Spin-energy conversion via emergent electromagnetic fields

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When nonuniform magnetization textures such as magnetic domain walls and Skyrmions are in motion emergent electromagnetic fields acting on conduction electron spin are induced. Spinmotive force [1] is one of the emerging effects which allows direct conversion of magnetic energy to electric voltage in magnetic nanostructures.

Striking features of the spinmotive force are listed as follows: (1) In contrast to the inductive voltage that requires the time variation of magnetic flux, DC magnetic fields can generate electric voltages. (2) The conversion rate is represented by fundamental constants apart from the material-dependent spin polarization, offering high energy conversion efficiency. (3) Applications using this effect can operate as active devices with zero stand-by power and such a power-conversion ability between magnetic and electric systems might open up spin-based power electronics [2].

Motivated by recent extensive studies on spin-orbitronics, in which spin-orbit couplings (SOCs) play significant roles, the concept of spinmotive force has been extended by incorporating such effects. As an important example, we investigate spinmotive force generated by the translational motion of magnetic Skyrmion [3]. We obtain the expression for the spinmotive force, considering the Rashba and Dresselhaus SOCs as well as the so-called β term arising from the nonadiabaticity in the electron spin dynamics. Our results reveal the dependence of the SMF on the Skyrmion profile and the SOC parameters, which offers an estimation of the SMF for a given experiment.

The estimation of SOC contributions in spinmotive force is particularly important when one designs the so-called emergent inductor proposed in [4] since it uses spiral magnets that are inevitably accompanied by sizable SOCs.

[1] J. Ieda and S. Maekawa, Ch.7 Spinmotive force in *Spin Current* 2nd ed. (Oxford University Press, Oxford, 2017).

[2] J. Ieda and S. Maekawa, *Appl. Phys. Lett.* **101**, 252413 (2012).

[3] Y. Yamane and J. Ieda, *J. Magn. Magn. Mater.* **491,** 165550 (2019).

[4] N. Nagaosa, *Jpn. J. Appl. Phys.* **58**,120909 (2019).