Sub-10 mK "in-cell" magnetic refrigeration for cryogen-free cryostats

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Advances in cryogen-free technologies have made millikelvin platforms broadly available for quantum-technology research. Cooling electrons in low-dimensional systems such as graphene or GaAs heterostructures remains challenging because electron–phonon coupling is weak at ultralow temperatures. Compact, modular ^{3}He immersion cells, designed for cryogen-free cryostats, are routinely operated at the MagLab High B/T Facility to improve the thermal coupling between the sample electrons and the lowest thermal reservoir.

A new method for reaching sample temperatures below 10 mK in cryogen-free cryostats has been experimentally verified. Copper powder or flakes are suspended in pure ^{3}He and serve as the thermal medium inside the immersion cell. The cell was designed, tested, and refined using the Bay 1 instrument in the MagLab High B/T Facility. The 14 T magnet spin-polarizes the copper nuclei, reducing their entropy, and subsequent slow demagnetization then cools the copper refrigerant and the device it supports to sub-10 mK temperatures.

Using only 66 g (1.04 mol) of copper, a dramatic reduction compared with conventional bundle-stage approach that requires several kilograms of material, "in-cell" magnetic refrigeration below 2 mK has been demonstrated with a cryogen-free refrigerator. Since the design does not alter the commercial cryostat, it offers a practical pathway for cooling nanoelectronic devices to sub-5 mK in finite magnetic fields, thereby opening a wider range of magnetic field and temperature phase space for the discovery and study of new quantum states.

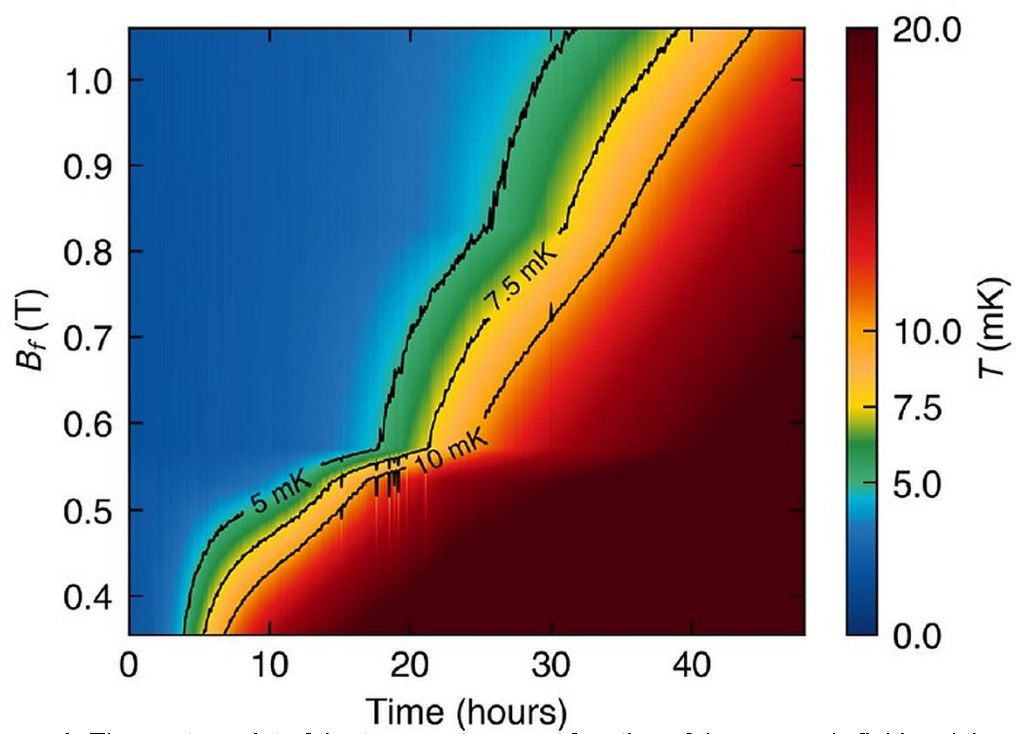

Figure 1: The contour plot of the temperature as a function of the magnetic field and time illustrates the performance during the post-demagnetization warm-up. The black lines show the equal temperature lines across the various runs. The hold time, defined as the interval of time the sample remails below 5 mK while the field is above 500 mT, varies from 18 to 30 hours.

Facilities and instrumentation used: High B/T Facility (University of Florida): Bay 1 dilution refrigerator equipped with 14 T magnet

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