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Lambda-SQUIDs SQUID-based superconducting microcalorimeters with in-situ tunable gain for high-resolution X-ray emission spectroscopy

Cryogenic microcalorimeters such as superconducting transition-edge sensors or magnetic microcalorimeters are outstanding devices for any application requiring an energy-dispersive photon detector with cutting-edge energy resolution and close to 100% detection efficiency. They are hence ideally suited for X-ray emission spectroscopy (XES) that relies on photon detection with utmost precision and highest efficiency. Nevertheless, cryogenic microcalorimeters can't yet compete with state-of-the-art wavelength-dispersive grating or crystal spectrometers that often provide one or two orders of magnitude better energy resolution, at the cost of a significantly lower detection efficiency. However, as some applications such as XES of dilute or radiation sensitive samples requires both, utmost energy resolution and highest detection efficiency, at the same time, it is worth continuing to develop novel detector concepts that potentially bridge this gap. One such concept is the Lambda-SQUID that we have recently introduced and that is based on the strong temperature dependence of the magnetic penetration depth of a superconducting material that is operated below but close to its transition temperature. By embedding a coil made of this material directly into a dc-SQUID loop or into an intermediate flux transformer that is inductively coupled to a state-of-the-art dc-SQUID and using a special input circuit configuration, a temperature change of an X-ray absorber that is connected to the coil is transduced into a change of magnetic flux threading the SQUID loop. The resulting temperature-to-flux transfer coefficient can be tuned in-situ and allows suppressing SQUID noise well below the thermodynamic noise floor that is inherent to any cryogenic microcalorimeter. Moreover, the device promises to reach deep sub-eV energy resolution while maintaining a quantum efficiency close to 100%. In this contribution, we comprehensively discuss our novel detector concept and gauge its possible performance using device simulations and latest experimental data. Moreover, we discuss important design considerations such as the optimal choice of sensor and absorber heat capacity or the best device geometry. We finally summarize the latest stage of device development.

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