Multilayered Coatings Made Easy

Single bath electrodeposition allows low-cost and user-friendly processing.

By A. Ollagnier and P. Benaben, Dept. Traitements de Surfaces, Centre Sciences des Materiaux et Structures

Multilayered coatings are well known for their many interesting properties, especially enhanced mechanical behavior such as supermodulus[1] and corrosion resistance.[2] By alternating the multilayers, material behavior can be modified. Moreover, these coatings have interesting magnetic applications if the thicknesses are carefully chosen—superconductivity,[3] giant magnetoresistance, and current polarization in spin,[4] with recent application such as electron filters.

They are of great interest when efficient and rapid hard disk drives and magnetic recording and reading heads of reduced size are required. It is known as "spintronics," or spin electronics, where information is vehicled by a magnetic wave. For "microelectronic," it is an electric charge.

Many multi-element layered systems have been studied to improve speed and capacities but they are produced by physical methods (physical vapor deposition, molecular beam epitaxy, ion beam sputtering, etc.), which require expensive apparatus and qualified staff.

The interest in single bath electrodeposition is well known—simple and low-cost apparatus, relative low pollution and oxidation, and a user and environment friendly process.

GIANT MAGNETORESISTANCE (GMR)

Ferromagnetic behavior is characterized by a permanent macroscopic magnetic moment. This is mainly due to the ordering of atomic moments and dissymmetric energy distribution in spin at the macroscopic scale. Therefore, the outgoing current of a ferromagnetic material should be polarized (see Figure 1) and the electrical resistance of minority spin (Rw) is lower than those of the majority spin (Rh). This phenomenon is called magnetoresistance effect (Ω = (Rh-Rw)/Rw).

However, the spin of electrons is conserved on a distance of a few nanometers called "spin diffusion length." This effect is generally not measurable due to its short length. Baibich et al.[4] and Valet and Fert[6] attempted to amplify this phenomenon, assembling this system[5] several times, where spin would be conserved. They sandwiched thin ferromagnetic and nonmagnetic layers (called spacers) insid, in which the spin of each electron was conserved within every layer. When spin moments of ferromagnetic layers are not parallel (see Figure 2), an electron of the majority band diffuses rapidly within ferromagnetic M_1 (due to its high energy). Its spin is conserved inside the nonmagnetic layer and it reaches the following magnetic layer (M_2).

The preservation of electron spins at the interface implies that incoming spins have to be returned; either the lifetime of the spin moment is short and the electron is reflected (the spin is thus "destroyed"), or it is sufficiently long and the spin is "flipped" and hardly diffuses in the minority band.

Furthermore, many spins accumulate inside the spacer and spin flip is not spontaneous, amplifying the spin destruction phenomenon. Meanwhile, an electron of the minority band almost does not diffuse within ferromagnetic M_1. After one spatial period, the outgoing current is randomly oriented in the

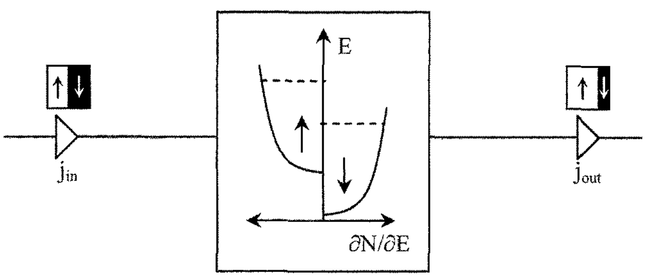

Figure 1: Effect of current through a ferromagnetic material. N is the number of electrons and E is the corresponding energy.

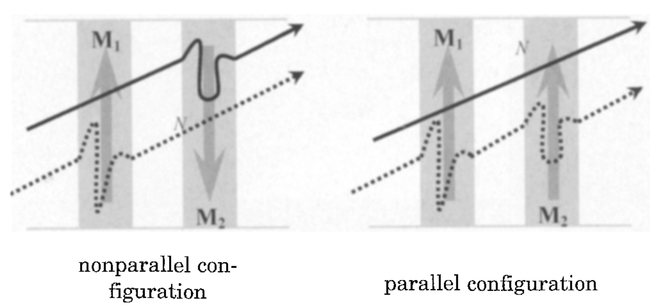

Figure 2: Representation of the GMR effect with currents of the majority spin (solid lines) and minority spin (dotted lines).

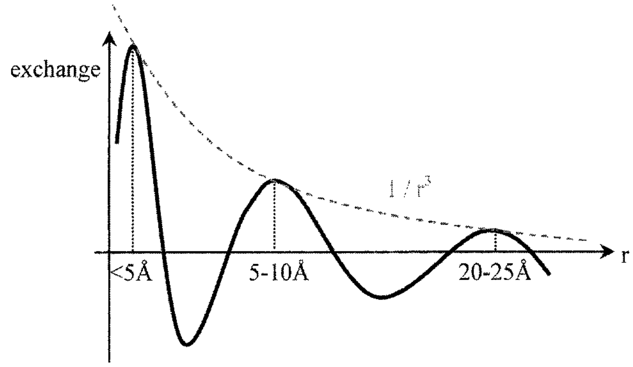

Figure 3: Magnetic coupling of ferromagnets in multilayer systems. r is the distance between two consecutive magnetic layers.

spin and electrons have been decelerated in one of the four layers of the period, so that at macroscopic scale, no polarization is observed and electrical resistance (R^{AP}) is high.

Applying a magnetic field is the best solution to align the moments along the same direction. All moments become parallel to the field above a critical threshold. The energy shifts are cumulative every two layers (one period) so the outgoing macroscopic current is strongly polarized. Moreover,

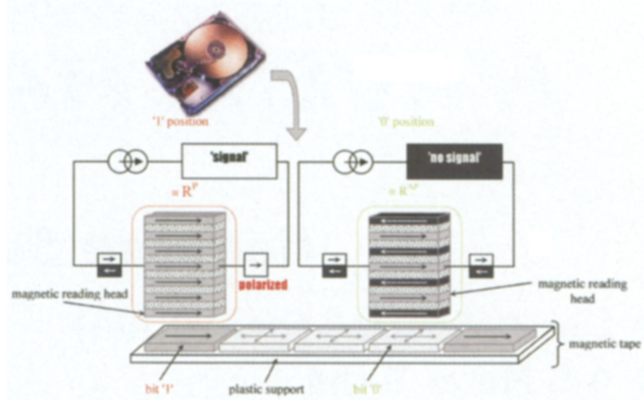

Figure 4: Schematic representation of a multilayered GMR magnetic reading head.

majority spin electrons are short-circuited and electrical resistance (RP) is low. The ratio $\Omega_{GMR} = (R^{AP}-RP)/RP$ is called giant magnetoresistance (GMR).

Other highlights appear due to the fact that electrons do not diffuse only in one direction but are kept in an average cylinder. That is why the GMR effect could be observed in the current-in-plane (CIP) geometry, which is different from the classical current-perpendicular-to-plane (CPP) represented