Nuclear Spintronics in Semiconductor Hetero and Nanostructures

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Nuclear magnetic resonance (NMR) is widely used in the physical, chemical and biological science. Nuclear spins have well-defined coherent characteristics and are naturally a good candidate of quantum bit. However, standard NMR technique needs a relatively large sample including more than 10^{11} nuclear spins and is not suitable to investigate a single layer (or a nanostructure), which is essential for semiconductor devices. In this presentation, I will discuss a novel NMR technique, i.e., restively-detected NMR, suitable for semiconductor systems. The obtained results open a way to a novel spintronics including nuclear spins.

The fractional quantum Hall regime at a Landau-level filling factor of ν =2/3, in which coupling of nuclear spins to conduction electrons is known to be pronounced [1,2], has been used in this novel NMR scheme. A dynamic nuclear spin polarization is realized by flowing a certain current at the ν=2/3 degenerate points. In addition, the total longitudinal magnetization, M_z, coming from nuclear spin polarization is detected by measuring the R_{xx} value. This scheme is extended to a point contact device where antenna gate is integrated to apply electromagnetic radiation at the NMR frequency [3]. Strikingly clear oscillations reflecting all possible transitions between the four nuclear spin states of each nuclide (namely, ^{69}Ga, ^{71}Ga and ^{75}As) in a GaAs point-contact structure were observed. The obtained results open up new approaches that may enable us to freely and precisely control nuclear spin states in semiconductor nanostructures. This novel point contact device also provides a way to study characteristics of nuclear spins, such as decoherence and quadrupolar splitting, in nanoscale GaAs structures.

The nuclear spin relaxation rate ($1/T_1$) is proportional to the spectral density of transverse electron-spin fluctuation at the NMR frequency. This unique feature can be extended to unveil collective electron spin characteristics, which are difficult to detect in conventional transport and optical measurements. The low-frequency mode arising from correlated electron spins in bilayer two-dimensional electron system has been sensitively detected by monitoring nuclear spin relaxation [4]. Enhancement of the electron spin fluctuation under strongly asymmetric confinement was also detected [5]. Nuclear spins will play an important role to study the correlations of electron spins in semiconductor nanostructures.

This study was carried out in NTT Basic Research Labs. in collaboration with G. Yusa*, K. Muraki, N. Kumada, K. Hashimoto* and K. Takashina. (*present address: Tohoku Univ.)

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