Miniature Field-Rotatable Calorimeter for High Field Low Temperature Measurements

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Introduction

Many high field, low temperature thermal, magnetic, and transport experiments at NHMFL would benefit from the availability of a general purpose magnetic-field-calibrated field-rotatable temperature-controlled platform for samples in vacuum. Such a platform should be small enough to fit in the top-loading single-axis rotator probe for the portable dilution refrigerator (PDF) — which in turn fits inside the DC field user facility's 35 T resistive and 45 T hybrid magnets — and should allow the quick variation and accurate control of temperature between 0.1 K and 10 K (or better) without undue warming of the dilution refrigerator.

In this project — NHMFL Proposal P02447 — we are constructing two prototype miniature experimental capsules — one dedicated to heat capacity measurements and one that can be customized for other experiments — designed to meet these requirements. This requires the design, construction and testing of a miniature cylindrical vacuum chamber (with a diameter of 0.300 inch and height less than 0.500 inch) containing a temperature controlled platform, a carefully designed platform to bath weak-thermal link, a set of field-calibrated platform thermometers, room for attaching a commercially (zero-field) calibrated thermometer and, in the case of ac calorimetric measurements, up to 8 additional leads for the sample heater and thermometer.

Experimental

To date, we have designed, constructed, repeatedly thermally cycled, and successfully tested (in fields up to 18 T and at temperatures down to 50 mK) a 0.300" diameter prototype top-loading sample-in-vacuum capsule containing a temperature controlled platform with interchangeable sample heater and thermometer sensor holders (to allow easier sample mounting, calibrations, and thermometer exchanges). The design is based in part on a larger (0.450" diameter cylinder) calorimeter capsule [1] and field calibration method [2] successfully used for a variety of calorimetric experiments at dilution temperatures as a function of field angle up to 18 T. In follow-on experiments next year, we plan to carry out trial measurements of specific heat known standards and new materials as a function of field and field angle down to 0.1 K in fields up to 45 tesla.

Results and Discussion

One of the most important design criteria is the thermal conductance of the weak thermal link between the interior temperature-controlled platform and the exterior cryogenic bath (3He-4He mixture, in the case of a dilution refrigerator) operating at base temperature. Maintaining a suitably weak thermal link despite the shorter lengths required careful redesign of the calorimeter materials. Comparing the power required to bring the interior platform to any particular temperature (by raising it above the temperature of the bath) for the new 0.300" diameter capsule and the original 0.450" diameter capsule, we find they remain comparable. We are able to quickly and easily change (and then regulate) the platform temperature of the new prototype over a wide temperature range from 0.1 K at 30 nW to 14.4 K at 3.6 mW, with the time to reach equilibrium on the order of a few minutes. A platform heater power of 90 uW raises the platform temperature to 1.0 K but the fridge remains below 50 mK.

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References

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[2] Fortune, N. A*., et al.,* Rev. Sci. Instrum. **71**, 3825-3850 (2000).