# Nuclear Magnetic Resonance in Semiconductor Quantum Structures

**Yoshiro Hirayama**

*Graduate School of Science, Tohoku University*
*ERATO Nuclear Spin Electronics Project*
*e-mail: hirayama@m.tains.tohoku.ac.jp*

Nuclear magnetic resonance (NMR) is widely used in the physical, chemical, and biological sciences. However, conventional NMR based on induction-detection has drawbacks of low-sensitivity and the need of a large volume of sample. It is not suitable to investigate semiconductor quantum structures, whose characteristics are controlled by gates. To overcome these drawbacks, we have developed a resistively-detected technique relying on enhanced interactions between electron and nuclear spins at the $\nu = 2/3$ fractional quantum Hall state. It should be stressed that the special states of $\nu = 2/3$ are needed for dynamic nuclear-spin polarization and $M_z$ detection, but we can apply NMR spectrum and nuclear-spin relaxation ($T_1$ time) measurements for any state we want to estimate [1].

These NMR and relaxation measurements have been successfully applied to semiconductor nanostructures as well as heterostructures. We clearly observed NMR spectra of $^{69}$Ga, $^{71}$Ga and $^{75}$As in GaAs point contact region. The quadrupolar splitting found for the point contact devices was highly sensitive to a tiny strain in the structure. The nuclear-spin-based measurements are also successful to observe electron spin features, which are difficult to detect in conventional transport and optical measurements. For example, the spin texture called Skyrmion was detected as a strong enhancement of nuclear spin relaxation on either side of $\nu = 1$. Such relaxation measurement has been extended to quantum wires and the obtained results suggest mutually correlated Skyrmions in the wide 2DEG and its melting in the narrow wire structure [3].

As a novel manipulation of nuclear spins, we have demonstrated nuclear spin resonance using RF electric field instead of magnetic field [4]. The experiments were carried out at the $\nu = 2/3$ transition point. After dynamic polarization of nuclear spins, an RF electric field was applied to the gate. When the RF frequency is set at the resonance frequency of nuclear spins, the $R_{xx}$ enhancement is suppressed, indicating that nuclear spins are depolarized. This nuclear electric resonance (NER) is induced by a temporal oscillation of the hyperfine field due to domain-wall spatial oscillations, which are excited by the RF electric field. The RF power and duration dependence of the NER spectrum provides insights into the interplay between nuclear spins and the oscillating domain walls [4]. Since RF electric field can be generated by exciting a gate, this technique has an advantage of spatial selectivity.

The experiments discussed here were carried out in collaboration with K. Muraki, G. Yusa, K. Hashimoto, N. Kumada, T. Kobayashi, S. Watanabe, G. Igarashi, and F. M. Hamzah.

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