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Resonance-Assisted Absorption in Concentric Spherical Microshells with Omnidirectional Supersensitivity for Use in Space

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Abstract

We demonstrate a novel, feasible strategy on practical application of UV photodetectors using multishelled hollow ZnO microspheres integrated by nanodots for space application with omnidirectional sensitivity. Due to the resonance-assisted effect by the convex shells, the microsphere devices exhibits enhanced absorption and optoelectronic performance. Moreover, the response and recovery speed are promoted (response/recovery times: 0.8/1.2 ms) because of the existence of junction barriers between microspheres. We also demonstrated the omnidirectional detectability both for incident angle and light polarizations. Finally, proton tolerance ability of the microsphere devices as a reliable test for space use. The concept employing multishelled hollow ZnO microspheres paves a new way to realize nanostructured photodetectors using in harsh environment and space mission.

Introduction

Nanomaterial-integrated photosensitive devices (PDs) have shown superior sensitivity, operating speed, signal-to-noise ratio, and power consumption, comparing to their bulk counterparts. With advances in nanotechnology, designing the “architecture” of nanomaterials becomes possible which allows the optoelectronic performance to be promoted. For example, nanodevices integrated by micro- and nano-scaled structures have shown enhanced light-trapping ability and omnidirectional detectability. Such a hierarchical concept has been employed by a variety of optoelectronics, *e.g.*, photodetectors, solar cells and light emitting diodes. After being trapped, subsequent “light management” could further maximize the interaction between light and matter. For instance, antenna effect in Ge nanowires (NW) can effectively enhance light absorption in certain wavelength. Moreover, whispering-gallery mode in nanospheres has shown broadband enhancement for potential photovoltaic applications. Taking advantage of optical resonance, light can be spatially concentrated in certain region, *e.g.*, pn junctions, enabling the device performance to be optimized.

Going along with the high surface-to-volume ratio, surface effects are pronounced in metal-oxide nanocomposites, leading to their intriguing optoelectronic properties. Those effects are attributed to the bending of surface band and its ultrasensitive modulability to light; experimentally, surface band bending (i.e. depletion region) up to 1.5 eV was probed in ZnO NWs by both optical and electrical methods. Since the bending region is only a few nanometers, light should be absorbed near the surface for the ease of photo-carrier gathering. Therefore, in contrast to the conventional optoelectronics that required absorption at pn junctions at inner region, metal-oxide PD prefers light absorption near the surface. Hence, facilitating near-surface absorption is of practical importance, yet only a few works for this purpose have been proposed.

Besides, a fundamental issue accompanying the surface effect is the inevitable degradation of response speed owing to the slow adsorption/desorption process. This side effect put a limit on the speed of ZnO-based PDs to an inapplicable value ranging from several to several hundred seconds. Some strategies have been proposed to improve the speed with retention of high photogain. For example, Zhou *et al*. reported the use of one-side Schottky-contact geometry, through which both the sensitivity and response speed of a ZnO NW PD can be greatly promoted (rise time ~ 0.6 s). Moreover, nanomaterials integrated in a network scheme exhibit improved speed (recovery time ~ 0.5 s) due to the existence of multiple junctions. Modification via nanostructure design, for example, core-shell geometries or decoration of metal particles, also provides viable routes for the same purpose. However, there is still a lot of room for further improvement.

In this study, we demonstrated the enhanced detectability in multiple ZnO spherical shells taking advantage of the resonant-assisted absorption. The hollow microspheres are integrated by strongly light-absorbing ZnO nanodots, from which incident photon could be efficiently converted to charged carriers, whereas some of them remain trapped in nanodots, resulting in photogain. Due to the multiple convex ZnO shells, whispering-gallery modes take place in the spherical cavity, leading to an enhancement of photoresponse. Multiple internal reflections within the inter-shells further reduce the light escapes, resulting in highly efficient absorption and omnidirectional detectability. In addition, a network fashion enables the response and recovery speed to be promoted (response/recovery times: 0.8/0.7 ms) due to the existence of junction barriers between microspheres. In the end, we will show the results of proton bombardments as a reliable test for space uses. The multi-shelled hollow spherical geometry reported herein explores a new pathway for the next envisaged optoelectronic functionalities, energy-harvesting applications and the possibility for exploring the Universe.