Magnetism in Reduced Dimensions – Multilayers

In this chapter we will discuss systems which consist of a lot of magnetic thin films (so-called multilayers).

The principle arrangement consists of a ferromagnetic bulk-like or thin film substrate covered by a non-magnetic thin film which itself is capped by a ferromagnetic layer. This stacking may be continued by additional non-magnetic and ferromagnetic thin films. The non-magnetic layer consists of a metal, an oxide, a semiconductor, or vacuum. The latter case stands for two ferromagnetic electrodes which are separated by several Å. An important feature is given by the coupling over the interface, the so-called interlayer exchange coupling (IEC).

Additionally, the electrical resistance or the electrical conductance of this layered system depends on the relative orientation of the magnetization of two neighbored ferromagnetic layers. The resistance of an antiparallel orientation \( R_{\text{ap}} \) is enhanced compared to a parallel alignment:

\[
R_{\text{ap}} > R_{\text{p}}
\]

This phenomenon is called magnetoresistivity and will be discussed in more detail in Chap. 16.

15.1 Interlayer Exchange Coupling (IEC) Across a Non-Magnetic Spacer Layer

The coupling between two localized magnetic moments being separated by a non-magnetic material can be described by means of the RKKY exchange interaction (see Chap. 4.3):

\[
J_{\text{RKKY}}(R) \propto \frac{x \cos x - \sin x}{x^4} \xrightarrow{x \to \infty} \frac{1}{x^3}
\]

with \( x = 2k_F R \) and \( R \) the distance between the moments. This oscillatory behavior is exemplarily shown in Fig. 15.1 for Mn atoms embedded in a Ge
matrix. This dependence is different in magnetic thin film systems being separated by a non-magnetic interlayer. Assuming an interlayer thickness of $z$ the exchange coupling constant exhibits the dependence of:

$$J_{\text{RKKY}}(z) \propto \frac{1}{z^2}$$ (15.3)

which is schematically shown in Fig. 15.2. In layered systems the RKKY interaction is a pronounced effect and acts over long distances. A positive value of $J$ means a ferromagnetic coupling between both ferromagnetic thin films whereas $J < 0$ results in an antiferromagnetic arrangement. We directly see that the thickness of the spacer layer determines the type of coupling.