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BOOK REVIEW
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Book Review: Spin Current

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A Book Review on

Spin Current
S. Maekawa, S. O. Valenzuela, E. Saitoh, T. Kimura (Oxford, UK: Oxford University Press), 2017, ISBN: 97801910907380191090735

The second edition of *Spin Current* has been published in September 2017 by the Oxford University Press [1]. The book covers the fundamental description of a spin-polarized electron (hole) current in various systems. The book is divided into three parts: spin current, spin Hall effect, and spin transfer torque. The principles to generate spin currents are listed in the first part, which overlaps with the scope of this review cluster on "Spin-current generation." In the second part of the book focuses on one of the major spin generation method, the spin Hall effect and associated phenomena based on devices with a current flowing in the plane. The final part of the book provides recent experimental and theoretical progress in devices using the spin transfer torque, which is the other major method for spin generation. However, the principles are categorized based on their physical origins in this book, while they are categorized by their physical phenomena in this cluster. Since some of the principles for the spin-current generation are not covered in this cluster, this book offers an ideal complementarity to this cluster.

In the book, the authors partially discussed the spin-current generation efficiency clearly, which is the most critical figure of merit for device applications. The generation efficiency (η) can typically be defined as the generated spin current per unit energy introduced, e.g., the electron-spin-current density generated (j_s) divided by the electron-charge-current density introduced (j_C): $\eta = j_s/j_c$ [2]. Here, j_s is commonly deduced from a measured voltage and its magnitude is dependent upon the theoretical model exploited to interpret it. In some devices with a current flowing in the plane, e.g., devices used for spin-orbit torque, spin-torque ferromagnetic resonance and spin-Hall measurements, it is very difficult to measure j_s and it is widely known that j_s is assumed using models, such as parallel conduction, leading to overestimation of η. As can be seen in **Table 1**, a series of spin-current generation methods without using systems including interfaces have much higher efficiency than those with interfaces, which is favorable for device applications. For example, an interface between a ferromagnet and a non-magnet for spin injection and electromagnetic wave is limited by their efficiency to be ∼20% [4, 9]. Note that in Tashiro et al. [9], the efficiency is calculated as a ratio between the absorbed and introduced microwave power, which can provide an indicative efficiency. This is predominantly due to the interfacial spin scattering by the presence of defects and contaminations. By utilizing a highly spin-polarized ferromagnet, such as a half-metallic Heusler alloy, the efficiency can be increased up to almost 30% to date [3]. It is therefore very difficult to increase the efficiency significantly unless a new half-metallic ferromagnetic material or a new device-fabrication process is developed for the realization of a very sharp interface against a non-magnet.

On the other hand, 100% generation efficiency of spin currents is predicted to occur in non-magnetic materials under certain conditions [12]. For example, a topological

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TABLE 1 | List of spin-current generation efficiency using various methods.

Method	System	Efficiency (η)	References
Spin injection	Lateral spin-valve: $Co_2FeSi/Cu/Co_2FeSi$	27%	[3]
	Spin Hall: $Pt_{0.85}Hf_{0.15}$ (5.5)/Pt (0.5)/Co (1) (nm)	(23 ± 2)%	[4]
	Topological insulator: $(Bi_{1-x}Sb_x)_2Te_3$ thin films	45∼57% (max)	[5]
	Quantum spin Hall: HgTe/(Hg,Cd)Te	100%	[6]
Magnetic field	(Stray field from a ferromagnet)	N/A	[7]
Electric field application	(Interfacial band changes under a field)	N/A	[8]
Electromagnetic wave	Spin pumping: $Y_3Fe_5O_{12}/Pt$	∼20%	[9]
Zeeman splitting	(Intrinsic Zeeman splitting at low temperature)	N/A	[10]
Thermal gradient	$Pt/Ni_{0.2}Zn_{0.3}Fe_{2.5}O_4$ film	10^{-3}%	[11]
Berry phase	(Geometrical phase introduced by a field)	100% (theory)	[12]
Mechanical rotation	(Electrical motor for mechanical rotation)	N/A	[1]

insulator is experimentally demonstrated to generate a spin current with η to be up to ∼60% [5]. This is the maximum value reported to date but it is under debate [13]. A mechanically-induced spin current to be generated in a non-magnet with a large spin-orbit coupling is also expected to have a high efficiency of up to 100% in theory [1], which is governed by the efficiency of the electrical motor to rotate the object[1]. It is therefore important to discuss the spin-current generation efficiency of each method in details. Some of the systems may be difficult to be realized experimentally but they may hold the key for the future design of spintronic applications. It would therefore be useful to include a chapter to discuss the spin-current generation efficiency in their next revision.

AUTHOR CONTRIBUTIONS

The author confirms being the sole contributor of this work and approved it for publication.

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[1] Available online at: https://www.energy.gov/sites/prod/files/2014/04/f15/10097517.pdf

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