Hyperpolarized Imaging Applications based on Ultra-sensitive Magnetometry

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Currently, quantum spin based imaging applications get attention from many research groups who have been dealing with various magnetometry. Especially, there were lots of efforts to find novel contrasts or applications in nuclear magnetic resonance imaging with sensitive magnetic field sensors such as superconducting quantum interference devices (SQUID), optically pumped magnetometer (OPM), and diamond nitrogen vacancy (DNV) centers. In such trials, the polarization of a sample is generally not enough due to the limitation in use of a strong polarization magnetic field under an operation condition of a sensitive sensor and in field cycling interference with shielding structure in micro-tesla applications.

Hyperpolarization can be an effective solution in order to increase the signal and spatial resolution in the imaging technology. In this presentation, we introduce hyperpolarization techniques and applications in ultra-low field nuclear magnetic resonance imaging (ULF-MRI). The scope of talk consists of Overhauser dynamic nuclear polarization (O-DNP), the signal amplification by reversible exchange (SABRE) technique with para-hydrogen, and optical DNP.

O-DNP can significantly enhance the intensity of the MRI signal in comparison to the thermal magnetization. Even in a zero magnetic field, there is a finite hyperfine energy splitting with a radical, which guarantees a certain level of polarization and numerically infinite enhancement factor at zero field through the cross relaxation between electron spins and nuclear spins. However, in practice, an overlap of opposite absorption lines cancels out the enhancement. By applying circularly polarized magnetic field, we could make a selective excitation and achieved a sub-millimeter resolution even in ULF-MRI.

Meanwhile we demonstrate real-time SQUID-based MRI in the micro-Tesla range magnetic field using the SABRE technique after designing a separated bubbling phantom. A maximum enhancement of 2,650 for ^{1}H was achieved for pyridine in Methanol. A clear SABRE-enhanced MR image of the phantom was successfully obtained at 34.3 μT and the enhanced polarization accelerated the acquisition time drastically. The results show that SABRE can be successfully incorporated into an ultralow-field MRI.

Finally, we introduce several applications with nano-diamonds and DNV nano NMR microscopy.