Magnetostriction and Thermal Expansion Study of the Field-induced Ordering and Itinerant Electron Metamagnetism in Heavy Fermion Compound URu$_2$Si$_2$

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Introduction

URu$_2$Si$_2$ is a heavy fermion compound the low-temperature high-magnetic field phase diagram of which is characterized by the formation of multiple field induced ordered phases between 34 and 39 T upon suppression of the so-called Hidden Order (HO) phase around a putative metamagnetic quantum critical point located at 38 T [1]. Important volume effects associated with the Itinerant Electron Metamagnetism are expected as observed in the 4f analog CeRu$_2$Si$_2$ [2] and a strong magneto-elastic coupling at the transition into the ordered phases. Here, we report on the dilatometry measurements on URu$_2$Si$_2$ carried out between 1.5 and 24 K in DC fields between 12 and 45 T in the Hybrid magnet at NHMFL, Tallahassee, FL.

Experimental

The single-crystal (L=2.97 mm) was glued with GE-varnish on the sample platform screw of a 0.75 in. diameter Ti capacitive dilatometer [3] so that the expansion $\Delta L$ is measured along the easy axis of magnetization $c$ and the field aligned with $c$. The capacitance was set at about 12 pF. The dilatometry cell is screwed to the brass bottom part of a probe allowing it to enclose it in a conical seal. The sample space was pumped down to a 10$^{-5}$ mbar and about 2 mbar He$_3$ exchange gas was inserted. A thermometer was placed on the top of the cell and another one close to the sample. A 75 $\Omega$ heater was wrapped around the brass piece above the cell and another one around a Ti piece screwed onto the sample screw platform. Heat was applied on each heater up that the two temperature controllers indicates a same temperature at the top of the cell and at the bottom of the cell. This procedure allowed it to overcome the built up of a linear thermal gradient over the height of the cell. We performed field sweeps between 12 and 45 T at several different temperatures below 25 K at rates of 0.5 and 1 T/min and temperature sweeps between 2 and 24 K at several different fields at rates of 0.3 and 0.6 K/min.

Results and Discussion

As shown [Fig.1], important lattice length changes occur upon cooling at entrance into the HO phase below 35 T and into phase III between 36 T and 39 T. The transition into phase II is expected at 6 K at 35.9 T and is not much visible. Computation of the coefficient of linear thermal expansion $\alpha_c = -1/Lx \Delta L/dT$ allows it to unveil at temperatures above the ordering a sign change of $\alpha_c$ at the metamagnetic transition field as previously observed in the 4f analog CeRu$_2$Si$_2$. In the magnetostriction curves (not shown), exit from the HO phase and from phase III both yield a jump in $\Delta L/L$ of a 2.10$^{-5}$ K$^{-1}$ magnitude. Outside the ordered phases, an important contraction is shown to follow the field-induced polarization of the 5f electrons.

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References