Universidade Federal do Rio de Janeiro
Instituto de Física

Magnetotransporte em nanoestruturas

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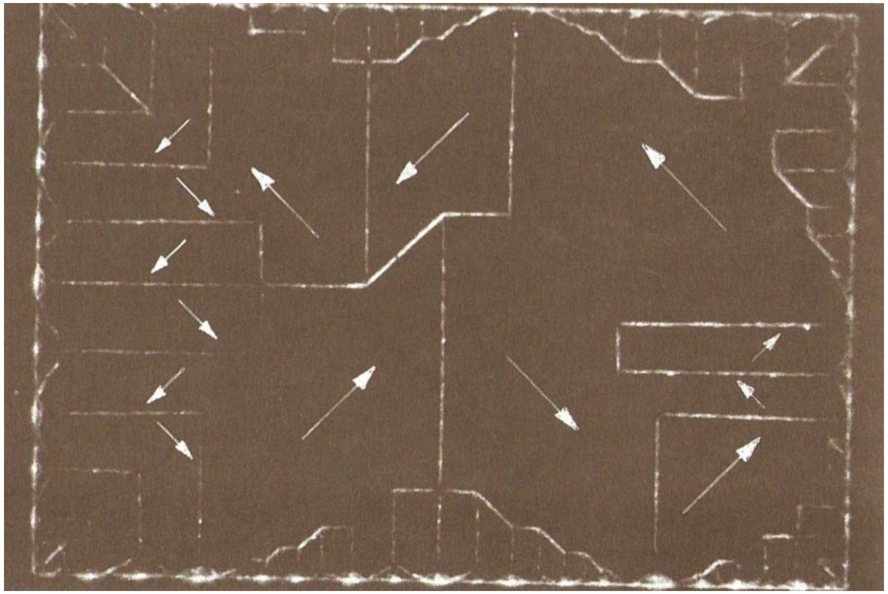
Domain wall

- Magnetic domains are fundamental structures in ferromagnets



Domain wall

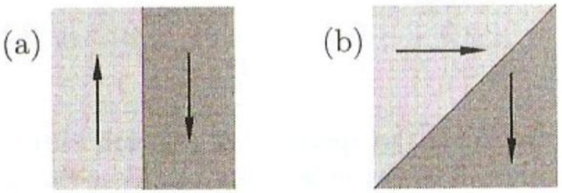


Fig. 6.19 (a) 180° domain wall. (b) 90° domain wall.

Domain wall

- In general terms, the thickness of a DW in a ferromagnetic material is determined by the competition between the interatomic exchange interaction and the magnetic anisotropies

- For Fe, Co, Ni and their alloys, typical values of the DW thickness are of the order of 100 nm.

Domain wall

- Magnetic domain walls in ferromagnets have become the subject of intense research in the past years.
- The interaction between spin polarized current flowing in a ferromagnet and the domain wall is regarded as providing a new way of exploiting the spin degree of freedom.
- However, details of the interaction between current and DWs remain unclear.

Domain wall

- **For a long time, DWs were considered as having no appreciable effect on the resistance of 3d ferromagnets**

Cabrera and Falicov, Phys. Stat. Sol. (b) (1974); Berger, J. Appl. Phys. (1978)

180^o DW with thickness L ≥ 10 nm
→ negligible contribution to resistance

Domain wall

- **Gregg *et al.* [PRL 77 (1996)]**

→ **first direct observation of ferromagnetic domain wall scattering**

FIG. 2. Domain patterns for a 1000 Å thick cobalt film as imaged by magnetic force microscopy. (a) The initial domain configuration in zero applied field. (b) The beautiful parallel stripe domain pattern which may be prepared by single domaining the film in a large magnetic field applied in the plane of the film, then demagnetizing the film by cycling the in-plane field.

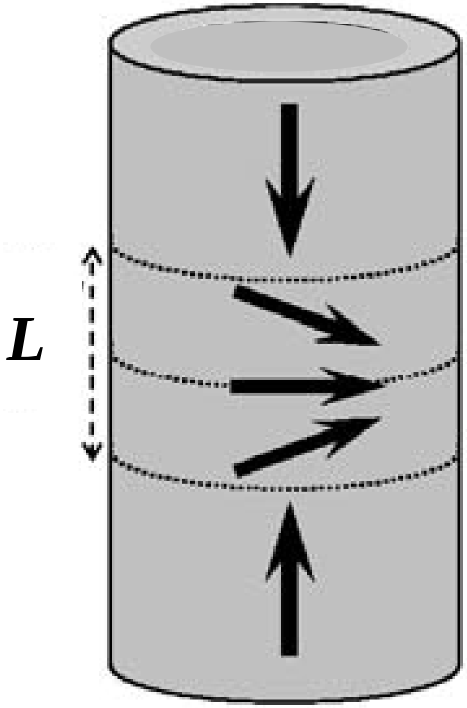
Domain wall thickness

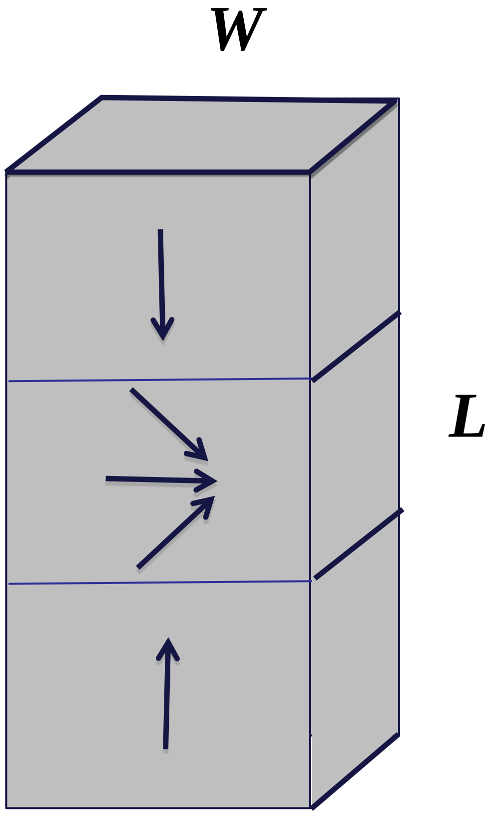
A. Ben Hamida, O. Rousseau, S. Petit-Watelot and M. Viret

EPL, 94 (2011) 27002 **EPL, 94 (2011) 27002**

Domain wall

- **Ferromagnetic nanowires**





ac and dc current-induced motion of a 360° domain wall

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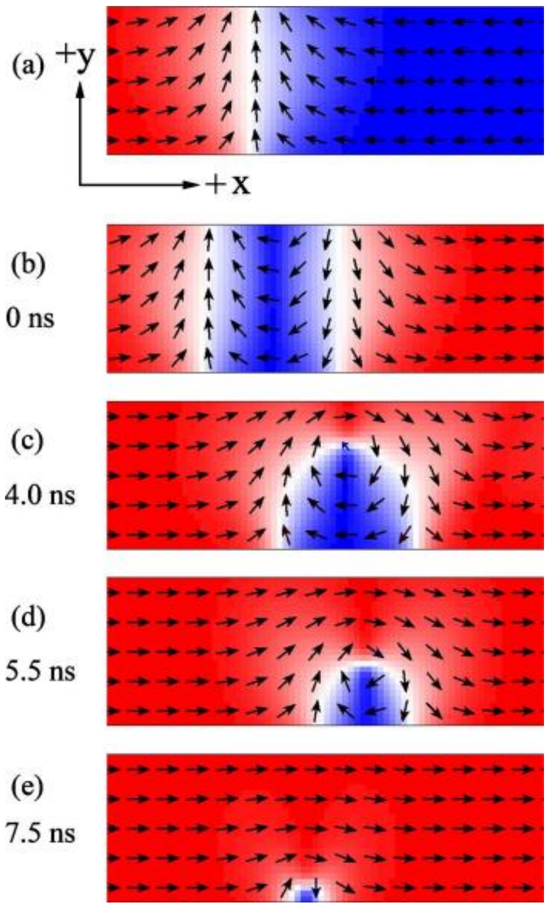


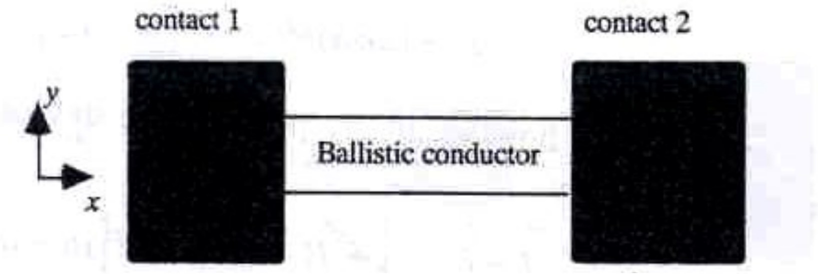
FIG. 1. (Color online) (a) Part of stripe showing the equilibrium transverse 180DW structure. Axes are indicated. (b) The equilibrium 360DW structure at zero field. (c) Part way through the annihilation process of a 360DW showing a reverse domain bounded by a U-shaped 180DW. [(d) and (e)] Successive snapshots of the 360DW annihilation process.

Points of interest

- Dependence of the resistance on the the DW thickness
- Dependence of the resistance on the material parameters
- Contributions from spin-flip and non-spin-flip processes to the conduction across a DW
- Magnetoresistance associated with DWs

Landauer formalism

- Ballistic regime: mean free path λ >>L



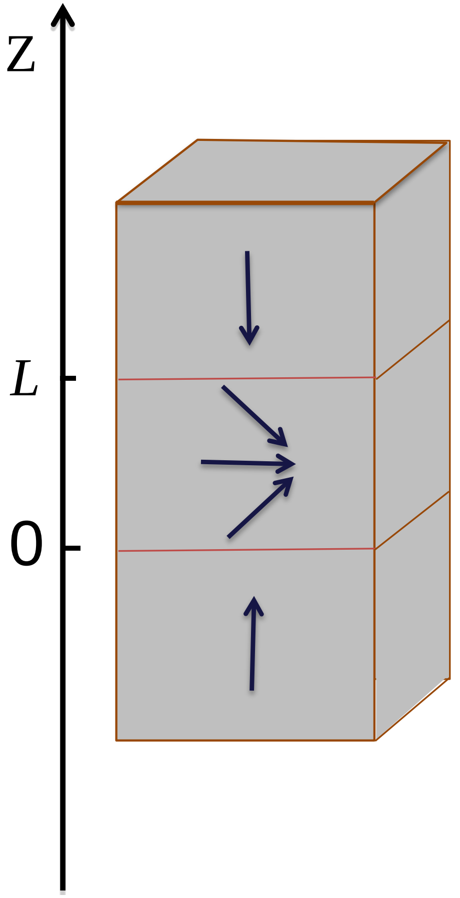
- Conductance G

$$G = \left(\frac{e^2}{\hbar}\right) \sum_{\sigma\sigma'} \sum_{\alpha} T_{\alpha}^{\sigma\sigma'}(E_F)$$

T = transmission coefficient

α = channel index

Domain wall



exchange field

$$\overleftrightarrow{V}\left(\theta\left(z\right)\right)=V\begin{pmatrix}-\cos\theta & -\sin\theta & \\ -\sin\theta & +\cos\theta & .\end{pmatrix}$$

$$0 £ z £ L \quad Þ \quad 0 £ q £ p$$

discretization

$$q_i = p\,\frac{i}{N} \qquad with \qquad i = 0,1,2,3,\ldots,N$$

solution within each interval

Domain wall

- by matching the solutions at the boundaries of subsequent intervals we obtain

➔ transmission coefficients

$$[T] = \begin{bmatrix} T^{--} & T^{-+} \\ T^{+-} & T^{++} \end{bmatrix}$$

- from which we get

$$[G] = \begin{bmatrix} G^{--} & G^{-+} \\ G^{+-} & G^{++} \end{bmatrix}$$

Domain wall

- **non-spin flip conductance**

$$\boxed{G_{nsf} = G^{--} + G^{\overline{\quad}}}$$

- **spin-flip conductance**

$$\boxed{G_{sf} = G^{-\,\overline{\ }} + G^{\overline{\ }\,-}}$$

Domain wall

- **magnetoresistance ratio**

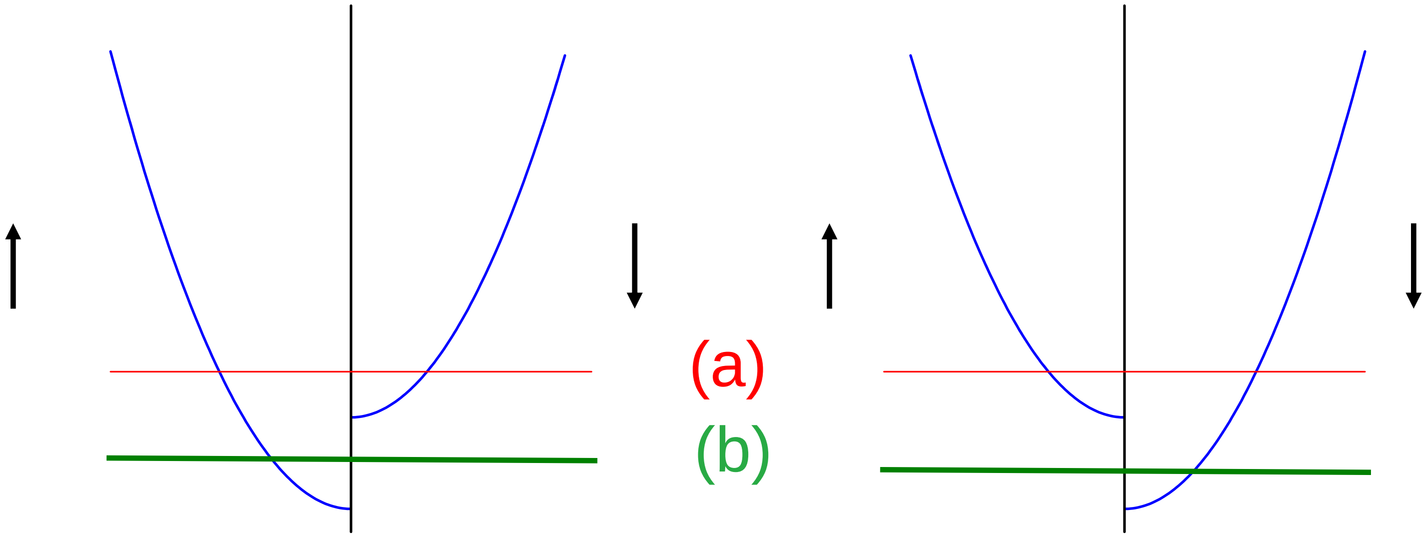
$$MR = \frac{R - R_0}{R_0} = \frac{G_0}{G} - 1$$

where R_0 and G_0 are the resistance and conductance in the absence of the wall

- **normalized conductance**

$$\bar{G} = G / G_0$$

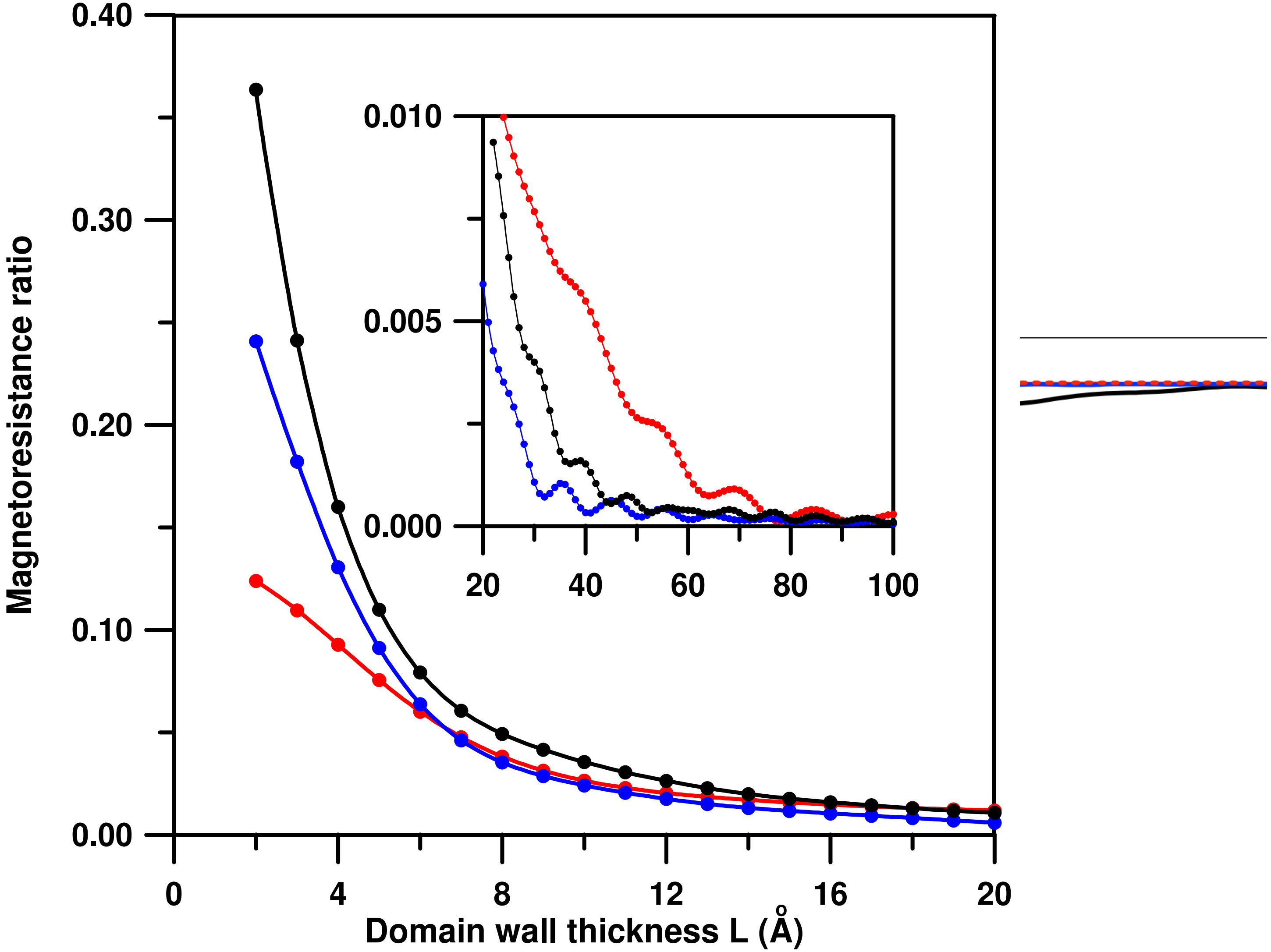
Domain wall



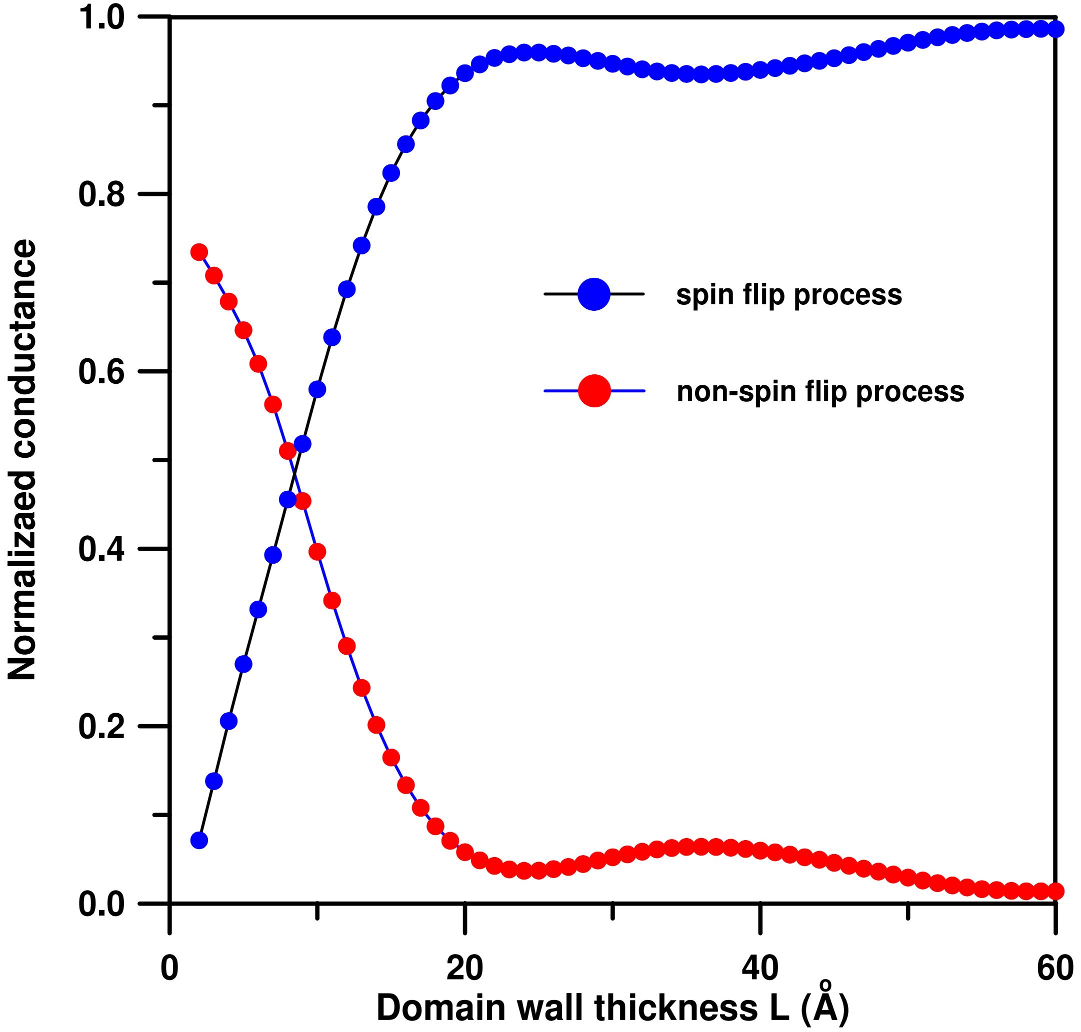
(a) Weak ferromagnet (eg. Fe)

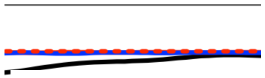
(a) Strong ferromagnet (eg. Ni, Co)

(a) Weak ferromagnet

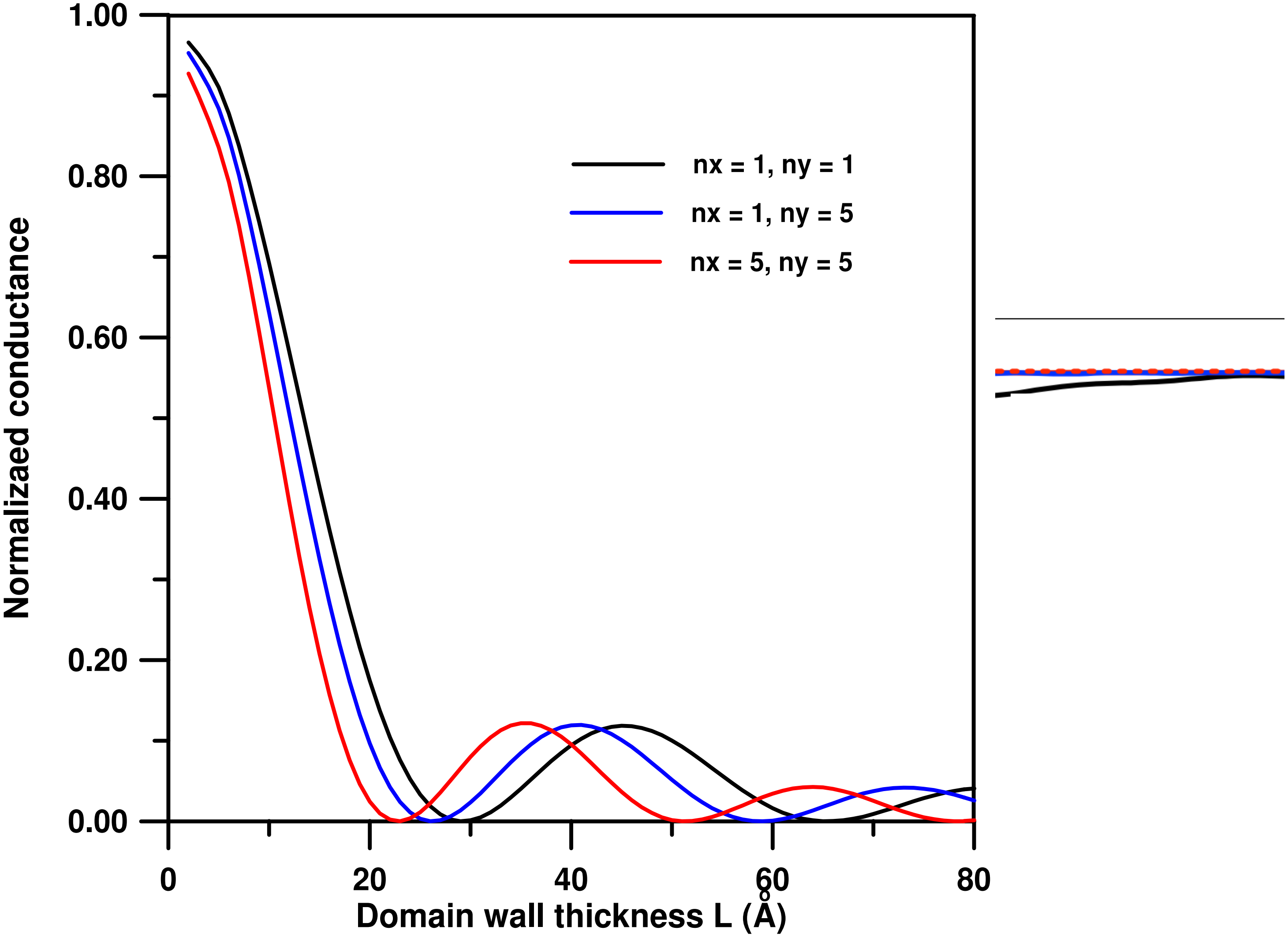


(a) Weak ferromagnet

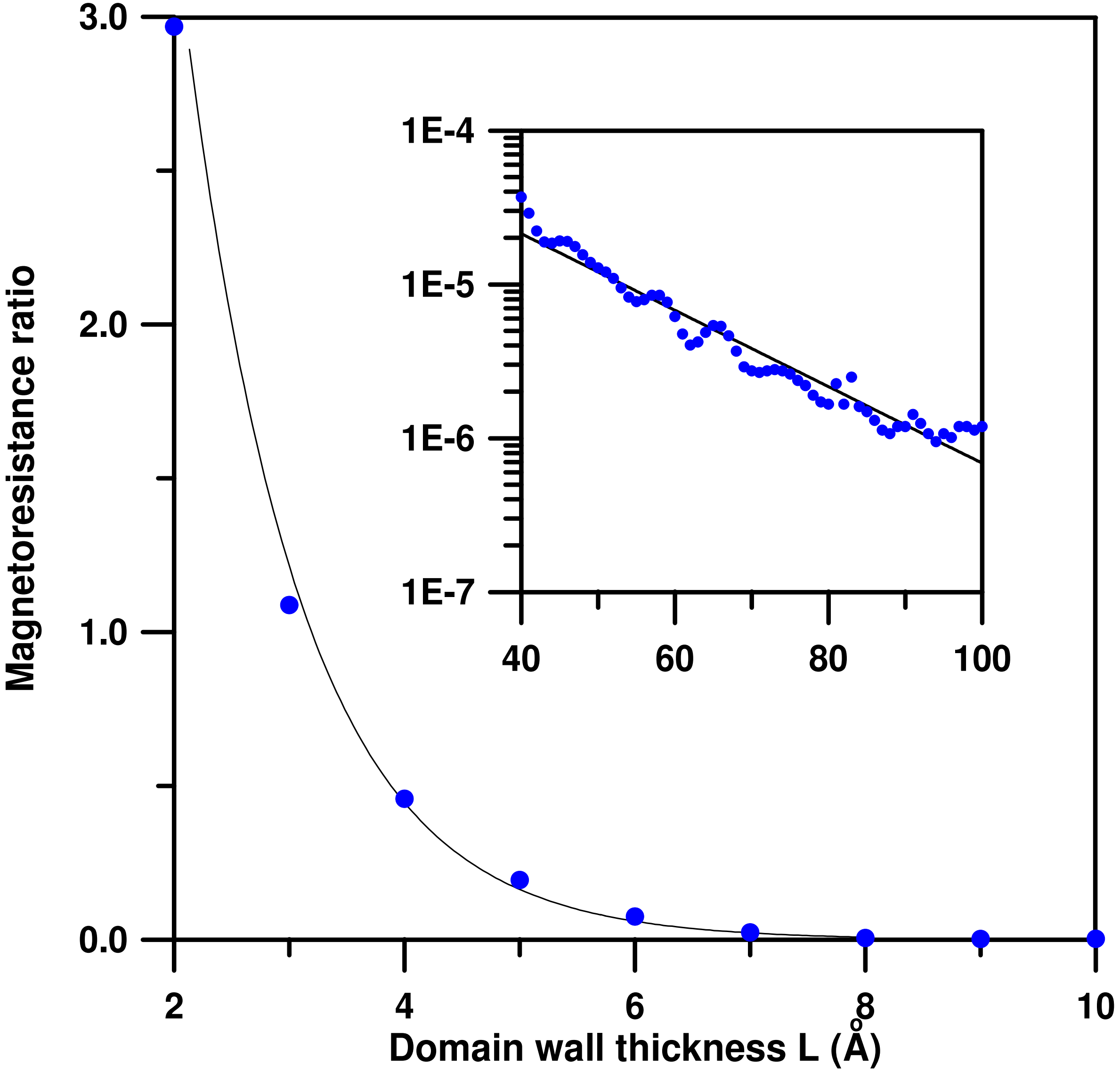




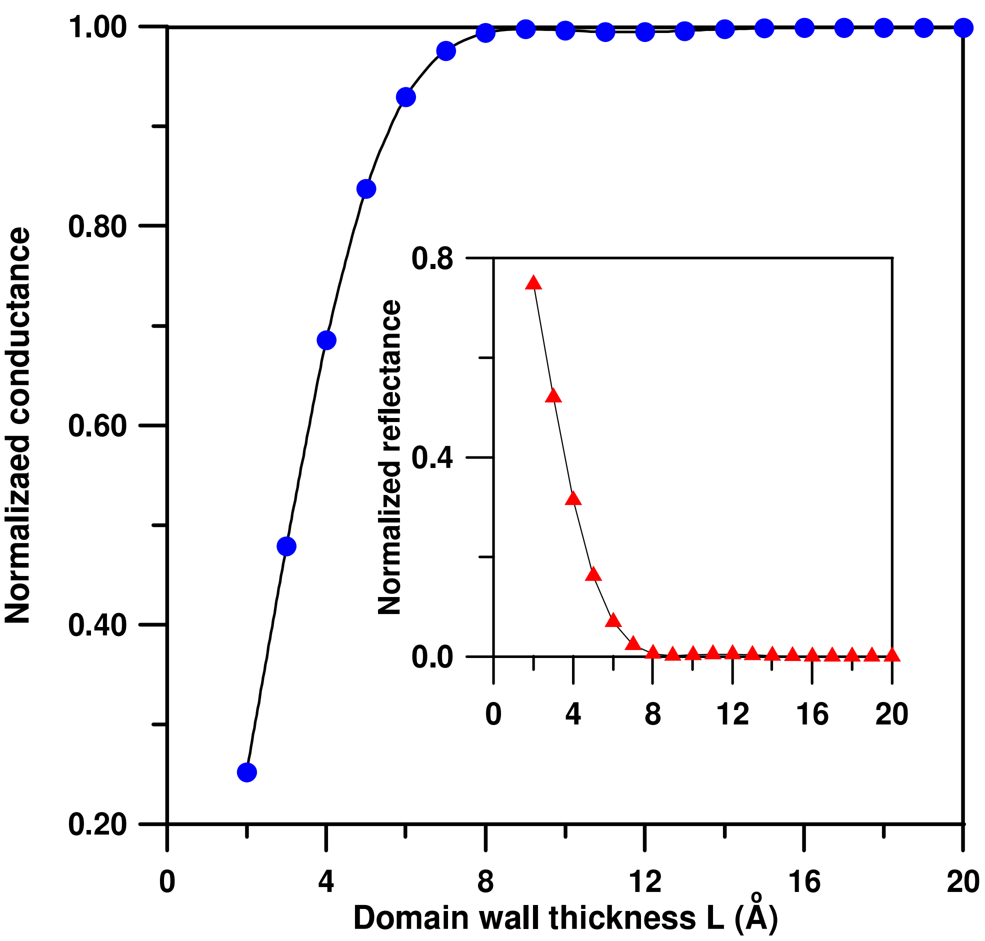
(a) Weak ferromagnet



(a) Strong ferromagnet



(a) Strong ferromagnet



Conclutions

- Positive contribution of the domain wall to the electrical resistance in the ballistic regime.
- magnetoresistance ratios as high as 20% or even larger can be obtained for a proper choice of materials.
- Two regimes within which transport is dominated either by the non-spin-flip or by the spin-flip regime
- Presence of quantum interference effects in the process.