SQUID systems for ultra-sensitive magnetometry

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More than fifty years after its invention in the 1960's, the low-T_c Superconducting QUantum Interference Device (SQUID) remains the most sensitive detector for magnetic flux and it has been used, amongst other, in fundamental science, material characterisation, metrology and biomagnetism. Apart from the exquisite sensitivity it also features an enormous bandwidth, for instance, in flux locked loop (FLL) mode bandwidths of 300 MHz have been demonstrated. Frequently, a current sensor configuration is used where a pick-up coil is inductively coupled to the current sensor SQUID via an on-chip input coil. Accordingly, the resolution depends on the flux noise $\sqrt{S_\Phi}$ and on the coupling coefficient k between input coil and SQUID with inductance L. A common figure of merit is the coupled energy resolution $\varepsilon_c = \varepsilon/k^2$, where $\varepsilon = S_\Phi/2L$ is the energy resolution of the uncoupled SQUID.
When used as a sensor of magnetic fields originating from macroscopic objects at room temperature operation in a non-magnetic, non-metallic liquid Helium (LHe) dewar is required. Here, the system noise is typically limited to the low fT $Hz^{-1/2}$-range due to thermal noise in the superinsulation and heat shields. However, LHe dewars with negligible noise have been constructed and our SQUID system with a 45 mm pick-up coil reaches a measured ε_c of <40 h corresponding to a white noise below 200 aT $Hz^{-1/2}$ with an FFL bandwidth of 2.5 MHz [1]. The system is also robust to pulsed magnetic fields up to 50 mT and mainly used for biomagnetic measurements.
An improvement in sensitivity can be achieved by cooling the SQUID to lower temperatures T, reducing the SQUID inductance L or decreasing the Josephson Junction (JJ) capacitance C. As a small L impedes the coupling to the SQUID, we focussed on reducing the size of the JJ from 2.5 µm to below 1 µm. For the evaluation of the Nb-AlOx-Nb process miniature SQUID magnetometers were fabricated. For a device with square junctions of 800 nm, the measured white flux noise was about 330 $n\Phi_0\ Hz^{-1/2}$ corresponding to an ε of 5 h at 4.2 K. The noise increases at lower frequencies with a typical value of 900 $n\Phi_0\ Hz^{-1/2}$ (ε ~40 h) at 1 Hz. For integrated current sensors with $k = 0.75$ the expected ε_c is 10 h at 4.2 K corresponding to an equivalent field noise of ~90 aT $Hz^{-1/2}$ for a 45 mm diameter 1st order gradiometric pick-up coil coupled to a 400 nH input coil.
The current sensor configuration allows flexibility in the pick-up coil design and enables the optimization for individual experiments e.g. in fundamental physics.

References

[1] J.-H. Storm, et al., Applied Physics Letters **110**, 072603 (2017)