Nanoscale Chemical Characterization of Novel Semiconductor Materials using Tip-enhanced Optical Spectroscopy

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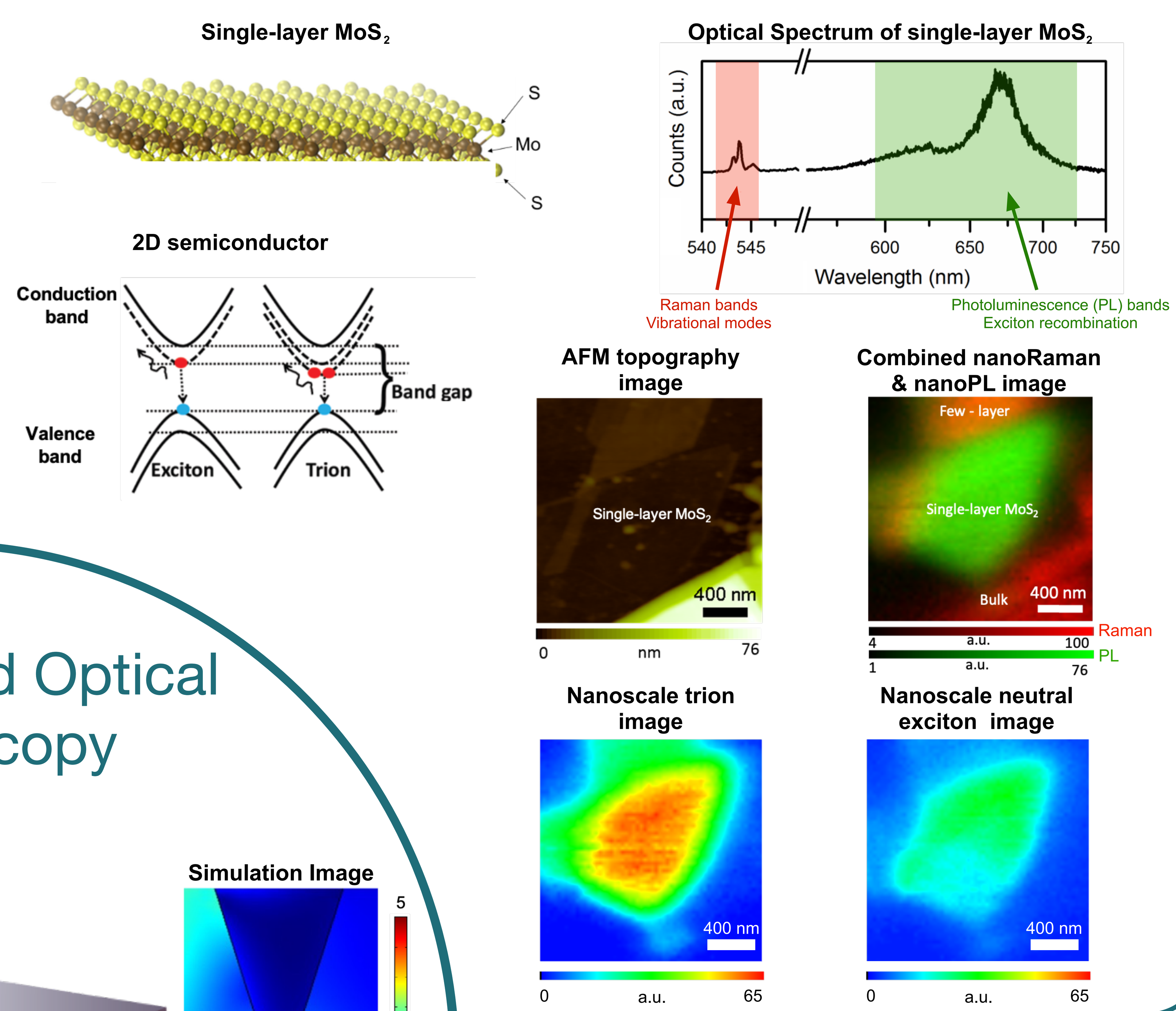
Introduction

Herein, I present an overview of our fundamental research on the development of tip-enhanced optical spectroscopy (TEOS) [1] and its application to the nanoscale investigation of two classes of novel semiconductor materials: two-dimensional (2D) transition metal dichalcogenides (TMDs) and organic photovoltaic (OPV) devices.

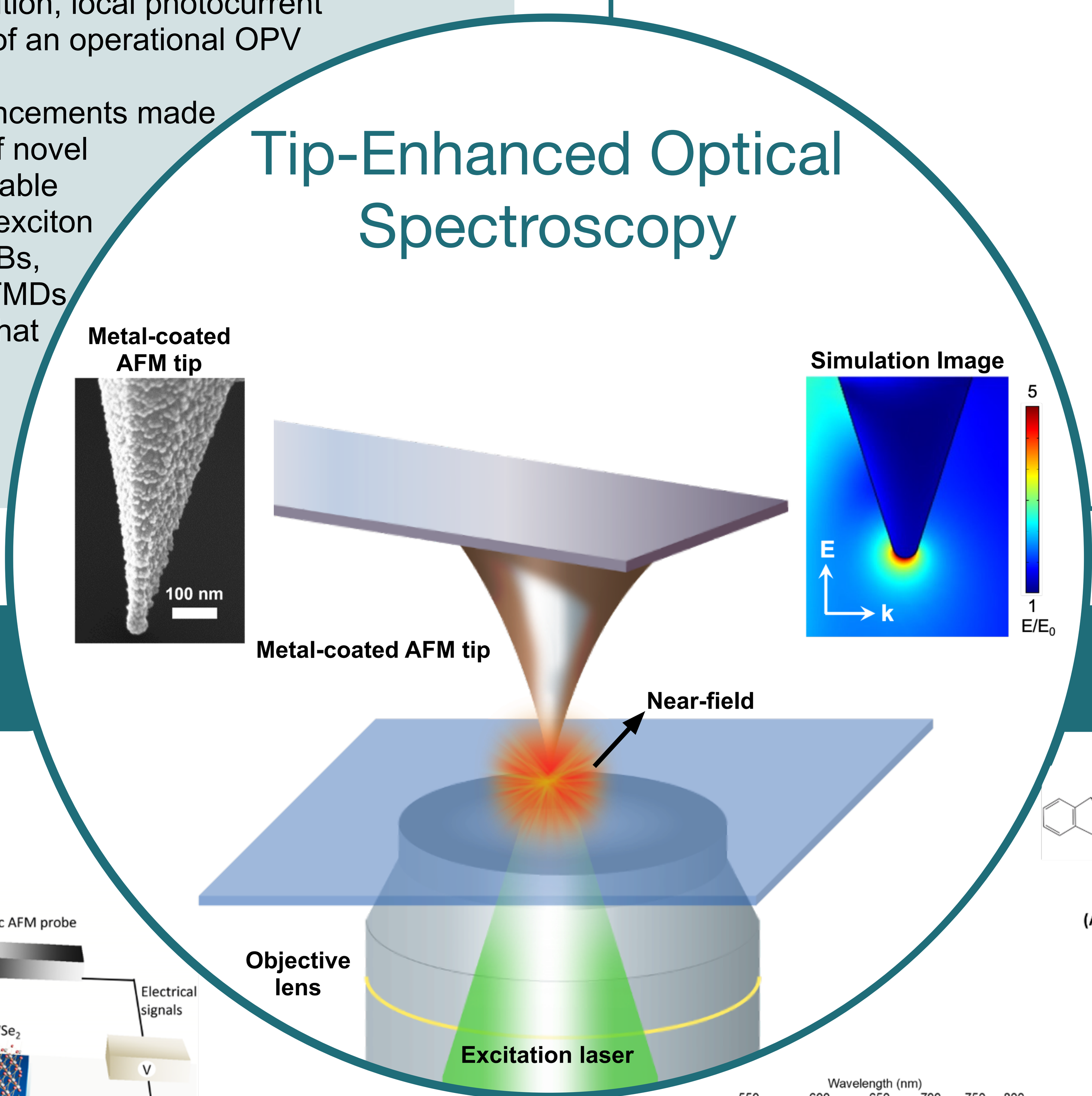
In 2D TMDs, we demonstrate the application of hyperspectral TEOS imaging to investigate local excitonic processes in single-layer (1L) MoS_2 and WSe_2. Exciton and trion populations in 1L MoS_2 were mapped with an unprecedented spatial resolution of 20 nm [2]. Furthermore, we combined TEOS with Kelvin probe force microscopy (KPFM) to reveal the optoelectronic properties of grain boundaries in merged 1L WSe_2 sheets with 50 nm resolution [3]. For OPV devices, we introduced a novel methodology called simultaneous topographical, electrical, and optical microscopy by combining TEOS with photoconductive (PC)-AFM [4]. This approach enabled the simultaneous measurement of topography, chemical composition, and photoelectrical properties with sub-20 nm resolution and revealed correlations between surface and subsurface molecular distribution, local photocurrent generation, and macroscopic device performance of an operational OPV device.

The significance of our research lies in the advancements made in nanoscale characterization and understanding of novel semiconductor materials. Our findings provide valuable insights into excitonic processes, heterogeneity of exciton and trion populations, optoelectronic behavior of GBs, and the structure-property relationships in the 2D TMDs and OPV semiconductor materials. We anticipate that our research on the advancement of novel nanoanalytical technologies will facilitate the development of next-generation optoelectronic devices and OPV technologies.

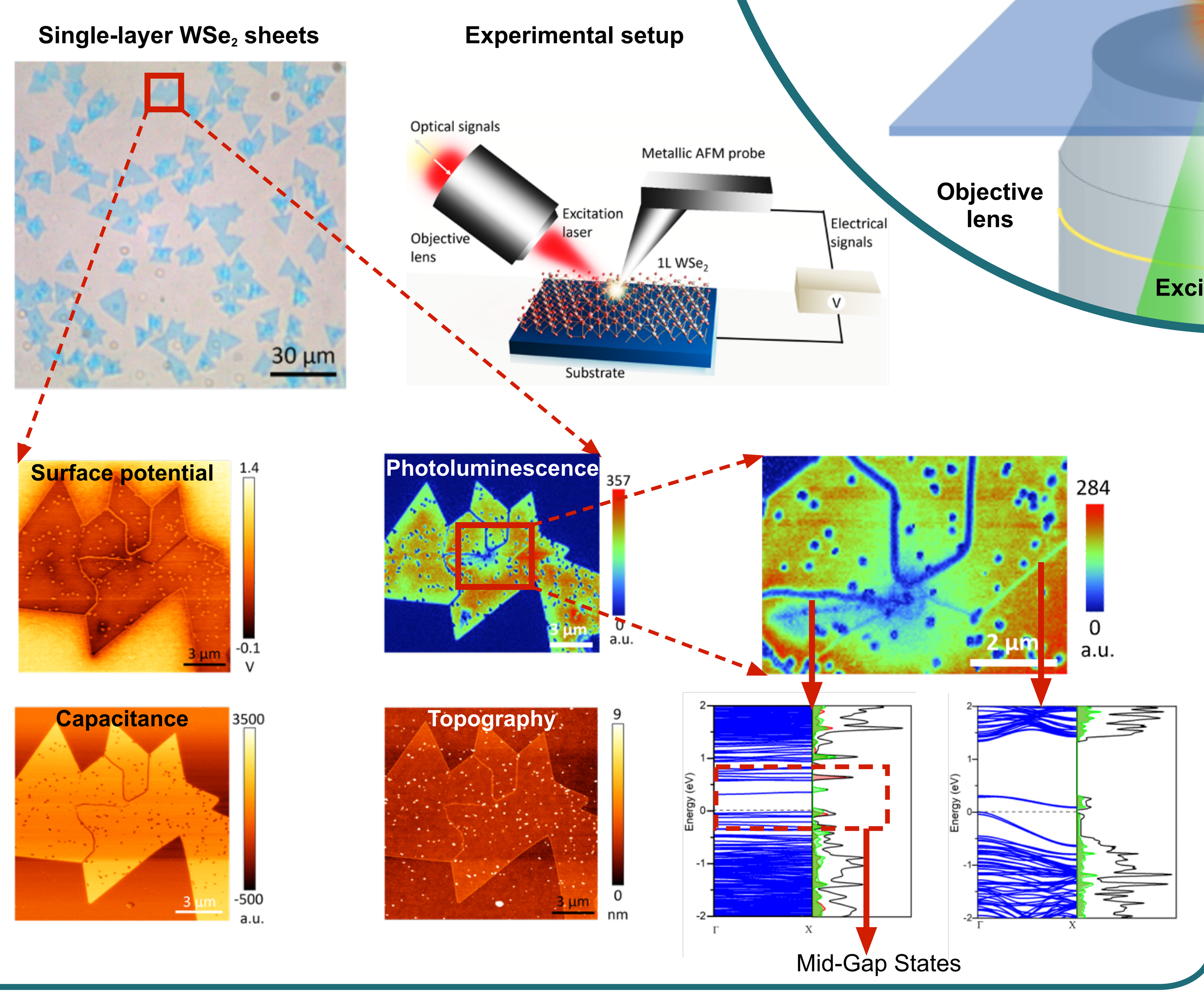
Nanoscale Imaging of Excitonic Processes in 2D Semiconductors



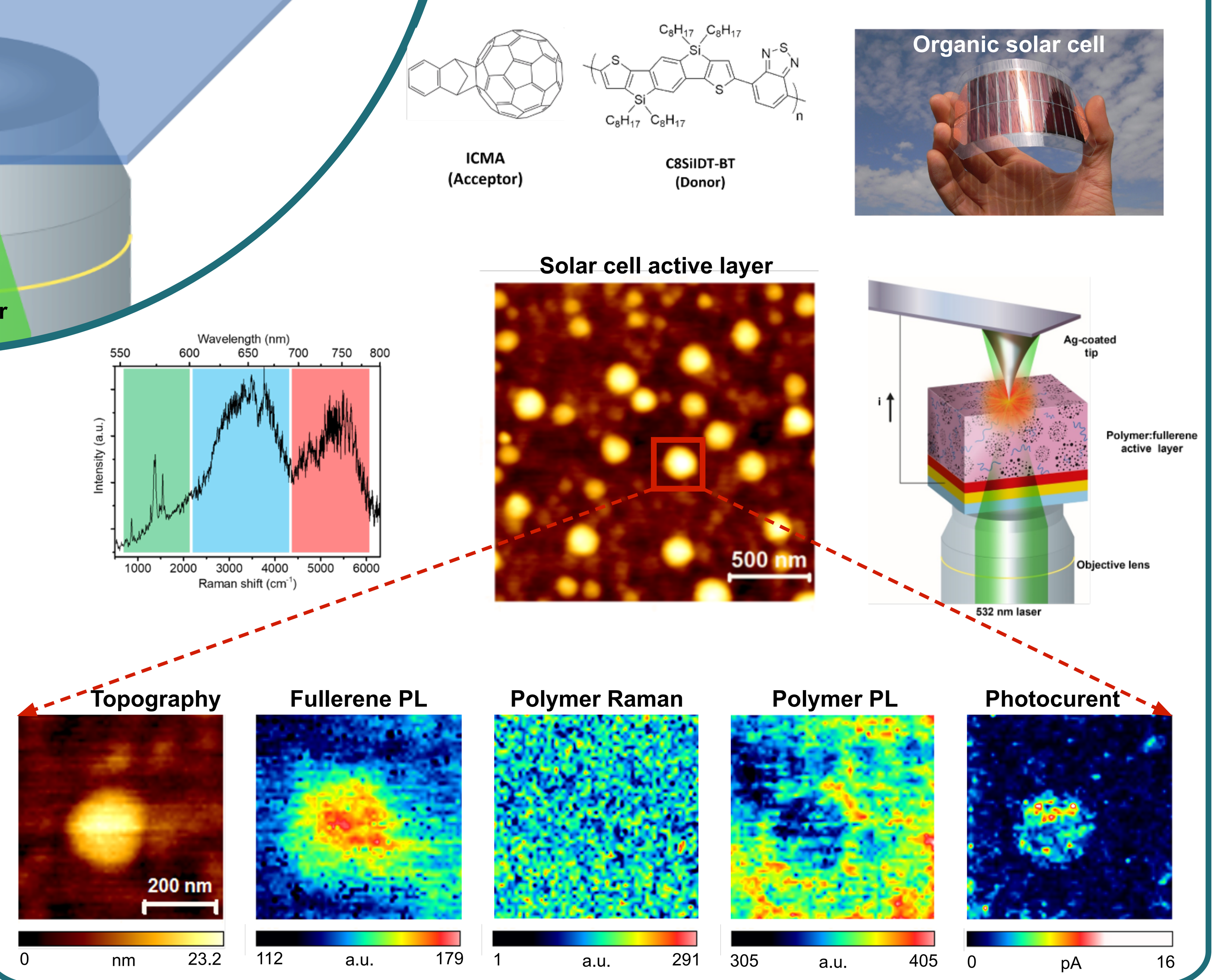
Tip-Enhanced Optical Spectroscopy



Nanoscale Investigation of Grain Boundaries in 1L WSe_2



Simultaneous Topographical, Electrical & Optical Microscopy (STEOM)



Conclusions

- Significant advancements made in development of non-destructive and label-free nanoimaging under ambient conditions and its application to 2D and organic semiconductor materials.
- In 2D semiconductors, combination of TEOS with KPFM allowed in situ topographical, photoluminescence, Raman and electrical imaging at the nanoscale revealing novel insights into the local excitonic and optoelectronic properties.
- In organic semiconductors, combination of TEOS with PC-AFM allowed simultaneous topographical, electrical, and optical microscopy of operating solar-cells providing 3D surface chemical information at the nanoscale. Macroscopic performance could be understood in terms of the nanoscale characteristics of the organic solar cell.
- Development of these cutting-edge nanoanalytical tools is expected to accelerate the realization of the next-generation optoelectronic devices and organic photovoltaic technologies.

References

[1] Kumar et al., Nature Protocols, 2019, 14, 1169-1193.
[2] Su and Kumar et al., Nanoscale, 2016, 8, 10564-10569.
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[4] Kumar et al., Nanoscale, 2017, 9, 2723-2731.

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