Recent progress on electrodeposited multilayer films with giant magnetoresistance (GMR) behaviour

Imre Bakonyi* and László Péter +
Research Institute for Solid State Physics and Optics, Hungarian Academy of Sciences.
H-1525 Budapest, P.O.B. 49, Hungary

Whereas early studies of GMR discovered in 1988 were performed on magnetic/non-magnetic multilayers prepared by physical methods (sputtering, evaporation, molecular-beam epitaxy), it was reported in 1993 that electrodeposited multilayers films can also be produced with sufficiently good quality to exhibit a GMR effect [1]. Specifically, a GMR of about 15 % could be achieved in electrodeposited Co-Ni-Cu/Cu multilayers at room temperature in a magnetic field of H = 8 kOe. This result raised an increased interest in producing electrodeposited multilayers films with GMR behaviour. Since then, a total of about 70 papers have been published in this field (for a summary of the early works, see Ref. 2).

The key issues regarding the differences of the GMR of electrodeposited multilayer films in comparison with similar systems produced by physical methods can be summarized as follows:
(i) the magnitude of the GMR is smaller (typically by at least a factor of two) in electrodeposited multilayers;
(ii) in most cases, no GMR oscillation with spacer layer thickness can be observed in electrodeposited multilayers in contrast to multilayers produced by physical methods;
(iii) the MR(H) curves of electrodeposited multilayer films usually do not show the bell-shaped form characteristic of an antiferromagnetic (AF) coupling between the magnetizations of neighbouring magnetic layers but rather mostly exhibit fairly sharp split peaks;
(iv) the MR curves of electrodeposited multilayer films, especially for low individual layer thicknesses, usually do not saturate for magnetic fields up to more than 10 kOe whereas for multilayers prepared by physical methods the MR reaches saturation in magnetic fields of about 5 kOe or even less.

All these features of GMR in electrodeposited multilayer films are, of course, strongly interrelated with each other. They were established already by the results of the very first study [1] and have persisted up to now. Instigated by the challenge to improve the GMR of electrodeposited multilayer films, we have made some efforts over the last few years and performed detailed studies of self-supporting electrodeposited multilayer films [3-13]. We have paid particular attention (i) to studying the influence of preparation conditions on structure, chemical composition and physical properties, (ii) to investigating possibly several properties on the same multilayers, mainly magnetic properties and electrical transport parameters both in a magnetic field and in zero external field, (iii) to measuring the magnetic and magnetotransport properties as a function of magnetic field and temperature and (iv) to analysing not only the magnitude of the GMR but also the magnetic field dependence of the magnetoresistance.

The aim of the present talk is to summarize recent progress achieved and to give an overview on our current understanding about multilayer formation by electrodeposition and about the ways how deposition conditions may have an influence on the GMR of such multilayer films.

In particular, we intend to discuss the consequence of different types of pulse combination in multilayer formation and the role of exchange reaction in chemical intermixing at the interfaces, in layer thickness changes and in layer thickness fluctuations. It will be pointed out that although the exchange reaction in general has a deleterious effect on the layer structure, a fairly large GMR can be observed even if a strong exchange reaction is allowed to take place. On the other hand, although we have elaborated a method to eliminate the exchange reaction, even in such cases the asymmetry of the mutual nucleation of Co on Cu and Cu on Co may result in a GMR behaviour very similar found often with exchange reaction. It was found that a thin Cu layer (about 2 nm effective thickness or less) is in most cases not able to completely cover a Co surface and pinholes remain in the Cu layer. A key point is furthermore whether there is any coupling (antiferromagnetic or ferromagnetic) between the magnetic layers. It appears that in most electrodeposited multilayers the coupling is very weak or is completely absent. This feature, on the other hand, together with the eventually discontinuous Cu layer, gives explanation for the lack of GMR oscillation with spacer thickness. Another issue is the presence of super-paramagnetic (SPM) regions in electrodpeosited multilayers. It has been recently evidenced that under some deposition conditions, the magnetic layers will not completely exhibit a ferromagnetic behaviour but some parts of them are magnetically decoupled from the ferromagnetic regions and exhibit a SPM behaviour. The SPM regoins can be made mainly responsible for the high observed saturation field of the MR in these multilayers.

* E-mail: bakonyi@szfki.hu
+ Electrochemical Society Active Member

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