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Engineering vertical heterostructure of Bi_2Se_3-VSe_2: A novel wet chemical synthetic approach

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Owing to the combined advantageous property and emergence of non-trivial features, vertical heterostructures based on layered two dimensional (2D) materials have been extensively explored in micro/nano electronics,1 opto-electronic devices,[1] and catalysis.[2] Due to van der Waal interaction between the layers, layered materials can be stacked in desired sequences with required properties. Tailoring the property of layered materials chalcogenides via heterostructure formation are promising for both band alignment engineering and improvements of existing applications and also for the discoveries of completely new phenomena.

Both VSe_2 and Bi_2Se_3 belongs to the class of layered materials. Crystallographically, VSe_2 has Se-V-Se layers and Bi_2Se_3 has quintuple Se-Bi-Se-Bi-Se layers and are held together by van der Waal forces. From electronic point of view, individually VSe_2 is semi-metallic in nature and Bi_2Se_3 is a well-known topological insulator. Recently, Sinkovic et. al. have shown the emergence of flat band on formation of heterostructure based on VSe_2- Bi_2Se_3.3 The flat band electronic states are predicted to achieve various quantum states of matter at high temperature such as high temperature superconductivity,[4] fractional quantum hall effect[5] and ferromagnetism.[6] However, synthesis of such heterostructure via a facile wet-chemical method is challenging in terms of obtaining high quality crystals. Herein, using microwave method we have synthesized Bi_2Se_3 nanosheets and Schlenk line method has been used to synthesize single crystalline VSe_2 nanosheets. Further, we have extended our Schlenk line method to synthesize Bi_2Se_3-VSe_2 vertical heterostructure, using the Bi_2Se_3 nanosheets as template.

Synthesized nanostructures are characterized using different techniques. Microstructural characterization has been performed using (scanning)-transmission electron microscopy ((S)- TEM). Figure 1(a) shows low-magnification bright-field TEM micrograph of Bi_2Se_3 nanosheets and corresponding SAED pattern is shown in figure 1(b). Regular hexagonal pattern and single diffraction spots reveals the single crystalline nature of as-synthesized Bi_2Se_3 nanosheets. Figure 1(c, d) shows microstructure of as-synthesized VSe2 nanosheets. Low-magnification bright-field TEM micrograph of VSe_2 is shown in figure 1(c) which shows the ultra-thin sheet morphology of VSe_2 nanostructure. Diffraction pattern shown in the figure1(d) shows the single crystalline nature of the nanosheets. Figure 2 shows the microstructures of as-synthesized Bi_2Se_3-VSe_2 heterostructures. SEM micrograph of the heterostructure reveals the formation of sheets as shown in figure 2(a). Low-mag bright field transmission electron microscope image of heterostructure is shown in figure 2(b) showing the formation of VSe_2 sheets over regular hexagonal Bi_2Se_3. Corresponding SAED pattern as shown in figure 2(c), reveals the double diffraction pattern with regular hexagonal pattern around each primary spots indicating the formation of vertical heterostructures. In order to further confirm the heterostructure formation HAADF-STEM imaging was performed. Figure 2(e) shows the HAADF-STEM micrograph and elemental distribution map of V, B, Se. The elemental map confirms the presence of all three elements Bi, V and Se through-out the heterostructure with the atomic percent ratio close to 24:12:64 showing the formation of heterostructure with 1:1 ratio of Bi_2Se_3 and VSe_2. Similarly, these wet chemical synthetic approaches could be further extended to synthesize large number of heterostructures using two different 2D layered materials.

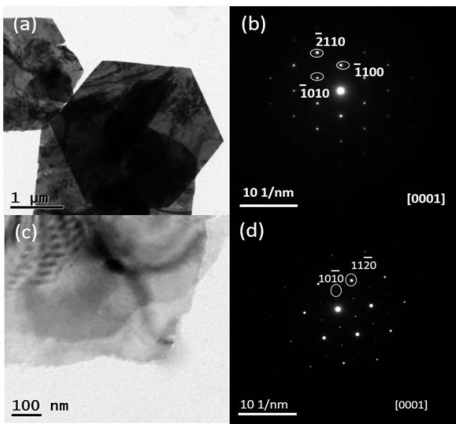

Figure 1. Microstructural characterization of Bi_2Se_3 and VSe_2. (a, and b) Low-mag bright-field TEM micrograph and corresponding SAED pattern of Bi_2Se_3 respectively; (c, and d) Low-mag bright-field TEM micrograph and corresponding SAED pattern of VSe_2.

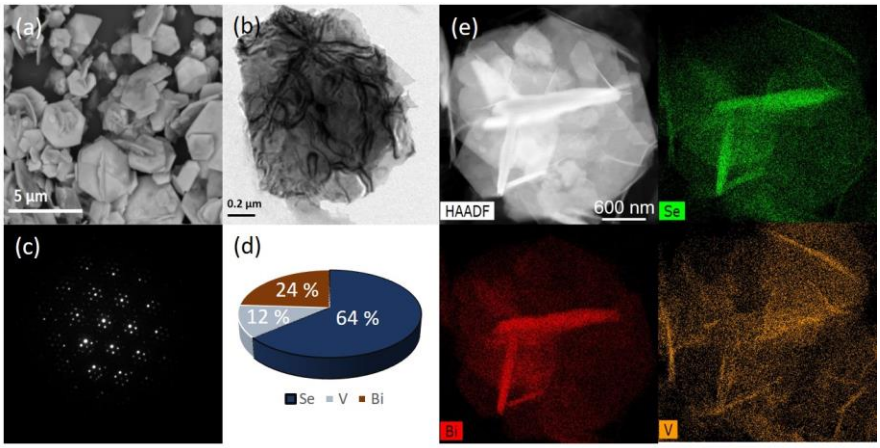

Figure 2. Microstructural characterization of Bi_2Se_3-VSe_2 heterostructure. (a, b, and c) SEM micrograph, low-mag bright-field TEM micrograph and corresponding SAED pattern of heterostructure showing double-diffraction pattern respectively; (d) pie chart showing the elemental composition of Bi, V and Se in the heterostructure; (e) HAADF-STEM micrograph and elemental distribution map of Bi, V, and Se in the heterostructure.

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