Magnetics

(1) Consider a large free-standing rectangular shaped ferromagnetic object with 500 nm in long axis and 200 nm in short axis and a variable thickness from 2 nm to 50 nm. Assume this ferromagnetic material is single crystal (002) iron (Fe) in body center cubic crystalline structure. Explain why magnetic domain walls could be formed in such a magnetic structure. Schematically show a Bloch domain wall and a Néel domain wall in this structure with spin configuration related to the film plane. If this Fe structure has a film thickness less than 5 nm, explain why Néel walls or Bloch walls be in favor. (0.7 points)

(2) Uniformly shrink this Fe structure to a small size (25 nm in length and 10 nm in width) with a fixed thickness (2 nm). Plot and explain the trend of the coercivity vs. the length of the long axis for this Fe structure. What is the necessary effective magnetic anisotropy constant for this Fe structure to be thermally stable at room temperature? Assume the required thermal stability factor is 60. Boltzmann constant is 1.38×10^{-16} erg K^{-1}. (0.8 point)

(3) Stacking an Fe layer and Cr layer into an artificial multilayer structure $[Fe/Cr]_n$ with a proper sub-layer thickness and repetition led to the discovery of the giant magnetoresistance (GMR), which won the Nobel prize in physics in 2007 for Profs. A. Fert and P. Grunbergh. Point out the two key fundamental aspects, which jointly enable the discovery of the GMR effect. Assume the magneto-transport testing was done on $[Fe/Cr]_4$ using a current-perpendicular-to-plane (CPP) mode. Explain the (GMR) effect using a two-channel model (also named as two-resistor model). (1.5 point)

(4) A current-perpendicular-to-plane (CPP) giant magnetoresistance (GMR) device for the read sensor application uses a tri-layer structure, also called a spin-valve structure. Use Fe as both the free layer and fixed layer and Ag as the spacer layer. The Fe free layer possesses a large anisotropy that is not favorable for sensing purpose. Suggest one materials engineering approach to lower the anisotropy thus the hard-axis coercivity of the free layer, e.g. doping or alloying. Explain why your approach works. The fixed Fe layer is pinned by an antiferromagnetic layer. Calculate the exchange bias field for the Fe fixed layer with 3 nm in thickness and 1700 emu/cm^3 magnetization. Assume the exchange coupling constant between the iron layer and the antiferromagnetic layer is 0.075 erg/cm^2. Without sacrificing the Fe fixed layer thickness or using new antiferromagnetic layer, suggest an approach to enhance the exchange bias; You may assume that the smooth antiferromagnetic surface has all spins in same direction (1.0 point);