Strong light–matter coupling in two-dimensional atomic crystals

Quantum electronics
Keio University

Santacatterina Simon

Agenda

- Introduction

- Part1: Observations
- Part2: Model – Explanation

- Conclusion

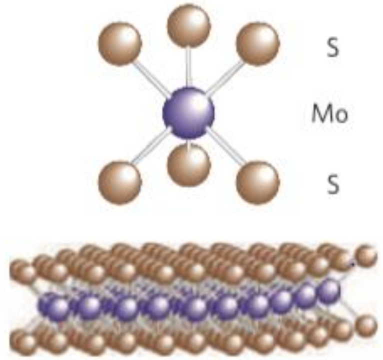
Introduction

Device of interest

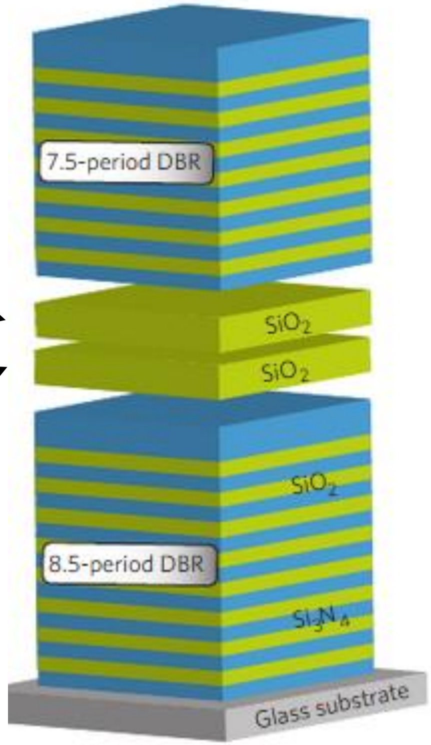
Made up of:

- Dielectric **microcavity**
- Monolayer of **2-D $\mathbf{MoS_2}$** atomic crystal

MoS_2



Optical Resonator



Material selection

Traditional and organic materials :

- Only suitable at **cryogenic T**
- Strong **localization**
- **Restricted** to short wavelength
- **Sophisticated** growth techniques

$\mathbf{MoS_2}$:

- Excitonic devices at **room temperature**
- Enhanced **direct-bandgap** photoluminescence
- **Broad** wavelength range
- **Cheap** and **abundant** material
- 2-D dipole orientation
  ➡ excitonic emission highly **anisotropic**

Light–matter coupling : polaritons

Cycle:

1. Interaction between **resonant light** and **monolayer** in cavity

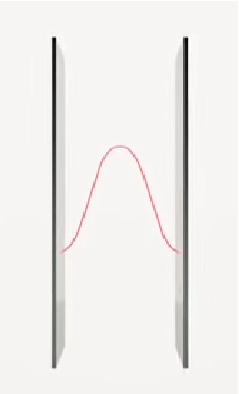
⬇

2. **Excitons** : electrons-holes quasi-particles

⬇

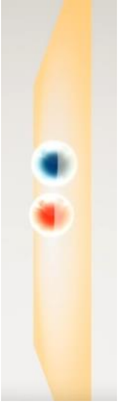
3. Excitons recombination : light recreated

Light



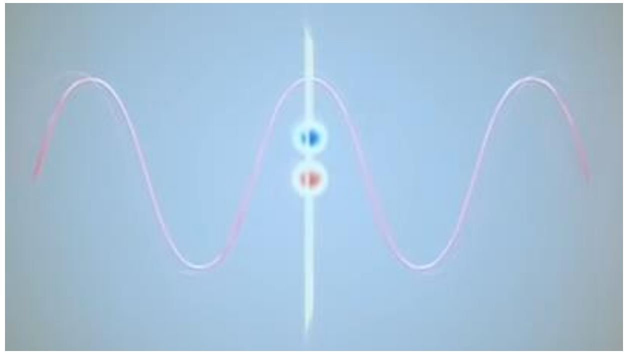
+

Excitons



⬇

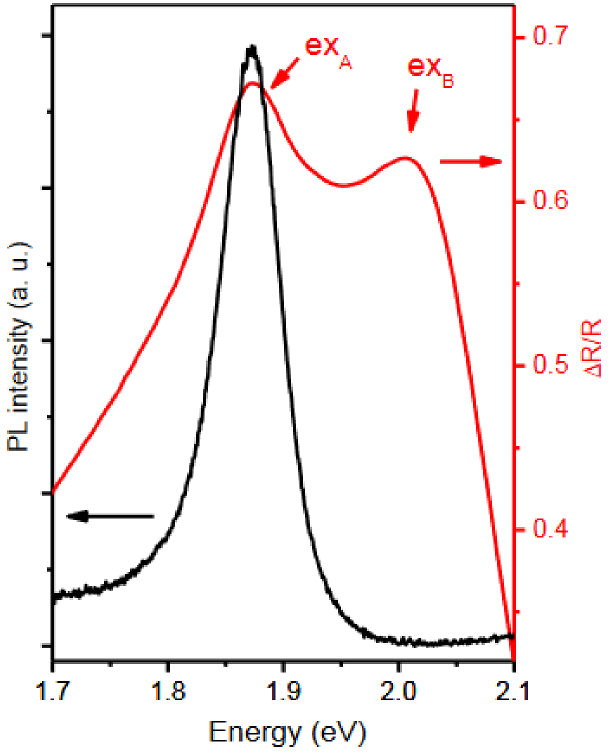
Polaritons



Observations

Experiment : Light–matter coupling

System characterization

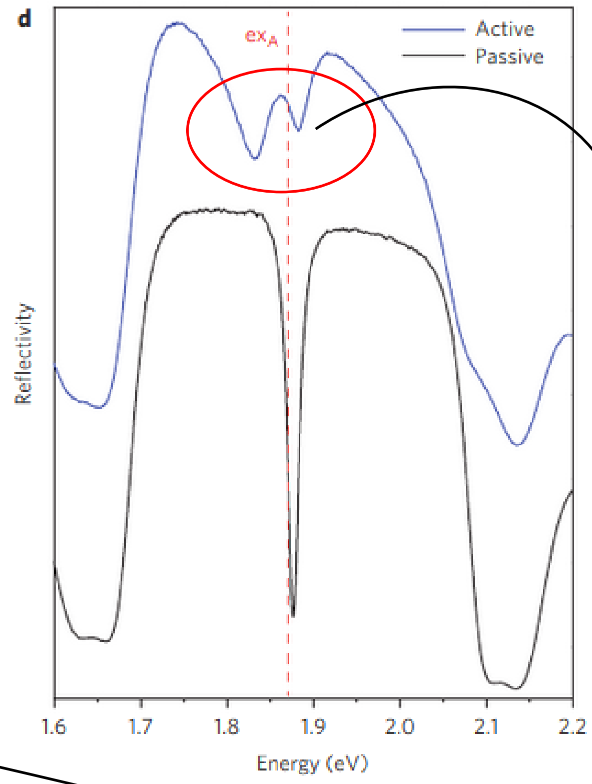


ExA's experiment

Passive : no monolayer experiment

Active : monolayer experiment

ExA excitation



Two excitons for the cavity : A and B

- A is the only one excited and emitting
- **Exciton A is of interest**

Two distinct dips, energetically shifted : indicating the presence of new eigenstates -> polariton states ?

Model - Explanation

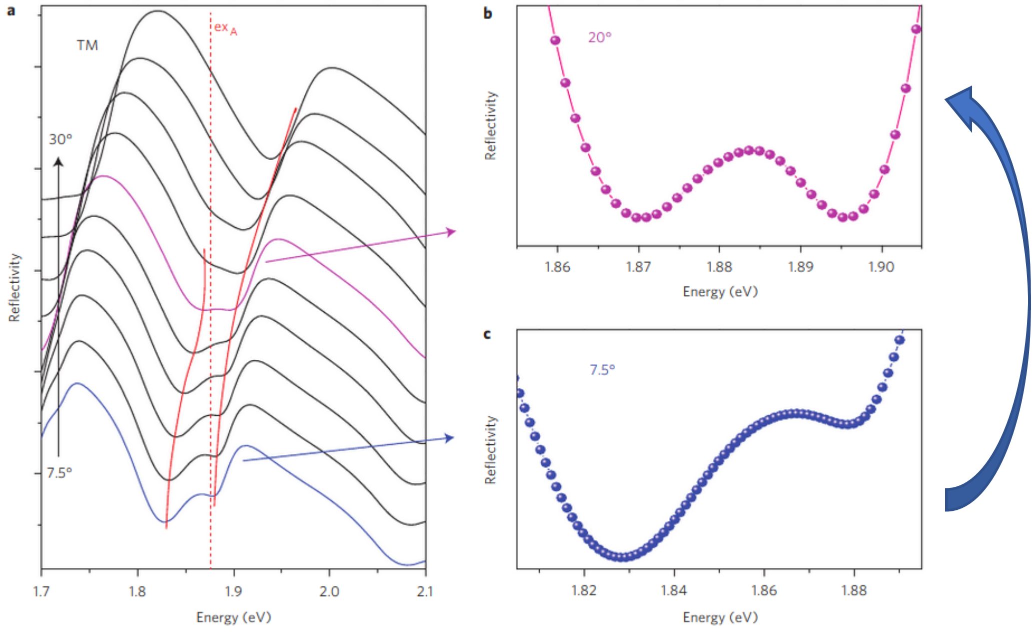
Validation of polaritons state and strong coupling

Model for **polaritons dispersion** : **eigenstates α** and **β**

$$\begin{pmatrix} E_{cav}(\theta) + i\hbar\Gamma_{cav} & V_A \\ V_A & E_{ex} + i\hbar\Gamma_{ex} \end{pmatrix} \begin{pmatrix} \alpha \\ \beta \end{pmatrix} = E \begin{pmatrix} \alpha \\ \beta \end{pmatrix}$$

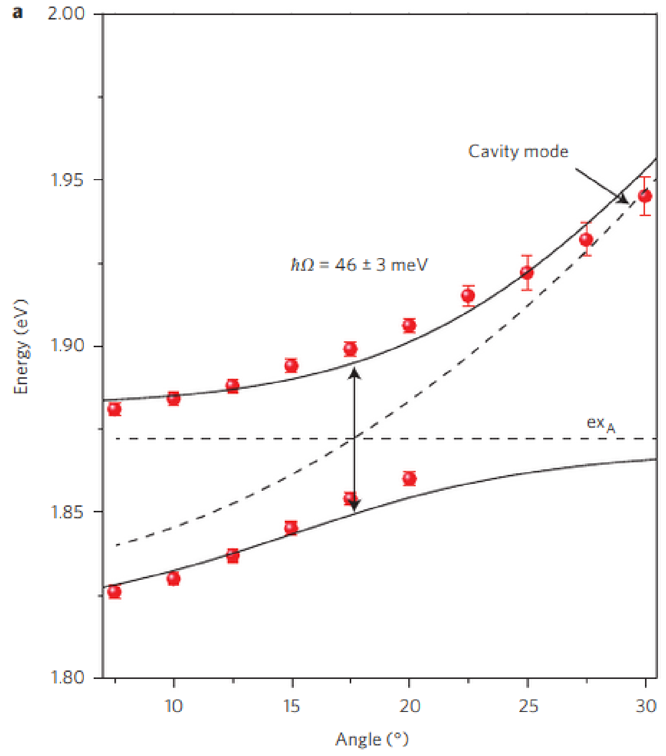
Consistent with model? Analyze how the states change

Lower Polarization Branch and Upper Polarization Branch



LPB vanishes,
UPB moves away

Fit of the polariton branches (dots) using a coupled oscillator theoretical model (black continuous lines)

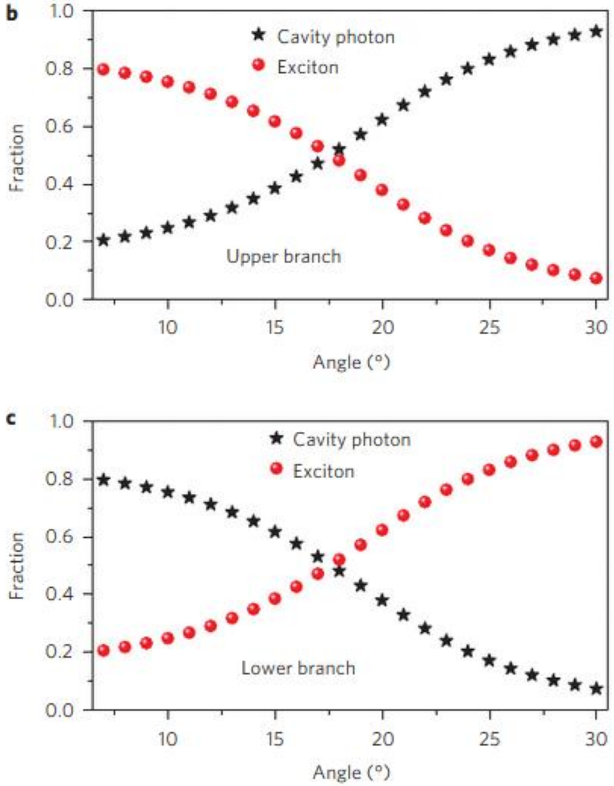


The experimental data fit the polariton model:

- One branch (LPB) tends to the exciton A energy
- The other (UPB) tends to the cavity mode
- **The polariton** : a **mix of exciton and cavity mode**

Interpretation of eigenstates α and β

α and **β** construct the eigenvector : **weighting coefficients** of the **cavity photon** and **exA** for each polariton state

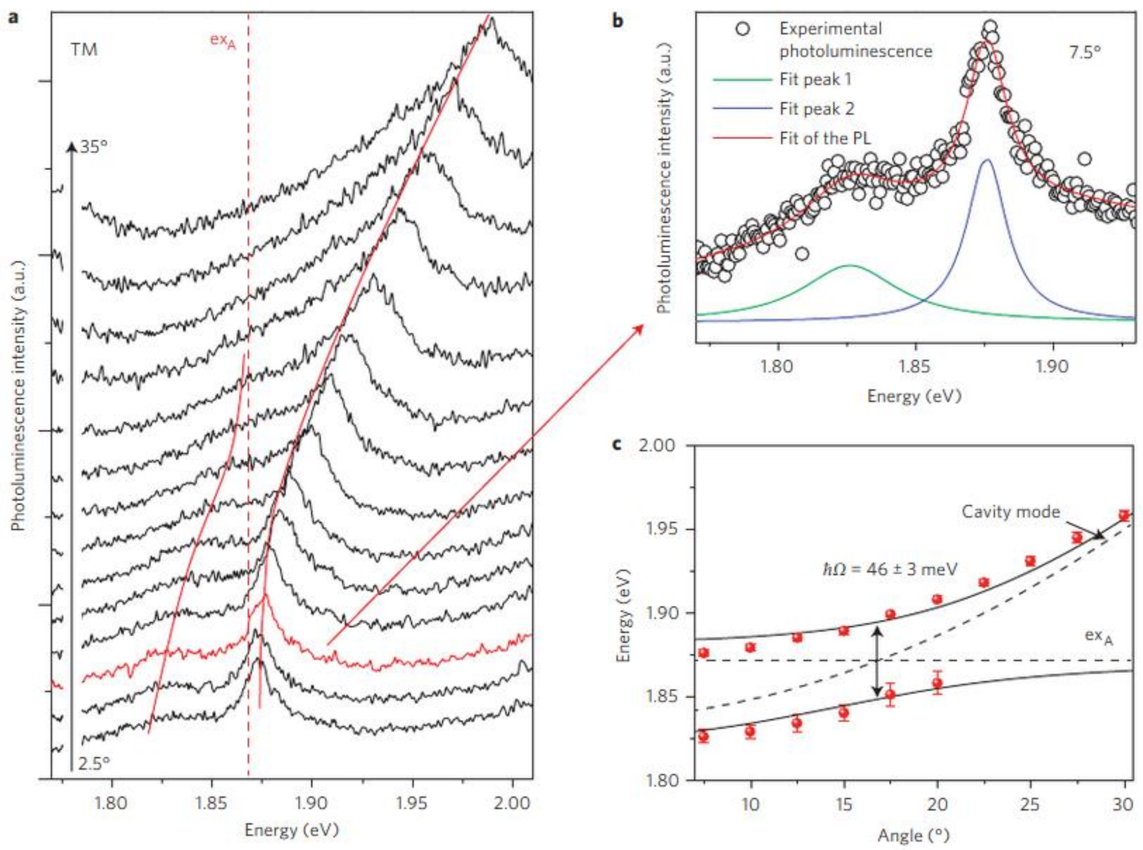


UPB

LPB

Polaritons : at the same time matter and light but with different proportions α and β

Consistency of the Photoluminescence



The peaks behave in the same way as the previous dips :

- The more the polariton states **tend to an optical component**, the **higher** the intensity of **photoluminescence**

Same relations are found with the model

Conclusion

Conclusion

- $\mathbf{MoS_2}$ shows excellent properties and is suitable for application
- **Polaritons** exhibits both **light and matter** properties
- The proportions of light and matter is tunable (take the best of both)
- For the first time strong-coupling regime is observed
- Applications : logic gates, spin switches