EE-517: Bio-Nano-Chip Design

Exercises 12: Bio-CMOS interfaces in voltage scan

December 1, 2020

Problem 1

Consider a redox reaction of the type

$$\alpha A + \beta Ox + n e^- + \gamma H^+ \rightarrow \delta Red + \epsilon B \qquad \alpha = \beta = \gamma = \delta = \epsilon = 1,\ n = 1$$

Evaluate the change in concentration of the compound Red (at constant pH) that would induce a similar change in potential than a pH increase from 6 to 8.

Initial concentration of Red: $[Red]_0 = 1\,mM$

Problem 2

In *cyclic voltammetry* (CV), the electrochemical cell potential is scanned as $E = E_0 - \nu t$. The **Randles-Sevcik** equation relates the peak current, around the redox potential, to the concentration of the redox compound C as

$$i_{peak} = 0.4463\,nFA\sqrt{\frac{nFD\nu}{RT}}\,C$$

n: number of electrons exchanged
A: active area of the electrode
D: diffusion coefficient of the redox compound
ν : voltage scan rate
C: concentration of the redox compound

The calibration of the sensor yields faradaic currents ranging from $80\,\mu A$ to $100\,\mu A$, for concentration varying from $200\,\mu M$ to $700\,\mu M$.

Compute the concentration of the redox compound if the peak current measured is of $92\,\mu A$.

Problem 3

In CV experiments, a voltage sweep is needed to stimulate the electrochemical cell. A *Direct Digital Synthesizer* (DDS) is used to output staircase waveforms in a form of sub-Hz triangular signals. Consider that the DDS is implemented with a Timer/Counter module of an on-chip micro-controller unit and a 10-bit *Digital-to-Analog Converter* (DAC). Each time the Timer/Counter overflows, the DAC outputs a voltage shifted by the step voltage δE of the desired stair-case waveform.

What should be the overflow period of the timer if a scan rate of $20\,mV \cdot s^{-1}$ is required?
(a) Assume that the LSB of the DAC is used as voltage step, that is $\delta E = LSB_{DAC}$.
(b) Assume that $\delta E = 5\,mV$.

Supply voltage: $V_{cc} = 3.3\,V$

Problem 4

Consider a three-electrodes electrochemical cell able to detect both *Flurbiprofen* and *Naproxen* with CV technique. The latter has a peak current around 50 mV, while the former drug has its peak current around 0 V when a voltage ranging from –100 to 200 mV is swept to the cell.

(a) Design the circuit that allows the aforementionned detection by using a single sensing electrode. Include a peak detector in the readout circuitry.
(b) Draw the Randles equivalent circuit of the electrochemical cell.