Supplemental Information

Vertically-aligned ZnO nanorod smooth thin films for planar device applications

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The synthesis of ZnO nanorod thin films

Pre-treatment of the substrates: ZnO thin films were deposited on (100)-oriented silicon (Si) substrates by HiTUS sputtering, and were used as seeding layers for chemical solution growth. The substrates were ultrasonically cleaned in acetone and ethanol for 10 min, followed by rinsing in deionized (DI) water. They were dried with nitrogen gas before being introduced into the sputtering system for seed layer deposition. Seed ZnO thin films were sputter-deposited at room temperature using a Zn target (99.999% purity) in a gas mixture of Ar and O_2.
Chemical solution growth: All chemicals were ordered from Sigma Aldrich Co. Ltd with analytical reagent grade and used without further purification. The precursor solutions were prepared by mixing Zinc Nitrate ($Zn(NO_3)_2 \cdot 6H_2O$ with 99.9% purity) and HMTA (99.9% purity) with DI water. While keeping their volume ratio and the concentration ratio at 1:1, their concentrations in solutions were varied from 0.03 M to 0.12 M to investigate the effect of chemical concentrations on the morphology of the ZnO nanorods and nanofilms. The growth was carried out at temperatures from 50 to 95 °C in a sealed glass beaker placed in a kettle by immersing the pre-treated substrates with the top side down in precursor solutions (50 mL). Unless specified, the growth time was 4 hrs. Finally, the samples were thoroughly washed with DI water to remove any residual salt and dried by N_2 gas.

Characterization of the materials

Surface morphology of the nanorods and films were studied using a SEM (Hitachi S-3400) and the surface roughness were characterised using an Agilent 5500SPM AFM. Crystalline structure of the nanorod films was determined by XRD analysis using a Rigaku diffractometer. The surface properties and impurities were investigated by XPS (Kratos Axis Nova XPS system with an Al Kα (1486.6 eV) source). PL spectra were measured under the excitation of 300 nm at room temperature by Perkin Elmer LS-55 spectrometer. The PL spectra were excited by pulsed-xenon lamp as source and detected by a CCD detector after dispersed by a concave grating.

SAW device fabrication and characterization

SAW devices on nanorod films were fabricated by standard photolithography process. The ZnO nanorod films with a thickness of ~4 μm were used for SAW device fabrication. SAW devices consist of 30 pairs of interdigitated transducer (IDT) fingers. The aperture of the IDTs is 4900 μm, a spatial periodicity (wavelength) is 64 μm and the distance between the two IDT electrodes is 4 mm. Aluminium (Al) of ~100 nm thick was used for the IDT electrodes which were formed by thermal evaporation and lift-off process. The transmission

characteristics of the SAW devices were measured using an Agilent E5061A Network Analyzer.

Surface roughness measurement

Fig. SI1 is an AFM image obtained from the ZnO nanorod film corresponding to the film shown in figures 1(c) and 1(f). The RMS roughness of the nanorod film with a thickness over 4 µm is about 2.55 nm, much smaller than those for ZnO films deposited by other methods such as magnetron sputtering etc, demonstrated excellent smoothness of the surface of the ZnO nanorod films grown by the chemical synthesis method.

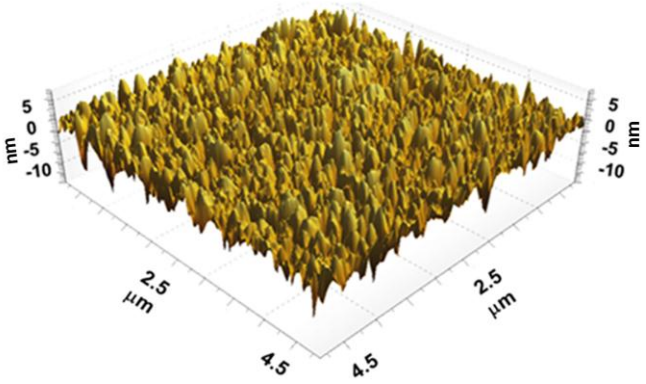

Fig. SI1 an AFM Image of an as grown ZnO nanorod film. The RMS roughness of the film with a thickness of over 4 µm is about 2.55 nm over a large area of 5x5 µm.

X-ray-diffraction (XRD) curves

Fig. SI2 is the X-ray-diffraction (XRD) curves for the films grown at different concentrations with discrete NRs and continuous film which correspond to the material structures shown in Fig. 2(b) and 2(c). It shows that both the discrete nanorods and the nanorod films have a dominant diffraction peak at 34.2°, corresponding to the (002) ZnO plane. The peak intensity of the dense film is much larger than that of the discrete nanorods. The intensity for the peak of (103) crystal orientation is relatively larger for the discrete nanorods, and becomes smaller for the nanorod films, manifesting the preferential (002) orientation for the films with a suppressed growth in other crystal directions.

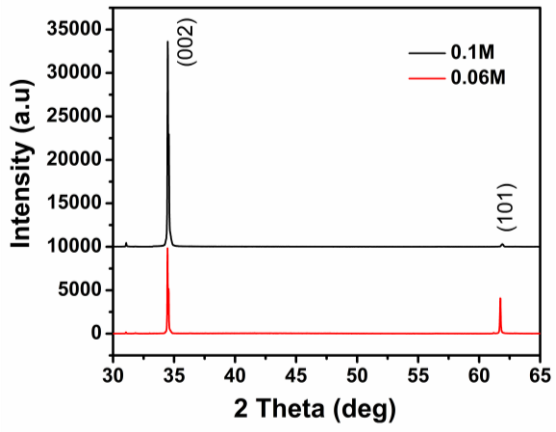

Fig. SI2 XRD results of ZnO nanorod materials grown at two different precursor concentrations of 0.06M (discrete nanorods) and 0.1M (densely packed nanorod thin film), corresponding to the structures shown in Fig. 2(b) and 2(c).

XPS measurement

X-ray photoelectron spectroscopy (XPS) measurement was used to study the elements of the ZnO films, hence the purity of the materials prepared by chemical synthesis method. Fig. SI3 is typical XPS spectra from the ZnO discrete nanorods and dense film, showing well resolved peaks corresponding to Zn and O elements only, which can be attributed to the formation of hexagonal ZnO nanorods. There is no additional peak related to impurities and other elements, indicating the high purity of the materials grown.

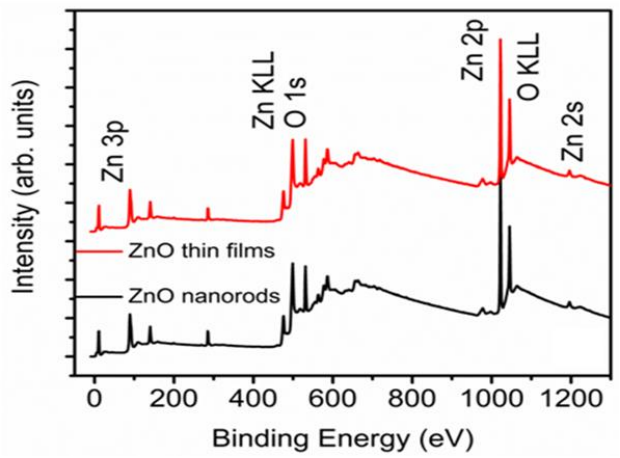

Fig. SI3 Typical XPS spectra of ZnO discrete nanorods and dense film with a wide energy scanning range. There exist peaks corresponding to Zn and O elements only, no additional peak was found for other elements.