Written Reexamination EITP25

August 18th 2021

Useful constants:

$$\hbar = 1.055 \times 10^{-34}\, Js$$

$$k_B = 1.381 \times 10^{-23}\, J/K$$

$$m_0 = 9.109 \times 10^{-31}\, kg$$

$$\varepsilon_0 = 8.85 \times 10^{-12}\, Fm^{-1}$$

$$e = q = 1.602 \times 10^{-19}\, C$$

$$c = 2.998 \times 10^{8}\, m/s$$

Solve the Five tasks below. Maximum score is 60p.

1. Conventional memory technology: (12 p)
    a. What is DRAM, how does one write to it, and why DRAM is not used for solid state drives? (4p)
    b. A FLASH memory cell with L = 10 nm, an Al floating gate and Al_2O_3 oxide barrier (E_b = 2 eV, m = m_0) should have 10 year retention. How thin can the Al_2O_3 layer be? (Assume $f_0^* = 10^{13}\, s^{-1} nm^{-2}$) (4p)
    c. Explain why GPU's are beneficial for machine learning tasks and how it performs a matrix multiplication operation. (2p)
    d. What is typically limiting performance of a GPU and TPU in the case of a small CNN? (2p)
2. Machine learning (12p)
    a. Describe the purpose of and the steps of the backpropagation algorithm. (4p)
    b. Explain how a convolutional neural network works, and name two benefits of it compared to a fully connected network. (4p)
    c. Explain what lateral inhibition of neurons is and in what way it can benefit learning in a Spiking Neural Network. (4p)

3. MRAM and PCM: (12p)
    a. Explain how spin-torque transfer can be used to write to an MRAM device. (4p)
    b. Compare the WRITE energy consumption of PCM and MRAM and motivate your answer. (4p)
    c. Explain how a 2-PCM synapse works and why one wants to implement a synapse that way. (4p)

4. Ferroelectric memory: (12p)
    a. Describe the steps involved in the PUND method used to measure ferroelectric polarisation. (4p)
    b. FeFETs can have issues with retention, explain why and give an example of how to design the FeFET to avoid it. (4p)

c. Explain how one would go about to achieve $R_{off}/R_{on} > 10^6$ with FTJs. Motivate your answer. (4p)

5. ReRAM: (12p)
    a. Explain the difference between how electrochemical metallization and valence change memory operates to form a conductive filament form. (4p)
    b. What determines R_{on} in a ReRAM device, and how can one control it? (2p)
    c. What determines R_{off} in a ReRAM and how can avoid its cycle-to-cycle variation? (2p)
    d. What would be a suitable selector device for a bipolar ReRAM device? Motivate your answer. (4p)