Mathematical models of MRAM cells with the different types of anisotropy

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1. Magnetization dynamics in a three-layered Co/Cu/Co structure driven by an external magnetic field and a spin-polarized electric current was investigated using methods of the theory of bifurcations. The mathematical model is based on the Landau–Lifshits–Gilbert equation with the current term in the Slonczewski–Berger form. We considered two cases. In the first case, the direction of the applied magnetic field was in line with the anisotropy axis. The system of equations has the form of the nonlinear dynamical system with the polynomial right-hand sides. The analysis of singularities of the dynamical system was performed that allowed us to find the values of the applied magnetic field *h* and current *j*, for which the phase portraits of the dynamical system are topologically equivalent. The qualitative changes of the phase portraits, associated with bifurcations of singular points, were investigated. The mathematical simulation of magnetization dynamics for typical values of field and current was performed. The range of parameters for complete switching of magnetization from parallel to anti-parallel configuration was determined. It was brought to light that there is a region of control parameters *h* and *j*, where complete switching does not take place, but the free layer can be switched to one of two intermediate axis-symmetrical positions (incomplete switching). The intervals of the field and the current where magnetization can be switched to three equally probable types of dynamics were found.

2. The second case under investigation was the model with the perpendicular anisotropy. The system of ordinary differential equations in the approximation of uniform magnetization distribution for magnetization dynamics in the valve with perpendicular anisotropy was derived. It was shown that in such a system, in contrast to the system for the in-plane anisotropy, there are only two equilibrium positions of the magnetization vector, namely $(0, 0, \pm 1)$. The stability analysis of the stationary points of the system allowed us to obtain the analytical expressions for the threshold values of switching magnetic fields and currents and to construct the bifurcation diagram of the magnetization dynamics. The classification of types of dynamics versus field and current values was performed. The regions of limit cycles existence and the regions of optimal magnetization switching were revealed. The results were compared with those for the cell with in-plane anisotropy. It was found that the switching current for the cell with perpendicular anisotropy is an order lower than this one for the cell with in-plane anisotropy.

References

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