#### UNIVERSITY OF CALIFORNIA College of Engineering Department of Electrical Engineering and Computer Sciences

EE 130/230A Fall 2013 Prof. Liu

### Homework Assignment #9

Due at the beginning of class on Thursday, 10/31/13

#### **Problem 1: MOS Capacitor - Areal Charge Density**

Consider an n+ poly-Si-gated capacitor ( $\Phi_{\rm M} = 4.05 \text{ eV}$ ) with oxide thickness  $x_o = 3 \text{ nm}$  and p-type Si substrate doping  $N_{\rm A} = 10^{17} \text{ cm}^{-3}$ , maintained at T = 300K.

- (a) Calculate the flatband voltage,  $V_{\text{FB}}$ .
- (**b**) Calculate the threshold voltage,  $V_{\rm T}$ .
- (c) Plot the value of the total areal charge density (in C/cm<sup>2</sup>) in the Si as a function of gate voltage  $V_{\rm G}$ , for each of the regions of operation (accumulation, depletion and inversion). Indicate the numerical values of areal charge density in the Si at  $V_{\rm G} = V_{\rm T}$  and  $V_{\rm G} = V_{\rm T} + 1$  Volt.

## **Problem 2: MOS Threshold Voltage**

Consider an NMOS capacitor with oxide thickness  $x_o = 3$  nm, maintained at T = 300K.

- (a) Generate a plot of the threshold voltage (on a linear scale) vs. Si dopant concentration (on a log
  - scale), for p-type substrate doping  $N_{\rm A}$  ranging from  $10^{15}$  cm<sup>-3</sup> to  $10^{18}$  cm<sup>-3</sup>, for two cases:
    - (i) Gate material is n+ poly-Si ( $\Phi_M = 4.05 \text{ eV}$ )
    - (ii) Gate material is a "mid-gap" metal ( $\Phi_M = 4.6 \text{ eV}$ )
- (b) From your plot in (a), estimate the value of  $N_A$  corresponding to a threshold voltage of 0.5 V, for each of the two cases.
- (c) Qualitatively, how would your answers to part (b) change if the oxide thickness  $x_o$  were to be decreased (*e.g.* to 2 nm)?

# Problem 3: MOS C-V characteristic

The gate capacitance vs. gate voltage characteristic of a p+ poly-Si gated MOS capacitor ( $\Phi_M = 5.17 \text{ eV}$ ) of area 1×10<sup>-4</sup> cm<sup>2</sup>, is as shown:



- (a) Is the semiconductor (silicon) substrate doped n-type or p-type? Explain briefly.
- (b) Is the measurement frequency low or high? Explain briefly.
- (c) What is the thickness of the gate oxide  $(SiO_2)$ ,  $x_0$ ?
- (d) Estimate the semiconductor doping concentration. (Note: You should be able to estimate the flatband voltage,  $V_{\text{FB}}$ , from the C-V plot above.)
- (e) Based on your answers to (c) and (d), calculate the value of the minimum capacitance,  $C_{\min}$ .