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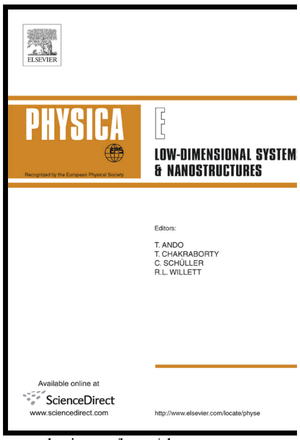

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Nanomagnet coupled to quantum spin Hall edge: An adiabatic quantum motor

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Abstract

The precessing magnetization of a magnetic islands coupled to a quantum spin Hall edge pumps charge along the edge. Conversely, a bias voltage applied to the edge makes the magnetization precess. We point out that this device realizes an adiabatic quantum motor and discuss the efficiency of its operation based on a scattering matrix approach akin to Landauer-Büttiker theory. Scattering theory provides a microscopic derivation of the Landau-Lifshitz-Gilbert equation for the magnetization dynamics of the device, including spin-transfer torque, Gilbert damping, and Langevin torque. We find that the device can be viewed as a Thouless motor, attaining unit efficiency when the chemical potential of the edge states falls into the magnetization-induced gap. For more general parameters, we characterize the device by means of a figure of merit analogous to the ZT value in thermoelectrics.

1. Introduction

Following Ref. [1], Meng *et al.* [2] recently showed that a transport current flowing along a quantum spin Hall edge causes a precession of the magnetization of a magnetic island which locally gaps out the edge modes (see Fig. 1 for a sketch of the device). The magnetization dynamics is driven by the spin transfer torque exerted on the magnetic island by electrons backscattering from the gapped region. Indeed, the helical nature of the edge state implies that the backscattering electrons reverse their spin polarization, with the change in angular momentum transfered to the magnetic island. This effect is not only interesting in its own right, but may also have applications in spintronics.

Current-driven directed motion at the nanoscale has also been studied for mechanical degrees of freedom, as motivated by progress on nanoelectromechanical systems. Qi and Zhang [3] proposed that a conducting helical molecule placed in a homogeneous electrical field could be made to rotate around its axis by a transport current and pointed out the intimate relations with the concept of a Thouless pump [4]. Bustos-Marun *et al.* [5] developed a general theory of such adiabatic quantum motors, used it to discuss their efficiency, and emphasized that the Thouless motor discussed by Qi and Zhang is optimally efficient.

It is the purpose of the present paper to emphasize that the current-driven magnetization dynamics is another – perhaps more experimentally feasible – variant of a Thouless motor and that the theory previously developed for adiabatic quantum motors [5] is readily extended to this device. This theory not only provides a microscopic derivation of the Landau-Lifshitz-Gilbert equation for the current-driven magnetization dynamics, but also allows one to discuss the efficiency of the device and to make the relation with the magnetization-driven quantum pumping of charge more explicit.

Specifically, we will employ an extension of the Landauer-Büttiker theory of quantum transport which includes the forces exerted by the electrons on a slow classical degree of freedom [6, 7, 8, 9].