Optically Pumped Atomic Magnetometers: Perspectives for New Optical Biomagnetic Imaging Systems

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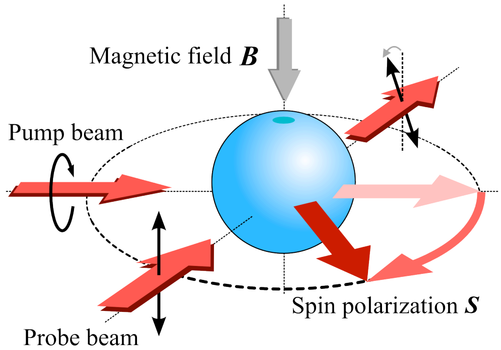

In recent years, **optically pumped atomic magnetometers** (**OPMs**) operating under **spin-exchange relaxation-free** (**SERF**) conditions have reached sensitivities comparable to and even surpassing those of superconducting quantum interference devices (SQUIDs) [1-3]. OPMs are based on the detection of electron spin precession in alkali-metal atoms contained in glass cells. In the pump-probe arrangement as shown in the right figure, a circularly polarized pump laser beam and a linearly polarized probe laser beam crossed orthogonally in the center of the glass cell including vaporized alkali-metal atoms. At present, the most sensitive OPM has sensitivity of 160 fT/Hz$^{1/2}$ in a gradiometer arrangement with a measurement volume of 0.45 cm^3 at the frequency range lower than 100 Hz. In addition, OPMs have the intrinsic advantage of not requiring cryogenic cooling. Therefore, OPMs are currently expected to overtake SQUIDs and the possibilities for using OPMs for biomagnetic field measurements and MRI have been demonstrated.

We have been developing OPMs with pump-probe arrangement since 2006 [3-6] and started to fabricate compact and portable potassium OPM modules in 2012 [7]. The figure at the bottom illustrates one of our OPM module reported in 2015 [8]. The sensitivity of the OPM module reached 21 fT/Hz$^{1/2}$ at 10 Hz, so that we carried out measurements of human magnetoencephalograms with it. Compared with the results obtained with SQUID-based magnetometers, we could successfully observe distinct features of event-related desynchronization in the 8-13 Hz (alpha) band associated with eyes open [8].

Meanwhile, we have also been challenging to detect NMR signals and MRI with OPMs [9] at ultra-low field (ULF) below several hundred μT. Since sensitivity of OPMs does not depend on frequency, OPMs are suitable to be used as receiving sensors for ULF-MRI systems. In 2017, for the first time, we have shown that MRI and NMR signals could be acquired with the same OPAM module described above operating at a Larmor frequency of 5 kHz without the use of any cryogenics [10].

We believe that the applicability of new ultra-sensitive optical biomagnetic imaging systems might provide important advancements in neuroscience and also improve the clinical diagnosis of neurological and psychiatric disorders.

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