Enriching the library of axial superlattice nanowires

Li Zhai^{1,2}, Zijian Li¹ and Hua Zhang^{1,2,3*}

Integrating functional materials to form heterostructures with novel, sophisticated architectures has attracted extensive interest in chemistry and materials science [1]. Heterostructures are expected to exhibit superior electrical, thermal, optical and magnetic properties due to the synergistic effect of their different components. Therefore, the rational design and preparation of heterostructures with controlled compositions, dimensions, crystal phases, spatial arrangements and interfaces are very important for their unique physiochemical properties and promising applications. As known, epitaxial growth has emerged as a versatile strategy to control the growth of various novel heterostructures [2,3]. In particular, it has been proved to be effective for the phase engineering of nanomaterials (PEN), which brings about a library of novel crystal phase-based heterostructures [4]. However, components in epitaxial heterostructures are still limited since a small lattice mismatch between them is normally required during the epitaxial growth. To further enrich the library of heterostructures, the combination of epitaxial growth and cation exchange reaction has been proved as an ideal strategy to rationally construct phase-segregated heterostructures with tunable components and interfaces, which could allow the large lattice-mismatch between different components.

Very recently, Yu and coworkers [5] from the University of Science and Technology of China rationally constructed a library of one-dimensional axial superlattice nanowires (ASLNWs) (Fig. 1a). Through integrating axially epitaxial growth with precisely controlled cation exchange reactions, one-dimensional heterostructures with various components and tunable sizes have been obtained [6].

Inspired by their previous work on the colloidal synthesis of quantum-dots-in-nanowires [7], Yu and coworkers finely tuned the structure of axially epitaxial CdS-ZnS nanowires *via* the pulsed axial growth strategy.

Figure 1 (a, b) Schematics of one-dimensional axial superlattice nanowire (a) and regioselective axial encoding strategy to produce a library of ASLNWs (b). Reprinted with permission from Ref. [5]. Copyright 2021, American Chemical Society.

These one-dimensional CdS-ZnS heterostructures were further used for the predesigned cation exchange reactions, and ultimately transformed into a library of highly controlled ASLNWs, including Cu_{1.8}S-ZnS, Ag₂S-ZnS, Co₃S₄-ZnS, Ni₃S₄-ZnS, PbS-ZnS, HgS-ZnS, CuInS₂-ZnS and CuSnS₂-ZnS (Fig. 1b). Metal chalcogenides with plasmonic, electrocatalytic, or near-infrared-active properties were integrated into the ASLNWs to improve the

¹ Department of Chemistry, City University of Hong Kong, Kowloon, Hong Kong, China

² Hong Kong Branch of National Precious Metals Material Engineering Research Center (NPMM), City University of Hong Kong, Hong Kong, China

³ Shenzhen Research Institute, City University of Hong Kong, Shenzhen 518057, China

* Corresponding author (email: hua.zhang@cityu.edu.hk)

charge-separation efficiency in photocatalytic hydrogen reactions. As a proof-of-concept application, the precisely tailored $\text{Cu}_{1.8}\text{S}$ -ZnS ASLNWs exhibited a remarkable photocatalytic hydrogen production rate.

This work has demonstrated an encoding strategy to synthesize a new class of highly ordered and sophisticated one-dimensional heterostructures, i.e., ASLNWs, which could attract much attention in the chemistry and material communities.

Received 20 May 2021; accepted 27 May 2021;
published online 9 June 2021

1 Carbone L, Cozzoli PD. Colloidal heterostructured nanocrystals:

- Synthesis and growth mechanisms. *Nano Today*, 2010, 5: 449–493
- 2 Tan C, Chen J, Wu XJ, *et al.* Epitaxial growth of hybrid nanostructures. *Nat Rev Mater*, 2018, 3: 17089
- 3 Li X, Zhang Y, Zhai L, *et al.* Rational synthesis of 1D hyperbranched heterostructures with enhanced optoelectronic performance. *Angew Chem Int Ed*, 2021, 60: 3475–3480
- 4 Chen Y, Lai Z, Zhang X, *et al.* Phase engineering of nanomaterials. *Nat Rev Chem*, 2020, 4: 243–256
- 5 Li Y, Zhang C, Zhuang TT, *et al.* One-dimensional superlattice heterostructure library. *J Am Chem Soc*, 2021, 143: 7013–7020
- 6 Li Y, Zhuang TT, Zhang C, *et al.* Axially segmented semiconductor heteronanowires. *Acc Mater Res*, 2020, 1: 126–136
- 7 Li Y, Zhuang TT, Fan F, *et al.* Pulsed axial epitaxy of colloidal quantum dots in nanowires enables facet-selective passivation. *Nat Commun*, 2018, 9: 4947