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Virtual Observation of Femtosecond Spin Dynamics Mechanism in Graphene

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***Abstract*—The mechanism of the femtosecond spin dynamics is still not properly understood. The remodeled Bloch – Schrödinger equation was incorporated into the Hamiltonian. The mechanism of the femtosecond dynamics was investigated under three quantum states. The spin relaxation mechanism operated in a single continuous time scale (>70ps) which was in variance with knownpostulate. The transient reflectivity was measured to be within an angular range of 18.6o to 90.0o at a pulse range of 1MHz to 6.5 MHz. Beyond the pulse intensity of -2.5, the system elapsed into a quasi-equilibrium state which explains the independence of the magnetic moment on the pulse intensity. Different possibilities of the femtosecond spin dynamics were worked out for future study.**

***Index Terms*—femtosecond spin dynamics, Schrödinger, Bloch NMR, spin relaxation**

I. Introduction

Justifying novel experimental research by theoretical models is fast deviating from the usual practice of merely combining theories and mathematical conditions into a robust process of setting pace for experimental research by proactive theoretical models. The femtosecond spin dynamics of materials is a typical research area which has shown as much complexities as the superconducting medium. For example, the graphene was reported to be in the class of an ideal spintronics (1). Its spin relaxation mechanism still remains uncertain due to wide discrepancies between experimental (2) and theoretical (3) efforts. The spin relaxation in graphene and spintronics had been reported to dependent on adatoms (4), curvature (5), substrate effects (6), vacancies (7) and contacts (8). Often times, there had been scientific reports of strange twist of behavioral and functionality of materials at certain conditions. For example, at the same time scale i.e. 100ps, spin relaxation time in graphene is due to resonant scattering by local magnetic moments (9); in GD, spin-lattice interaction is dominant (10); in nickel, a sharp decrease of magnetization was observed (11). These discoveries show that theoretical research may be unable to discover the mechanism of different material due to dissimilar reactions to physical conditions (12).

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Theoretically, some quantum state referred to in the later part of this paper e.g quasi-equilibrium state does not evolve under Hamiltonian system except they are reduced with the eigenbasis blocks of the spin environment Hamiltonian (13). This problem was solved in this paper by estimating-differently for the reduction of the eigenbasis blocks of the spin environment Hamiltonian - using the Bloch NMR equation to solve the Schrödinger equations (14) and then inserting the solutions (which are the reduced eigenbasis) into a spin environment Hamiltonian in order to analyze the mechanism of femtosecond spin dynamics.

II. THEORETICAL BACKGROUND

Previously, the spin density matrix was calculated as [15]

$$R(t) = \exp(i\omega_{\alpha}t)\, R \qquad (1)$$

Now, we mathematically accounted for the reduction of the eigenbasis blocks of the spin environment Hamiltonian - using the Bloch NMR equation to solve the Schrödinger equations and then inserting the solutions (which are the reduced eigenbasis) into a spin environment Hamiltonian in order to analyze the mechanism of femtosecond spin dynamics in the next section.

III. RESULTS AND DISCUSSION

The initial assumption made in this paper is that the nucleus and the electrons are enclosed in a spherical boundary called atom. We applied the Christoffel's second rank tensor analysis within a spherical polar coordinate.

$$(ds)^2 = (dr)^2 + r^2(d\theta)^2 + r^2 sin^2(\theta)(d\emptyset)^2 \qquad (2)$$

The many solutions can be found in Gupta [16] as

$$\sigma = sin\theta cos\theta \qquad (3a)$$

$$\sigma = cot\theta \qquad (3b)$$

$$\sigma = -r sin^2\theta \qquad (3c)$$

The solutions in equation 3a-c are important to characterize the spin relaxations under three conditions (low transverse magnetization, moderate transverse magnetization and high transverse magnetization) at 100ps time scale. This idea would avail us the validity to affirm the presence of magnetic deflagration in the graphene sample (see figures 1-3). Magnetic deflagration has been earlier reported as the signature of magnetic material prepared in a metastable spin configuration [17].

Experimentally, the time needed to reverse spins is given as about 100ps [18]. Also, the characteristic time for establishing a thermal equilibrium between the lattice and the spin system is also within the range of 100ps [10]. We restricted the research within the 0ps- 100ps because the spin lattice

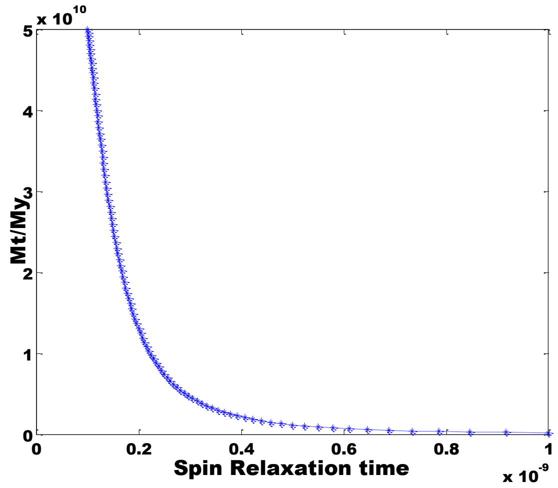

Fig. 1. spin relaxation at low transverse magnetisation

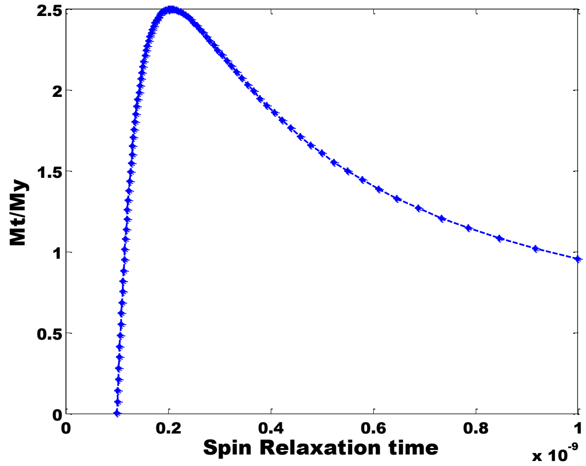

Fig. 2. spin relaxation at moderate transverse magnetisation

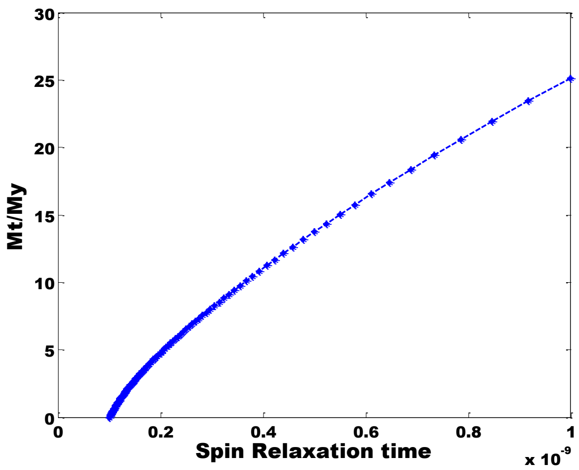

Fig. 3. spin relaxation at high transverse magnetisation

interaction for some materials [11] seems to be more visible at this range. One of the significant successes of the Bloch – Schrodinger solutions was the splitting of overlapping resonances without the usual long measuring times as shown in Fig. (1-3). Also, the Bloch –Schrodinger solutions could be used to analyze coupled spin systems unlike the restriction to the uncoupled spin which the Bloch NMR equation is known for. When the applied transverse magnetization is very low, the features in figure (1) reveals the following occurrences: the magnetic ratio $(\frac{M_T}{M_y})$ curve defines the nature of demagnetization on the femtoscale as electronic [11]; two-spin correlations dominates the coherent dynamics during the early timescale [11]; the transition from ferromagnetism to paramagnetism is not restricted only to heating the system temperature above the Curie point. Changing the pulse sequencing of the applied transverse magnetization could also initiate the transition from ferromagnetism to paramagnetism [18]. The experimental effect of pulse sequencing of the applied transverse magnetization e.g. competing relaxation pathways was accounted for in this calculations. At about 40ps (as shown in fig. (1)), the spin system recognized the impact of the total effect of the magnetic field on the material nuclei. This can be practically summarized that low applied transverse magnetization favors the analysis of Gd whose spin-lattice relaxation time was experimental reported as 48ps [19].

IV. CONCLUSION

In conclusion, three states were discovered in the femtosecond spin dynamics mechanism. The first is the blocking state where the electrons are in a non-equilibrium state. The measurement at this state specifies that its transient reflectivity is within an angular range of 18.6° to 90.0°. The pulse was within the range of 1MHz to 6.5 MHz. The second was the equilibrium state where the spin flip increases the number of electrons with opposite sign. The third is the quasi-equilibrium state where the pulse intensity had moderate impact on the magnetic moment under the bleaching effects when $I \leq -2.5$. Beyond the intensity $I > -2.5$, there is no effect on the magnetic moment because it is at its quasi-equilibrium state.

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