Dynamic nuclear polarization and resistively-detected NMR in semiconductor quantum systems

Yoshiro Hirayama
Physics Department, Graduate School of Science, Tohoku University
Center for Spintronics Research Network, Tohoku University

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Abstract

Recently, a great interest appears in nuclear spintronics. The nuclear spins have a long coherent time and a good candidate of a quantum memory. More interestingly, recent progress of resistively-detected nuclear-magnetic-resonance (RDNMR) provides us a versatile tool to study physics in low-dimensional semiconductor structures.

The RDNMR needs dynamic nuclear polarization (DNP) and sensitive detection of nuclear polarization. In semiconductor quantum systems, the DNP is achieved by a current flow through a domain structure appearing in the quantum Hall ferromagnet (QHF) at the spin phase transition of v = 2/3 or v = 2. The DNP can also be achieved by a quantum Hall breakdown and irradiation of a circularly polarized light. The situation necessary for the DNP also provides us sensitive detection of the nuclear polarization. Especially, a modulation of the domain structure by the DNP changes resistance value dramatically in the QHF. The important role of the chiral edge channel on RDNMR is also addressed by using the v = 2 QHF.

We can clarify many interesting physics from RDNMR measurements. The Knight shift provides us information of electron spin polarization and/or charge/spin ordering. The nuclear relaxation (T_1) includes information of electron spin fluctuation. The quadrupolar splitting gives us a microscopic information of the strain. The novel Dicke-type interaction is also suggested between ensemble of nuclear spins and ensemble of electron spins with a linear dispersion mode.

Furthermore, the nuclear resonance measurement has been extended to a microscopic imaging by a combination of the RDNMR and a sophisticated scanning-nanoprobe system operating at dilution temperatures. Quadrupolar coupling enables us rf electric field manipulation of nuclear spins. This manipulation has an advantage of the higher spatial resolution than the conventional manipulation by rf magnetic field. Successful mapping of NMR signal intensity and Knight shift has been demonstrated in the quantum Hall breakdown regime.

About the Speaker

Yoshiro Hirayama received Bachelor, Master, and Ph.D degrees of Electronics Engineering from the University of Tokyo at 1978, 1980, and 1983, respectively. He joined NTT Basic Research Laboratories in 1983 after receiving the Ph.D. degree from the University of Tokyo. In NTT, he served as Group Leader, Distinguished Technical Member and Executive Manager. From July 2006, he moved to Tohoku University. His current interests are transport properties of semiconductor heterostructures and nanostructures, especially putting emphasis on nuclear spin related phenomena. He was a leader of a couple of NEDO and JST projects concerning semiconductor quantum transport, carrier interaction, and quantum coherent system. Especially, he was a research director of ERATO-JST " Nuclear Spin Electronics " project (2007-2015, including two year extension), where electron and nuclear spin interactions are extensively studied. He is now a project leader of Grant-in-Aid for Scientific Research on Innovative Areas "Science of Hybrid Quantum Systems" (2015-2020), where he build the new research group pursuing hybridization of the quantum systems. He was a guest scientist in Max-Planck-Institut (Stuttgart) during 1990-1991 and in Paul-Drude-Institut (Belrin) in 2004. He was an invited professor of Hokkaido University during 2001-2002. He is a Fellow of Institute of Physics (IOP, London) and the Japan Society of Applied Physics (JSPS). Other honors and awards he has received include NTT R&D Award (2001), JJAP Editorial Contribution Award (2004), JJAP Best Paper Award (2004, 2008), SSDM Paper Award (2007), and ISCS Quantum Device Award. He is a member of the Physical Society of Japan. His publication record includes more than 350 refereed journal articles, books and book chapters related to semiconductor heterostructures and nanostructures.