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Resonance excitation of the spin-wave current in hybrid structures

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Abstract

Using the non-equilibrium statistical operator method (NSO), we have investigated the spin transport through the interface in a semiconductor/ferromagnetic insulator hybrid structure. We have analyzed the effective parameters approximation, when each of the considered subsystems (conduction electrons, magnons, and phonons) is characterized by its effective temperature. We have constructed the macroscopic equations describing the spin-wave current caused by both the resonantly exciting spin subsystem of conduction electrons and an inhomogeneous temperature field in the ferromagnetic insulator. We have shown that the spin-wave current excitation under combined resonance conditions exhibit a resonant nature.

Keywords: thermoelectric effect, spin current, resonance
PACS: 72.15 -b, 71.15

One of the central issues of spintronics is the development of new methods of generation and control spin currents in solids. There are different methods to implement the spin current: optical, magnetic, and what is particularly important for use in various devices, by an electric current. Usually an external perturbation acts on kinetic degrees of freedom. The spin-orbit interaction (it couples translational (kinetic) and spin degrees of freedom) plays a main role to form the resulting spin response. The latter can be exemplified by the spin Hall effect (SHE) [1],[2] that is exhibited as a spin current perpendicular to a charge current. It is the effect that is chiefly applied to create spin accumulation of conduction electrons in studying spin-thermal effects in metal/magnetic ferromagnet hybrid structures [3, 4]. The spin Seebeck effect (SSE) in such structures can be realized by exciting a system of localized spins. In this case, inelastic scattering of the spin-polarized electrons on localized moments located at the (N/F) interface leads to a non-equilibrium distribution of magnons.

Among other ways of observing SSE there are resonant methods of influencing on the conduction electron subsystem to disturb the magnetic spin localized subsystem. For example, the magnetic subsystem, when disturbed by an alternating magnetic field under ferromagnetic resonance conditions, causes the effect of electron-spin pumping or creates an electron-spin current. Using of the given method allows one to generate the electron-spin current without transporting the spin-polarized charge carriers through the interface, thereby avoiding the problem of conductivity mismatch (the mismatch problem) [5, 6, 7]. However, the method above is not applicable to the SSE because of a feedback required - the electron subsystem should transfer the angular momentum to the localized magnetic moments subsystem. As it will be seen below, the spin-orbital interaction realizes the desired ”resonance” scenario that results in resonantly exciting spin-wave current.

The spin orbit interaction (SOI) couples the kinetic (translational) and spin subsystems of conduction electrons. Thus, the SOI is one of the possible channels to act on one of the subsystems via another, for example, on the spin subsystem of conduction electrons via the kinetic subsystem and vice versa. Due to the translational and spin motion chaining, the quantum transitions cannot be conventionally divided into pure configurational (orbital) and pure spin ones. We can only talk about either predominantly configurational or predominantly spin transitions. However, this circumstance significantly changes the conditions for the excitation of different transitions. Namely, the electrical component of an electromagnetic field initiates the spin transitions, and the magnetic component the orbital ones. The spin orbit interaction gives rise to the resonant electron transitions at frequencies being linear combinations of the cyclotron and Zeeman frequencies. Besides, such tran-