Motivation

It is attractive to utilize the Giant-Magneto-Resistance (GMR) effect in the Current-Perpendicular-to-Plane (CPP) geometry for two reasons:
- theoretical reason: high symmetry of the problem enables a better physical understanding
- application related reason: the perpendicular effect is typically a factor of 2 to 3 times larger than the corresponding Current In Plane magnetoresistance effect.

Therefore the theoretical prediction and analysis of the resistance and magnetoresistance of realistic CPP structure is very important for further implementations.

Valet-Fert-Model:

In 1993 T. Valet and A. Fert* published a paper in which they calculated the transport properties of CPP multilayers by starting with a Boltzmann equation. They took the spin-diffusion length into account and they also included both volume and interface spin-dependent scattering. Their model is very helpful for theoretical calculations of CPP-GMR devices and for understanding the physical process in those magnetic multilayers.


Goal:

Finite elements implementation of the Valet-Fert theory to study CPP-GMR in realistic 3D-structure.

Theoretical background: $l_{sf} \gg \lambda$

If the spin-diffusion length, $l_{sf}$, is much longer than the mean-free-path, $\lambda$, the Boltzmann equation can be approximated by a macroscopic model.

Analytic solution:

The resulting equations relate the spin-dependent electrochemical potentials $\bar{\mu}_+, \bar{\mu}_-$ to the spin dependent current densities $J_+^{\pm}, J_-^{\pm}$ by introducing macroscopic transport coefficients such as the spin-dependent conductivity $\sigma_+, \sigma_-$ and the spin-diffusion length $l_{sf}$:

$$\frac{e}{\sigma_s} \frac{\partial J_s}{\partial z} = \frac{\bar{\mu}_s - \bar{\mu}_{s-}}{l_{sf}^2}, \quad J_s = \frac{\sigma_s}{c} \frac{\partial \bar{\mu}_s}{\partial z}$$

with spin index $s \in \{+, -\}$

The CPP-GMR problem including spin-flip effects can be treated by two coupled second order differential equations for the electrochemical potentials:

$$\frac{\partial^2 \Delta \mu}{\partial z^2} = \frac{\Delta \mu}{l_{sf}^2}$$

$$\frac{\partial^2}{\partial z^2} (\sigma_+ \bar{\mu}_+ + \sigma_- \bar{\mu}_-) = 0$$

with $\Delta \mu = \frac{\bar{\mu}_+ - \bar{\mu}_-}{2}$ (spin accumulation term)

Boundary conditions for interface at $z = z_0$:

$$\lim_{\varepsilon \to 0} \left\{ J_s(z_0 - \varepsilon) - J_s(z_0 + \varepsilon) \right\} = 0$$

$$\lim_{\varepsilon \to 0} \left\{ \bar{\mu}_s(z_0 - \varepsilon) - \bar{\mu}_s(z_0 + \varepsilon) \right\} = r_s \left[ J_s(z_0) \right]$$

with $r_s$ spin dependent boundary resistance

First implementation in COMSOL:

- finite dimensions
- coupled second order differential equations
- Neumann and Robin boundary conditions

Next Steps:

- example with $r_s \neq 0$
- extension to 3D equations
- modeling realistic CPP-GMR structures
- comparison with experimental results