# ELEG 667–016; MSEG-667-016 - Solid State Nanoelectronics – Fall 2005

## Homework #5 - due Tuesday, 17 October 2005, in class

1. **Néel wall:** The direction of magnetization change in a domain wall goes from that of the Bloch wall to that of a Néel wall (see Figures and description below) in thin films of material of negligible crystalline anisotropy energy (i.e. no preferred axis of magnetization) such as Permalloy. The intercept of the Bloch wall with the surface of the film creates a surface region of high demagnetization energy. The Néel wall avoids this intercept contribution, but at the expense of a demagnetization contribution throughout the volume of the wall. The Néel wall becomes energetically favorable when the film becomes sufficiently thin. The energy per unit area of wall is the sum of contributions from exchange and anisotropy energies: $\sigma_w = \sigma_{ex} + \sigma_{anis}$

For a wall on which a change in spin angle of $\pi$ occurs in N equal steps, then the angle between neighboring spins is $\pi/N$, and the exchange energy per pair of neighboring atoms is $w_{ex} = JS^2(\pi/N)^2$ and the total exchange energy of a line of N+1 atoms is $Nw_{ex} = JS^2\pi^2/N$ , which is valid for a line of atoms perpendicular to the plane of the wall. For a lattice contact of ***a***, the energy density is then $\sigma_{ex} = JS^2\pi^2/Na^2$ For a Bloch wall, the anisotropy energy is of the order of the anisotropy constant times the thickness *Na*, or $\sigma_{anis} \cong KN\boldsymbol{a}$. The total wall energy is the sum of these two terms, and the minimum can be obtained by taking the derivative of $\sigma_w$ with respect to N.

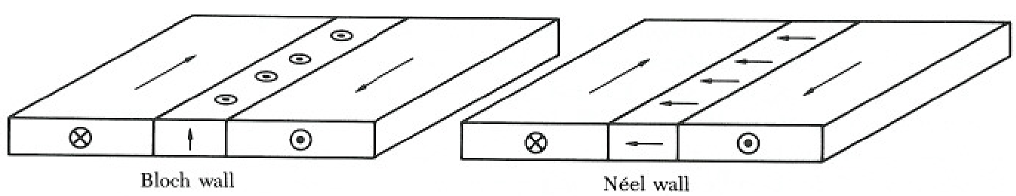


**Figure 1.** A Bloch wall and a Néel wall in a thin film. The magnetization in the Bloch wall is normal to the plane of the film and adds to the wall energy a demagnetization energy $\sim M_s\delta d$ per unit length of wall, where $\delta$ is the wall thickness and *d* the film thickness (N***a***). In the Néel wall the magnetization is parallel to the surface; the addition to the wall energy is negligible when $d \ll \delta$. The addition to the Néel wall energy when $d \gg \delta$ is the subject of this problem.

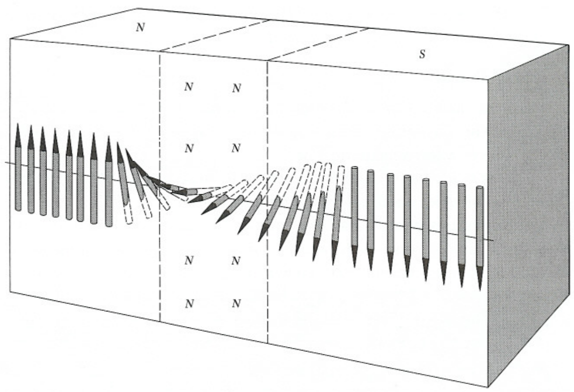


**Figure 2.** The structure of the Bloch wall separating domains. The exchange energy is lower when the change is distributed over many spins. The Heisenberg model for the exchange energy between two spins gives $w_{ex} = -2J\mathbf{S}_i \cdot \mathbf{S}_j$. Approximating $\cos\phi$ by $1 - ½\,\phi^2$, then apart from an additive constant, $w_{ex} = JS^2\phi^2$ is the exchange energy between two spins making a small angle $\phi$ with each other, which is used in the problem statement above. As a particular example, in iron the thickness of the transition region is about 300 lattice constants.

Consider, however, the energetics of the Néel wall in bulk material of negligible crystalline anisotropy energy. There is now a demagnetization contribution to the wall energy density. The energy per unit area of wall is the sum of contributions from exchange and demagnetization energies: $\sigma_w = \sigma_{ex} + \sigma_{demag}$. Show that $\sigma_w = (\pi JS^2/Na^2) + (2\pi M_s^2 Na)$ . Find N for which $\sigma_w$ is a minimum. Estimate the order of magnitude of $\sigma_w$ for typical values (e.g. iron and permalloy) of J, $M_s$, and $\boldsymbol{a}$.

2. **Néel temperature ($T_N$):** Taking the effective fields on the two-sublattice (i.e. A and B) model of an antiferromagnetic material as

$$B_A = B_a - \mu M_B - \varepsilon M_A; \qquad B_B = B_a - \mu M_A - \varepsilon M_B$$

for applied field $B_a$. In the mean field approximation, assume that each sublattice obeys Curie's law with $\chi = C/T = \mu_o M_i/B_i$ , where i = A,B. Using the conditions for a non-trivial simultaneous solution for $(M_A, M_B)$ in the two equations above when $B_a = 0$, obtain $T = T_N$ in terms of C, $\mu$ and $\varepsilon$. Next find an equation for $\chi = \mu_o(M_A + M_B)/B_a$ in terms of these same parameters, and put it into the conventional form for antiferromagnetic materials: $\chi = \text{const}/(T + \theta)$ to show that $\theta/T_N = (\mu+\varepsilon)/(\mu-\varepsilon)$

Homework assignments will appear on the web at:
http://www.ece.udel.edu/~kolodzey/courses/eleg667_016f05.html

Note: On each homework and report submission, you must please give your name, the due date, assignment number and the course number.