INSTRUCTIONS

- Write your name and ID on all answer booklets used.
- There are FOUR (4) questions in total.
- All questions are equally weighted.
- **Answer ALL Questions**
- 3 hours are available.
- Closed-book exam, prohibited materials include:
  - *PDAs*
  - *Cellphones*
  - *Notes/books*

FUNDAMENTAL CONSTANTS:

h	6.626×10^{-34} Js	N_A	6.022×10^{23} mol^{-1}
$\hbar$	1.055×10^{-34} Js	k_B	1.38×10^{-23} JK^{-1}
q_e	-1.602×10^{-19} C	c	2.998×10^{8} ms^{-1}
m_e	9.11×10^{-31} kg	μ_0	$4\pi \times 10^{-7}$ Hm^{-1} (WbA^{-1}m^{-1})
m_p	1.67×10^{-27} kg	ε_0	8.854×10^{-12} Fm^{-1}

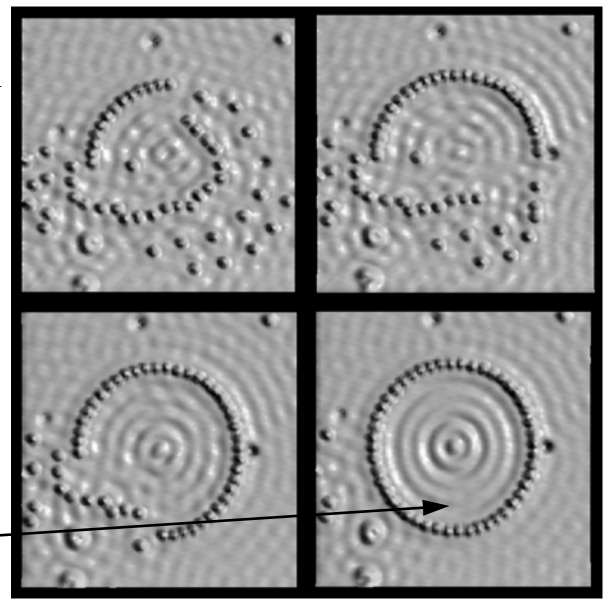
UNIVERSITY OF MANITOBA

Department of Electrical & Computer Engineering
PhD Candidacy Examination 2013
Nanoelectronics
3 hours maximum

1. Three distinct regimes may be described for electron transport in materials: *macroscopic*; *mesoscopic*; and *quantum*. In point form, discuss how electron transport is described in these three regions and what length scales can be used to suggest which of these descriptions is most appropriate for electrons confined to a given structure.

2. You are asked to fabricate a quantum dot system using GaAlAs barriers in the conduction band of a GaAs host.
   a. Draw a band structure diagram of this system showing the key parameters that determine the spacing of energy eigensolutions in the quantum dot and the expressions that best approximate these.
   b. Sketch the transmission characteristics (probability) for electron transport in the conduction band.
   c. Consider the two cases: (i) of photons emitted/absorbed as a consequence of transitions between eigenstates within the quantum dot; and (ii) of photons emitted/absorbed as the result of transitions between an eigenstate and either the conduction or valance band edge. Explain why the lineshapes of these spectra respond to substantial changes in ambient temperature.

3. This question relates to techniques employed in scanning tunneling microscopy.
   a. With the assistance of a diagram, summarize the operation of a scanning tunneling microscope.
   b. The figure (opposite) shows an arrangement of iron (Fe) atoms on a Cu(111) surface, sometimes termed a “quantum corral”. The figure is a scanning tunneling microscope image that has been reproduced from data associated with Crommie *et al.*, *Science* **262** (1993) p218. Explain the origin of the concentric rings found in the image indicated by the arrow.



4. The following question relates to the fabrication of gold interconnects as model systems for those found in integrated circuits (ICs). The cross-section of the interconnects discussed below had widths ranging from 40 nm – 800 nm wide, were 250 nm high and their length was on the order of 200 µm.
   a. In the fabrication process described, tantalum was used as an “adhesion layer”. Explain what an “adhesion layer” is and the additional (important) functions of adhesion layers in IC interconnects.
   b. Assume that annealing and other fabrication steps are undertaken to minimize the scattering due to grain boundaries (i.e. the resultant wires are as close to a “bamboo microstructure” as can be attained). Consider a hypothetical comparison between two wires fabricated in this fashion, one with the tantalum adhesion layer and one without. Explain the differences that might be observable between these wires in terms of both electromigration and the contribution of specular reflection as a consequence of wire dimension.
   c. In point form, describe the physical basis of electromigration in metallic interconnects and why it represents a significant failure mechanism.

- END OF EXAM PAPER -