Homework 4: Hot Carrier Degradation

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We discussed HCI degradation in Lectures 13-16. Among the various features, we discussed the universality of time-degradation, voltage acceleration factors, and negative temperature coefficient, making hot carrier a more difficult concern at lower voltages.

Part I: Review Questions for Self-Test

1. Both SiH and SiO are involved in HCI degradation. Give two evidences.
2. Why doesn't HCI occur during NBTI stress condition?
3. I suggested that HCI curve can shifted horizontally to form a universal curve, do you believe that I can do a corresponding vertical shift to form the universal curve?
4. What is the physical origin of distribution of bond-strengths for SiO bonds?
5. Why is it that SiH bonds are easily repassivated, while SiO bonds are not? What can you do to repassivate these bonds?
6. HCI is a bigger problem for NMOS compared to PMOS – what could be the reason.
7. Why did people expect HCI to disappear below 1V?
8. Why is Isub called a thermometer of hot electron distribution? Why can you not simply measure hot electrons by looking at the drain current?
9. What are the three methods of HCI voltage acceleration?
10. If theory of universal scaling is so good, why not use it all the time? (Hint: Think about measurement time issue)
11. How many devices and how long do you need for HCI testing based on hydrodynamic theory? What about Universal scaling theory? What about direct lifetime projection?
12. What determines HCI failure times?
13. Could the methodology discussed could also be used to calculate hot hole current?
14. If Monte Carlo simulation is so good, why does not everyone use Monte Carlo simulator to do lifetime testing?

Problem 2: Channel Field Profile in a MOSFET

a) Follow the analysis in Chapter 2, p. 54 of the book by Lundstrom/Guo (Nanoscale Transistors) to derive the relationship $(V_D - V_{D,sat}) \sim U_0\, exp\left(\frac{x}{l}\right)$ and $E\_max = (V_D - V_{D,sat})/l$?

b) What is the physical meaning of l? The potential drops quadratically upto the pinch-off point, but then drops exponentially with the pin-off region. Can you physically explain the result?

c) Theoretically, one can show that $l = \sqrt{\frac{\kappa_{si}}{\kappa_{ox}} T_{ox} \times x_j^{'}}$, but empirically one finds $l \sim 0.22\, t_{ox}^{\frac{1}{3}} \times x_j^{\frac{1}{2}}$, where $t_{ox}\ and\ x_j$ are thickness of the gate oxide and junction depth, respectively. Regardless, can you review the derivation in part (a) to argue why l should depend on $x_j\ and\ T_{ox}$ dependencies arise?

Problem 3: Understanding the meaning of universal scaling

This problem is based on a 2008 publication in the Proc. of International Reliability Physics Symposium by Dhanoop Varghese. The problem involves discovering the universality of the HCI damage through Idlin degradation data for DeNMOS and DePMOS transistors taken at various stress drain biases.

- Obtain the ZIP file 'Universal-degradation-hw4'. You can use notepad or word-pad to review the data.

- Open the NMOS Idlin data obtained by stressing the device at 6V (nmos_perc_didlin_vd6). Two columns of data – time and shift in threshold voltage – are given. If you compare this data with another NMOS dataset obtained a different stress voltage (e.g. nmos_perc_didlin_vd5.5), you will find that the time axis is the same, but degradation (2nd column) is different.

- Use the matlab program provided to see how the data at various voltages can be scaled to obtain the universal curve.

- Given these scaling factors, find the voltage acceleration factor for DeNMOS.

Extra Problem: Hot Electron Distribution by Monte Carlo Simulation

There are a set of very nice Monte Carlo simulation tools in nanohub.org to help you visualize the carrier profiles as a function of position along the device (e.g. nanohub.org/resources/demons). If you are interested in carrier profiles in uniform field (i.e. long drift region), you could use nanohub.org/resources/bulkmc. The corresponding topic page in nanohub.org/topics/BMC contains a lot of background information.

To access SDemon or bulkmc, go to *www.nanohub.org*, select *Tool Index* under Online Simulation. If this is your first time at the nanoHUB, you'll be asked to request an account. After filling out the form, you'll get an account automatically and then be able to log in. Use *Help* on each page for instructions on what to do.

Use the bulkmc code to answer the following questions.

a) First, simulate for silicon the carrier distribution profile for three different fields $10^3\,V/cm$, $10^5\,V/cm$, and $10^7\,V/cm$, all at 300 C.
b) Plot initial energy distribution, and distribution of energy for each of the fields. You may wish to download the comparison. How does the energy distribution changes with applied field? Can the distribution of carriers be represented by a single-temperature Boltzmann distribution?
c) Compare the changes in the valley occupation as a function of electric field?
d) Plot velocity along the field? Can you explain the physical origin of the velocity overshoot very early in the simulation? Hint. You should look for the valley occupation plot and explore the relative subpopulations.
e) Redo the simulation for 100 C. Are the carriers more, or less heated when the lattice temperature is reduced to 100 C from 300 C? Can you explain why?