FA12 Nanoscale Devices & Systems MS Exam

1. For small semiconductor quantum dot structures, the single-electron charging energy can become comparable to the quantum confinement energies in the dot. Consider a spherical semiconductor quantum dot of radius a in which the semiconductor material has band gap E_g = 1.0 eV, dielectric constant $\varepsilon = 10\varepsilon_0$, electron effective mass $m_n^* = 0.1m_0$, and (heavy) hole effective mass $m_p^* = 0.5m_0$, where m_0 is the free electron mass. An infinite potential energy barrier is present for $r>a$ (in spherical coordinates). The dielectric constant for $r>a$ is ε_m.
   (a) Obtain an expression for the electrostatic energy required to place a single electron charge onto the quantum dot, as a function of a and ε_m. For purposes of computing the capacitance of the quantum dot, you may assume it behaves electrostatically like a metal.
   (b) Compute and plot, in eV, the quantum confinement energy for the electron (conduction-band) ground state, and the single-electron charging energy, for $\varepsilon_m = \varepsilon_0$ and $\varepsilon_m = 4\varepsilon_0$, as functions of a for 2nm < a < 20nm.
   (c) Suppose an electron-hole pair is created in the semiconductor quantum dot by excitation of an electron from the valence band to the conduction band. How would you expect the single-electron charging energy to influence the energy of the photon that would be required to create the electron-hole pair? Explain your answer.

2. A 2D electron gas in Si MOSFET has mobility of 1×10^5 cm^2/V-s at low temperature. If Fermi energy is 0.1 eV calculate the scattering mean free path. (Si $m^* = 0.2\ m_0$, $m_0 = 9.11\times10^{-31}$kg)