Micromagnetic Simulation

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Since the pioneering works by Brown and LaBonte[1-3], micromagnetic simulation has been used to calculate the magnetization distribution and its dynamics in nanoscale magnetic materials. Because of the limitations of the calculation speed of the computers, they proposed the simple algorithms to obtain the energy minimum state, and solved the problem within these limitations[1-6]. Usually, the exchange, anisotropy, Zeeman, and the demagnetizing energies are considered in micromagnetic simulation.

$$\varepsilon = A\left(\nabla \mathbf{m}\right)^2 + K_u \sin^2\theta - \frac{1}{2}\mathbf{H}^D \cdot \mathbf{m} - \mathbf{H}^E \cdot \mathbf{m}. \qquad (1)$$

Here, A, K_u, $\boldsymbol{H^D}$ and $\boldsymbol{H^E}$ are the exchange stiffness constant, the uniaxial anisotropy constant, the demagnetizing field and the external field, respectively.

In 1980s, third generation supercomputers appeared and they extended the limitations. Micromagnetic simulation was used to solve some problems, i.e., the magnetic domain wall dynamics[7,8], magnetic fine particle[9,10], magnetic thin film[11], magnetic recording media[12], and magneto-optical recording media[13]. In these reports, Landau-Lifshitz-Gilbert equation was used.

$$\dot{\mathbf{m}} = -\gamma \mathbf{m} \times \mathbf{H} - \frac{\alpha}{M_s}\dot{\mathbf{m}} \times \mathbf{m}. \qquad (2)$$

$$\rightarrow \dot{\mathbf{m}} = -\frac{\gamma}{1+\alpha^2}\left[\mathbf{m} \times \mathbf{H} + \alpha\left[\mathbf{m} \times \left(\mathbf{m} \times \mathbf{H}\right)\right]\right]. \qquad (3)$$

$$\mathbf{H} = -\frac{\delta\varepsilon}{\delta\mathbf{m}}. \qquad (4)$$

Here $\boldsymbol{H}$ is the effective field acting on the magnetic moments. It is calculated by using eq. (4). However since the calculations of the demagnetizing field required a lot of calculation time even with the supercomputers[14,15], they could not solve the LLG equation with original form in many cases. However in these cases, they only needed the switching field of magnetic fine particles or thin films, and did not need the dynamics of the magnetic moments. In the cases, they dropped the gyroscopic term from the LLG equation (eq.(5)), and used a unity of the Gilbert damping constant to reduce the calculation time [9-12].

$$\dot{\mathbf{m}} = -\frac{\gamma}{1+\alpha^2}\left[\alpha\left[\mathbf{m} \times \left(\mathbf{m} \times \mathbf{H}\right)\right]\right] \qquad (5)$$

In 1990s, the fast Fourier transform (FFT) algorithms were introduced to calculate the demagnetizing field[19,20]. It reduced the calculation time drastically. By using this algorithm, the LLG equation with original form can be solved, and larger scale and longer time simulation can be done with personal computers. Nowadays, there are many open source programs and products for micromagnetic simulation[21], micromagnetic simulation is used in many fields, such as nanospintronics, permanent magnet, etc, not only to analyze the experimental results, but also to obtain the optimum conditions of nanodevices. Recently, many effects except for in eq. (1) are discussing, such as Rashba field effect, spin hall effect, Dzyaloshinsky-Moriya interaction, etc. These effects can be adapted to the simulation as the effective field. However even with the personal computers in recent years, the size of the simulation region, which can be simulated within the acceptable time, is about ～0.5 μ m^2 in 2D model case. For larger scale or long time simulations, special computers such as GPU or massively parallel computers are required[22].

For the experimentalist, one of the interested points for the simulation is comparison of the simulation and experimental results. In case of the simple structure target, such as a single crystal material, simulation results in good agreement with the experimental results without special modification of the simulation model. However in case of the complex structure target, such as polycrystalline material, many modifications of the simulation model are required. In the presentation, the simulation results in these two cases will be presented[23-24]. The important points for the simulation will be also presented.

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