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Electromechanical characterization of polymer based ordered ZnO nanowire array – Toward application of pressure bio-sensor

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Abstract

It is well know that zinc oxide (ZnO) is one of the most significant II-VI semiconductor materials attracting enormous interests and research, especially in the application of optoelectronic, electromechanical, electrochemical, photovoltaic devices, etc. owing to its excellent intrinsic properties. In addition, innovative designs of various configuration structures of ZnO nanowires (NWs)/substrate have been developed for enhancing performance and multifunctional applications as piezoelectric nano-generators and sensors. In our project, the vertically aligned ZnO NW arrays exhibiting a 1031 nm length and 80-100 nm diameter, are grown on a 40nm-thick ZnO seed layer deposited on top of a 500µm-thick silicon substrate, and are embedded in a 1464 nm dielectric layer of polymethyl-methacrylate (PMMA). Up to now, a lot of publications has been reported on exploiting piezoelectric behavior of ZnO nanowire for various applications but very few of them provided a reliable method of characterization for these materials. Thus, the idea of this study focuses on characterizing the electromechanical response of vertically aligned ZnO NW arrays/polymer composite structure via an experimental test bench. Under dynamic mechanical excitation at 1 Hz , two electric configurations were performed including an application of a dynamic electric excitation from a sinusoidal voltage of 1 kHz and a short-circuit condition. The static electrical measurment confirmed the capacitive property of composite is dominant with respect to the resistive one and electromechanical characterization demonstrated an existence of piezoelectric property of the ZnO structure (d_{33} ~ 1.25 pC/N). The results will lead to a better understanding of the multi-physic coupling of ZnO materials in order to validate its feasibility for flexible sensors adapted to biological media. In the future, different designs of tunable ZnO NW length and radius, together with optimization of base structure and polymer matrix will be explored in order to drastically boost the electromechanical coupling of the proposed material.

Nanowires (NW) are defined here as metallic or semiconducting particles having a high aspect ratio, with cross-sectional diameters « 1 µm, and lengths as long as tens of microns. Well-aligned one-dimensional nanowire arrays have been widely investigated as photoelectrodes for solar energy conversion because they provide direct electrical pathways ensuring the rapid collection of carriers generated throughout the device , as well as affording large junction areas and low reflectance owing to light scattering and trapping.

Solar energy conversion is a highly attractive process for clean and renewable power for the future. Excitonic solar cells (SCs), including organic and dye-sensitized solar cells (DSSC), appear to have significant potential as a low cost alternative to conventional inorganic photovoltaic (PV) devices. The synthesis and application of nanostructures in solar cells have attracted much attention. Metal oxide nanowire (NW) arrays with large surface area and short diffusion length for minority carriers represent a new class of photoelectrode materials that hold great promise for photoelectrochemical (PEC) hydrogen generation applications. Up to now, various metal oxide nanostructures such as TiO_2, ZnO, Fe_2O_3, ZrO_2, Nb_2O_5, Al_2O_3, and CeO_2 have been successfully employed as photoelectrodes in SCs. Among the above-mentioned metal oxide nanostructures, the study of TiO_2 and ZnO is of particular interest due to the fact that they are the best candidates as photoelectrode used in SCs. However, the advantage offered by the increased surface area of the nanoparticle film is compromised by the effectiveness of charge collection by the electrode. For DSSCs, the traditional nanoparticle film was replaced by a dense array of oriented, crystalline nanostructures to obtain faster electron transport for improving solar cell efficiency. A typical high-efficiency DSSC (Grätzel, 2009) consists of a TiO_2 nanocrystal thin film that has a large surface area covered by a monolayer of dye molecules to harvest sunlight. Comparedwith TiO_2, ZnO shows higher electron mobility with similar bandgap and conduction band energies. ZnO is a direct wide bandgap semiconductor (E_g = 3.4 eV) with large exciton binding energy (~60 meV), suggesting that it is a promising candidate for stable room temperature luminescent and lasing devices. Therefore, ZnO nanowires is an alternative candidate for high efficient SCs.

So far, various ZnO nanostructures have been extensively investigated for SCs. In the early reports on ZnO-based DSSCs, ZnO nanoparticles were often used as the photoanode prepared by a conventional doctor blade technique (Keis et al., 2002; Keis et al., 2002). Lévy-Clément et al. (2005) reported experimental results on a new ETA solar cell fabricated from an electron-accepting layer of free-standing ZnO nanowires. Law et al. (2005) presented first the ordered nanowire DSSC. The nanowire DSSC is an exciting variant of the most successful of the excitonic photovoltaic devices. As an ordered topology that increases the rate of electron transport, a nanowire electrode may provide a means to improve the quantum efficiency of DSSCs in the red region of the spectrum, where their performance is currently limited. Raising the efficiency of the nanowire cell to a competitive level depends on achieving higher dye loadings through an increase in surface area. Law et al. (2006) described the construction and performance of DSSCs based on arrays of ZnO nanowires coated with thin shells of amorphous Al_2O_3 or anatase TiO_2 by atomic layer deposition.