Spin Relaxation in Magnetic Nanostructures

by: Ehsan Barati Supervisor: Dr. hab. Marek Cinal

Abstract

The thesis presents theoretical investigation of spin relaxation in magnetic nanostructures within the quantum-mechanical approach, including novel methods developed in this PhD project. The Gilbert damping constant α which enters the Landau-Lifshitz-Gilbert (LLG) equation describing the dynamics of magnetisation is found for bulk ferromagnetic transition metals and various ultrathin magnetic metallic layered systems employing the torque-correlation model by Kamberský. The expression for α is generalised to an arbitrary direction of magnetisation. Calculations are performed within a realistic tight-binding model including the spin-orbit interaction and their efficiency is remarkably improved by introducing finite temperature into the electronic occupation factors and subsequent summation over the Matsubara frequencies. Furthermore, two alternative formulas, not limited to the TB model, for α in terms of the Green function are derived. The results are reported for bulk ferromagnets, ferromagnetic films, ferromagnet/nonmagnet (Co/NM) bilayers (NM=Cu, Pd, Ag, Pt and Au) as well as NM/Co/NM, Co/NM1/NM2 trilayers, $L1_0$ Co/NM superlattices (ordered alloys) and $[\mathrm{Co/NM}]_N$ multilayers. The obtained dependence of α on the electron scattering rate for bulk Fe, Co and Ni is in good agreement with the previous *ab initio* calculations. The dependence of α on Co and NM thicknesses and the effect of the nonmagnetic caps are investigated and found to be in accord with experiment. The calculated α in Co/NM bilayers and Co/NM1/NM2 trilayers is enhanced due to adding the nonmagnetic caps, particularly in the case of NM, NM2=Pd and Pt. This enhancement is explained by the large spin-orbit coupling of such NMs, combined with their large density of states at the Fermi level ϵ_{F}. The enhancement in Co/NM1/Pt trilayers is shown to decay with the increasing thickness of the spacer NM1=Cu and Ag. Nonlocal origin of the damping enhancement is proved by visualising large contributions to α from the nonmagnetic part. Contributions to α from individual atomic layers and its $\boldsymbol{k}$-space distribution are determined and analysed in several layered systems. It is revealed that in the Co/NM bilayers including NM metal with the d band crossing ϵ_{F} the major contributions to the Gilbert damping come from a few atomic layers in the NM close to the Co/NM interfaces, whilst for those with NM d bands below ϵ_{F} the main contributions originate from the Co part. Investigations in the $\boldsymbol{k}$-space show the existence of hot spots in the Brillouin zone that give the largest contributions to α. Additionally, the nonadiabatic spin-transfer torque coefficient β entering an extended form of the LLG equation is calculated for bulk ferromagnets and ferromagnetic films. Its evaluation method is improved by using the Hellmann-Feynman theorem to calculate the electron velocity. In each case, comparison with results of other theoretical approaches, such as the *ab initio* calculations and the spin pumping theory, as well as experiment is performed.