Simple QED in Magnetic Recording

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Abstract: Spin-valves comprising alternating nanoscale layers of ferromagnets (FMs) separated by mon-magnetic (NM) spacers are generally thought to produce parallel electron-spins that lower the giant magneto-resistance (GMR) of the disordered state, the change in resistance allowing data storage in magnetic recording. Almost a decade ago, the author showed lowering of the GMR was not caused by spin, but rather by EM radiation induced by conserving Joule heat from the electrical current writing and reading in the recording, the EM radiation at UV levels by photoelectric charging the FM and significantly lowering the GMR. Since then, the theory of simple QED induced heat transfer at the nanoscale has advanced to prompt the instant updated version of spin consistent with other simple QED applications. Having nothing to do with Feynman's QED, simple QED is based on the Planck law that denies the atoms in FMs under nanoscale EM confinement the heat capacity to conserve Joule heat by an increase in temperature, and instead the heat is conserved by creating non-thermal EM waves standing across the FM layer. The EM radiation is ionizing having sufficient Planck energy to create excitons of holon and electron pairs, the holons as charge carriers lowering the GMR by the dramatic decrease in the resistance of the FM layers even approaching super-conductivity at ambient temperature.

Keywords: spin-vales, ferromagnetic, Casimir, nanoscale heat transfer, Planck law, simple QED

I. INTRODUCTION

Heat transfer mechanisms at the nanoscale differ significantly from classical physics because the Planck law [1] of quantum mechanics (QM) denies the atom the heat capacity necessary to conserve heat by an increase in temperature. The heat transfer restriction not only applies to atoms in nanostructures, but also to atoms in the surface of nanoscale vacuum gaps between macroscale bodies.

Recently, phonons assisted by quantum fluctuations in the Casimir effect were proposed [2] to explain heat transfer across a nanoscale vacuum gap between macroscopic bodies. A few decades ago, black body radiation given by the Stefan-Boltzmann law depending on surface temperature was shown [3] not applicable to vacuum gaps d << hc/kT. Instead, near-field thermal radiation by evanescent waves was suggested, but still depended on temperature of the gap surfaces. Later, the heat transfer mechanisms between evacuated nanoscale gaps [4] included phonons assisted by quantum fluctuations and which require distinctly different temperatures that cannot exist at the nanoscale. Similarly, spin caloritronics [5] in the lowering of GMR for temperatures > 6 K is clearly precluded by the Planck law.

Indeed, all known nanoscale heat transfer mechanisms including near field radiation, quantum fluctuations, evanescent waves, and Casimir assisted phonons assisted by van der Waals or electrostatic forces find basis in temperature dependent Planck energy $E = (hc/\lambda)/[\exp(hc/\lambda kT) - 1]$ or $E = kT$ that vanish at the nanoscale. What this means nanoscale heat transfer is only possible with temperature independent mechanisms.

II. PURPOSE

To propose the simple QED mechanism of heat transfer explains heat transfer across nanoscale FM layers the lowers the GMR in magnetic recording without electron spin. Although consistent with the physics in an earlier [6] paper, terminology is updated.

III. BACKGROUND

Spin-valve ferromagnetism is based on theoretical pre- dictions by Slonczewski [10] and Berger [11] over a decade ago. Spin-valves comprise alternating nanoscale layers of FMs separated by NM spacers. Spin polarized current is produced by passing un-polarized current through the first FM layer, the polarization unchanged as the current flows through the NM spacer. Upon interaction with the second FM layer, the GMR is thought to transfer the spin angular momentum from the first to the second FMs as a physical spin-torque, the process tending to produce parallel spins that significantly lower the GMR.

However, the significant reduction in the GMR by the alignment of spins remains controversial even to this day. The relatively rigid lattice shields the spins so that any physical transfer of spin-torque from the first to the second FM is unlikely. Further, spin-torque propagates by phonons through the FM lattice limiting spin-transfer to frequencies < 10 GHz having response times > 100 ps. However, electron spins are observed to respond much faster.

Laser studies [12] in femto-magnetism by show nanoscale FMs demagnetize on a sub- picosecond time scale (< 350 fs) far faster than phonons can respond. Since about 10 ps are required [13] for the lattice to thermalize, the spin- valves were proposed [14] to demagnetize by light and not spin-transport through the lattice as the dynamics are only observed while the laser field interacts with the FM – an observation bearing remarkable similarity [15] with the EM confinement described by a quasi-bound MDR state, trapped in a potential well but leaking to the outside world by tunneling. MDR stands for morphology-dependent resonance.

Spin transfer through the lattice therefore cannot be the mechanism for demagnetization. In this regard, spin-transport was found [16] inconsequential in Fe/Alq3/Co spin valves compared to the switching by holes only common to non-volatile electrical switching. Alq3 stands for tris-(8-hydroxyquinolate) aluminum representative of organic spin-valves. The fact that non-volatile electrical switching was recently proposed [17] to coexist with spin-transport only supports switching by holes alone.

Like any other nano-electronic circuit element, spin-valves by the Planck law lack the heat capacity [18] to conserve Joule heat by an increase in temperature. Notions of demagnetizing FMs by exceeding the Curie temperature with laser heating as suggested by Bigot et al. [13] and others based on temperature changes may be safely dismissed.

Simple QED induced radiation [6,18] requires the frequency up-conversion of Joule heat to the EM confinement frequency of the FM to create excitons (holon and electron pairs) at UV levels, the holons (or holes) of which the holons act as charge carriers that dramatically increase the FM conductivity by significantly reducing the GMR while writing data in magnetic recording heads. In erasing data, the GMR is promptly recovered by simply reversing the bias polarity.

IV. THEORY

Simple QED is a nanoscale heat transfer process based on the Planck law [1] of quantum mechanics differing significantly from classical physics by the heat capacity of the atom as illustrated in Fig. 1.

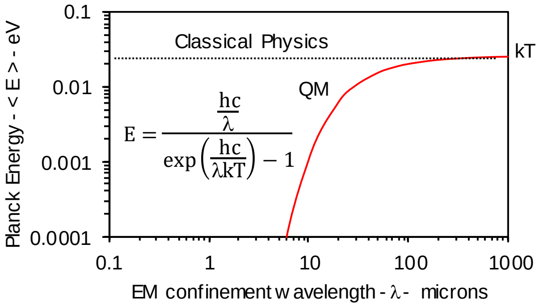

Figure. 1: Planck law of the Atom at 300 °K
In the inset, E is Planck energy, h Planck’s constant, c light speed, k Boltzmann’s constant, T absolute temperature, and λ the EM wavelength.

The Planck law at 300 K shows classical physics allows the atom constant kT heat capacity over all EM confinement wavelengths λ. QM differs as the heat capacity of the atom decreases for $\lambda < 200$ microns, and may be said to vanish at submicron levels. Implicitly, all nanotechnology comprising submicron nanostructures is subject to the same Planck constraint.

A decade ago, simple QED nanoscale heat transfer [6,18] was based on the argument that the Planck law requires energy U be conserved by creating non-thermal EM radiation. QED stands for quantum electrodynamics, a complex theory based on *virtual* photons advanced by Feynman [19] and others. In contrast, simple QED has nothing to do with *virtual* photons and only requires the heat capacity of the atoms in nanostructures or on the surface of nanogaps to vanish allowing conservation to proceed by the creation of *real* photons forming EM waves that stand across the nano structure or gap. Hence, the Planck energy E of the simple QED state is,

$$E = \frac{hc}{2nd}$$

where, n is the refractive index of the FM material. Like electron level quantum states with EM waves standing across orbitals, simple QED quantum states are size dependent based on the dimension of the nanostructure or nanogap over which EM waves stand.

But absorbed Joule heat Q by the FM cannot be conserved by an increase in temperature. EM confinement at the FM surfaces is required to form the non-thermal standing EM waves as depicted in Fig.2.

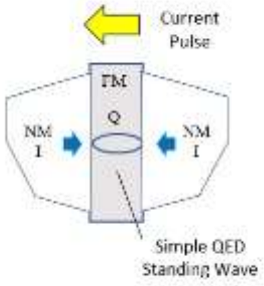

Figure 2. EM confinement of FM layer

The NM regions on both sides of the FM having thermal energy $U = N_{atoms} \cdot kT$ act as external sources of thermal EM radiation with inward Poynting vectors that transmit momentum I = U/c to both FM surfaces. Since thermal radiation cannot exist inside the FM, the thermal momentum I can only exist at FM surfaces. Hence, the inward directed momentum I provides the EM confinement to constrain the heat Q in creating the non-thermal standing simple QED radiation.

The momentum I_W of a standing EM wave is, $I_W = E/c = h/2nd$. Therefore, EM confinement occurs as $I >> I_W$ allowing heat Q to continuously create simple QED radiation E = hc/2nd that beyond the UV ionizes the FM, the holons of which lower the GMR.

IV. APPLICATION

A. Simple QED radiation and Excitons

QM restrictions on heat capacity require the power P to be conserved by simple QED inducing the creation of a number N_{ex} of excitons in the surface of the FM. The rate dN_{ex}/dt of excitons created depends on the Planck energy E of simple QED radiation inside the FM,

$$\frac{dN_{ex}}{dt} = \frac{P}{E}$$

where, P is Joule heat, P= IV = I^2R, and V, I, and R are the FM voltage, current, and resistance.

Under the electric field F across the FM, the holons separate from their paired electrons. However, only a fraction η of the excitons produce holons in the FMs that lower the GMR, the remaining fraction (1-η) upon recombination emit EM radiation that is lost to the surroundings. For the FMs,

$$\frac{dN_{ex}}{dt} = \frac{\eta P}{E}$$

B. Holon Dynamics

In the FM, the rate of creating excitons ηP/E is balanced by the number of electron Q_E and holon Q_H charges moving in the electric field F toward opposite polarity voltage terminals by their respective μ_E and μ_H mobilities,

$$\frac{dQ_E}{dt} = \frac{\eta P}{E} - Q_E \frac{\mu_E F}{d}$$

$$\frac{dQ_H}{dt} = \frac{\eta P}{E} - Q_H \frac{\mu_H F}{d}$$

For simplicity, consider only the holon Q_H equation and take F = V_o/d,

$$\frac{dQ_H}{dt} = \frac{\eta P}{E} - Q_H \frac{\mu_H V_o}{d^2}$$

The solution for the number Q_H of holons is,

$$Q_H = \frac{d^2}{\mu_H V_o}\left\{\frac{\eta P}{E}\left[1 - exp\left(-\frac{\mu_H V_o}{d^2}t\right)\right] + \frac{\mu_H V_o}{d^2} Q_{Ho} exp\left(-\frac{\mu_H V_o}{d^2}t\right)\right\}$$

C. Electrical Response

On average, the excitons (holons and electrons) are centered in the FM thickness d and need to move d/2 to reach the voltage terminals, the spin-valve resistance R is,

$$R = \rho\frac{d}{2A} = \frac{d}{2A}\left[\frac{Ad^2}{\mu_E Q_{Eo} + \mu_H Q_{Ho}}\right] \approx \frac{d^2}{4\mu_H Q_H}$$

For simplicity, the resistance R assumes $\mu_E = \mu_H$ with the same number Q_E of electrons as Q_H holons. Note the resistivity requires units of per unit volume, where volume is Ad and A is the FM area. The resistance R_o corresponds to the initial number Q_{HO} of holon charges,

$$Q_{Ho} = \frac{d^2}{4\mu_H R_o}$$

The current I,

$$I = \frac{V}{R} = \frac{V_o}{R}$$

D. Mobility

Since current is proportional to both mobility and conductivity, Chen et al. [14] expressed mobility μ at ambient temperature by,

$$\mu = \mu_o \exp\left(\alpha F^{1/2}\right)$$

where, μo is the mobility at zero field. For Alq3, α= 9.22×10^{-3} $(cm/V)^{1/2}$ and $\mu_o = 3.04 \times 10^{-7}$ cm^2/V-s.

E. Simulations

The simulation simple QED response of magnetic recording was simulated in a Fortran program. The write/read switching was obtained for Alq3 film thicknesses of d = 10, 20, 50, and 100 nm having refractive index n = 2.5. The power P = 10 mW was assumed totally converted to excitons, η =1. All films were assumed to have an initial GMR of Ro = 1×10^6 ohms. A voltage Vo = +1 V was applied for 10 ns followed by reversing the voltage polarity Vo = -1 V for 10 ns. The resistance and holon response are shown in Figs. 3 and 4.

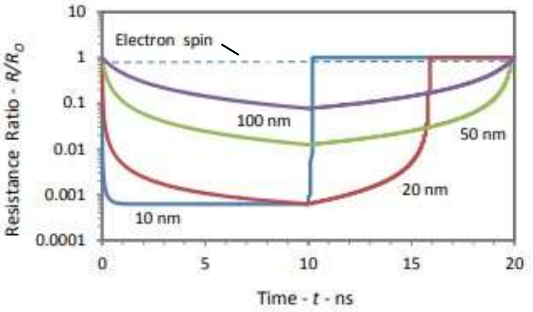

Fig. 3 Simple QED Induced GMR Resistance Ratio R/Ro v. Time – ns (+1 V write and -1 V erase)

Fig. 3 shows the simple QED induced reduction in GMR is observed to change significantly depending on the FM thickness. For the 100 nm layer, the R/Ro ~ 0.1 at 10 ns means the GMR is reduced ~ 90%. In comparison, the GMR reduction for 125 nm Alq3 film [17] at 100 K shown as dotted line (noted Electron spin) gives a GMR reduction of only about 22% corresponding to R/Ro = 0.78 or (R ~ 0.78×10^6 ohms). As the Alq3 film thickness increases, the simple QED induced GMR reduction decreases.

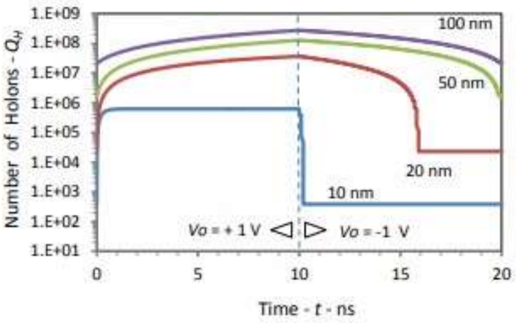

Fig. 4 QED Induced Number of Holons v. Time – ns (+1 V write and -1 V erase cycles)

Fig. 4 shows the holon response for + 1 V writing and – 1 V of erasing data. Reversal of voltage Vo shows an abrupt recovery of the GMR for the 10 nm film. The significant GMR reduction for the 10 nm Alq3 film predicted by simple QED induced conductivity suggests superconductivity is possible in FMs at ambient temperature

V. CONCLUSIONS

The Planck law denies atoms in FM layers the heat capacity to conserve heat by an increase in temperature. Phonons depending on temperature do not exist in in FMs which means heat transfer occurs by simple QED induced EM radiation.

Simple QED based on the Planck law conserves heat in the FM layer by the prompt creation of standing EM radiation beyond the UV that promptly ionizes the FM to form holons that lower the GMR.

FMs that demagnetize on a sub-picosecond time scale (< 350 fs) is consistent with simple QED induced heat transfer at the nanoscale.

Simple QED requires brief EM confinement of the heat to produce non-thermal EM waves standing across the FM layer. TIR was used in the early paper, but EM confinement of the standing EM waves is updated here to the inward impulsive momentum to both FM surfaces of thermal kT radiation from respective external regions to the FM having finite temperature.

The simulations of simple QED induced switching from writing to reading for the 100 nm layer showed 90% GMR lowering compared to the 22% in the experiment. But simple QED assumed 100% conversion of power to excitons. Since the FMs are stacked on top of each other, the assumption all power is converted to excitons is reasonable.

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