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Featured Letter

Near-infrared graded-index antireflection coating from ZnSe hollow nanospheres

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ABSTRACT

A double-layer broadband antireflective coating (ARC) with graded-index was prepared on ZnSe substrate by using ZnSe hollow nanoparticles (HNPs). The bottom high-refractive-index layer (HIL) was made by closed-packed ZnSe HNPs array, and the top low-refractive-index layer (LIL) was gained by a sacrificial template method. The refractive indices of both layers are close to the theoretical model. A high transmittance, up to 91.5%, is achieved in the near-infrared spectral range with incident angles ranging from 0° to 30°. It also exhibits excellent mechanical stability, and sustains high transmittance over a much wider optical band, compared to the single-index ARC, making it promising for further applications.

1. Introduction

Optical antireflection coatings (ARCs) with graded refractive indices can achieve broadband antireflection [1–5]. Up to date, studies on graded-index ARCs (GI-ARCs) have primarily focused on the visible band for solar cell applications [6], in which silica is the most appropriate material. However, for infrared spectral regime where broad-band ARCs are highly demanded for many applications, such as space remote sensing, infrared thermal imaging, detection devices, etc, the silica-based ARCs are not applicable any more, and the assembling of near-infrared GI-ARCs is still challenging. Zinc selenide (ZnSe) has low absorption coefficient in a wide range of infrared band (0.6–16.5 μm). However, its high refractive index (n = 2.46) leads to a high reflectivity and thus low transmittance (less than 70%). So it is necessary to construct ARCs on ZnSe substrates to substantially improve the transmittance for optical uses. However, it is still challenging to achieve broadband high transmittance in the near-infrared region [7]. Besides, the available ARCs for ZnSe substrates have poor adaptability to the environment and low mechanical properties [8]. Note that, ZnSe is a promising coating material for ZnSe substrates, which will guarantee not only low absorption in near-infrared and also good adhesion to the substrates. To realize GI-ARCs made of ZnSe, hollow structures are highly desired, since low refractive indices and good mechanical properties can be simultaneously achieved.

In our previous work [9], we have successfully synthesized ZnSe hollow nanoparticles (HNPs) and assembled a single-index ARC on the ZnSe substrate to achieve 88% transmission at 840 nm, but the transmission band was very narrow. Herein, we design and assemble a double-layer GI-ARC based on ZnSe HNPs for the ZnSe substrates, and realize high transmittance over a broad band in the near infrared.

2. Experimental

2.1. Perparation of ZnSe HNPs and silica NPs

ZnSe HNPs were obtained by laser ablation in liquid and hot-injection methods [9]. For the preparation of Silica NPs, 100 mL of ethanol, 10 mL of ammonium hydroxide, and 12.5 mL of tetraethylorthosilicate solution were mixed under stirring for 2 h at 55 °C.

2.2. Assembly of double-layer GI-ARC on the ZnSe substrate

30 g L^{-1} colloidal ZnSe HNPs dispersed in a mixture of n-hexanol and cyclohexane (volume ratio, 1: 4) were deposited onto both sides of the ZnSe substrate via spin-coating (2000 rpm). The

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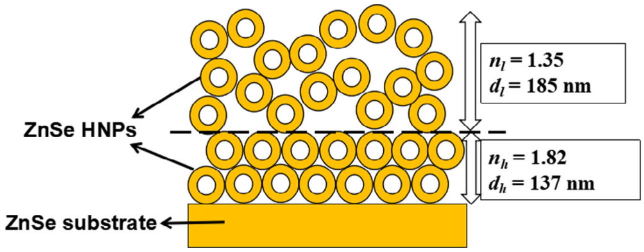

Fig. 1. Theoretical model diagram of double-layer GI-ARCs.

coated substrate was annealed at 400 °C for 30 min in vacuum, resulting in high-refractive-index layers (HIL) on both sides. A mixture of ZnSe HNPs and silica NPs were deposited on top of HIL by spin-coating (1500 rpm). After being annealed under the same condition, the coated substrate was etched by hydrofluoric acid (HF, 20%) for 20 min to eliminate silica NPs and thus further increase porosity. The double-layer GI-ARCs were obtained after rinsing by deionized water.

2.3. Characterization

X-ray diffraction patterns (XRD) were taken on a Bruker D8 Advance diffractometer. Transmission electron microscopy (TEM) images were taken by using an FEI Tecnai G2 F20 TEM. Scanning electron microscopy (SEM) images and energy dispersive spectroscopy (EDS) spectra were acquired on Hitachi S-4800. Atomic force microscopy (AFM) measurements were performed using Agilent AFM5000. The transmission and reflection spectra were recorded by UV-Vis-NIR spectrophotometer (Hitachi U-4100). The refractive indices were measured using the ellipsometer (TFProbe 3.3, Angstrom Sun Technologies Inc.).

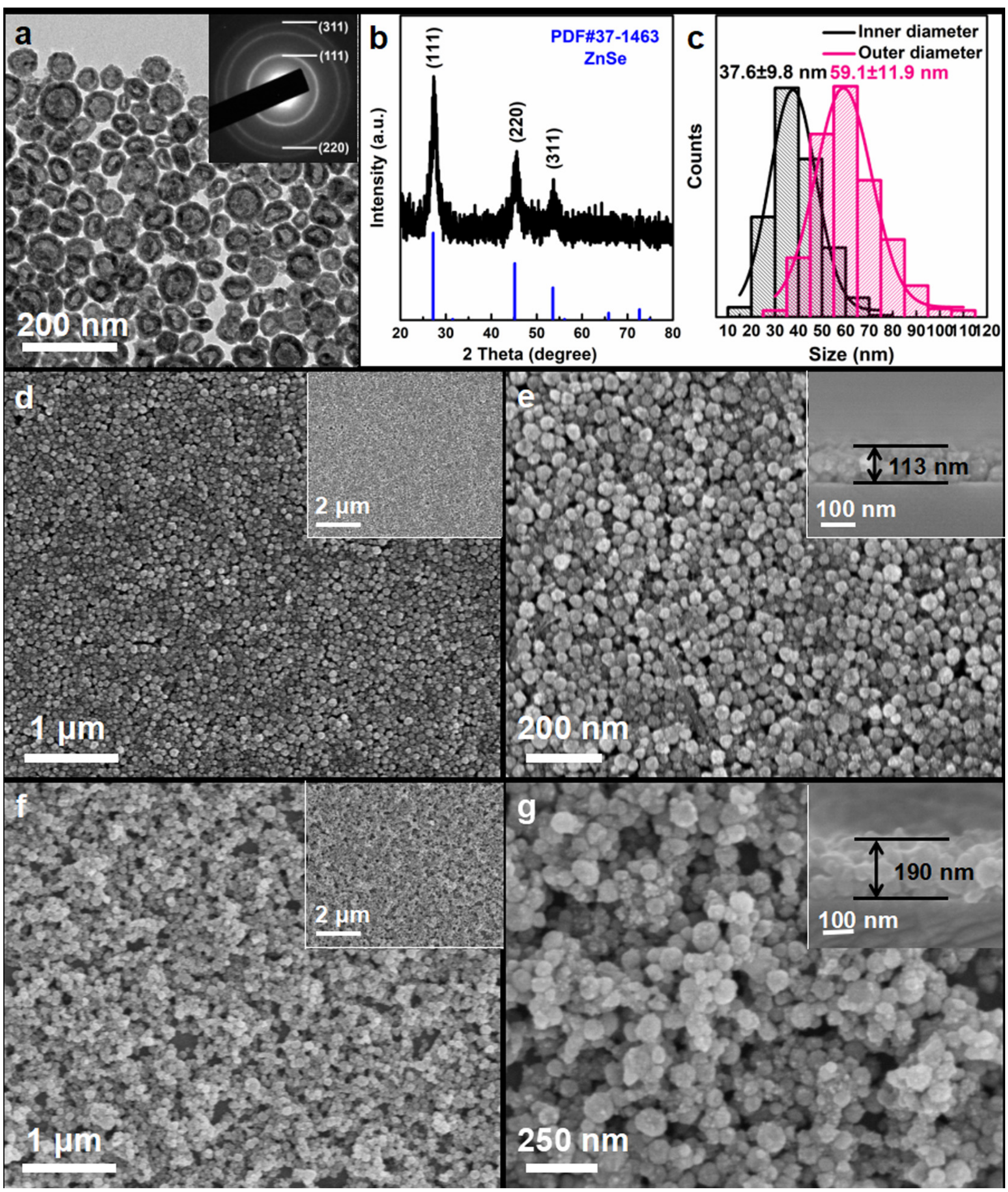

Fig. 2. TEM image and SAED pattern (a), XRD pattern, and statistics of inside and outside diameters of the ZnSe HNPs. SEM images of HIL (d and e) and LIL (f and g) at different magnifications.