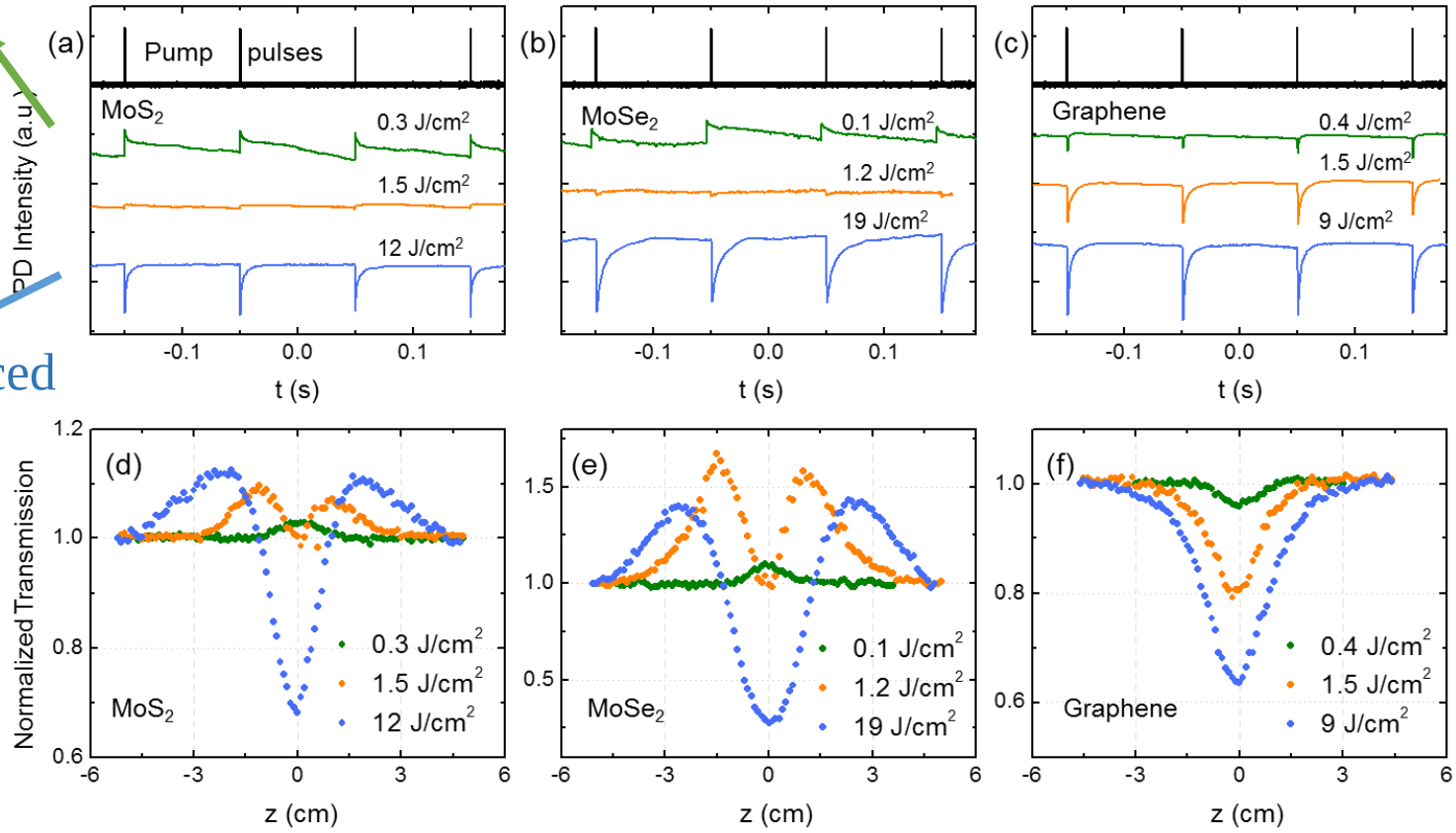


(a)-(c): Optical modulation results.

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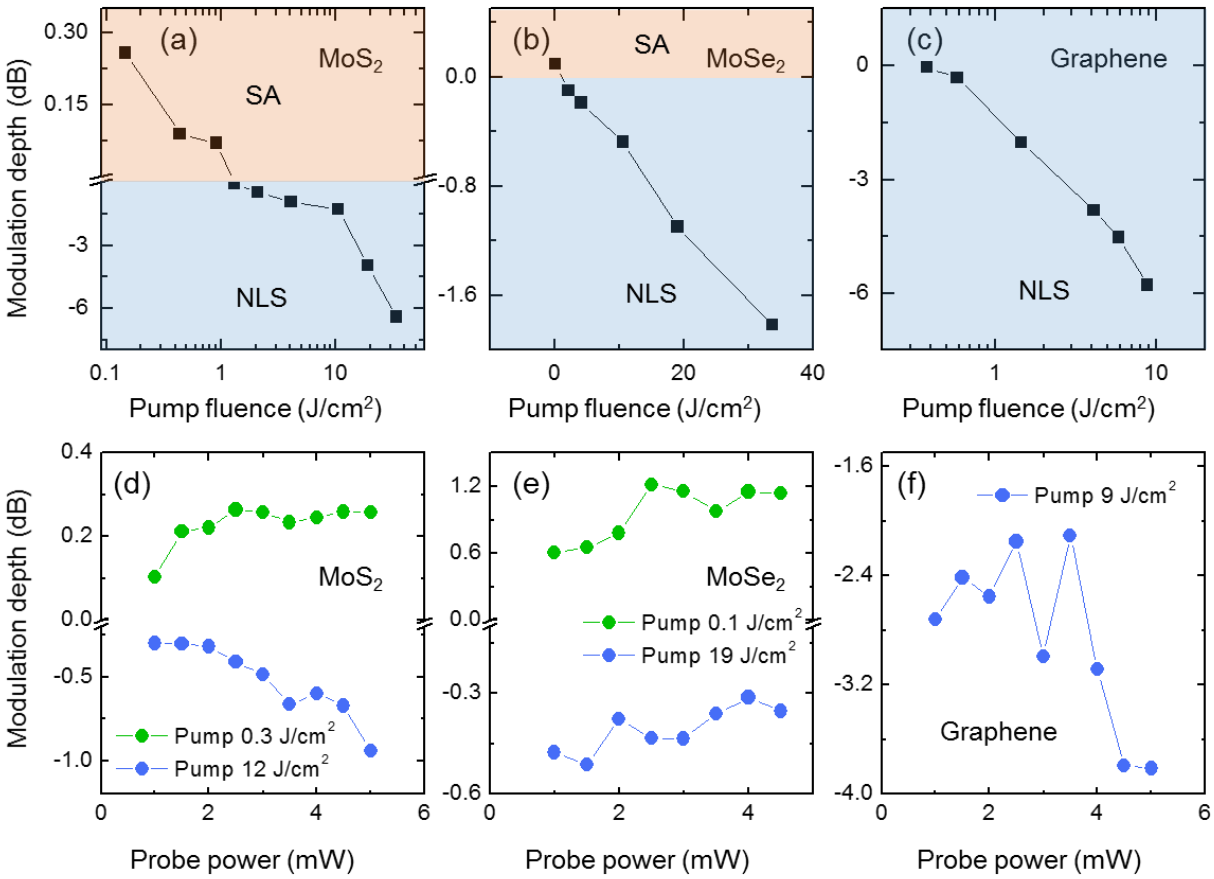
# Optical modulation depth – laser energy dependent




Optical modulation depth:

$$10 \times \log_{10}(T_m/T_0)$$

$T_m$: maximum (minimum) transmittance of the peak (valley)

$T_0$: linear transmittance for the cw light

(a)-(c): Optical modulation depths under different pump fluences with the 633 nm cw probe light of 5 mW .

(d)-(f): The variation of the depth with different probe light power.

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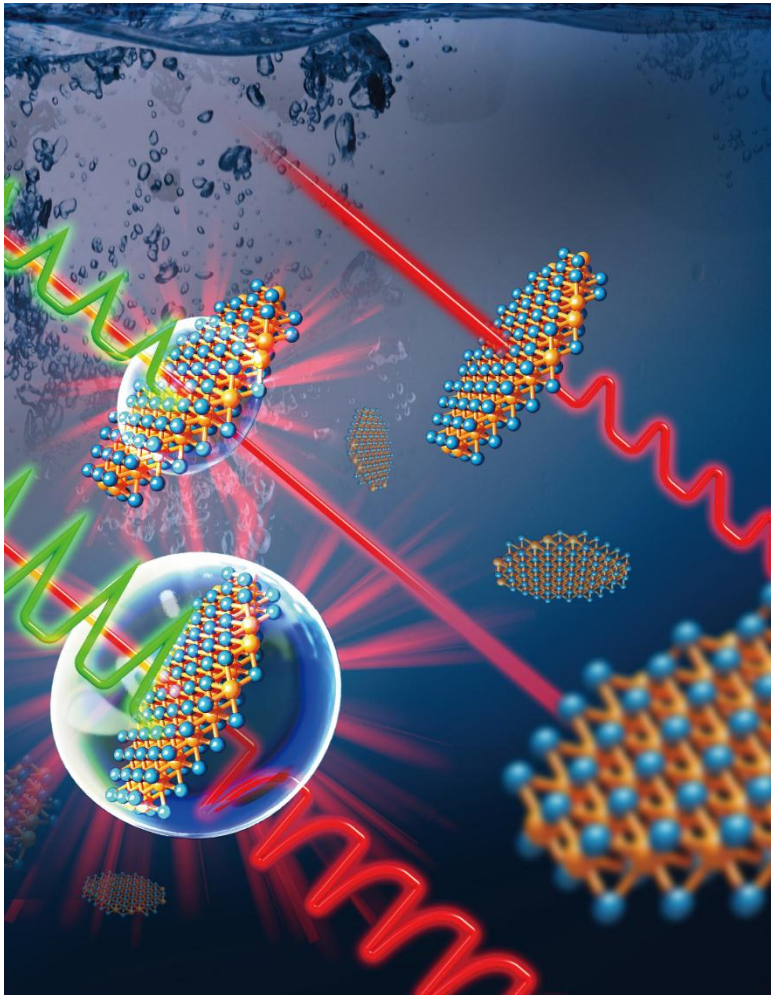
# Summary



1. The 632.8 nm cw probe light can be modulated to transparency and extinction in these nanosheets dispersions under the 532 nm ns pump laser pulses.
2. NLO mechanism: combined of SA and NLS.
3. The maximum modulation depth ~7 dB.
4. Multiple nonlinear optical mechanisms coexisting ⟹ promising candidate materials for diverse photonic applications.

https://doi.org/10.1002/adom.201700543

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Submit a designed cover image to **Advanced Optical Materials**.

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## Group

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## The collaborators

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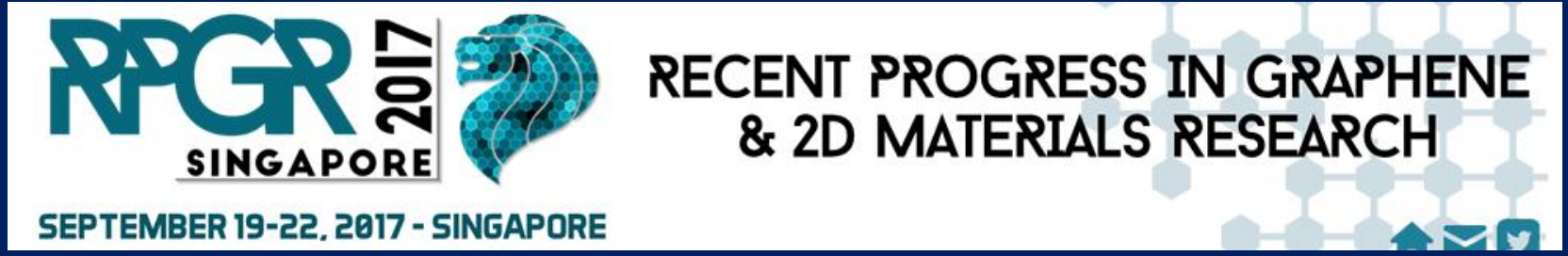
  - SIOM: Prof. L. Zhang
  - ECUST: Prof. Yu Chen
- Ireland
  - Prof. W. J. Blau, Prof. J. N. Coleman, Prof. G. S. Duesberg, Dr. Niall McEvoy

Nanoscale Nonlinear group




# Thank you for your time!

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n.n.dong@siom.ac.cn

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