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On spin-current injection problem
A research project

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Abstract

The dynamics of the bulk magnetization of the ferromagnets is studied under the action of the externally injected spin-polarized currents. Various instabilities, like spin-density waves (SDW), soliton lattice (domain walls), as well as their own excitations, are studied, in order to get a comprehensive picture of transport features in controlling the magnetization in nanostructures with spin currents.

A charge-magnetization interaction has recently been devised,[1] in an effective hamiltonian (or lagrangean), which has the merit of highlighting basic questions related to the spin-injection problem, over the usual direct treatment of equations of motion. The charge-magnetization interaction has two distinct parts, one related to the spin of the charged particles (electrons),[2] the other being an implicit current-magnetization coupling. Together with the former, the latter is especially responsible of a few relevant things in the present context, to be described below. Noteworthy, the interaction is quartic in magnetization, properly.

Making use of this hamiltonian the equations of motion for the spin excitations are linearized, and the spin-waves spectrum is computed explicitly. This is a classic approach to such kind of problems. The spin excitations spectrum signals out, however, a spin instability (by their frequency becoming imaginary), which is a well-known spin-density wave (SDW). The SDWs, like the CDWs (charge-density waves), are an extensive topic in the modern condensed matter physics. The SDW instability occurs for a certain wavevector, controlled by the ratio of the exchange to anisotropy coupling constants (anisotropy is an essential ingredient). Noteworthy, the spin waves merely signal out the SDW, the properties of this latter state being left to be computed distinctly. The properties of the SDW are to be computed in their own, according to standard procedures.

The picture is rather well-known up to this point (a rather classic subject in theoretical physics of condensed matter). The novelty here consists in the electric current, which plays the role of an external control parameter (which is precisely what we are interested in, as we want to control the magnetization by currents, spin-polarized currents). Therefore, the whole SDW picture depends on, and changes with, changing the current. The relative novelty lies in the fact that the SDW instability disappears above a certain critical value of the current, as a consequence of that implicit current-magnetization interaction in the hamiltonian. Actually, this is a rather general property of the condensates (SDW in our case), providing they contain an external control parameter, like the current here, and originates in the mean-field treatment of the condensates, which is, basically, a self-consistent linearization. Such a linearization is not appropriate anymore for large parameters, above a threshold critical current, such a large value requires a full treatment of the equations of motion, which are nonlinear. Expecting various instabilities, or dramatic changes in magnetization, like a presumable "parametric resonance", is definitely related to the non-linear character of the equations of motion.[3]

The non-linear solution in this case is also well-known, it is a soliton (actually a soliton lattice), or a domain wall. It is well-known, but Ref.1 rather expedites it (as it does for the SDW properties). In fact, this soliton lattice, or domain walls' lattice, is nothing but a pinned SDW, a subject of great interest also in the recent past. It needs to be worked out in detail for this particular case of magnetization dynamics under spin-current injection. Now, a lattice of domain walls means another, different vacuum, distinct from the uniform magnetization (this is the "fate" of uniform ferromagnetism under spin currents), and lower in energy (like the SDW itself, too). This new vacuum has its own elementary excitations (as the previous SDW does, phasons, amplitudons, but usually we never work them out carefully, though they do contribute to transport). Consequently, the walls excitations must be worked out, and, for high enough values of the current we see that such excitations are in fact almost free, inertial movements of the walls under the action of the current.[4] A full picture may be obtained this way, of the magnetization movement under the effect of the external control parameter, which is the spin polarized (and unpolarized) current - the main objective of this investigation.

For an analogy, we may think of the external controlling parameter - the current for this problem - as temperature, and raising the temperature new phases appear, the condensate phases disappear, etc, which is very interesting, and a nice piece of physics.

Beside solving the problem, an important task is to make crystall clear all this beautiful physics behind the subject, because the theoretical solutions, though simple in their nature, are not quickly grasped, usually.

Consequently, as a matter of opinion and belief, this problem would not deserve a quick work, but rather a deeply involving physics, which requires much, well-organized, and systematically pursued work.

A full research program would be sketched as follows:

A. Derivation of the hamiltonian from basic principles in the presence of current, anisotropy included, modified Landau-Lifshitz equations, their semiclassical treatment.

B. Full working out of the SDW instability, its own excitations included, with special attention to its energetics.

C. Full soliton solution, soliton lattice, characterization of the domain walls, their excitations, full attention to its energetics, connection to the pinned SDW.

D. If everything is true, then the motion of the domain walls might be seen experimentally, as function of the injection current, by various techniques (neutron diffraction?, induction?, resonances, etc, etc; is not it connected to the Barkhausen effect?).

Of course, these points sketched above ought to be expanded into a reasonable description of work.

This programme is a complex theoretical-experimental-applicative programme. The theoretical part comprises a few research structures of great respiration and complexity, like the physics of SDWs, the physics of magnetic solitons, the physics of the magnetic domain nucleation (because the transitions from one state to another are phase transitions, the SDW a 2nd order one, the soliton latice a 1st order one, very likely- this is another great topic), each with its own theoretical tools. It is a forefront research, with attractive applicative implications.

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