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Influence of lead concentration on morphology and optical properties of Pb-doped ZnO nanowires

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Abstract

Undoped and Pb-doped ZnO nanowires with different lead concentrations were grown on Si(111) substrates using a thermal evaporation method. Scanning electron microscopy (SEM) results showed that, the undoped ZnO nanowires were well aligned with uniform diameters and lengths. On the other hand, the Pb-doped ZnO nanowires were tapered and not aligned in a unique direction. X-ray diffraction patterns and Raman measurements clearly indicated hexagonal structures for all of the products. In addition, the Raman results demonstrated that the Pb-doped ZnO nanowires had a lower crystalline quality than the undoped ZnO nanowires. Photoluminescence (PL) studies also confirmed the Raman results and showed a lower optical property for the Pb-doped ZnO nanowires compared to the undoped ZnO nanowires. Moreover, the PL results showed a smaller band-gap for the Pb-doped ZnO nanowires compared to the undoped ZnO.

Keywords: C. Optical properties; Pb-doped ZnO nanowires; Thermal evaporation

1. Introduction

Zinc oxide (ZnO) is an n-type metal oxide semiconductor with a wide band-gap (3.36 eV) and large exciton binding energy (60 meV). These characteristics make this material interesting for many applications such as solar cells [1], field emission materials [2], nano-electronic devices [3], antibacterial applications [4], and photocatalyst properties [5]. The key factors affecting these applications are the shape, size, impurities, doping, structures, and phases. To obtain the desired properties, many researchers in recent years have focused on the synthesis of doped and undoped nanocrystalline materials such as ZnO. Doping semiconductors with various elements is known to affect many of the basic physical properties of the semiconductor, including its electrical, optical, and magnetic properties, which are all crucial for most of the practical applications. In addition to ours, many other groups have also reported the synthesis of doped ZnO nanostructures with various morphologies using different methods [6–9].

Pb is also an important element with various applications in the semiconductor industry. Yet few studies [10–12] have investigated the properties of Pb-doped ZnO nanostructures. Thus, a detailed study of Pb-doping is still necessary to understand the role of Pb in ZnO nanostructures. Therefore, the effect of this element on the properties of the ZnO is very important. The main focus of the present work was an investigation of the effect of Pb-doping on the physical properties of ZnO nanowires. We believe that a high temperature can make it possible to obtain doped ZnO nanomaterials with high optical and structural quality. Accordingly, in the present work, a high temperature method was used to grow Pb-doped ZnO nanowires.

2. Experimental

The growth of undoped and Pb-doped ZnO nanowires was performed in a horizontal tube furnace. First, Si(111) substrates were ultrasonically cleaned using ethanol and de-ionized water.

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They were then lightly etched with an HF (43%) and deionized water mixture (1:10) for about 10 min to remove the native oxide layer. A mixture of lead oxide powder (99.99%), zinc oxide powder (99.99%), and commercial graphite powder in an x(1 and 3):10:10 weight ratio was used as the precursor material to grow the Pb-doped ZnO ($ZnPbO_1$ and $ZnPbO_2$). The precursor material was placed at the closed end of a small quartz tube and a Si(111) substrate was placed above of the precursor material, as shown in Fig. 1. The small tube was then inserted into the vacuum chamber so that the closed end was at the center of the furnace. The precursor materials and silicon substrate were heated to 1000 °C. High purity N_2 gas was fed at about 200 sccm into the furnace at one end, while the other end was connected to a rotary pump. The growth process was allowed to proceed for 1 h.

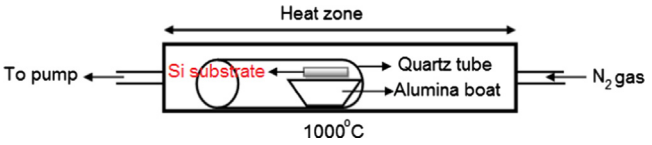

Fig. 1. Schematic of set-up used for growth of undoped and Pb-doped ZnO nanowires.

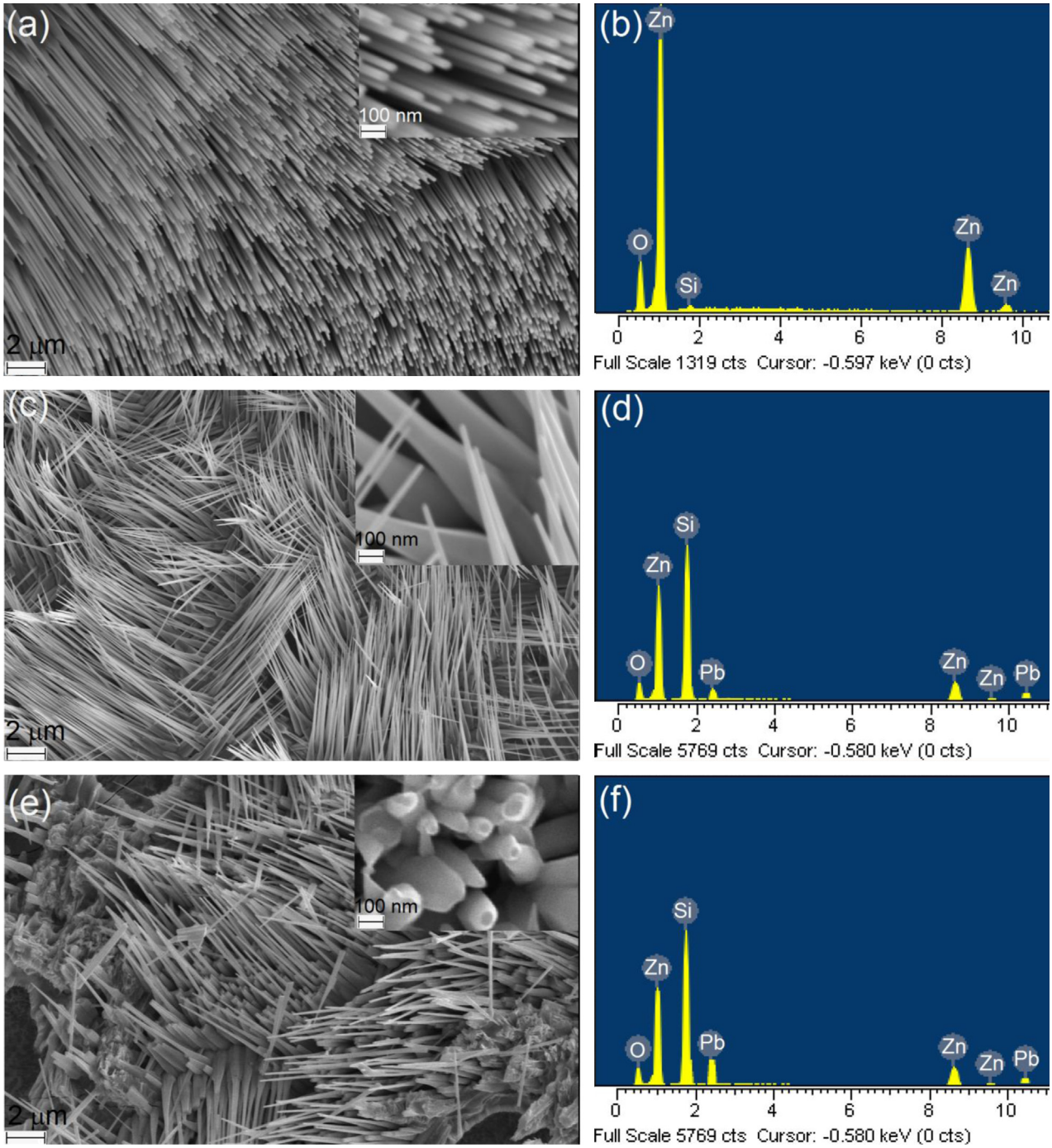

Fig. 2. (a,b) SEM images and EDX spectrum of the undoped ZnO nanowires. (c,d) SEM images and EDX spectrum of the Pb-doped ZnO nanowires (1:10, $ZnPbO_1$ nanowires). (e,f) SEM images and EDX spectrum of the Pb-doped ZnO nanowires (3:10, $ZnPbO_2$ nanowires).