Theory of spin motive force originating from Rashba spin-orbit coupling

Kyoung-Whan Kim[1]*, Jung-Hwan Moon[2], Kyung-Jin Lee[2], Hyun-Woo Lee[1]
[1]PCTP and department of Physics, Pohang University and Science and Technology, Pohang, 790-784, Korea
[2]Department of Materials Science and Engineering, Korea University, Seoul, 136-701, Korea

1. Introduction

Spin motive force (SMF) [1-3] is spin dependent force induced by magnetization dynamics. In spite of its scientific importance, SMF has not been received attention so much since the magnitude is very small [4-6]. However, in the presence of spin-orbit coupling (SOC), we found that SMF can be not only greatly enhanced but also modified qualitatively. We here focus on Rashba SOC (RSOC) [7] which can show up generally in ferromagnetic nanostructures including inversion asymmetry [8, 9]. The modified SMF is so strong that it can qualitatively affect magnetization dynamics. Consequently, SMF is raised from weak effect of scientific interest to a technologically important effect in magnetic device applications.

2. Method

There are three ways to obtain the spin force generated by magnetization dynamics in the presence of RSOC.

The first approach is using anomalous velocity due to SOC. Since the anomalous velocity is proportional to local spin of the conduction electron, it is a functional of local magnetization if the adiabatic approximation is used. Then, the velocity has time derivative in the presence of magnetization dynamics, so acceleration (and force) is induced. This force is essentially spin dependent force generated by magnetization dynamics.

The second approach is Volovik's formalism. In this formalism, SMF is given by SU(2) gauge field in the adiabatic limit. After rotating the frame to the local magnetization, one obtains effective vector and scalar potential which a conduction electron feels. Then, SMF is given by spin dependent Lorentz's force.

The third approach is Yamane's formalism [10]. In this formalism, SMF determined by spin misalignment ; how much the adiabatic approximation fails. After finding the average direction of the spin density, the SMF is obtained by Hersenberg's equation of motion.

3. Result and Discussion

The three approach gave the same result that another type of SMF is generated in the presence of RSOC having some unexpected properties. This result will make the scope where SMF is not ignorable much wider.

The resulting spin force is 10-100 times larger than the conventional SMF, so SMF is greatly enhanced by RSOC. Thus, our result raise SMF from just a scientifically interesting effect to technologically relevant effect.

The generated spin current by our result has almost the same order of the threshold current density of the magnetization dynamics in domain wall or magnetic tunnel junctions. Therefore, RSOC SMF will affect magnetization dynamics significantly.

Since RSOC originates from inversion asymmetry, our result has a very different nature of symmetry from the conventional SMF. We claim that the applicable area of SMF becomes wider by taking advantage of this asymmetric nature.

4. Conclusion

We obtained the modified expression of SMF in the presence of RSOC. RSOC modifies SMF not only quantitatively but also qualitatively. Thus, in the presence of RSOC, SMF becomes an important concept for both scientific study of magnetization dynamics and magnetic nanodevice applications.

5. References

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