4 - 26 Theoretical Calculation of the Coercivity of Cu/Ni Multilayer Nanowire Arrays

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As a member of 1D nanostructured materials, the ferromagnetic and nonmagnetic multilayer nanowires exhibit tremendous potential applications in many fields due to their unique magnetic and electrical properties. The basic property of multilayer nanowire arrays, such as coercivity, is crucial important for the future application. In order to obtain the coercivity information, besides directly measuring it through experiment, theoretical calculation also provides a useful and fast way to evaluate the multilayer's coervicity. Fig. 1(a) and (b) demonstrate a single multilayer nanowire and nanowire arrays embodied in a matrix, respectively. In this work, by improving Pant's model, we developed the new model and successfully predicted the relationship between the coercivity changing of Cu/Ni multilayer nanowire arrays and structual parameters.

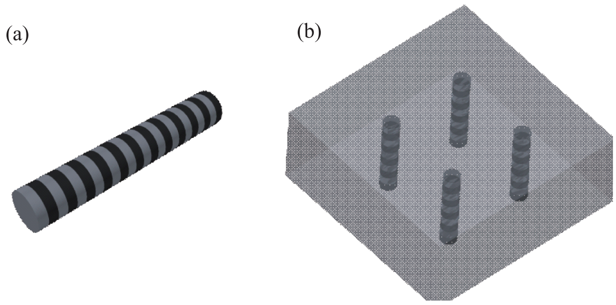

Fig. 1 The sketch map of Cu/Ni multilayer nanowires. (a) single Cu/Ni multilayer nanowire, (b) Cu/Ni multilayer nanowire arrays embodied in the matrix.

According to our previously analysis, the Pant's model[1] is suitable for the ferromagnetic/nonmagnetic multi strips alternately spreading on substrate with the essential conditions, $t \ll l \ll L$, where t, l and L represent the thickness, the width and the length of the strip, respectively, shown in Fig. 2(a). In our case, shown in Fig. 2(b), the strip length, L, is instead by the nanowire diameter, d, which is comparable to the thickness of Ni layer, g. The contribution fields from edges of non-neighbouring strips, such as H_1, H_2, $\cdots\cdots$, is much lower while comparing to H. In Cu/Ni multilayer nanowire, every Ni layer could be treated as single magnet moment which only couples with the two neighbouring Ni layers. When an external magnetic field is applied, the demagnetization field will be the sum of fields from its own edges, H, plus the average stray field contributions from the neighbouring magnets, $H^{'}$, as shown in Fig. 2(b). The demagnetization field dominated by H according to Pant's model can be modified as follows:

$$H_{\mathrm{eff}}^{\mathrm{Cu/Ni}} = H_0 + \frac{1}{n+1}\sum_{j=1}^{n} H_j^{'} = 2\pi M_s(1-3P)\left(1-3\left(N_0+\frac{1}{n+1}\sum_{j=1}^{n}N_i^{'}\right)\right), \tag{1}$$

where H_0 is the self-demagnetizing field of single Ni layer mainly caused by the shape anisotropy, $H_j^{'}$ and $N_j^{'}$ are the coupling field and the coupling factor between the neighbouring Ni layers external field was applied, $n+1$ is the number of magnetic layers in the multilayer nanowire with n starting from 0. The average coupling factor between the neighbouring Ni layers can be obtained as:

$$\frac{1}{n+1}\sum_{j=1}^{n}N_j^{'} = \frac{1}{n+1}\left(\sum_{i=0}^{n}N_i - N_0\right) = \frac{1}{n+1}\sum_{i=1}^{n}N_i, \tag{2}$$

Combining Pant's model, Eqs. (1) and (2), the formula of demagnetization field can be written as the following form:

$$H_{\mathrm{eff}}^{\mathrm{Cu/Ni}} = 2\pi M_s(1-3P)\left(1-3(N_0+\frac{1}{n+1}\sum_{j=1}^{n}N_j^{'})\right) = 2\pi M_s(1-3P)\left(1-3(N_0+\frac{1}{n+1}\sum_{i=1}^{n}N_i)\right) \tag{3}$$

In Eq. (3), the Cu/Ni multilayer nanowire array should possess homogenous structure, *i.e.*, the multilayer nanowires should have the same Ni layer thickness and Cu layer thickness along the wire long axis.

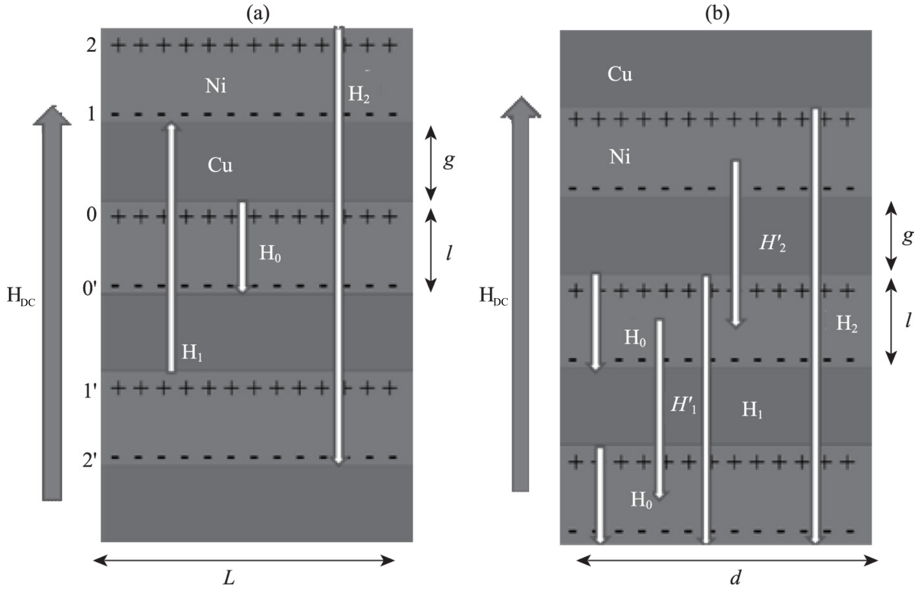

Fig. 2 Lateral sketch of a multilayer nanowire with diameter d. the Ni and Cu layer of thickness are l and g, respectively. The demagnetizing fields H_n appear as a result of the polarization of the magnetic layers under biasing by magnetic field H_DC. (a) The model from Pant's work, (b) The improved Pant's model in present work.

According to Eq. (3), the improved Pant's model, the demagnetizing fields of Cu/Ni multilayer nanowire array with different diameters are modulated as a function of periodicity as shown in Fig. 3(a). The demagnetizing fields are sensitive to the periodicity when it is less than 10 which means the coupling effect among Ni layers takes an import role in the total demagnetizing field. If the periodicity continues increasing, the coupling effect increases as well but is less sensitive to the periodicity as before. Meanwhile, the nanowires with smaller diameter always present higher demagnetizing field than thicker ones which is in agreement with the our experiment results.

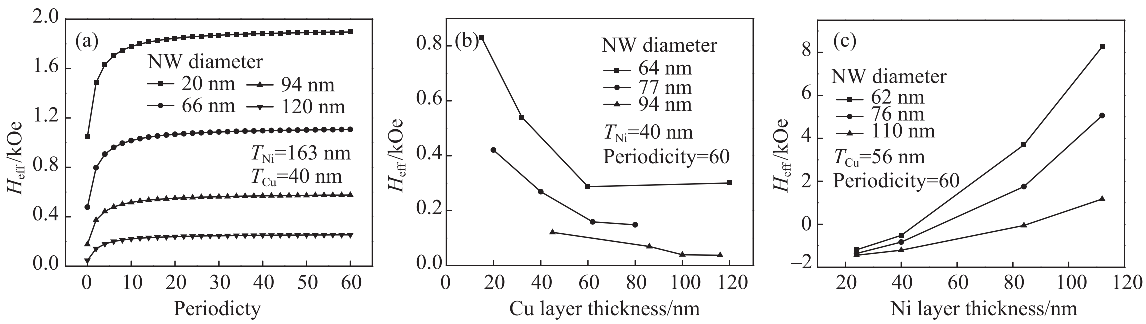

Fig. 3 The simulation results of demagnetizing field from multilayer Cu/Ni nanowire arrays related to (a) The periodicity, (b) Cu layer thickness, (c) Ni layer thickness. The Cu/Ni nanowire areal density is 1×10^9 cm^{-2}.

Fig. 3(b) and (c) give the demagnetizing field response curves as the Cu and Ni layer thickness varying, separately. In Fig. 3(b), as the Cu layer thickness increases, the space between the two coupling magnets increases and the corresponding dipole-dipole coupling effect decreases. Thereby the demagnetizing field, $H_\mathrm{eff}^\mathrm{Cu/Ni}$, decreased with increasing Cu layer thickness. Inversely, as increasing the Ni layer thickness while keeping Cu layer thickness constant, the self-demagnetizing field of single Ni layer, H_0, is significantly increased. As can be seen from the figures, the model describes are in good agreement with the behaviour observed from the experimental data.

References

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