CSCanada
Management Science and Engineering
Vol. 14, No. 1, 2020, pp. 5-8
DOI:10.3968/11516

ISSN 1913-0341 [Print]
ISSN 1913-035X [Online]
www.cscanada.net
www.cscanada.org

A Qualitative Review of Spintronics Devices With Apllications to Harness Ambient Energy at the Normal Temperature on the Basis of Quantum Thermodynamics

Kamal Nain Chopra[a],[b]*

[a]Department of Physics, Maharaja Agrasen Institute of Technology, GGSIP University, Rohini, New Delhi, India.
[b]Defence Research and Development Organisation (DRDO), Metcalfe House, Delhi, and Former Research Scientist, Photonics Group, Department of Physics, Indian Institute of Technology, Hauz Khas, New Delhi, India.
Department of Physics, Maharaja Agrasen Institute of Technology, GGSIP University, Rohini, New Delhi, India.
*Corresponding author.

Received 14 February 2020; accepted 4 May 2020

Abstract

A Qualitative Review of Spintronics Devices and their Applications to harness Ambient Energy at the Normal Temperature on the basis of Quantum Thermodynamics has been presented in this paper. The approach to design the devices on the basis of Mathematical equations, has been suggested. The importance of Nersnt equation in the analysis has been emphasized. The paper is expected to be useful to the designers and engineers engaged in developing Ambient energy generation devices.

Key words: Spintronics devices; Ambient energy; Power Generation engine; Quantum thermodynamics

Chopra, K. N. (2020). A Qualitative Review of Spintronics Devices With Apllications to Harness Ambient Energy at the Normal Temperature on the Basis of Quantum Thermodynamics. *Management Science and Engineering*, *14*(1), 5-8. Available from: URL: http://www.cscanada.net/index.php/mse/article/view/11516 DOI: http://dx.doi.org/10.3968/11516

1. INTRODUCTION

Spintronics, has recently evolved as an off-shoot (1) of Electronics. Due to the great importance of this topic, it has been applied to a large number of topics (2-11). Another field of great significance and importance is connected with the harvesting of renewable energy (12-18).In the last few years, interest has been shown by a number of researchers in the Interdisciplinary (Spintronics and Quantum Thermodynamics) research for Ambient energy. The present paper is an attempt made in this direction. Different approaches for the device designing have been suggested, and subsequently the use of quantum thermodynamics and especially Nersnt equation for harnessing ambient energy has been highlighted.

The concepts of Spintronics, and some Devices based on it, are illustrated in Figure 1.

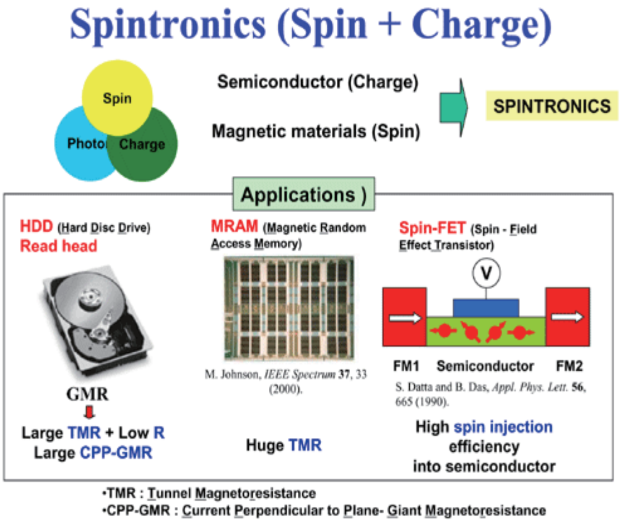

Figure1
Spintronics concepts

Windbacher et al (2015) have studied the Modeling of multipurpose spintronic devices.

2. MATHEMATICAL TREATMENT

The principal parameters for designing the Spintronic devices, are Magnetoresistance, Magneto Tunneling Junction(MTJ), and Tunneling Magnetoresistance (TMR), which have to be chosen and optimized differently for each spintronic device by following suitable model e.g., Yu and Flatte‘s Model and Monte Carlo Method.

The difference in the computed value and the experimentally achieved value has to be corrected by applying the feedback from the achieved value, which needs the experience and expertise of the designer, who has to perform much iteration with the help of software. Yu and Flatte‘s Model, has been found to be efficient for designing of the Spintronic devices, which assumes a bias-independent spin polarization at the interface, and is based on the introduction of a drift term. The spin injection demonstration device, used in Spintronics applications, has been shown below:

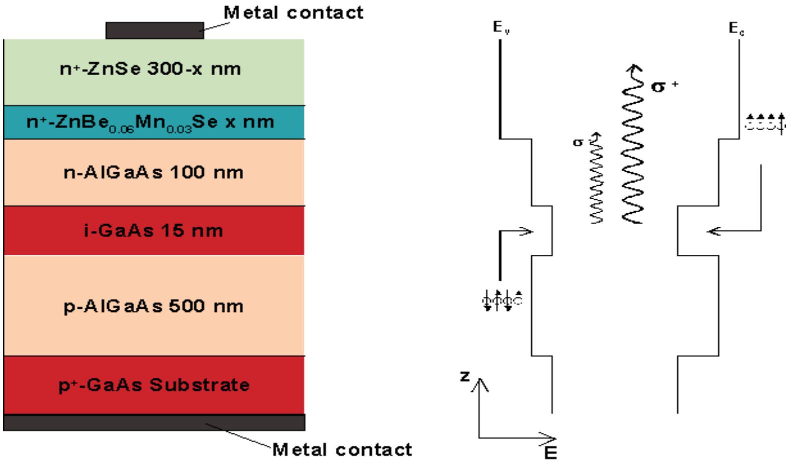

Figure 2
Spin injection demonstration device

Another simple approach is that of the semiclassical model of charge and spin transport using the drift–diffusion theory, based on considering transport in metallic/semiconducting nonmagnets and metallic ferromagnets, and by limiting the designing to diffusive dynamics, and assuming that the density and external fields are slowly varying on the scale of the mean free path λ, which is considered to be smaller than the spin diffusion length L.

The approach of transport description is semiclassical, in which the quantum tunneling and interference are neglected. This approach is based on assumptions: slow spin relaxation processes to eattain equilibrium polarization; weak external fields for ensuring the working to be within the linear response theory; absence of spin Hall Effect, spin Coulomb drag; and space charge effects.

This approach is based on considering the structure as shown in Fig. 3, consisting of a ferromagnet (F) in contact with a nonmagnet (N). Clearly, the F/N bilayer is under the effect of an electric field governed by the charge voltage Vc, and (ii) a magnetic field B= μ0H, where μ0 is permeability of vacuum and H is the magnetic field intensity).

Here, the ferromagnet is assumed to have in-plane magnetic anisotropy. However, the following results and analysis thereafter generally holds for ferromagnets with perpendicular magnetic anisotropy.

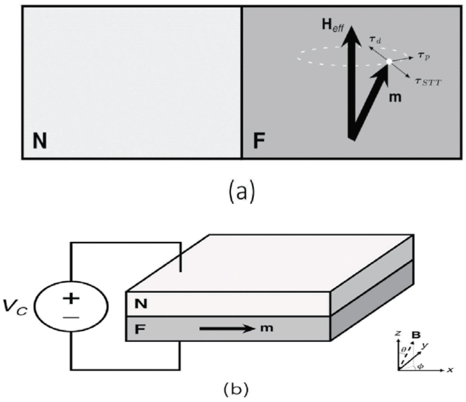

Figure 3
Schematic illustration of a ferromagnet/nonmagnet (F/N) bilayer

(a) 2-D view showing the rescale magnetization m, the effective magnetic field Heff, and the acting torques. (intrinsic damping τd, precession τp, and STT τST T (Sharma, Wen, Takanashi, & Mizuguch, 2019). (b) 3-D view showing the external fields: (i) an electric field E governed by a charge voltage VC and (ii) an arbitrarily oriented magnetic field of magnitude B and orientation angles ϕ and θ.

Following the approach of Yu et al (2002), the expression for the current density J↑(↓), carried by the electrons with spin up (down), is given by:

$J\uparrow(\downarrow) = e\, n\uparrow(\downarrow)\, \mu\, E + e\, D\, \nabla n\uparrow(\downarrow)$ ---- (1),

where D is the electron diffusion coefficient, μ is the electron mobility, E is the electric field, and e is absolute value of the electron charge. Also, the spin concentration is expressed as n↑(n↓), respectively. Therefore, the electron concentration is given by :

$n = n\uparrow + n\downarrow$---- (2),

and the spin density is defined as:

$s = n\uparrow - n\downarrow$ ---- (3). Hence, the electron charge (spin) current can be in the same manner given by the corresponding densities as:

$Jc(Js) = J\uparrow \pm J\downarrow$----(4). Subsequently, the spin polarisation is given as:

$P = (s/n)$; and by substituting the definitions from (1) into the steady state continuity equation and adding spin scattering leads to the following expression:

$\nabla\cdot J\,(\downarrow) = \pm e(n - n\downarrow)/\tau s$
---- (5)

where τs is the spin relaxation time. Following the same procedure on the Poisson equation, the electric field can be defined as:

$\nabla \cdot E = e\,(n\uparrow + n\downarrow - ND)/\epsilon Si$ ---- (6)

where ϵSi is the electric permittivity of silicon and ND is the doping concentration. Another parameter Vth, which denotes the thermal voltage is given as:

$Vth = kB\, T/q$ ---- (7),

where kB is the Boltzmann constant and T is the temperature. The designer has to consider the parameter- the intrinsic spin diffusion length (L), which is defined as:

$L = \sqrt{(D\tau s)}$ ---- (8),

and the diffusion coefficient D is related to the mobility by the Einstein relation D = μ Vth. The respective charge current and the spin currents are then given by:

$Jc = e\, n\, \mu\, E + e\, D\, dn.dx$
---- (9), and

$Js = e\, s\, \mu\, E + e\, D\, ds.dx$
---- (10).

The spin density equation is given by:

$d2s/dx2 + (1/Vth)d(Es)/dx - s/L2 = 0$ ---- (11),

where both s and E are position dependent. The spin injection into silicon, is studied by defining boundary conditions.

Alicki and Josloff (2018) have described Quantum Thermodynamics as a continuous dialogue between two independent theories: Thermodynamics and Quantum Mechanics. It has been discussed that when the two theories address the same phenomena, some new insight is emerged.

For computing the ambient energy produced at normal temperature, the Nernst equation is used, which In electrochemistry, is an equation relating the reduction potential of an electrochemical reaction (half-cell or full cell reaction) to the standard electrode potential, temperature, and activities of the chemical species undergoing reduction and oxidation, which is mostly approximated by concentrations. Thus, the Nersnt equation is a quantitative relationship between cell potential and concentration of the ions given as: $Ox + z\, e^{-} \rightarrow Red$ ---- (12).

According to standard thermodynamics, the actual free energy change ΔG is related to the free energy change under standard state $\Delta G^{\ominus}$ by the relationship:

$\Delta G = \Delta G^{\ominus} + RT \ln Q_r$
----(13),

where Q_r is the reaction quotient. Also, the cell potential E associated with the electrochemical reaction is defined as the decrease in Gibbs free energy per coulomb of charge transferred, leading to the relationship:

$\Delta G = -zFE$
---- (14) .

It has to be noted that the constant F (the Faraday constant) is a unit conversion factor $F = N_A q$, where N_A is Avogadro›s number, and q is the fundamental electron charge, which leads to the Nernst equation, which for an electrochemical half-cell is

$E_{red} = E^{\ominus}_{red} - RT/zF \ln Q_r = E^{\ominus}_{red} - RT/zF \ln a_{Red}/a_{Ox}$
----(15).

For the case of a complete electrochemical reaction (full cell), the equation can be written as:

$E_{cell} = E^{\ominus}_{cell} - RT/zF \ln Q_r$
---- (16),

where E_{red} is the half-cell reduction potential at the temperature of interest,

$E^{\ominus}_{red}$ is the *standard* half-cell reduction potential,

E_{cell} is the cell potential (electromotive force) at the temperature of interest,

$E^{\ominus}_{cell}$ is the standard cell potential,

R is the universal gas constant: $R = 8.31446261815324$ $J\,K^{-1}\,mol^{-1}$,

T is the temperature in kelvins,

z is the number of electrons transferred in the cell reaction or half-reaction,

F is the Faraday constant, the number of coulombs per mole of electrons $F = 96485.3321233100184\ C\ mol{-1}$,

Qr is the reaction quotient of the cell reaction, and a is the chemical activity for the relevant species, where a_{Red} is the activity of the reduced form and a_{Ox} is the activity of the oxidized form.

Thus, the designer has to optimize a large number of parameters to harness maximum ambient power after the efficient modeling of the Spintronic device. This is a complex process, which requires the skill, and experience of the designer, sometimes requiring the software to optimize and maximize the result.

3. DISCUSSION AND CONCLUSION

The interdisciplinary research of Spintronics and Quantum Thermodynamics for harnessing Ambient energy is drawing the attention of various researchers and device designers. The topic is on a sound footing and evolving fast.

4. ACKNOWLEDGEMENTS

The author is grateful to the Dr. Nand Kishore Garg, Chairman, Maharaja Agrasen Institute of Technology, GGSIP University, Delhi for his moral support. The author is thankful to Dr. M. L. Goyal, Vice Chairman for support. Thanks are also due to Dr Neelam Sharma, Director, and Dr. V. K. Jain, Deputy Director for their encouragement. The author is grateful to Prof. V. K. Tripathi of Physics Department, Indian Institute of Technology, Delhi, for motivating to work in this fascinating field; and to Shri G Krishna Rao, Director, Electro Optical Instruments Research Academy (ELOIRA), Hyderabad, and Shri Hari Babu, Director, Laser Science and Technology Centre, DRDO, Delhi, for many interactions and useful discussions culminating in huge improvements in the presentation and concepts of this paper.

REFERENCES

Bauer, G. E., Saitoh, E., & van Wees, B. J. (2012). Spin caloritronics. *Nat Mater., 11*, 39.

Chopra, K. N. (2013). A short note on the organic semiconductors and their technical applications in spintronics. *Lat Am J Phys E, 7*(4), 674-679.

Chopra, K. N. (2013). A technical note on spintronics (An off -shoot of electronics) – its Concept, Growth and Applications. *Atti Fond G. Ronchi, Italy, 68*, 293-303.

Chopra, K. N. (2013). New materials and their selection for designing and fabricating the spintronic devices – A technical note. *Atti Fond G. Ronchi*, *68*, 673-680.

Chopra, K. N. (2014). A short review on designing and fabrication of spintronic devices. *Atti Fond G. Ronchi, 69*(2), 223-234.

Chopra, K. N. (2014). Biophotonics and Optofluidics Technology –Technical Analysis and Qualitative Review of the Novel Applications. *Lat Am J Phys E, 8*(1), 533-540.

Chopra, K. N. (2015), Optimization of the conversion of the geothermal energy into electricity – A short note. *Atti Fond. G. Ronchi, Italy, 70*, 17-25.

Chopra, K. N. (2015). Technical analysis of the maximization of the thermo-chemical Solar power with special reference to Fulvalene Diruthenium, *Atti Fond. G. Ronchi, Italy, 71*(2), 213-220.

Chopra, K. N. (2016). Technical treatment of the efficiency maximization of the highly efficient oxygen-producing electrodes for splitting water technology. *Atti Fond. G. Ronchi, Italy, 71*(5), 579-587.

Chopra, K. N. (2019). *Spintronics - Theoretical analysis and designing of devices based on giant magneto resistance*. DESIDOC monograph series, DRDO, Ministry of Defence, Government of India. Chopra, K. N. (2020). *Recent novel advances in harnessing energy*. European biomass conference and exhibition, Marseille, France.

Gomonay, E. V., & Loktev, V. M. (2014). Spintronics of antiferromagnetic systems (Review Article). *Low Temp Phys., 40*, 1735.

Gomonay, H., & Loktev, V. (2013). Hydrodynamic theory of coupled current and magnetization dynamics in spin-textured antiferromagnets, arXiv:1305.6734.

Hals, K. M. D., Tserkovnyak, Y., & Brataas, A. (2011). Phenomenology of current-induced dynamics in antiferromagnets. *Phys Rev Lett., 106,* 107206.

Kamal Nain Chopra (2014). Mathematical Aspects of Spin-related Phenomena Models and the Associated Criteria for Spintronics. *Lat Am J Phys E, 8*, 4313-1-4313-6.

Li, X. X., Wu, X. J., & Yang, J. L. (2013). Control of spin in a La (Mn, Zn) AsO alloy by carrier doping. *J Mater Chem, C 1*, 7197201.

Sharma, H., Wen, Z. C., Takanashi, K., & Mizuguch, M. (2019). Anomaly in anomalous Nernst effect at low temperature for C1b-type NiMnSb half-Heusler alloy thin film. *Jpn J Appl Phys., 58,* SBBI03.

Windbacher, T., Ghosh, J., Makarov, A., Sverdlov, V., & Selberherr, S. (2015). Modelling of multipurpose spintronic devices. *Int. J. Nanotechnol., 12*(3/4), 313.

Yu, Z. G., & Flatté, M. E. (2002). Spin diffusion and injection in semiconductor structures: Electric field effects. *Phys. Rev. B, 66*(December), 235302.

Zhang, J. H., Li, X. X., & Yang, J. L. (2015). Electrical control of carriers' spin orientation in the FeVTiSi Heusler alloy. *J Mater Chem, C, 3*, 25637.