Light harvesting in large-area nanostructured 2D-MoS_2 layers

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Why this talk?

Evolution of solar cells:

1° generation → silicon (p-n junctions)

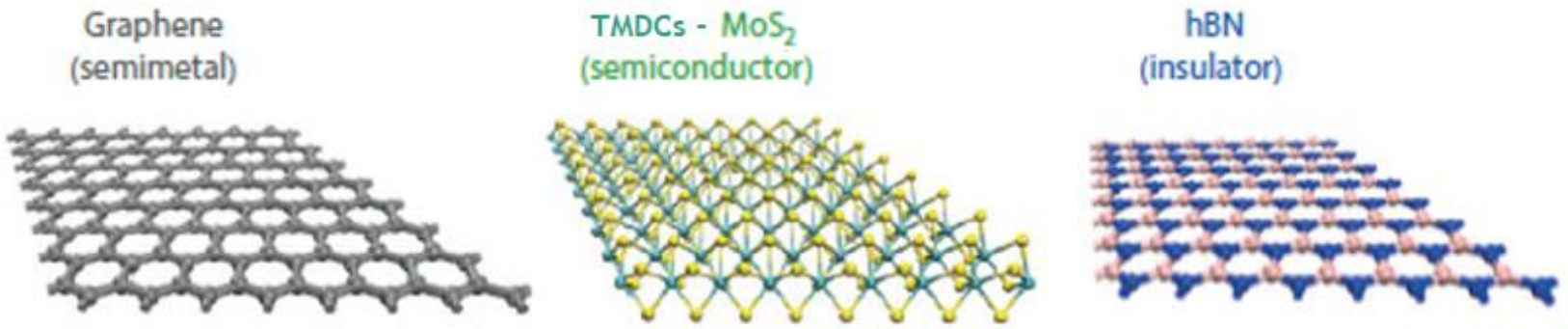
2° generation → thin films

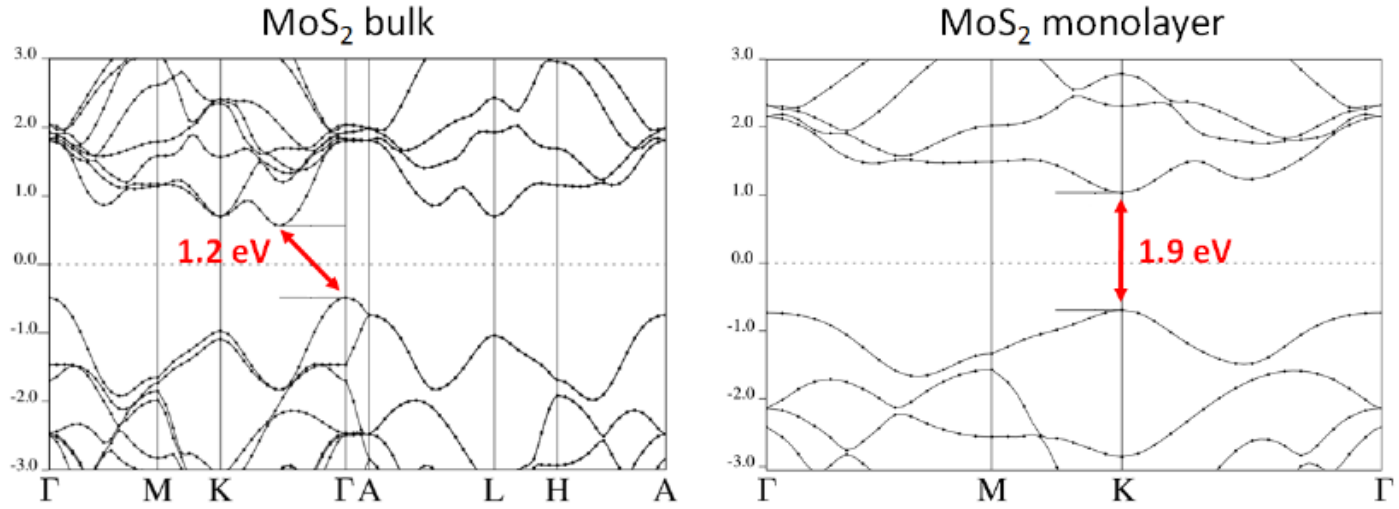
3° generation → new concepts (e.g. nanostructured solar cells)

- 2D-semiconductors (like MoS_2) represent ultimate thin films
- Efficient light harvesting is required for increasing optical absorption
- Absorption enhancement is only a first step towards competitive performances for solar cells (other challenges to be faced: e.g. high quality material growth, electrical performances)

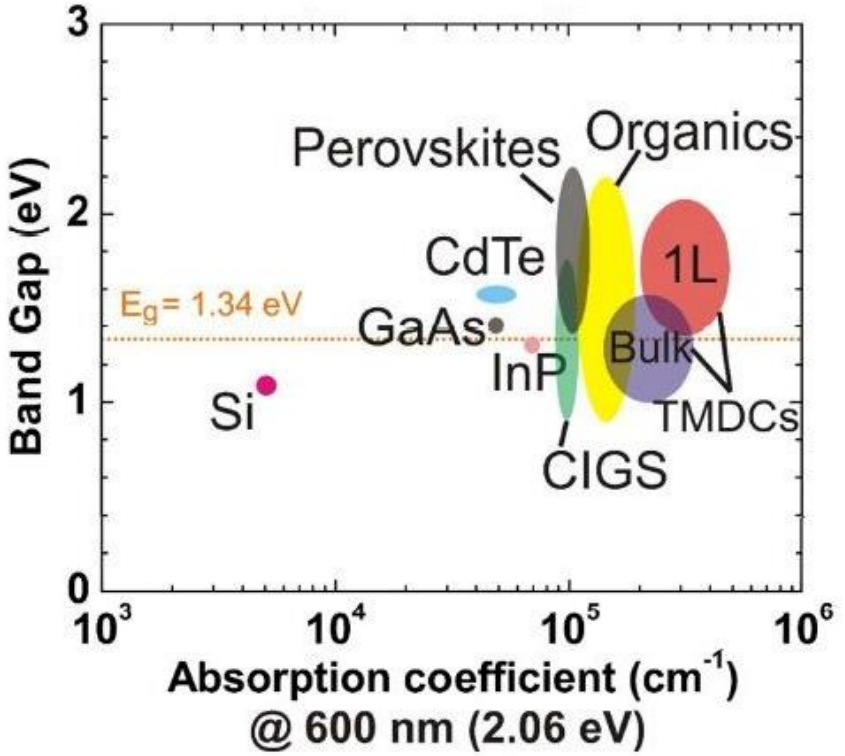
Transition Metal Dichalcogenides (TMDCs)

2D materials portfolio





MoS_2 bandgap energy between 1,2eV and 1,9eV

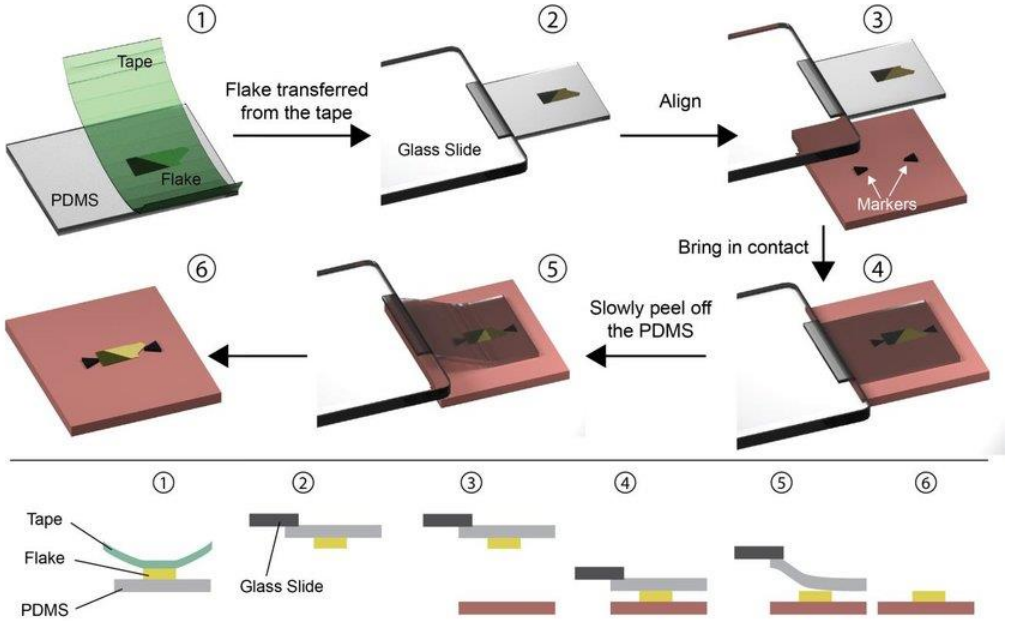


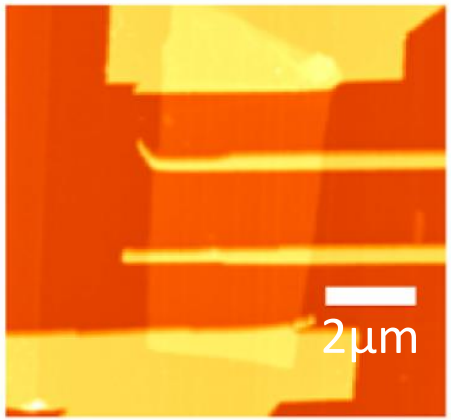
Jariwala *et al., ACS Photonics* 2017, 4, 2962−2970

TMDCs promising materials for opto-electronics and photovoltaics!

Fabrication routes

Mechanical exfoliation

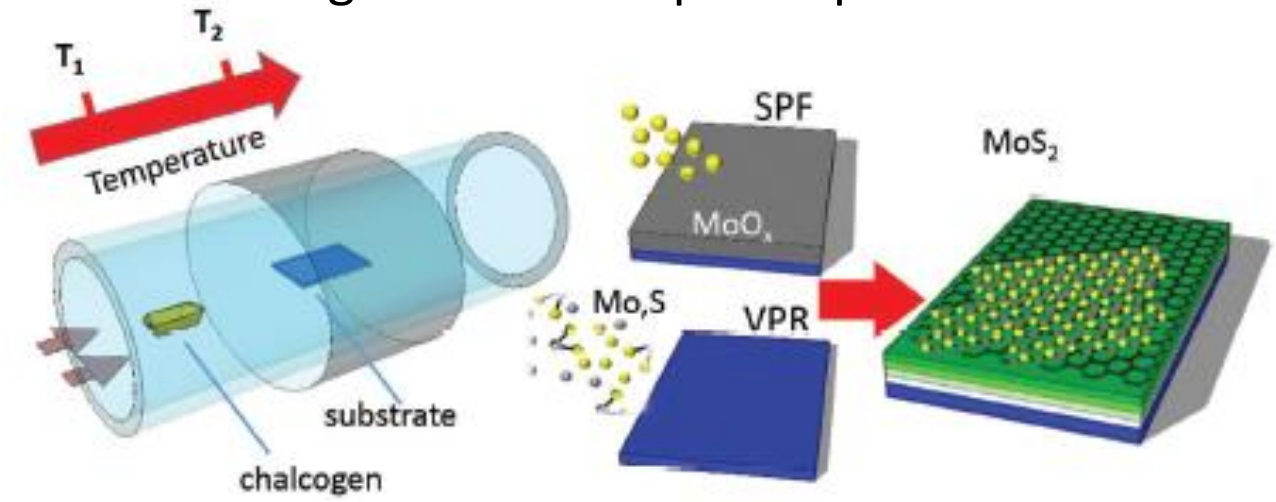




- crystalline quality
- good electronic properties
- small area
- randomic process
- expensive lithography

Large area growth

e.g. Chemical Vapor Deposition

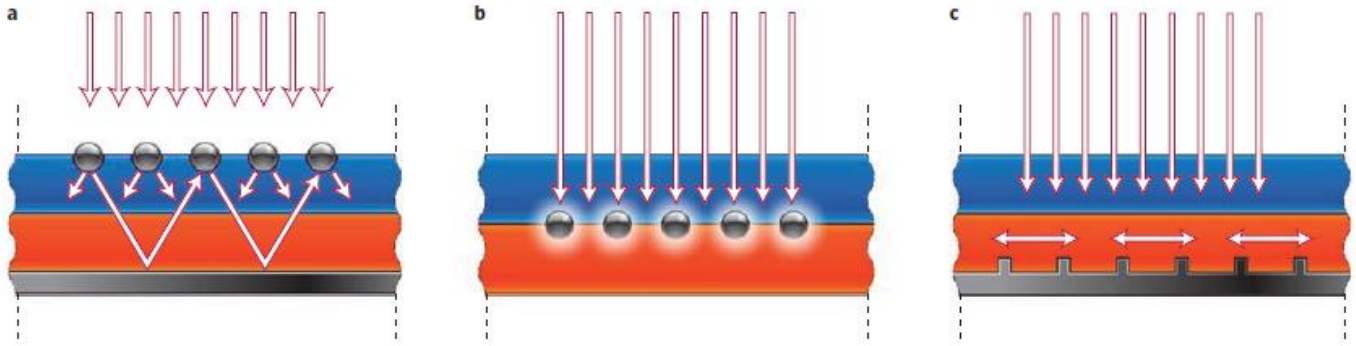


- large area
- scalable
- conformal growth
- polycristalline
- lower properties

Light harvesting strategies

Despite the MoS_2 high optical absorption coefficient, the atomical thickness reduces the effective absorption requiring light harvesting strategies

Plasmonic coupling



Atwater, Polman, *Nature Mater* **9,** 205–213 (2010)

- Light scattering
- Back-reflection
- Localized surface plasmons
- Surface plasmon polaritons

Diffractive anomalies

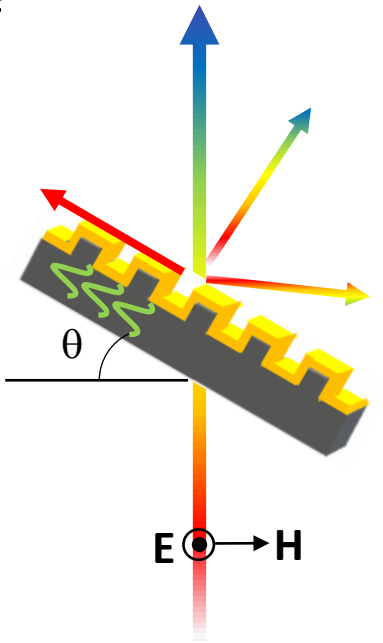
Light deviated parallel to the active 2D material surface

Rayleigh Anomaly

Guided Mode Anomaly

(launched by the grating)

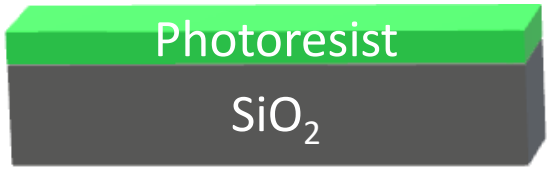
$$m\lambda_A = P \cdot (n + sin\,\theta)$$



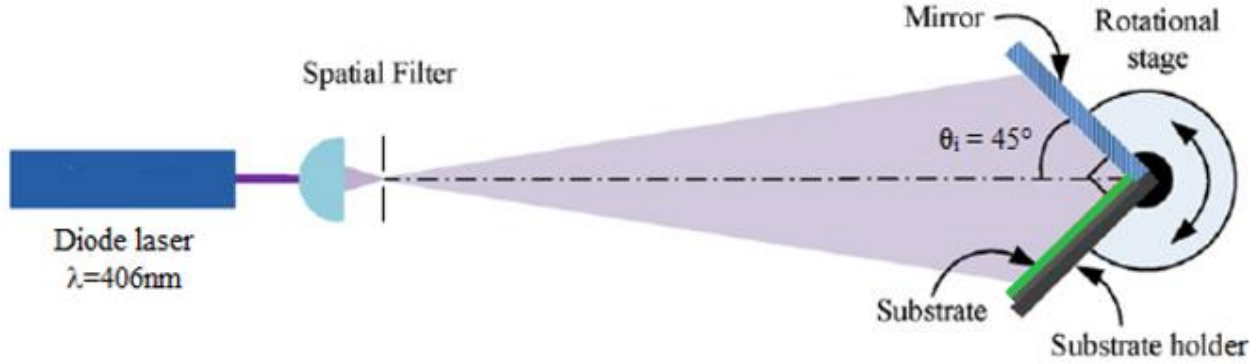
Bhatnagar et al., *Nanoscale*, 2020, **12**, 24385–24393

Bhatnagar *et al*., *ACS Appl. Mater. Interfaces* 2021, 13, 13508-13516

Large area (cm^2) gratings fabrication



Laser Interference Lithography (LIL)



$$P = \frac{\lambda}{2 \sin \theta_i}$$

Lloyd's mirror LIL configuration

Polymer mask

1

MoS_2 deposition

1. MoS_2 nanostripes arrays

2

Al deposition

Metal mask

Reactive Ion Etching

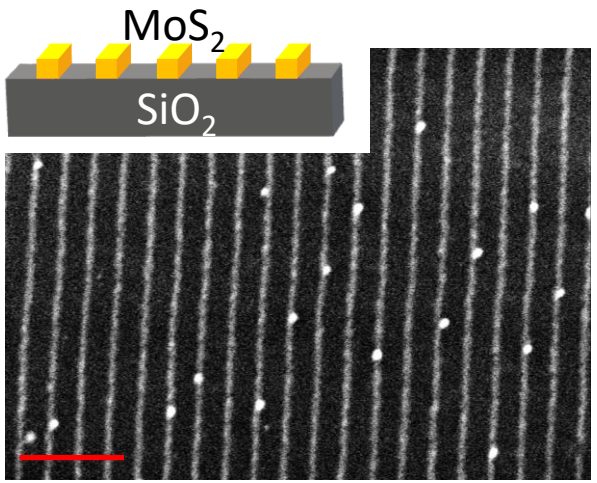
SiO_2 grating

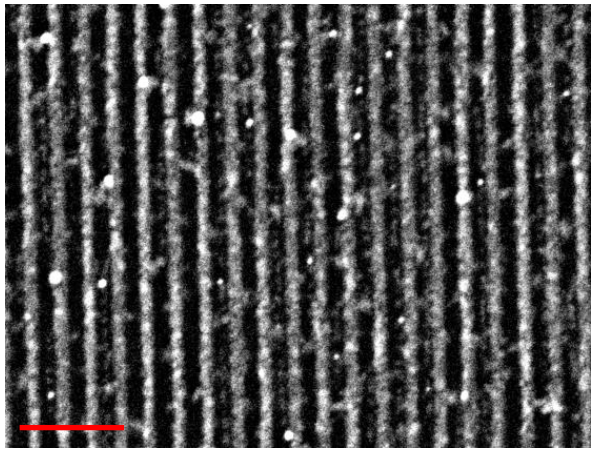
MoS_2 deposition

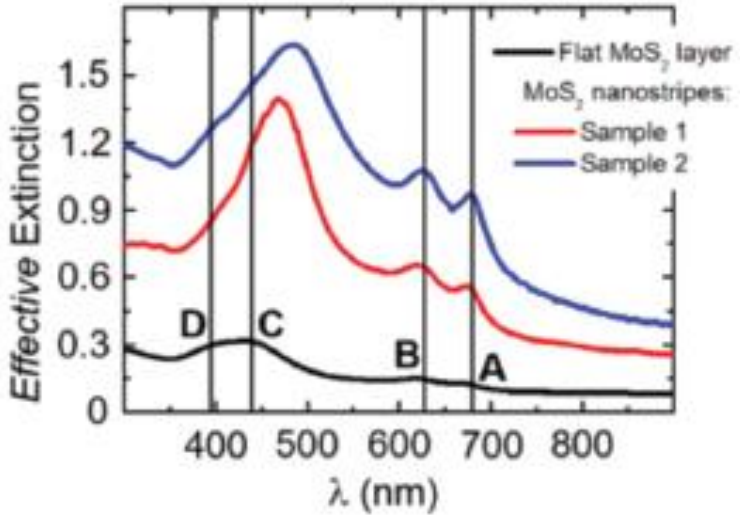
2. Continuous MoS_2 films on silica grating

MoS_2 nanostripes arrays

Growth of 4nm thick MoS_2 stripes (different stripes width)

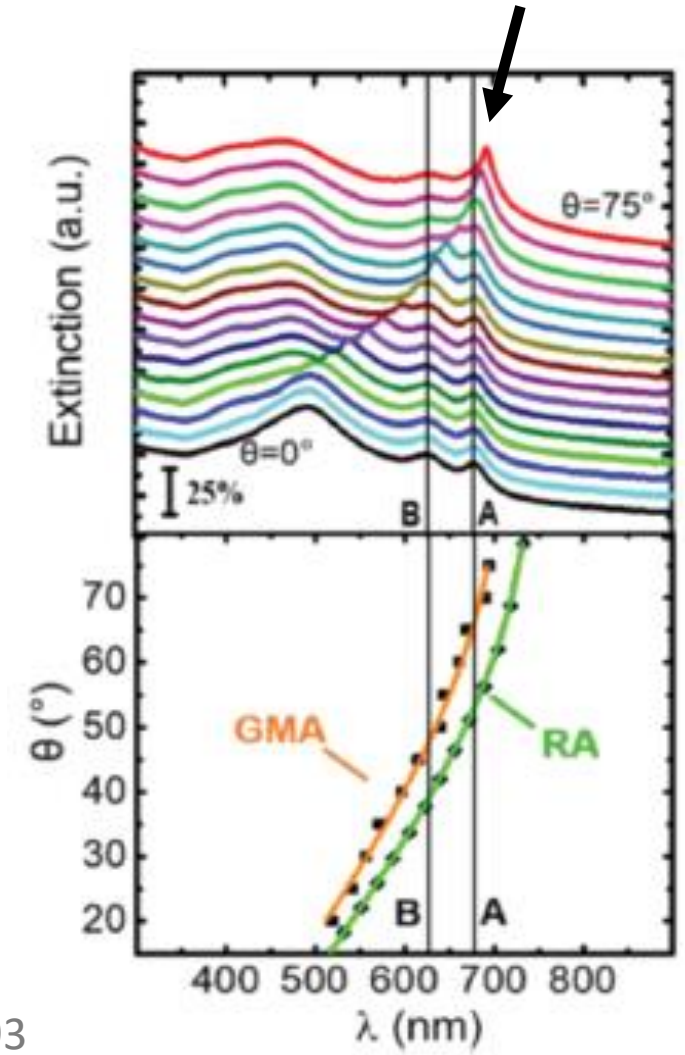






Normalizing to the MoS_2 surface coverage, higher extinction with less material comparing to continuous flat MoS_2 film!

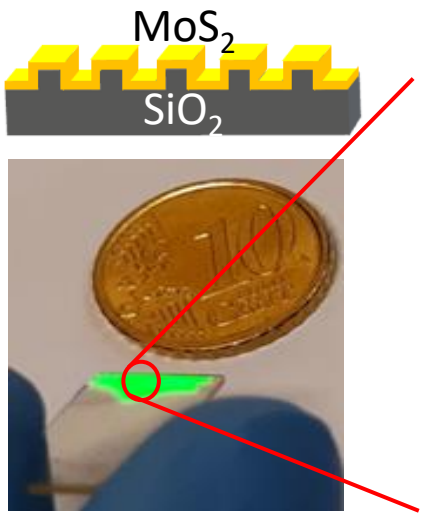
Diffractive anomaly

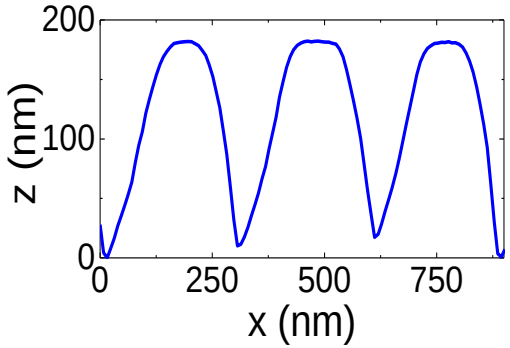


Bhatnagar et al., *Nanoscale*, 2020, **12**, 24385–24393

Continuous MoS_2 films on silica gratings

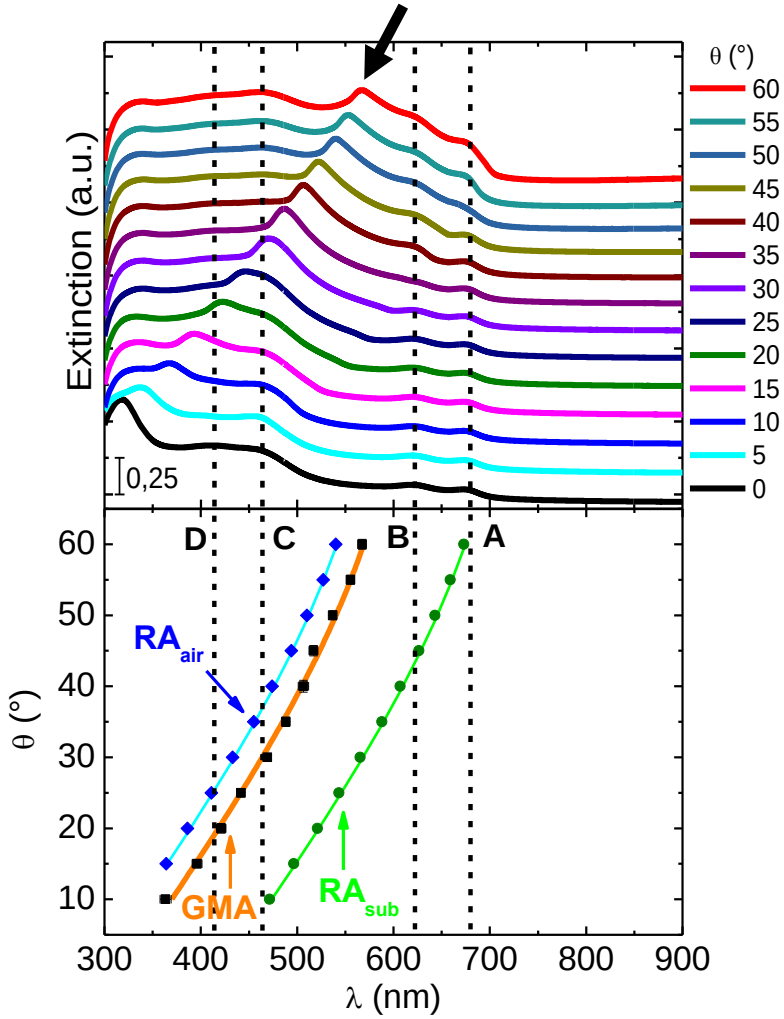
Conformal growth of 4nm MoS_2 layers on top of silica gratings



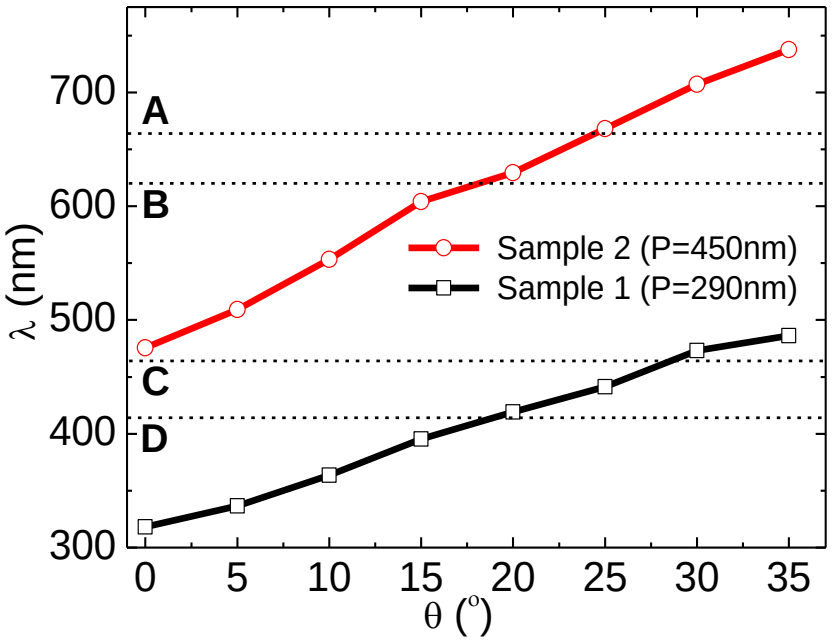


P=290nm

Diffractive anomaly



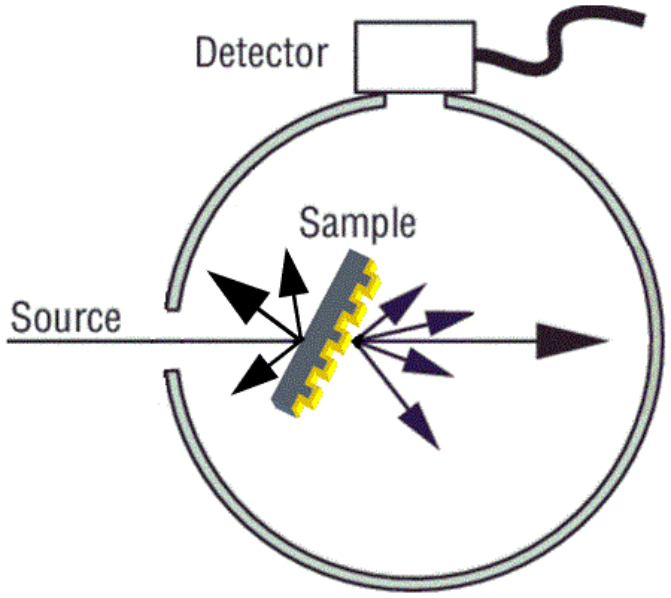
$$m\lambda_A = P \cdot (n + sin\,\theta)$$



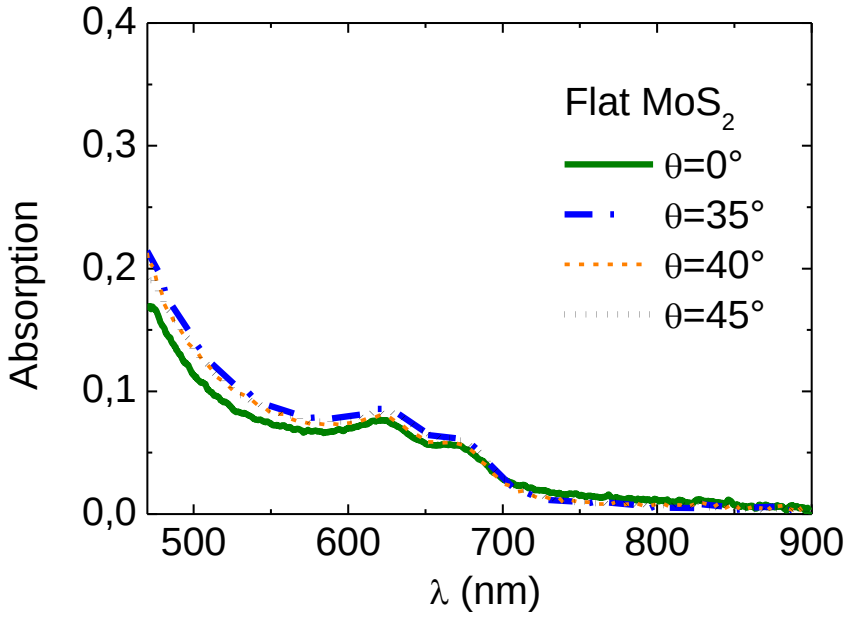
Tunability in a broad spectral range (300-700nm) by controlling either the period or the incidence angle

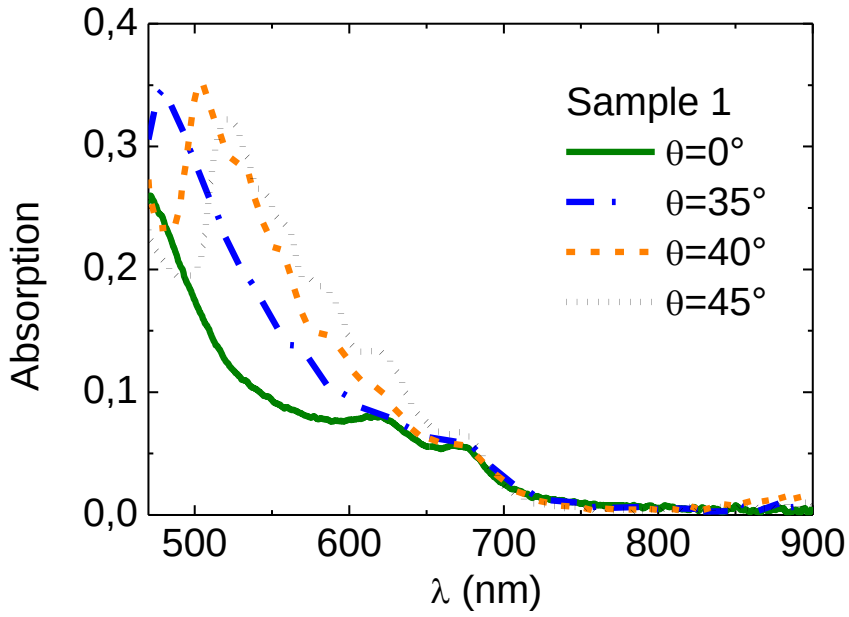
Bhatnagar *et al.*, *ACS Appl. Mater. Interfaces* 2021, 13, 13508-13516

Total integrated transmission measurements



Integrating sphere setup





Detected signal (S): integrated transmission, reflection and diffuse scattering

Absorption: A=1-S

- ✓ Resonant absorption enhancement up to 240% at θ=45°
- ✓ Averaged absorption gain (470-750nm) ≈110% at θ=45°

Bhatnagar *et al.*, *ACS Appl. Mater. Interfaces* 2021, 13, 13508-13516

Conclusions

- Scalable fabrication of large area nanostructured samples (either MoS_2 stripes arrays or conformal MoS_2 layers on silica gratings)
- Tunable and broadband absorption enhancement in MoS_2 ultra-thin films via diffractive anomalies

Co-authors acknowledgements

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