Fabrication and characterization of zinc oxide nanowires-based flexible biosensors

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In the past few years, flexible sensors have attracted large attention for their ease of integration into existing electronic components, portability and cost-effectiveness. Recently, a wide range of flexible sensors based on zinc oxide (ZnO) nanowires (NWs) have been investigated as biosensors[1], capacitive sensors and force sensors[2]. ZnO nanostructures are chosen due to their biocompatibility[3], high isoelectric point (IEP) (9.5[4]), low denaturation of proteins[5], electrical and intrinsic piezoelectric properties[6]. However, existing technologies to fabricate ZnO NWs on flexible substrates cannot be easily used for producing point-of-care devices on large scale.

We present a novel fabrication process (Fig. 1) where ZnO NWs are hydrothermally grown and patterned directly on flexible polydimethylsiloxane (PDMS) substrates using standard photolithography. The fabricated devices have been tested as protein sensors to detect bovine serum albumin (BSA) which is one of the most abundant proteins available and essential in a variety of clinical applications[7]. For this purpose, the response of the devices to the exposure to 0.1 µM of BSA over a period of 25 min at 22 ºC was investigated. The NWs were functionalized by 3-aminopropyl-trimethoxysilane (APTMS) which creates an open $–NH_2$ bond on the NWs. This increases the binding affinity and adsorption of BSA on the NWs thereby creating a strong NH-NH bond. For the purpose of comparison, Zn seed layer was also functionalized in which case the $–NH_2$ bonds are created on the Zn seeds. Biosensing tests were carried out by adding BSA solution on the functionalized NWs and on Zn seed layer. Due to a high IEP of ZnO at 9.5 and low IEP of BSA at 5.4, the NWs remain positively charged while BSA solution becomes negatively charged. Thanks to the 1D morphology of the NWs, the BSA molecules get adsorbed onto a specific location at the tip due to a combination of electrostatic forces and functional $–NH_2$ bond (Fig. 2) thereby decreasing the resistance from 3.37±1.46 kΩ to 879.38±52 Ω. On the contrary, when using the Zn layer, due to the 2D morphology of the seeds, the BSA molecules bind on and damage the entire seeds' surface thus making the device unusable. Fourier transform infrared (FTIR) spectra for NWs bonded with BSA reveals the characteristic amide I and II band peaks arising due to the presence of BSA on the NWs thus showing good coordination between them (Fig. 3). Surface roughness obtained using atomic force microscope (AFM) on NWs exposed to BSA (Fig. 3) showed a 15% increase in comparison with pure NWs due to the presence of bonded BSA molecules. Further characterization using x-ray diffraction (XRD) will be presented together with discussion on influence of the morphology of the active sensing layer for BSA detection of pico/femto molar concentrations. The presented fabrication process is highly reproducible and can be used to integrate NWs on flexible substrates for various sensors. These devices can be manufactured on large scale in a low-cost manner and integrated into existing electronic components.

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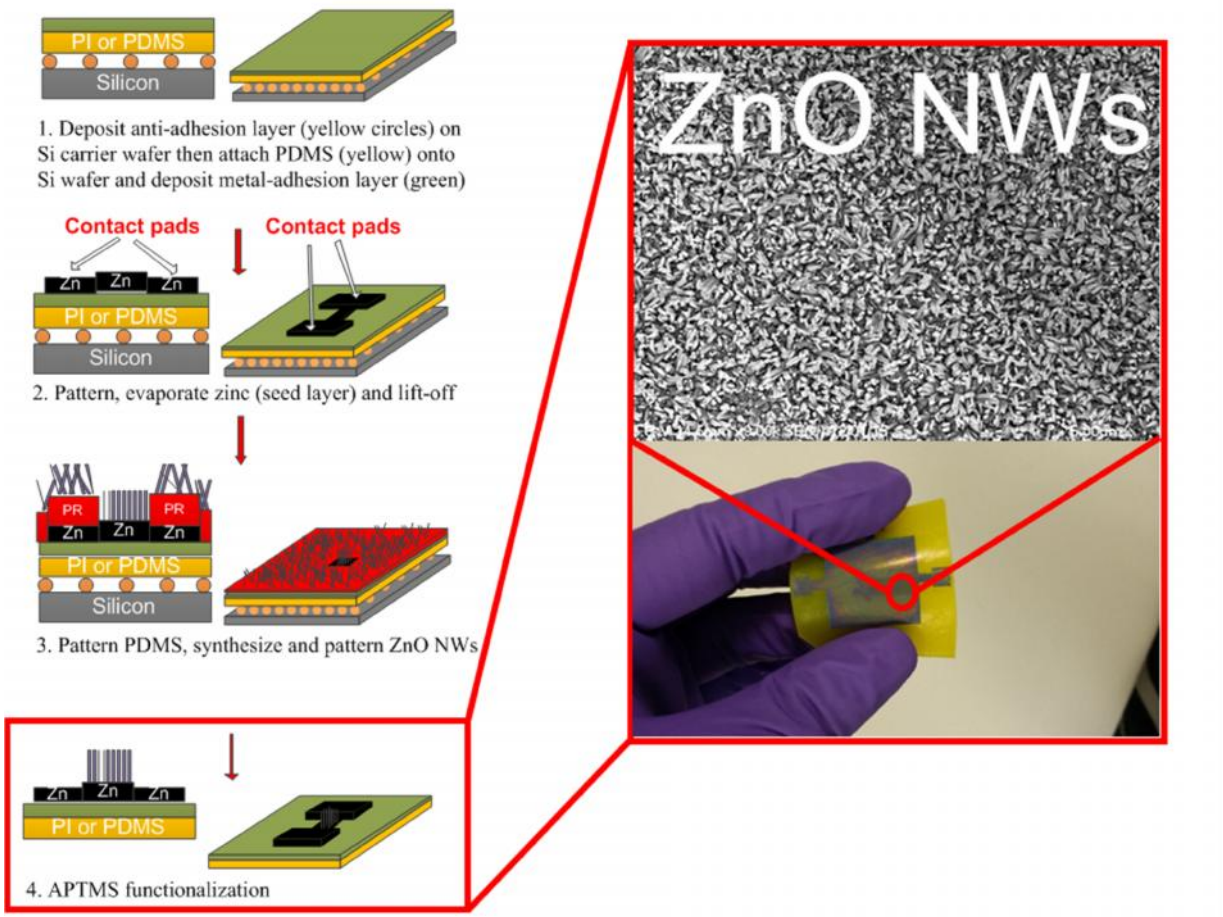

Figure 1: Fabrication process to grow and pattern ZnO NWs on PDMS. SEM images of ZnO NWs. Optical image of the fabricated device.

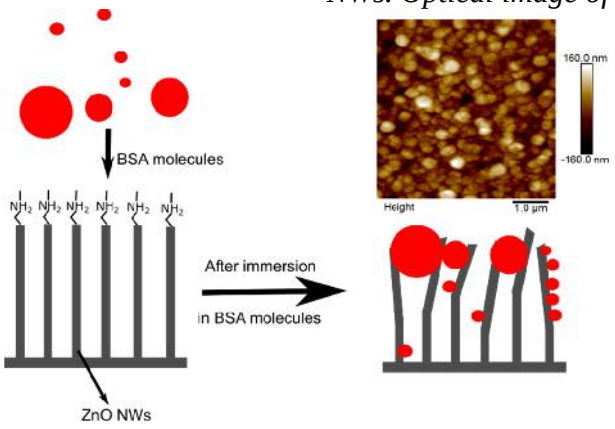

Figure 2: Illustration of BSA bonding with open -NH_2 bonds on the NWs. AFM height image of NWs with BSA.

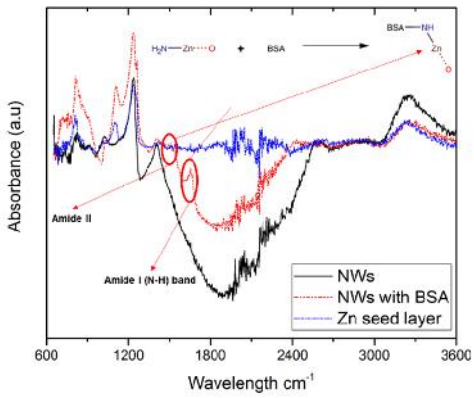

Figure 3: FTIR spectra for pure NWs, NWs in BSA and Zn seed layer