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Photocatalytic properties of shape-controlled ultra-long elemental Te nanowires synthesized via a facile hydrothermal method

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ABSTRACT

Herein, we report the synthesis of high-quality, shape-controlled, single crystalline, ultra-long Te nanowires (NWs) via a facile hydrothermal method. Based on micro-structural investigation, the most preferential growth direction of as-grown Te NWs was found to be along the *c*-axis. The as-synthesized Te NWs acted as potential catalysts to efficiently decompose organic toluidine blue O (TBO) dye (95%) within 1 h under ultraviolet (UV) light irradiation at room temperature. Additionally, when compared with the bulk form, ultra-long Te absorbs not only UV light, but also visible light at ~720 nm, indicating that ultra-long Te NWs may be able to utilize the full solar spectrum with a further decrease in size.

1. Introduction

Organic pollutants are a major global problem. A great deal of attention has been focused on developing high-efficiency photocatalysts. Most of the materials used in such photocatalysts function well only under UV light, while the conductivity, specific surface area, and surface properties of these materials vary [1]. An efficient photocatalyst must enable the electron to transfer in the appropriate amount of time, which means that high conductivity is vital. In order to contact pollution-causing organics, the photocatalyst material must have a high surface area. Finally, because of the pollution degradation that occurs, aqueous solution photocatalysts must exhibit good dispersibility in water [2].

Elemental tellurium is a well-known p-type semiconductor with a narrow-band gap of 0.35 eV, and has been considered an excellent candidate for future applications such as high-efficiency photoconductors, thermoelectric devices, and piezoelectric devices [3]. The anisotropic crystal structure and covalently-bonded atoms of elemental Te lead to the formation of unique helical chains. These chains are bound through weak van der Waals interactions and form hexagonal lattices [4]. This anisotropic crystal structure favors the easy formation of 1D Te nanostructures [5,6]. To date, significant progress has been made in the development of 1D Te nanostructures, including Te nanotubes, nanorods, NWs, and nanobelts through a variety of techniques [7a–e]; however, there is little application-oriented research based on elemental Te NWs. Semimetal Te has good photoconductive, electrical and FET properties [8,9], indicating the potential for excellent photoconductive properties with good light-absorbing capability. Researchers are currently interested in elemental nanostructures such as gold (Au) and silver (Ag); as well as embedded matrices such as Au-zeolite, Ag-zeolite, Au-TiO_2 and Au-ZrO_2 for enhanced photocatalytic applications across the entire solar spectrum [10]. Like Ag and Au nanocrystals, Te shows unusual behavior at the nanoscale, such as a high reactivity and good absorption in the UV and visible regions, as well as being easy to combine with zeolite systems [11]. The NWs we synthesized in the present study are ultralong, while most NWs are less than 20 nm in diameter and provide extremely high specific surface area. The Te NWs we fabricated exhibit impressive dispersibility in natural conditions, due to the high electronegativity and sufficient dangling bonds on the NW surfaces, which allow organic pollutants to closely contact the photocatalytic surfaces [5]. Based on these properties, we investigated the photocatalytic properties of ultra-long Te NWs under UV light. Based on our UV–vis spectral analysis, Te NWs show potential to function in the visible region of sunlight.

2. Experimental

Materials: Sodium tellurite (Na_2TeO_3), polyvinyl pyrrolidone (PVP), ammonium hydroxide (NH_4OH, 28%), and hydrazine hydrate (N_2H_4) were purchased from Aldrich and used without further purification.

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Synthesis: A standard Na_2TeO_3 reduction process using hydrazine hydrate was followed for the synthesis of Te NWs [7d,12]. Initially, PVP (0.2 mg) and Na_2TeO_3 (0.1 mg) were dissolved in deionized water. To this clear solution, 1 ml of N_2H_4 and 2 ml of $NH_4 \cdot H_2O$ were added and subjected to mild magnetic stirring. We took care to avoid the formation of Te through vigorous stirring, which led to the pre-nucleation and growth of particles. The autoclave containing the reaction mixture was placed into an oven and allowed to reach 180 °C at a rate of 5 °C/min. The reaction was carried out for 3 h, and the solution was allowed to cool naturally to room temperature. The Te NWs obtained exhibited high dispersibility in water (were highly hydrophilic) [13]; the precipitated NWs were washed several times with ethanol and water. The purified product was subjected to drying at 60 °C under vacuum.

Photocatalytic measurement: The photocatalytic reaction solution was prepared by adding Te NW powder (25 mg) to 50 ml of 0.05 mM TBO aqueous solution. First, the solution was stirred magnetically in the dark for 30 min to equilibrate the adsorption–desorption process of TBO. After the adsorption–desorption process, 3 ml of the solution was removed for analyses using a UV–vis spectrophotometer. Te catalyst-treated TBO solution (3 ml) was removed at regular intervals (10 min) and centrifuged to separate the catalyst NWs from the solution.

3. Results and discussion

Fig. 1(a–c) shows FE-SEM images of as-grown, ultra-long Te NWs obtained from hydrothermal reaction at various magnifications. The average diameter and length of the as-grown Te NWs were ~30 nm and ~100 μm, respectively. The aspect ratio of the as-synthesized NWs was 10^4.

The TEM image of a Te NW is shown in Fig. 2a. The NW surface is smooth. The indexed selected area electron diffraction (SAED) and HRTEM are shown in Fig. 2b and c, respectively. The index of the spots in the SAED pattern clearly indicates that the Te NWs have single crystalline structure and predominantly grew along the [001] direction. The difference between spot diameters may be

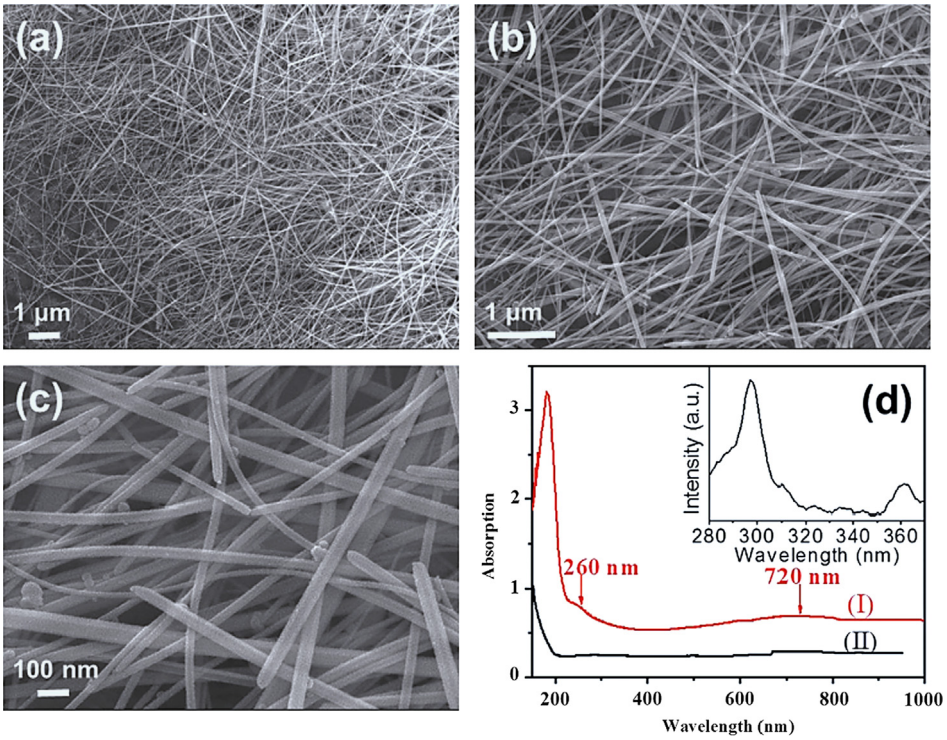

Fig. 1. (a), (b) and (c) As-grown, high-density, ultra-long Te NWs at various magnifications respectively, and (d) UV–vis spectrum of (a) bulk Te and (b) Te NW grown via hydrothermal method (inset shows the fluorescence spectrum).

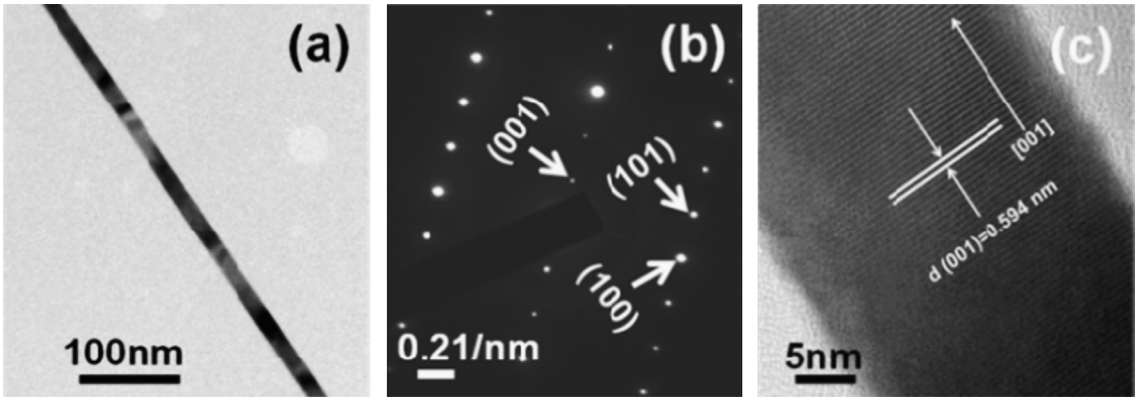

Fig. 2. (a) TEM image of an isolated Te NW, (b) SAED, and (c) HRTEM images showing individual NWs with [001] growth direction.