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Comprehensive correlative study of post-treated vertically grown ZnO nanowires

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Summary:

This paper presents the fabrication of vertically oriented zinc oxide nanowires (NWs) grown by Chemical Bath Deposition (CBD) and conduct different structural and electrical measurements such as AFM (PFM, SMIM and KPFM) on them. Moreover, we will present the first ever SMIM measurements on ZnO NWs. The correlation of these measurements will provide important information about their performance in piezoelectric transducing applications. **Keywords:** ZnO, piezoelectricity, nanowires, VING, AFM

Background, Motivation an Objective

Emerging energy transducers can gather energy from the surroundings. Solar, thermal, and mechanical energy can be converted into electricity in order to power electronic devices [1]. Mechanical energy is present in our everyday surroundings, such as airflow, noises, and human activity and can be converted into electricity using the piezoelectric effect [2]. The vertical integration of these NWs (also known as VING) is one of the most studied. This structure can also be used in mechanical sensing applications [3]. Vertically grown ZnO NWs as part of the VING structure will be examined in this study.

Novelty

The vertically oriented NWs will undergo different post treatment methods and then multiple AFM, XRD and PL measurements will be conducted on the same sample and correlated, providing important information for structural and piezoelectric properties for piezoelectric transducing applications. AFM measurements include Piezoresponse Force Microscopy (PFM) [4] and Kelvin Probe Force Microscopy (KPFM). In particular, Scanning Microwave Impedance Microscopy (SMIM) measurements will be performed, which have never been done before in this kind of structure. We will also present the study of the effect of different treatments (annealing among others) on these NWs.

A Si wafer covered with a thin layer of Si_3N_4 was used as substrate for the growth of ZnO NWs. A 10 nm layer of chromium followed by 200nm of gold were deposited on the substrate using electron beam evaporation. This is used as bottom electrode in the final device. Then, a texturized film of ZnO (seed layer) was deposited by sol-gel. XRD was conducted to check the correct texturization of the seed Layer. The growth of NWs was carried out using the CBD method at 90 ℃ for 2 hours [5]. The average length of the NWs was 800 nm and the average diameter was 82 nm (See Fig. 1). The as-grown NWs underwent post-treatment processes, which involved vacuum annealing at different temperatures and oxygen plasma exposure for varying durations, followed by subsequent structural and electrical characterization.

Results

To analyse the structural properties of ZnO NWs, XRD was recorded as depicted in Fig. 2. (a) It confirmed the texturization of about 92.3% for the NWs which supports the verticality of ZnO NWs. Defect studies were done using photoluminescence (see Fig. 2b). It shows that in comparison to the as-grown NWs, there was a decrease in the surface defects post-treatment. Local characterization of the NWs was performed using an AFM Icon (BRUKER) in DataCube and PeakForce modes. These modes allow periodic contact measurements with withdrawn in between, enabling contact mode measurements on non-planar materials. DataCube PFM provided the phase and the mechanical displacement of the NWs under electrical stress at 5V and 12kHz. Fig. 3. shows histogram PFM amplitude results extracted from a single NW. From the histrograms, the d_{33} coefficient is evaluated as **4.98 pm/V** for as grown ZnO NWs, **2.82 pm/V** for O_2 Plasma treatment and **4.25 pm/V** for annealing at 300 °C. Preliminary KPFM results can be found in the Fig. 4. The variation of the potential

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between NWs could be linked to a non-uniformity of the doping in different NWs. These initial measurements will be compared with results obtained on the samples after different treatments, possibly modifying their doping concentrations. This will provide insight on the piezoelectric performance in correlation to their semiconductor properties. While an enhancement in piezoelectric performance after post-treatment was expected, the present findings indicate a different trend. This could be due to an increase of doping concentration or decrease in surface trap density. The KPFM study indicated significant variances in work function across the samples, supporting the possibility of alterations in both doping and surface conditions. Additional exploration utilizing SMIM could provide more insights in understanding these results.

Illustrations, Graphs, and Photographs

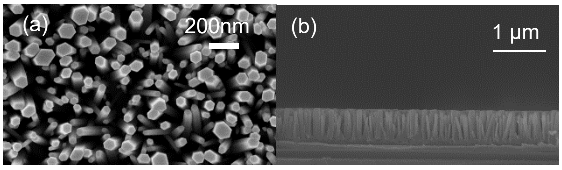

Figure.1. SEM Images of ZnO NWs on Au/Cr/Si_3N_4/Si Substrate (a) Top View (b)Cross Section

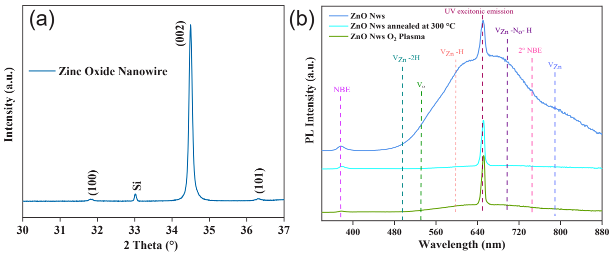

Figure. 2. (a) XRD measurements of as-grown ZnO NWs (b). PL measurements of as-grown and post-treated ZnO NWs

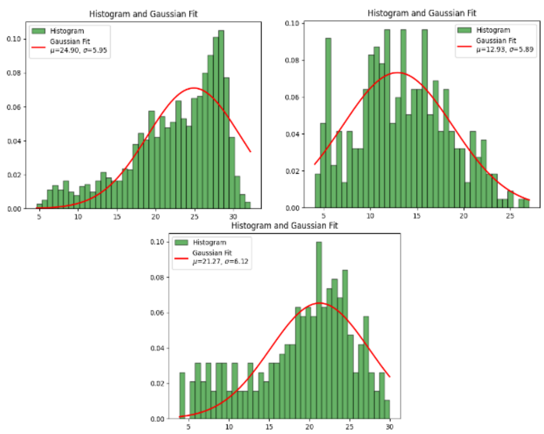

Figure.3. DataCube PFM of NWs (Histogram and gaussian fit of the PFM amplitude on a single NW of (a) of as-grown sample (b) O_2 Plasma treatment, (c) annealing at 300 °C

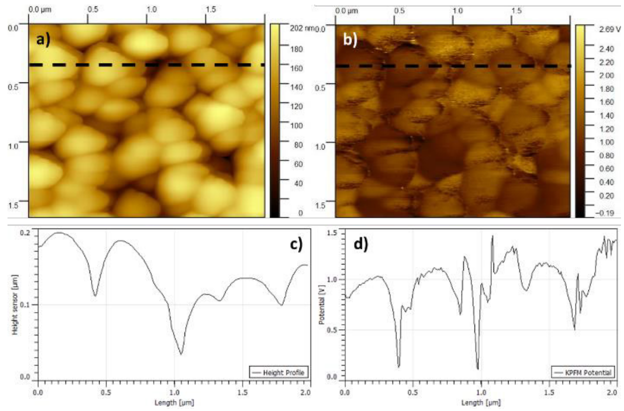

Figure.4. KPFM measurements of NWs (a) Topography (b) Potential (contact potential difference) (c) Cross section of the topography located on the black dash line (d) Cross section of the potential located on the black dash line

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