Magnetic Monopole Generated by Spin Damping with Spin-Orbit Coupling

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Aim of spintronics is to manipulate electron's spin degree of freedom besides its charge one. Today we can control spins by electric, magnetic, thermodynamic and optic means, and the spin transport is realized in various materials; in metals, in semiconductors and even in insulators. Although various spin-related phenomena have been discovered, it has not been explored so far how the spintronics is integrated in the conventional electromagnetism.
In this paper, we analyze spintronic phenomena theoretically from the viewpoint of the Maxwell's equations. We particularly focus on the case of electron transport in the presence of magnetization dynamics and spin-orbit coupling. We calculate an electric current and density, and derive the Maxwell's equations. Surprisingly, the Maxwell's equations constructed by this way involve generally a magnetic monopole contribution. This magnetic monopole arises from a conversion of the spin damping into the angular momentum by the spin-orbit interaction, and thus is called a spin damping monopole. We will discuss in detail the spin damping monopoles generated in a ferromagnetic-nonmagnetic junction, and their electric observation by use of the Ampère's law for monopoles. The monopole signal is expected in a similar geometry as the inverse spin Hall signal,[1] and we will show a way to distinguish those two origins.

[1]E. Saitoh, M. Ueda, H. Miyajima, and G. Tatara, Appl. Phys. Lett. **88**, 182509 (2006); A. Takeuchi, K. Hosono, and G. Tatara, Phys. Rev. B **81**, 144405 (2010).