Research Article

A Conceptual Approach for Using Spintronics and Quantum Thermodynamics to Fuel Power Based Testing Equipment in Aerospace and Aeronautics Industry

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ABSTRACT

A conceptual approach based on Spintronics and Quantum Thermodynamics to fuel the power based Testing Devices in the Aerospace and Aeronautics Industry has been suggested to provide clean renewable energy at room temperature. This opens up a new possibility to produce and use renewable energy in this industry as well as other related industries. The paper should be useful for the engineers and technicians engaged in the Aerospace and Aeronautics industry.

Keywords: Spintronics; Quantum Thermodynamics; Renewable energy; Power generating engine, Aerospace and aeronautics industry

INTRODUCTION

Spintronics has recently evolved as an off-shoot of Electronics. Due to the great importance of this topic, it has been applied to a large number of topics [1-6]. Another field of great significance and importance is connected with the harvesting of renewable energy [7,8]. 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 Nernst equation for harnessing ambient energy has been highlighted The principal parameters for designing the Spintronic devices, are Magneto resistance, Magneto Tunneling Junction (MTJ), and Tunneling Magneto resistance (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 Technique.

It has been established that 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 many iterations 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:

THEORY

It has been observed that the main parameters for designing the Spintronic devices are Magneto resistance, Magneto Tunneling Junction (MTJ), and Tunneling Magneto resistance (TMR). These have to be chosen and optimized differently for each spintronic device under consideration. The difference in the theoretical value and the 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 do a number of iterations with the help of software.

The MTJ in its simplest form consists of insulator sand witched between two feromagnets; one in parallel and the other in antiparallel configuration. The Tunneling Magneto resistance is given by:

$$TMR = \{(R_{ap} - R_p)\}/R_p \qquad \dots (1),$$

Where R_{ap} and R_p are respectively the resistance for the antiparallel configuration, and the parallel configuration. Hence,

the different options before the designer for increasing the TMR are: (i) by increasing the difference between Rap and Rp, and (ii) by minimizing Rp. The Magneto resistance (MR) depends strongly on the applied field, which clearly is low/high when the polarization of the magnetic layers is parallel/antiparallel. Thus, it is clear that TMR can be optimized, by selecting the proper electric field, and also considering the values of Rap and Rp. The designing of the Spintronic devices can be done efficiently by Yu and Flatte's Model, which assumes a bias-independent spin polarization at the interface, and is based on the introduction of a drift term in the equation describing spin injection:

Sq. of grad (nup-ndown)+e.E /kB T.grad (nup-ndown)= (nup-ndown)/sq. of L (s)   ---(2),

where up and down give respectively the numbers (in fractions) of electrons with upward spin and downward spin, e is the electron charge, E is the electric field, kB is the Boltzman constant, and L (s) is spin diffusion length. Interestingly, Drift term, at quite high fields causes: (i) Very large spin diffusion lengths in the NMS, so that effectively a=b, and (ii) A change in the conductivity of the spin-channels in the bulk of the NMS due to repopulation effects. By following the two current models, the total device resistance is given by:

Total device resistance=RFM+2RSC˜2RSC   ---(3),

Where RFM and RSC are respectively the ferromagnet resistance and semiconductor resistance. In addition, the current is determined only by semiconductor.

$$\frac{\Delta R}{R\ parallel} = \frac{sq.of\ \beta}{1-\ sq.of\ \beta} \cdot \frac{sq,\ of\ Rfm}{sq.of\ Rsc} \cdot \frac{4}{sq.\ of\ (2Rfm\,/\,Rsc\ +1)\ -sq.of\ \beta}$$

.... (4),

Where ΔR is the difference in the resistance values in the two states (parallel and antiparallel), and R parallel is the resistance for the parallel state. The designer has to optimize the value of TMR by properly choosing ΔR, RFM, RSC, and R par The designers have to confirm some fundamental design aspects of the operation of Spin Engine, and also achieve its reproducibility by controlling at the atomic level, both the position and properties of the PM centers in a suitable solid-state device, for implementing CMOS back-end integration for managing various engineering issues including heat flow and interconnect losses. In addition, they have to choose the

materials for minimizing the climate effect. Ambient power, or energy scavenging, is the process of deriving energy from external sources, like solar power, and wind energy, captured, and stored for small, autonomous devices, like those used in wearable electronics. There are many types of energy generation like from wind, water, and fossil etc. [7-9] (Figure 1). However, Spintronics and Quantum thermodynamics provide a novel approach of production of ambient power.

An alternative approach is that of the semi classical model of charge and spin transport based on the drift–diffusion theory, in which we consider transport in metallic/semiconducting nonmagnets and metallic ferromagnets, by limiting the discussion and 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 LSD, Also, as the transport description is semiclassical, the quantum tunneling and interference are neglected. This approach is based on the assumptions: (i) Slow spin relaxation processes to establish correct equilibrium polarization; (ii) Weak external fields to ensure the working to be within the linear response theory; (iii) Absence of spin Hall effects, and spin Coulomb drag; and (iv) No presence of space charge effects. For this approach, it is convenient to consider the structure as shown in Figure 2, which consists of a ferromagnet (F) in contact with a non-magnet (N). It can be seen that the F/N bilayer is under the effect of an electric field governed by (i) a charge voltage VC, and (ii) a magnetic field: B=μ_0H, where μ_0 is the 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 2 shows (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 [10]. (b) 3-D view showing the external fields: 1) an electric field E governed by a charge voltage VC and 2) an arbitrarily oriented magnetic field B of magnitude B and orientation angles φ and θ. Using the spin or Boltzmann equation, a set of flux equations can be derived for the four macroscopic quantities, which are: charge density n (r, t,) spin density s (r, t), charge current density JC (r, t), and spin current density JS (r, t), where r and t are space and time variables; and spin
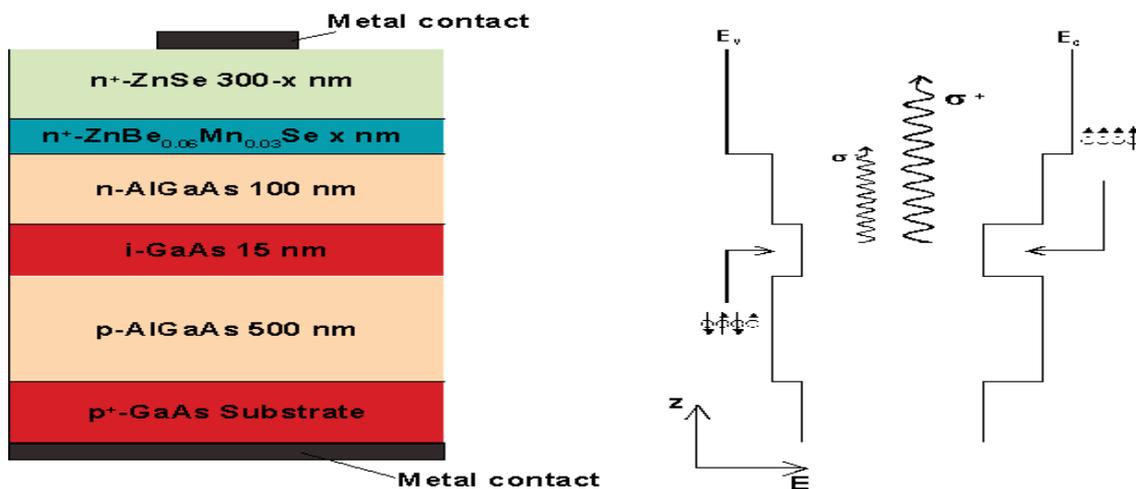

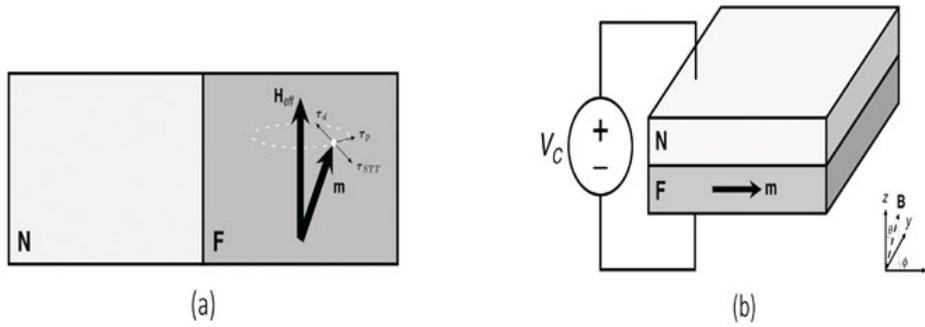**Figure 1:** Spin injection demonstration device.

Figure 2: Schematic illustration of a ferromagnet/non-magnet (F/N) bilayer.

density is defined as the total electron density of electrons of one spin minus the total electron density of the electrons of the other spin. The designer has to optimize these quantities for obtaining the maximum flux. For simplifying the treatment, 1-D transport along the z-axis in a non-magnet is considered, within a relaxation time approximation.

It has to be noted that the materials for fabricating devices based on Spintronics and Quantum thermodynamics have to be chosen separately for the two. There are about 50 Energy materials, 100 Metallic materials, and 200 Magnetic materials. The anomalous Nernst effect (ANE), one of the thermomagnetic effects studied by many researchers in various fields, has recently drawn the attention of the scientific community engaged in the Spitronics based devices, especially from the point of view of ambient power generation. It is really interesting to note that the ANE, which is produced from the fictitious fields in momentum space, has been able to understand the intersection among three different concepts of heating, spin, and charge in magnets. Also, contrary to the See beck effect, it has many advantages for application for highly efficiency energy-harvesting devices, since it can provide simpler lateral structure, higher flexibility, and most importantly, much lower production cost. The designer has to choose the method for modulating the ANE for its thermoelectric applications, and also to design materials for obtaining large ANE including Weyl magnets, and thermoelectric devices for efficiently using the ANE. In the last decade, the research field covering spintronics and the rmoelectrics, termed 'spin caloritronics', has drawn the attention of various research [9]. The advantage in case of thermoelectric conversion from heat to electric energy by using spin is that spin can be controlled easily by a small energy in the nanostructures, which has led to the development of the energy-harvesting technology. Here it is to be noted that though the See beck effect, as thermoelectric effect is widely used in many nonmagnetic thermoelectric devices, because it directly converts heat into electricity; which can be created along the direction of temperature gradient, yet the Nernst effect, another well-known thermoelectric energy, has been found to be useful for energy harvesting [9]. More novel Studies on this evolving topic have recently been reported [10,11]. Following the approach of the thermoelectric, the expression for the current density $J\uparrow (\downarrow)$, carried by the electrons with spin up (down), is given by:

$$J\uparrow (\downarrow)=e\, n\uparrow (\downarrow)\, \mu E+eD\nabla n\uparrow (\downarrow) \qquad\qquad -(5),$$

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 $n\uparrow$ $(n\downarrow)$, respectively. Therefore, the electron concentration is given by:

$$n=n\uparrow+n\downarrow \qquad\qquad \sim(6),$$

And the spin density is defined as:

$$s=n\uparrow-n\downarrow \qquad\qquad \sim(7).$$

Hence, the electron charge (spin) current can be in the same manner given by the corresponding densities as:

$$Jc\ (Js)=J\uparrow\ \pm J\downarrow- \qquad\qquad \sim(8).$$

Subsequently, the spin polarization is given as:

P= (s/n); and by substituting the definitions from (5) into the steady state continuity equation and adding spin scattering leads to the following expression:

$$\nabla\cdot J\ (\downarrow)=\pm e\ (n\text{-}n\downarrow)/\tau s \qquad\qquad \sim(9),$$

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

$$\nabla\cdot E=e\ (n\uparrow\ +\ n\downarrow-\ ND)/\in Si \qquad\qquad \sim(10),$$

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

$$Vth=kB\ T/q \qquad\qquad \sim(11),$$

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:

$$L=\sqrt{\ (D\tau s)} \qquad\qquad \sim(12),$$

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:

$$Jc=en\mu E+eDdn.dx \qquad\qquad \sim(13),\ and$$

$$Js=es\mu E+eDds.dx \qquad\qquad \sim(14)$$

The spin density equation is given by:

$$d^2s/dx^2+ (1/Vth)d\ (Es)/dx\text{-}s/L2=0 \qquad\qquad \sim(15),$$

Where boths and E are position dependent. The spin injection into silicon is studied by defining boundary conditions.

Alicki and Josloff [12] 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−→Red ⋯(16).

According to standard thermodynamics, the actual free energy change ΔG is related to the free energy change under standard state ΔGo by the relationship:

ΔG=ΔGo+RTln Qr ⋯(17),

Where Qr 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:

ΔG=-zFE ⋯(18).

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

Ered=Eored -RT/zF ln Qr=Eored-RT/zF ln aReaOx ⋯(19).

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

Ecell=E$_o$cell-RT/zF lnQr ⋯(20),

Where Ered is the half-cell reduction potential at the temperature of interest,

Eored is the standard half-cell reduction potential, Ecell is the cell potential (electromotive force) at the temperature of interest, Eocell 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 aRed is the activity of the reduced form and aOx is the activity of the oxidized form.

DESIGN CONSIDERATIONS

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 potential. From the laws of Electromagnetism, we know that when the temperature gradient (dT/dX) and the magnetic field (H), both normal to each other, are applied to a conductor, an electromotive force is induced perpendicular to both (dT/dX) and H, which gives rise to a Nernst

voltage. If we consider a case, if the material has a spontaneous magnetization, spontaneous term of the Nernst effect becomes superimposed on the normal Nernst term; and this spontaneous term is called the anomalous Nernst effect (ANE) and frequently observed in ferromagnetic materials.

Since, the normal Nernst effect is proportional to magnetic field B; therefore, enough magnetic fields are required for the thermoelectric conversion. However, to the contrary, the ANE is spontaneous at zero fields, and proportional to saturation magnetization in principle. It has been established by the recent experimental and theoretical studies that it originates from the fictitious field in the momentum space in magnets and can be particularly enhanced when the Weyl points are tuned to be close to the Fermi energy. Hence, the designer has to ensure the magnetic materials with large Qs and/or Ms are developed, and also, the remanence state is used, then ANE occurs even without applying a magnetic field. It is this unique feature of the ANE, which makes it suitable for the thermoelectric conversion process. However, it is still a challenge to developed actual devices based on the Nernst effect, or the ANE. It has been claimed that large ANE is observed in an antiferromagnetic bulk with a very small magnetization. The Nernst effect is a thermoelectric, or a thermomagnetic phenomenon, which is observed when a sample allowing electrical conduction is subjected to a magnetic field and a temperature gradient normal to each other, and thus, an electric field is induced normal to both. This effect is quantified in terms of the Nernst coefficient |N|, which is defined as:

$$|N| = \{\frac{(E_y \ / \ B_z)}{(dT \ / \ dx)}\}$$ ⋯(21),

Where E$_y$ is the y-component of the electric field resulting from the magnetic field's z-component B$_z$, and the temperature gradient (dT/dX). Thus, the designer has to optimize the increase in E$_y$, decrease in B$_z$, and also minimizing the derivative (dT/dX), i.e., the rate of change of temperature with distance.

A very important advantage of the Nernst effect is that the observed Nernst voltage is not governed by the temperature difference, but by the temperature gradient. Though, in case the See beck effect also, the voltage increase is proportional to the temperature gradient, the problem is that, a sufficient length of the material along the temperature gradient is needed for achieving a large temperature difference, which decides the See beck voltage. However, in case of the Nernst effect, if the temperature gradient is provided, not much length of the material along the temperature gradient is required, since the Nernst voltage increases with the transverse length normal to both the temperature gradient and the magnetic field. Hence, the Nernst effect has been established as suitable for the thermoelectric conversion system consisting of thin materials, and as a result is useful to design a flexible device to fit any type of curved surface of a heat source. Recent experiments have shown that the spin See beck effect has been found innovating from thermoelectric applications point of view. However, a spin detection material with a strong spin-orbit interaction (SOI) such as Pt is required for the spin Seebeck effect, as the thermally generated spin current is converted to voltage mate considerable [13-15].

DISCUSSION AND CONCLUSION

Thus, it is clear that it is possible to assemble an electrical generator which uses the electron spin to harvest thermal fluctuations at room temperature. The harvesting of ambient temperature occurs over paramagnetic (PM) centers, implying that the atom-level magnets whose orientation fluctuates because of heat. The Spin engine's electrodes are called spintronic selectors, which allow electrons of only one spin (↑ or ↓) to conduct. In modern times of the tremendous increase in the requirement of Energy, a new method of the Ambient Powed based on Spintronics and Quantum Thermodynamics seems to have a good potential. The recent spurt in the studies of Spintronics, and Nersnt Effect, seems to be having a lot of potential. The works on the individual technologies of Spintronics, Renewal Energy, and Anomalous Nersnt Effect, have been very successful. Still, the combined Technology based on all three is a quite daunting task. The designer has to choose such materials which satisfy all three basic technologies, and also to optimize various Parameters to achieve maximum output from each of them. This is quite complicated, and may require the experience and expertise of the designer, and also access to computer softwares.

Recently, some very useful research papers have appeared on this interesting topic. It is desired that some Laboratories should be set up in Aeronautics and Aerospace Industries to develop this type of ambient energy. To conclude, making this technology really useful, more concerted efforts have to be made. 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.

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