The H Field Dependence of Magnon Diffusion Length Basing on Boltzmann Transport Methods

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INTRODUCTION

Magnon transport and its efficient manipulation are important issues in modern spintronics research. Unlike traditional spin information transport carried by conduction electrons, magnon spin transport shows more advantages, such as the low energy loss. However, the magnon relaxation and decay processes in magnon transport are still in debates. Here, we started from the Hamiltonian of a general magnetically ordered system, and analyzed the complex scattering processes in spatial inhomogeneity systematically. Finally, we derived the general magnon Boltzmann transport theory.

Method

The magnon transport processes can be regarded as the spatial inhomogeneous evolution of quasi-particle boson gas in FI bulk layer. By considering the anti-diffusion driving term, and the local magnetic field and temperature gradient driving terms, we can derive the general Boltzmann equation:

$$v_k\frac{\partial n_m}{\partial r}-v_k\left(-\frac{\partial N_m^0}{\partial \varepsilon_k}\right)\left[\frac{\varepsilon_k}{T_m}(-\nabla T_m)+g\mu_B\left(\nabla H_{loc}+\frac{H_{loc}\nabla \bar{n}_m}{\bar{N}_m^0}\right)\right]=-\frac{n_m-\bar{n}_m}{\tau_m}-\frac{n_m-N_m^0}{\tau_{th}}.$$

Then, we apply the general Boltzmann equation to the NM/FI/NM CIP geometry and consider the one dimensional equation along the x-axis, namely:

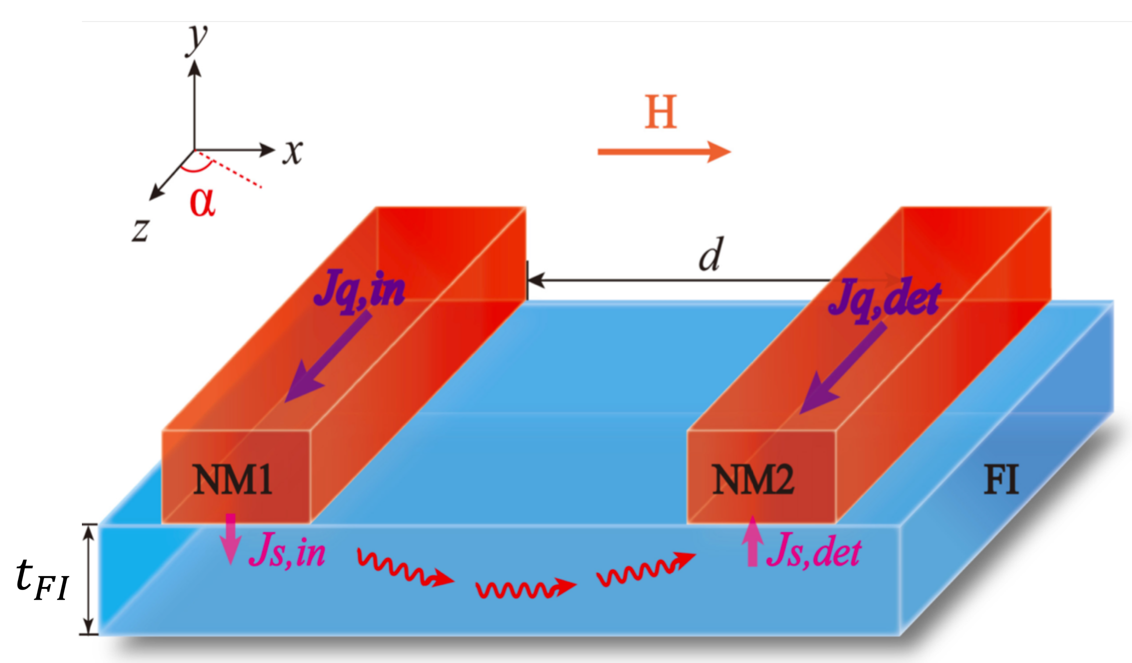
$$\frac{\partial n_m}{\partial x}+\frac{1}{v_x\tau_c}n_m=\left(\frac{1}{v_x\tau_m}-\beta H\frac{\mathrm{d}}{\mathrm{d}x}\right)\bar{n}_m-\alpha\frac{\mathrm{d}H}{\mathrm{d}x}+\frac{N_m^0}{v_x\tau_{th}},$$

where H is the local internal magnetic field, and the parameters above are:

$$\alpha=-\left(-\frac{\partial N_m^0}{\partial \epsilon}\right)g\mu_B;$$

$$\beta=-\left(-\frac{\partial N_m^0}{\partial \epsilon}\right)g\mu_B/\bar{N}_m^0;$$

$$\frac{1}{\tau_c}=\frac{1}{\tau_m}+\frac{1}{\tau_{th}}.$$



Schematic diagram of NM/FI/NM CIP geometry

This is a differential integral equation and we can easily find the solution to this equation: $n_m(x,v_x)$. Then, integrate on both sides of the solution and we could get the well-known Fredholm equation of the second kind:

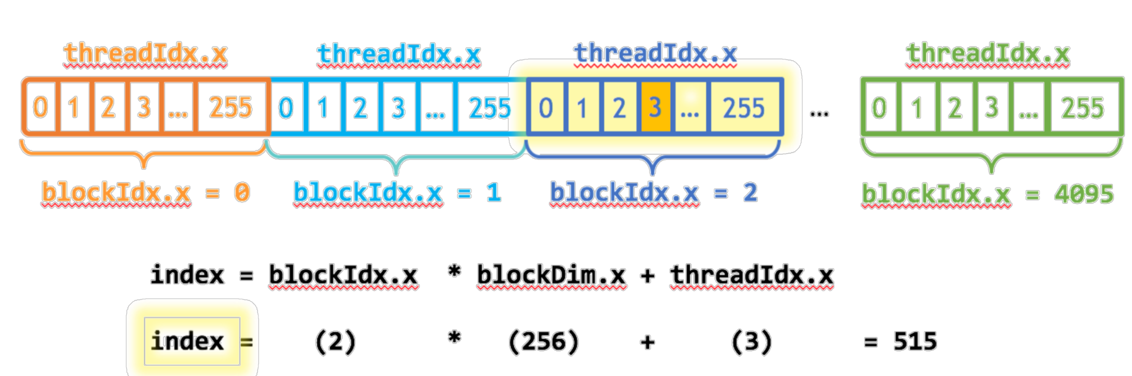
$$<\delta n_m>=(K-1)^{-1}<g>,$$

where $<g>$ is determined by the boundary condition and K is a complicated matrix. Then, this matrix equation can be solved by standard numerical methods.

Numerical Solution

The process to find the numerical solution to such a complicated matrix equation is not easy. Therefore, we accelerated the calculation by thousands of parallel threads running on 4 NVIDIA GPUs with CUDA (Compute Unified Device Architecture).

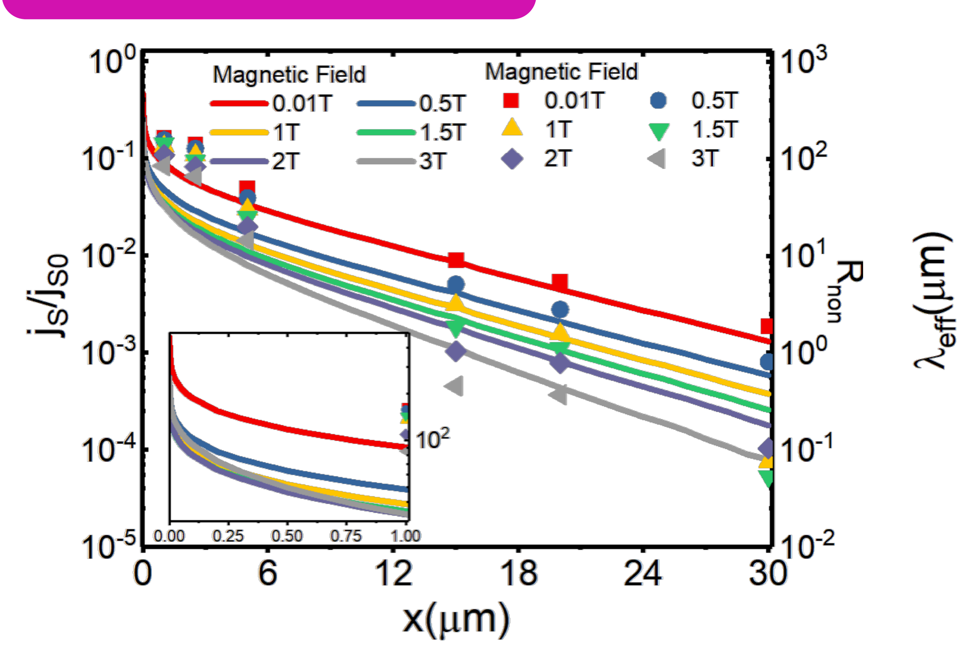
- Discretize the continued variable into a 1000×1000 matrix by Gauss-Legendre quadrature formula.
- Impose the boundary condition:
  $$<n_m\ (x=0)>=\mathrm{N}_0;$$
  $$<n_m(x=d)>=0,$$
  into our equation and get the expressions of the 1000×1000 matrix elements.
- To compute on the GPUs, we need to allocate memory for all the parameters and integrand functions accessible by the GPUs.



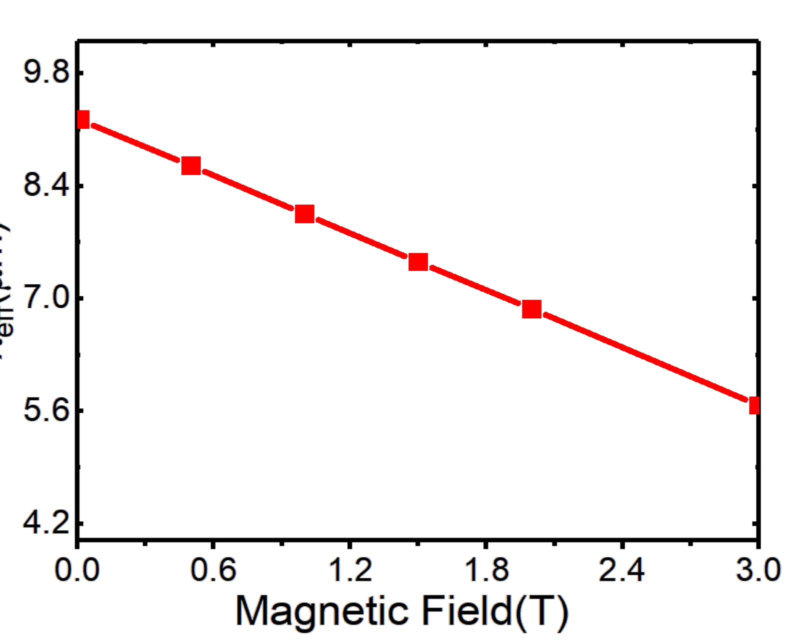
The CUDA parallel thread hierarchy

- The Streaming Multiprocessors composed of many parallel processors of GPUs will take full advantage of GPU threads and shorten the calculation time greatly.

Result



The numerical results of relative detective spin current j_S/j_{S0} as a function of distance x between the injection and detection for magnetic field strengths from B = 0.01 T to B = 3.0 T. The dots are the data obtained from the experiments.



By fitting the curves in the left figure with $Ce^{x/\lambda}/\lambda\left(1-e^{2x/\lambda}\right)$, we can find that the magnon propagation length λ_{eff} changes with the field changing from B = 0.01 T to B = 3.0 T.

CONCLUSION

✓ For such a complicated differential integral equation, we can transform it into Fredholm equation and find the corresponding matrix equation for numerical calculation.

✓ From the left figures, we can see that our numerical solutions perfectly match the experimental measurement quantitatively.

✓ Our Boltzmann theory can explain the suppression effect of magnon propagation induced by the external field, especially in bulk regime.