Impedance Modulation in Coaxial Nanoneedle Biosensor

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The most important issues for the current biosensors are sensitivity, detection range and multiplexing. Impedance biosensors are a class of electrical biosensors that show promise for point-of-care and other applications due to low cost, ease of miniaturization and label-free operation.

Refer to earlier work, our Coaxial Nanoneedle Biosensor shows a promise to overcome the current limitations of biosensors [1]. We study several capacitances being involved within the device structure and features as coaxial geometry. The system is optimized for the high sensitivity and low concentration detection. This preliminary study was performed to prove the feasibility of the direct impedance biosensor for detection of protein or nucleic acids, due to ionic current blockage and impedance modulation.

The coaxial nanoneedle (Fig 1, left) contains middle nano-core made of metal/doped semiconductor. An insulator area surrounds this layer. The next layer is another metal area followed by yet another protective insulator area. The sensor is functionalized by attaching probe bio-species to the top (or surrounding area) of the nanoneedle. The target molecule, when bonds to the probe, modulates the needle impedance (Fig 2).

Three main capacitances are of interest: bulk capacitance; fringing capacitance and double-layer: The bulk capacitance is the inherent capacitance of the nanoneedle due to electrical field between the inner and outer metal layers. A visual representation of the electrical field is shown in Fig 3, left. The electrical field configured between the metal layers indicates significant fringing capacitance. Fringing capacitance that is most sensitive to the attachment of target molecule. We modeled the fringing capacitance by modifying the bulk capacitance with interfering fringing fields and hence optimizing modulation monitoring (Fig 3, right). The ring structures represent bio-species such as protein or bio-molecules. The ring structures have been modeled in hollow or solid rings which represent attachment of bio-species to the middle insulator later or combined mid and core layers respectively.

Another type of capacitance being investigated is the double layer capacitance, which depends on voltage [2], because our nanoneedle is polarized relative to the ionized solution. This capacitance is due to attraction of ions of the opposite charge in the solution to the top surface needle. This is countered by the randomizing thermal motion of the ions, but results in a local buildup of excess ions of opposite charge (Fig. 4). Values of this double layer capacitance for different geometry and structures are shown in the table in Fig 4, right.

In conclusion, we study and optimize the impedance modulation of a sensitive nano-biosensor called coaxial Nanoneedle. This coaxial nanoneedle is suitable for protein detection, antibody-antigen interaction and enzyme conformational monitoring.

[1] H. Esfandyarpour, et al., Int'l COMSOL Conference, Proceeding of, Oct. 4-6, 2007, pp. 169-173.

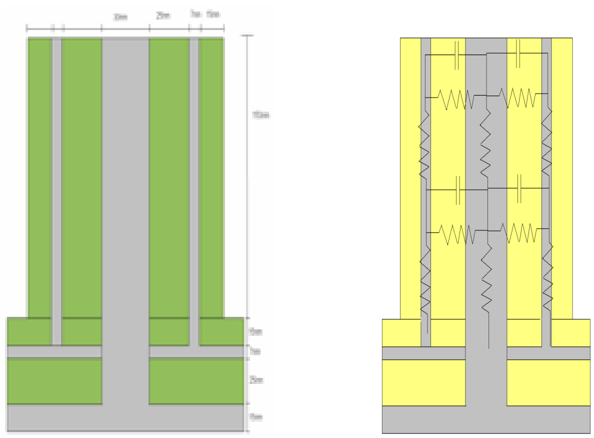

Figure 1. (Right) Schematic of Nanoneedle - (Core needle ~30nm diameter, Insulator layer ~25nm, second conducting layer ~7nm, Outside insulator protective layer ~15nm); Bulk Needle Impedance Model (left).

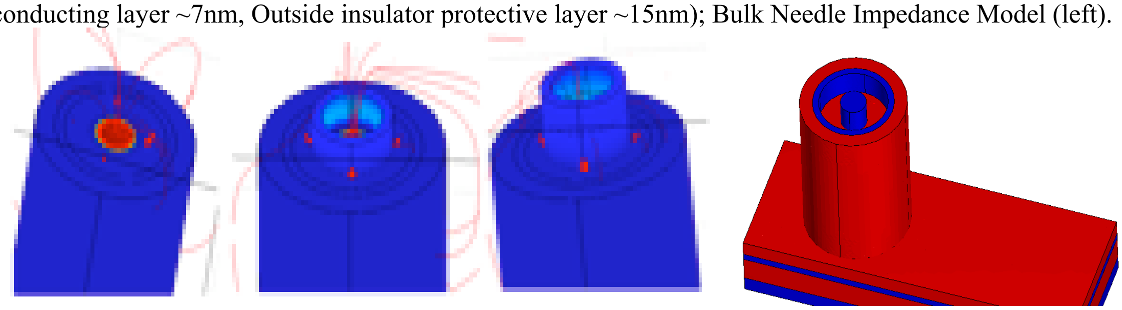

Figure 2. (Right) The three different binding Phases: 1) Bare Needle 2) Probe Molecule 3) Target + Probe Molecule; (Left) Etched Structure.

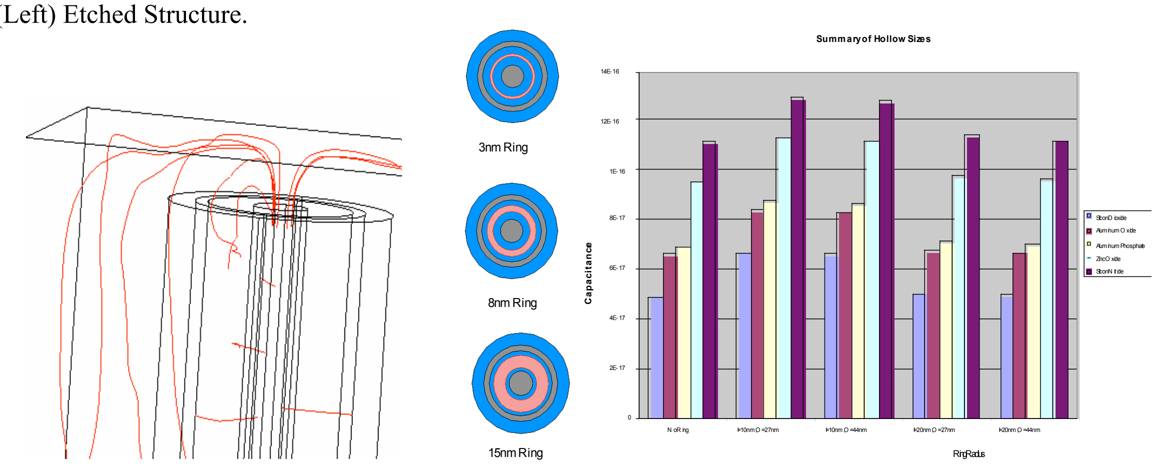

Figure 3. Left: Fringing field effects- (No target molecule attached). This field is being modified by bonding of bio-species on the top of the needle in loading and detection phases, Right: The combined bulk and fringing capacitance with hollow ring attached on top of the nanoneedle (bio-species on the top of middle insulator layer).

Electrolyte	Charge of Ion (Z)	Mol / L	Debye Length (nm)	Capacitance Density (µF/mm²)
10mM Magnesium Acetate	+ 2	1.00E-02	1.52E-09	1.13E+01
10mM Potassium Chloride	+ 1	0.001	9.61E-09	2.59E-01

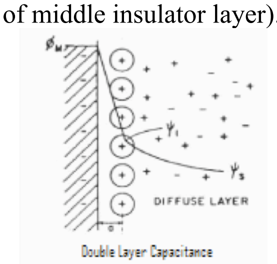

Figure 4. Double Layer Capacitance: Values through the two approaches used to surround the nanoneedle are shown (right), Schematic (left).