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Colloidal synthesis of alloyed monolayers of transition metal dichalcogenides

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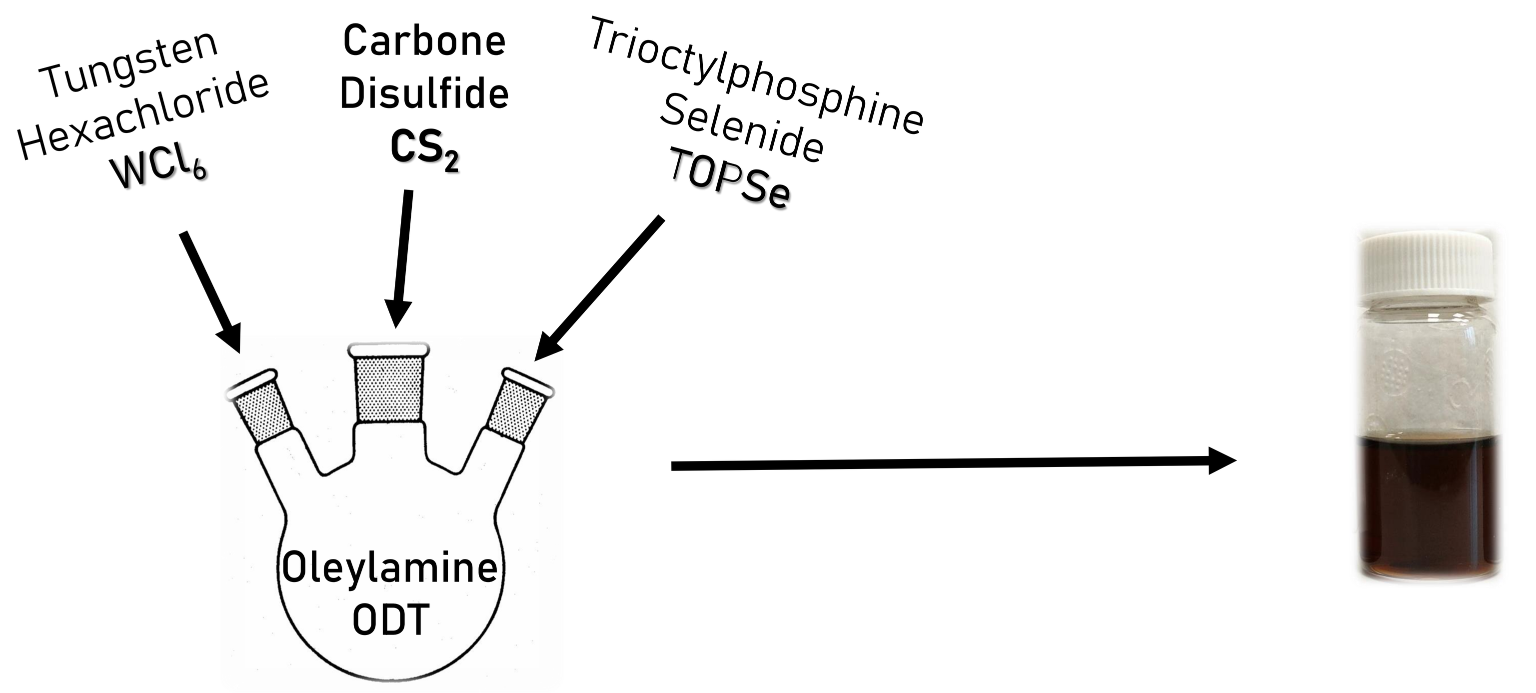
Introduction

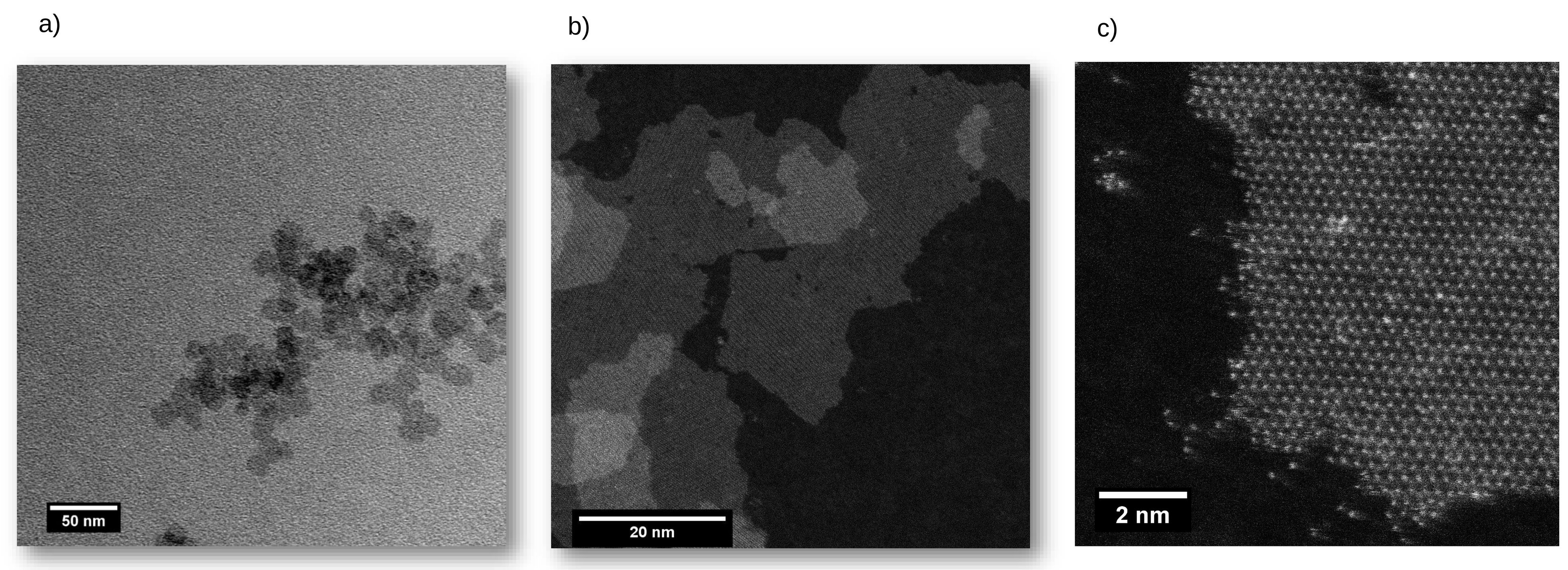
The bandgap tunability of two-dimensional (2D) transition metal dichalcogenides (TMDCs) makes them one of the best candidates in the domain of optics and electronics. This ability to tailor bandgap is accessible by alloying [1]. In this regard, most of the work has been conducted by using high-temperature chemical vapour deposition or molecular beam epitaxy techniques. We adopted a different low-temperature colloidal synthesis strategy as an efficient alternative to these previous methods. Two classes of alloys of TMDC using group VI transition metals and chalcogens are generally studied: one with varied composition of transition metals ($W_{(1-x)}Mo_{(x)}S_2$ or $W_{(1-x)}Mo_{(x)}Se_2$) and the other with varied composition of chalcogens ($MoS_{2(1-x)}Se_{2x}$ or $WS_{2(1-x)}Se_{2x}$). Due to their band structure and band gap position, each alloy exhibits special properties. Because these 2D materials can have 2 different phases, phase engineering is also important, and can significantly change their properties between the 1T (metallic) to the 2H (semiconducting) phases [2].

1- Colloidal synthesis



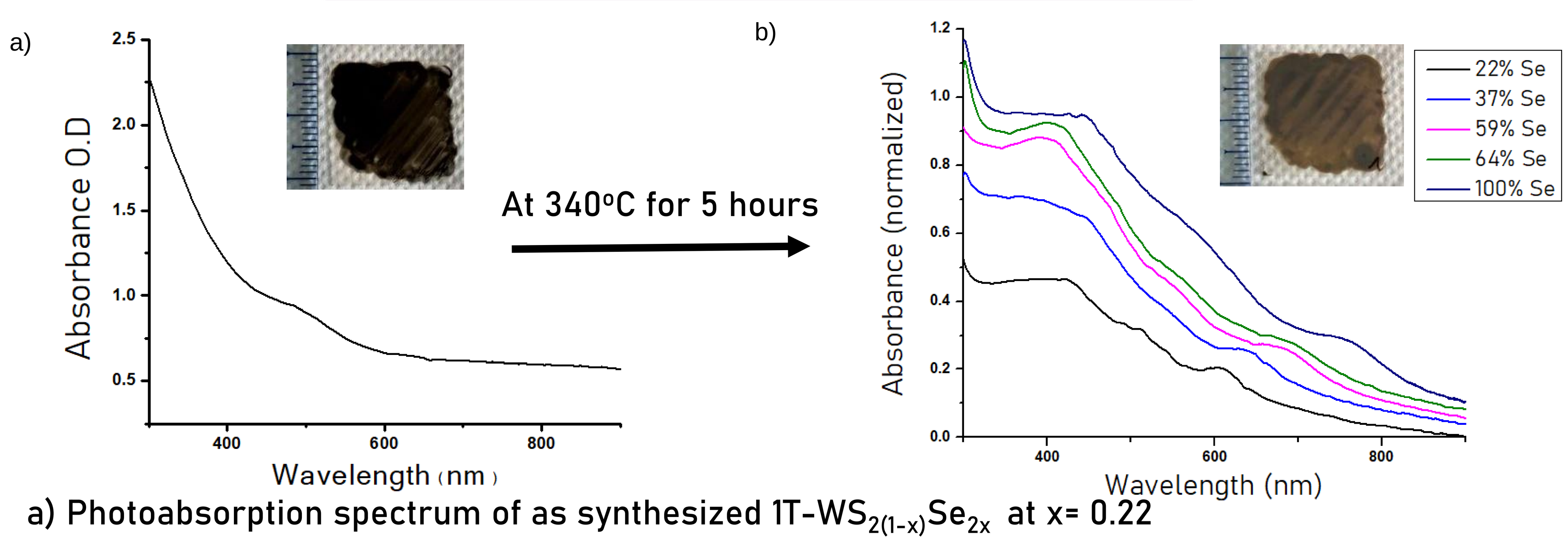
The synthesis method is thermal decomposition of precursor in a high boiling point solvent.

2- TEM and HRSTEM



a) TEM image of well-dispersed monolayers and multilayers of 1T-$WS_{2(1-x)}Se_{2x}$ at x=0,59.
b) The HRSTEM image of alloy of monolayers, bilayers, and three-layers of 1T-$WS_{2(1-x)}Se_{2x}$ at x=0.37.
c) The HRSTEM image of alloy of monolayers of 1T-$WS_{2(1-x)}Se_{2x}$ with low defect density. x= 0.37

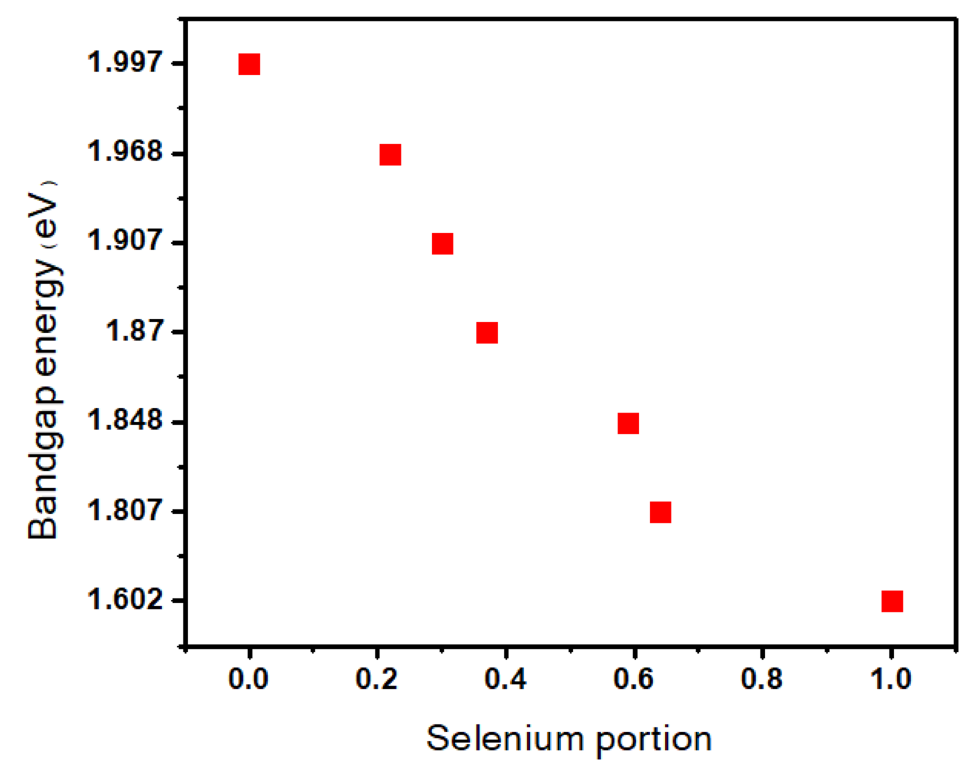
3- Optical spectroscopy



a) Photoabsorption spectrum of as synthesized 1T-$WS_{2(1-x)}Se_{2x}$ at x= 0.22

b) Photoabsorption spectrum of 2H-$WS_{2(1-x)}Se_{2x}$ with different amount of selenium in the final product, the change in the first excitonic peak position confirms the change in the amount of selenium in the alloys. The phase change happened by annealing the sample at 340°C.

4- Bandgap engineering



The bandgap energy depends on the amount of selenium in the final product.
The bandgap energy has been measured from position of first excitonic peak.

Conclusion

To conclude, a direct colloidal method to synthesize well-dispersed nanosheets of the whole range of alloys of $WS_{2x}Se_{2(1-x)}$ with 1T' structure was developed. The colloidal synthesis we developed can form stable monodisperse round-shaped alloys with 1T' structure. The ability to tailor the structure from 1T' to 2H helps us to control the structure during the synthesis between a semiconducting and a metallic phase. Photoabsorption spectroscopy approved the 1T' and 2H structure of the nanosheets before and after annealing, respectively. The exact composition of the final product has been checked with EDX and the results are favorable with the change in the position of the first excitonic peak from photoabsorption spectrum of 2H phase nanosheets. TEM images represent the well-dispersed monolayers with different size and HRSTEM reveals the nanosheets are monolayers with 1T' structure.

Future work

The control on the structure and the mean size of well-dispersed monolayers makes these nanosheets a promising candidate for catalysis, optoelectronics, and photovoltaics.

Acknowledgements

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