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Magnon–plasmon interactions

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Abstract

Spin polarized plasmons as well as the spin-polarized Drude tail have been examined as a function of wave vector for strained Gd on Mo(112). The magnon–plasmon interactions are shown to depend on wave vector while the wave vector dependence of the Drude tail is consistent with the spin polarized band structure of the Gd.

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The interplay between electronic, phononic, and magnonic degrees of freedom is key component of condensed matter physics, specifically the interaction of solids and surfaces with charged electromagnetic waves and particle beams. In contrast to the extensively investigated interactions between magnetic and electric degrees of freedom, magnon–plasmon interactions, without any coupling through phonons (lattice distortions), are almost never considered. Magnon interactions through electron–phonon coupling have been suggested [1–5], but magnon–plasmon interactions are generally ignored. This is surprising because the basis of ferromagnetism is the difference in electron populations in the different spin channels. Magnon–phonon coupling is fairly well established experimentally [6–10] and theoretically [9–11]. Recently, in considering the possibility of a spin-dependent Debye temperature, we suggested that magnon–phonon effects could be mediated by plasmons, although such plasmon mediated contributions to the magnon phonon coupling would be very small, as measured by electron spectroscopy [2]. Magnon–plasmon interaction are also expected [1,12,13]; the primary experimental challenge is the small magnitude of the effect.

Spin-polarized electron energy loss spectroscopy (SPEELS) is the most direct approach for the investigation of magnon–plasmon interactions. In this tech-

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nique, as used here, spin-polarized electrons are scattered off a spin polarized surface of a ferromagnet in the remanent magnetization state, and the resultant energies of the scattered electrons are analyzed to determine the loss structure. The technique has already been used to investigate Stoner excitations [14–22], spin waves [23–25] and interband transitions [26]. With only a few exceptions [16,26] electron energy loss spectroscopy has also proven to be an excellent method for probing surface and bulk plasmons [27,28]. here we use this technique to investigate strained Gd on Mo(112). Herein, there is an emphasis on the experimental details and on possible theoretical explanations of our results.

For a SPEELS experiment probing an interband transition, flip and non-flip scattering for incident electrons with spins parallel or antiparallel to the majority spin orientation of the substrate can occur. Flip scattering means that a Stoner excitation occurs or that an incident electron occupies an empty state just above the Fermi energy and transfers its energy to an electron of the opposite spin resulting in a configuration identical with the Stoner excitation. Spin dependent plasmons and small intraband excitations across the Fermi level do not involve a spin–flip scattering, so that spin detection after the scattering event (i.e., use of a Mott detector) is not necessary, if a spin polarized source is used. In theoretical models [12], the magnon–plasmon arises from the long-wavelength non-spin–flip part of the electron–magnon interaction Hamiltonian. In our experiments, we encounter long-range interactions between the incident electron and target electrons (dielectric dipole scattering) rather than short range interaction (impact scattering).

Fig. 1 illustrates the phenomenon of magnetic plasmons for the simple case of an inhomogeneous external magnetic field $\mathbf{H} = H(x)\mathbf{e}_z$ characterized by a positive magnetization gradient $\partial H/\partial x$. Since the Zeeman-interaction of a localized moment $\mathbf{m}$ with the external field is equal to $-\mu_0 \mathbf{m} \cdot \mathbf{H}$, moment-carrying electrons move towards regions of higher field intensity when the magnetic moment and the field are parallel as shown in Fig. 1. If the directions are antiparallel, the moment-carrying electrons move in the opposite direction. This corresponds to a spin dependent plasmon mode of some magnitude or displacement of the moment-carrying electron. Analyzing the phenomenon from a relativistic point of view [29,30] reveals that the effect, compared to the electrostatic interactions, is of the order of α^2, where $\alpha = 1/137$ is the Sommerfeld's fine-structure constant. This leads to very small electron displacements and explains why little or no experimental work has been done in this direction.

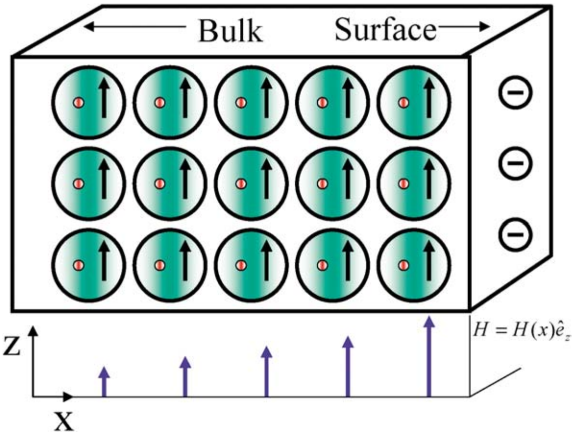

Fig. 1. Plasmon created by an inhomogeneous magnetic field H acting on a spin-polarized magnetic body. If the position of the body is fixed, the field creates a plasmon mode and electric surface charges. The arrows represent the direction of the localized magnetic moment of the Gd atoms.

The situation is different when experimental tools such as photoemission, inverse photoemission, or electron energy loss are used, where local magnetostatic fields are replaced by local exchange fields. The effect on the spin structure is similar [31], but the involved field gradients are much larger. First, exchange fields often exceed 1000 T, as opposed to typical laboratory-scale magnetostatic fields of the order of 1 T. Second, the quite localized nature of the interactions of the incident electron in the case of SPEELS [26,27] amounts to a considerable enhancement of the magnetization gradient, as compared to the macroscopic gradient shown in Fig. 1.

Fig. 2 illustrates some essential features of the interaction of a spin polarized electron with the ↑ and ↓ electrons of an atom in the ferromagnet. (The schematic picture ignores the k dependence of the phenomenon, which is realized by interatomic hopping and will be discussed elsewhere. In system investigated below, the character of the ↑ and ↓ electrons is predominantly 5d/6s.) The key feature is the relative orientation of the transversely polarized spins of