Optically-pumped magnetometers for biomagnetic measurements of the human brain

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Information processing in the brain generates a complex pattern of electric currents. Under favorable conditions, the magnetic fields of individual current sources sum up to produce a field (10–1000 fT) detectable outside the head with a sensitive magnetometer. When the field is measured at sufficiently many locations, the locations and activity time series of the neural sources can be estimated by solving an ill-posed inverse problem, which involves physical modeling of the measurement setup.

Magnetoencephalography (MEG) is the art of measuring the weak neuromagnetic fields and estimating the neural souces underlying the measurement to obtain information about brain activity [1]. Until recently, only Superconducting QUantum Interference Devices (SQUIDs) have provided sufficient sensitivity and sensor-size for MEG (∼fT/rHz and $\sim$cm^2). In SQUID-based MEG systems, the thermal insulation needed between the head and SQUIDs sets the sensor-to-scalp distance to approximately 2 cm limiting the signal amplitudes and information content of the measurements [2].

Optically-pumped magnetometer (OPM) [3] is a potential candidate sensor for a new generation MEG system. OPM measures the magnetic field by optically detecting the Larmor precession of a spin polarization that is generated into an alkali vapor by means of optical pumping. Under the limit of low ambient field, the spin-exchange relaxation can be suppressed leading to a sensitivity suitable for MEG. In addition, by using microfabrication techniques sufficiently small sensors can be made so that multichannel sensor arrays are feasible. Without the need of cryogenics, these sensors can be placed directly on the scalp of the subject leading to increased signal strength and spatial resolution [2].

In this presentation, I provide an introduction to MEG and OPMs, review the simulations we have performed to quantify the benefits of OPM arrays, present the initial MEG measurements with OPMs and discuss the approaches we have taken to establish multichannel OPM-based MEG array.

[1] Hämäläinen, M., Hari, R., Ilmoniemi, R.J., Knuutila, J., and Lounasmaa, O.V. (1993). Magnetoencephalography—theory, instrumentation, and applications to noninvasive studies of the working human brain. *Rev Mod Phys* 65:413–497.

[2] Iivanainen, J., Stenroos, M., and Parkkonen, L. (2017). Measuring MEG closer to the brain: Performance of on-scalp sensor arrays. *NeuroImage* 147:542–553.

[3] Budker, D., and Romalis, M. (2007). Optical magnetometry. *Nat Phys* 3(4):227–234.