Exploring fabrication methods to highly sensitive and selective InP nanowire biosensors

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Abstract. Fabrication methodologies for integration of nano-objects into microscale devices is still an active area of research. Here we analyze possible methods of incorporation of semiconductor nanowires into lithographically-defined electrode pads. Mechanically-transferred InP nanowires were metallized into Au and Pt pads using an electron-beam-induced Pt metallization. Atomic and Kelvin Probe Force Microscopies show that a contamination of Pt on the nanowire and the region around it can prevent application of this technique to biosensors in which surface functionalization protocols must be applied as part of the fabrication methodology. Other transfer methods with more controlled nanowire positioning, such as nanotweezers, may be necessary to overcome this problem.

1. Introduction

Specific detection of minute amount of biomarkers has tremendous impact in health care, biomedical research and environmental control [1-5]. Apart from several advances in different diagnostic tools, however, label-free operation, high sensitivity, and multiplex detection of various analytes are of paramount importance. In this context, one dimensional nanostructures, such as semiconductor nanowires are emerging not only in high throughput optoelectronic devices but also in realizing label-free direct electrical detection of specific disease biomarkers [6-13]. Successful implementations of nanowire based biosensing devices, however, involve several challenges, associated with high biochemical detection specificity, high detection sensitivity, reproducibility and chemical stability.

In a previous work, we developed reproducible yet simple and generic protocols for highly sensitive detection of different biomolecules using Indium Phosphide (InP) semiconductor nanowires as sensing transducer component of biosensor [14]. A series of biochemical processes were optimized in order to maximize the organochemical nanowire functionalization efficiency which has a direct impact on the overall biosensing performance. The evaluations of InP nanowire functionalization, biomarker immobilization efficiency and biomolecule passivation character of poly(ethylene glycol) (PEG) crosslinker coatings were performed via quantitative fluorescence microscopy as well as scanning Kelvin probe force microscopy. We observed that ethanolamine surface functionalization combined with PEG polymer coatings can vastly enhance biomolecule binding specificity and signal-to-noise ratio for biomarker detection. The simple yet powerful methodology was applied to our developed InP
nanowire based biosensor platform, achieving fM detection levels to DNA and Chagas disease biomarkers.

However, in order to achieve a reliable technology, it is important to have high yields of fabrication of these complex devices. Thus, in this work, we explore and characterize different methodologies to improve the yield of device fabrication, which can be used along with our developed functionalization protocols.

2. Experimental

InP nanowires were grown by Chemical Beam Epitaxy, as described elsewhere [14]. The obtained samples were analyzed by scanning electron microscopy (SEM, FEI Inspect F50). Au or Pt electrodes were defined lithographically in Si and InP substrates and InP nanowires. The InP nanowires were transferred mechanically (by abrasion) to the substrate with electrodes and subsequently these were placed in a dual beam FEI NanoLab 200 equipment in order to use the electron beam deposition of Pt from Trimethyl(methylcyclopentadienyl) platinum (IV). For the deposition, typical voltage/current conditions used were 5kV and 0.4nA.

3. Results and Discussion

Our original processing used microfluidics to align the nanowires on lithographically defined electrodes, using the configuration shown schematically in Figure 1. However, the yield of devices obtained with a single nanowire in between the electrodes was low, typically a few percent of the electrodes in the chip. Therefore, different fabrication methods were also explored. One of them was the mechanical transfer of nanowires from the as-grown sample to the device substrate, using electron-beam induced Pt deposition to extend the electrodes and make the electrical contact to the nanowires. A scanning electron microscopy image of the metallization is shown in Figure 2.
Atomic Force and Kelvin Probe Force Microscopy characterization of the sample, however, has shown a nanometer-thick region, which can reach up to 1 micron in length, around the Pt pad (Figure 3); surface potential shows that a large contamination of Pt in the region surrounding the deposited original Pt pattern. In some cases, a widening of the InP nanowire is observed as well (Figure 2, left), evidencing a drawback for this method of fabrication.

For that reason, a more precise method of positioning the nanowires directly on top of the electrodes, with no need to extend the electrodes, could provide a better yield of device fabrication. One such method relies on direct manipulation of the nanowires using suitable nanotools, such as nanotweezers. In that case, a second lithographic step can be used to properly contact the nanowires and assure that they will stay in place during the subsequent fabrication steps, as reported in [14]. Preliminary measurements have shown that this approach is valid and single nanowire transfer can be accomplished using a shape memory composite nanogripper.

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