Resistively-detected highly-sensitive NMR
抵抗検出高感度 NMR

NMR (Nuclear Magnetic Resonance) is widely used to chemical, medical, and physical studies. In spite of its excellent performance, however, NMR application to semiconductor systems, which play essential roles in recent electronics and cutting edge solid-state physics, is limited due to the low sensitivity of conventional NMR. Conventional NMR based on induction-detection requires multiple layers of quantum wells to achieve a sufficiently high signal-to-noise ratio and is not suitable for the analysis of semiconductor layer and nano structures where characteristics are controlled by the gate biases. Recently, we have demonstrated dynamic nuclear spin polarization induced by a current flow and, furthermore, resistance detection of nuclear spin polarization. Resistance can be measured for a single layer and even for a nanostructure, so we can extend the powerful feature of NMR to studies of semiconductor nanostructures. The following figures illustrate examples how we can get NMR spectrum and nuclear spin relaxation time (T_1) by using a novel resistance detection technique. It should be stressed that we need special states (for example, degenerate states at ν=2/3 or quantum Hall breakdown at ν=1) for dynamic nuclear polarization and its resistance detection, but we can apply these measurements for any states, which we want to estimate, thanks to gate controllability.

The RD-NMR (Resistively-Detected NMR) provides a powerful tool to clarify electron spin physics of semiconductor two-dimensional systems (for example, studies done by N. Kumada *et al.*, Phys. Rev. Lett. 99, 076805 (2007), Tiemann *et al.*, Science 335, 828 (2012), Tiemann *et al.*, Nat. Phys. 10, 648 (2014) in NTT&ERATO collaboration) and wire systems (for example, characteristics of Skyrmion confined in wire reported by T. Kobayashi *et al.*, Phys. Rev. Lett. 107, 120867 (2011)).

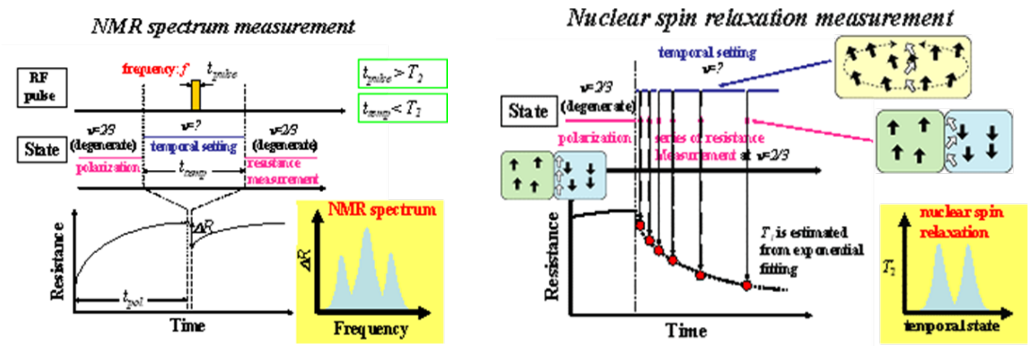

Fig. 1 Schematic procedures to get NMR spectrum (left) and nuclear spin relaxation time (right). The nuclear polarization and detection are based on the spin degenerate states at ν=2/3 in this example. However, one can use any polarization and detection method, such as quantum Hall breakdown at ν=1, for the RD-NMR.

Review Pubications:

1. Y. Hirayama, G. Yusa, K. Hashimoto, N. Kumada, T. Ota, and K. Muraki, “Electron-spin / nuclear –spin interactions and NMR in semiconductors”, Semicond. Sci. Technol. 24, 023001 (2009) [Topical Review].

2. Y. Hirayama “Contact Hyperfine Interactions in Semiconductor Heterostructures” Chapter 2.03, Pages 68-94 Comprehensive Semiconductor Science and Technology (Elsevier, 2011).

3. Yoshiro Hirayama “Hyperfine Interactions in Quantum Hall Regime” Chapter 38, Pages 730-753 Quantum Hall Effects (Third Edition) by Zyun F. Ezawa (World Scientific, 2013).