Eliminating Electrokinetic Cross-Talk in Nano-Channel Arrays for Biomolecular Detection

We have designed and tested nanochannel sensors for biomolecular detection using fundamental analysis of the underlying electrokinetic phenomena. These nanochannels are bounded by two micro-reservoir to allow high throughput. A different molecular probe (oligos for DNAs, antibodies for proteins) is functionalized onto the surface of each nanochannel to capture a specific molecular target that is driven electrophoretically, electro-osmotically or dielectrophoretically into the channel. Due to the small dimension of the channel, molecular capture can significantly change the complex cross-channel impedance signal, detected by the same microelectrodes that drove the molecules into the nanochannels. We find, however, that the impedance of a single channel is also sensitively dependent on the depletion and enrichment zones at the two ends of the nanoelectrodes. Both zones are produced by the conductivity jump across the nano/micro junction as double layer overlap in the nanochannels produce a higher ionic strength. We extend Dukhin, Rubinstein and our earlier one-dimensional steady-state theory for the extended polarized and diffusion layers of the depletion zone to AC conditions relevant to impedance measurements (Dukhin 1991, Ben & Chang 2002, Rubinstein & Zaltzman 2000). Furthermore, our experiments extend previous studies on DC concentration polarization effects at micro-nano junctions (e.g. Pu et al. 2004, Plecis et al. 2005, Kim et al. 2007) to AC conditions. Quite curiously, we find that the formation dynamics of these layers are diffusive in nature and are hence universal - frequency dependent. However, by designing channels with different dimensions, we can produce an internal impedance that is higher than the generic entrance impedance, thus endowing each channel with a different impedance signature with and without captured molecules. As a result, a multi-channel array can be designed to allow detection of a large number of targets, provided electric cross-talk does not occur between the channels. By analyzing the dynamics and extent of the depletion/enrichment layer for each pore, we eliminate this possibility by selecting the right frequency and channel spacing such that neighboring depletion layers do not overlap. This involves depletion layer formation in different geometries, with unique impedance signals of their own that can be monitored to ensure lack of cross-talk.

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