Enhancing the Performance of Fluidic Biosensors with Integrated Micro/Nano 3D Surfaces

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Statement of Purpose: Biosensors are important devices for monitoring biological compounds in various processes of biomedical, pharmaceutical, environmental and food safety concerns. The main challenges many biosensors face today include low sensitivity, poor specificity and proneness to fouling. Lately, improvements for the sensitivity and antifouling behavior have been explored through the incorporation of nanostructures into the electrodes of biosensors.[1-4] Here we investigated a new route to enhance the performance of fluidic biosensors by using electrodes made of integrated micro and nano structures with 3D surfaces.

Materials and Methods: To ensure that the integrated micro and nano structures are robust for biosensing applications, we developed an aqueous electrodeposition technique to fabricate them. Starting with a glass slide, a multi-layer (20 nm Ti, 20 nm Au and 1 μm Al) metallization process is applied in an E-Beam evaporator. The top Al layer is anodized in 0.3 M oxalic acid at 40 V to form a nano porous alumina template layer. After the removal of the remaining barrier layer in the porous alumina, gold nanopillars are electrodeposited through the open pores of the alumina template in Orotemp24 gold plating solution at a deposition current of 5 mA/cm^2 using a three-electrode electrochemical cell. Following this, the alumina template is dissolved in 2.0 M NaOH. After that, the gold nanopillar structure is converted into a three-electrode design through conventional photolithographic processes. The electrodes are further enclosed in a PDMS chamber to form a fluidic sensor. For evaluation, in each fluidic sensor, one electrode is functionalized with glucose oxidase and the other two nanopillar electrodes are used as the working and counter electrodes.

Results: Fig.1 shows some SEM images of the fabricated integrated micro and nano structures. The 3D surfaces have a roughness factor of about 18 estimated based on cyclic voltammetry. Fig.2 shows the calibration curve obtained for a fluidic sensor having electrodes of 3D surfaces in glucose detection. Clearly, the sensor exhibits fairly good linear response with a sensitivity value of approximately 35.9 $\mu A \cdot mM^{-1} \cdot cm^{-2}$. Compared with a micro fluidic device having only planar electrodes with a sensitivity value of about 7.50 $\mu A \cdot mM^{-1} \cdot cm^{-2}$, the sensitivity for the 3D-electrode case is about 5 times higher. Based on these results along with the Michaelis-Menten kinetic equation, we calculated the enzymatic kinetic parameters. The maximum current response (I_{max}) is 0.12 μA for the planar case and 0.14 μA for the 3D case, and the apparent Michaelis-Menten constant (K_m) is 11.7 mM for the planar case and 1.04 mM for the 3D case. These results indicate that not only the detection sensitivity is increased for the micro fluidic glucose sensor with electrodes of 3D surfaces, but its enzymatic activity is enhanced as well, when compared with the sensor with flat planar electrodes.

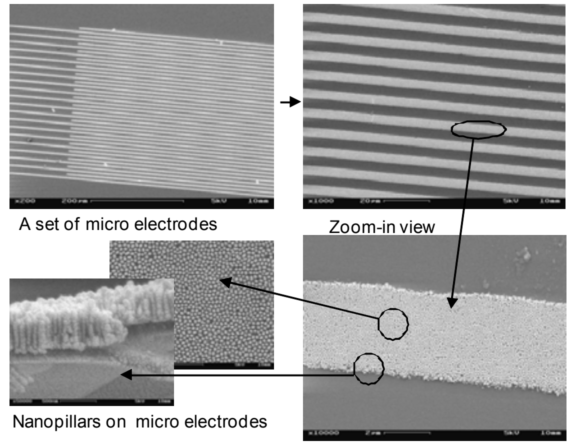

Fig.1 – SEM images showing a set of micro electrodes integrated with standing nanopillars to form electrodes of 3D surfaces.

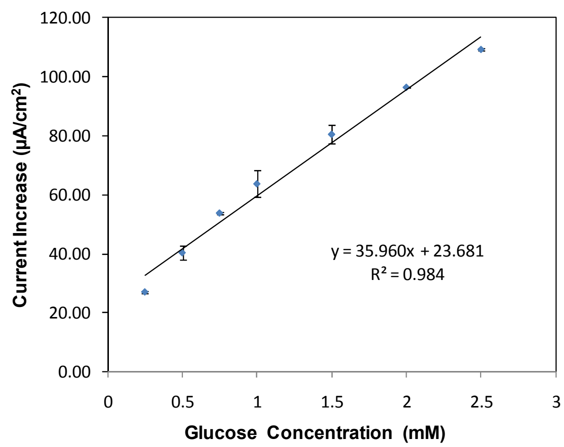

Fig.2 – Calibration curve in glucose detection for a micro fluidic glucose sensor with a set of electrodes made of 3D surfaces.

Conclusions: The detection performance of micro fluidic glucose sensors having electrodes made of integrated micro and nano structures with 3D surfaces has been evaluated. The sensors with electrodes of 3D surfaces exhibit an enhanced detection performance in comparison with the sensors with planar electrodes. We attribute this improvement to the use of 3D electrodes and the underlying convective flow as the added mass transport mechanism besides diffusion. Because of the combined diffusion and convection for mass transport, a high sensitivity value of 35.9 $\mu A \cdot cm^2\ mM^{-1}$ is achieved when the 3D surfaces have a roughness factor of 18. This sensitivity value is almost the same as that (36 $\mu A \cdot mM^{-1} \cdot cm^{-2}$) for the case with 3D surfaces of a roughness factor of 60 when diffusion is the lone mass transport mechanism.[5]

References:

1. Koehne et al., *J Mater Chem* 2004: 14(4) 676; **2.** Wang et al., *J Electroanal Chem.* 2005: 575, 139; **3.** Zhang et al., *J Biol Eng* 2007: 1, 1, 5; **4.** Zhang et al., *Inter J Nanomed* 2006: 1, 73; **5.** Zhang et al., *Nanotech* 2008:19, 395501.