Bull. Mater. Sci., Vol. 22, No. 3, May 1999, pp. 275–278. © Indian Academy of Sciences.

Evidence for supercooling across a vortex-matter phase transition: studies on $CeRu_2$ and $Bi_2Sr_2CaCu_2O_8$

P CHADDAH* and S B ROY

Low Temperature Physics Group, Centre for Advanced Technology, Indore 452 013, India

Abstract. **We present DC magnetization data indicating a first-order phase transition in the vortex state of $CeRu_2$, with the higher entropy phase exhibiting enhanced pinning. Minor hysteresis loops show evidence of supercooling of the higher entropy phase as the phase boundary is crossed both isothermally as well as at constant field. These features are shown to be absent across the Bragg-glass to vortex-glass transition in $Bi_2Sr_2CaCu_2O_8$. The supercooling is more persistent in the constant field case.**

Keywords. **Vortex-matter transition; supercooling; $CeRu_2$; $Bi_2Sr_2CaCu_2O_8$.**

1. Introduction

The most extensively studied phase transition in vortex matter is the first-order melting of the vortex lattice in high-T_C superconductors (HTSC) (see Blatter 1997). In this paper we concentrate on possible phase transitions below this melting line. In recent years the phase diagram of vortices in HTSC with weak disorder has been studied in great detail theoretically. The low-field Bragg-glass phase is expected to undergo a second-order or continuous phase transition, with increasing magnetic field, to a vortex-glass phase—with the driving mechanism being the proliferation of dislocation loops (Ertas and Nelson 1996). Recent experimental studies on various HTSC (Khaykovich *et al* 1996; Deligiannis *et al* 1997; Giller *et al* 1997) correlate onset of the peak effect with this continuous phase transition.

A first-order phase transition in the vortex lattice of paramagnetic superconductors, at high fields, was proposed over three decades ago (Fulde and Ferrel 1964; Larkin and Ovchinnikov 1965; Gruenberg and Gunther 1966). The anomalous peak effect observed in UPd_2Al_3 and $CeRu_2$ has, in various works, been discussed in this context (see for e.g. Modler *et al* 1996; Roy and Chaddah 1997a). In a generalized version of the original theory (Tachiki *et al* 1996; Takahashi *et al* 1996), the vortices are segmented into short strings with a concomitant enhancement of pinning. The onset of peak effect in these materials has been accordingly investigated as driven by a first-order phase transition to this generalized Fulde–Ferrel–Larkin–Ovchinnikov (GFFLO) state.

In this paper we shall present our detailed studies on the paramagnetic superconductor $CeRu_2$, where the anomalous magnetization just below H_{C2} was discovered by one of us (Roy 1992). We have studied a large number of doped and undoped samples, and the results to be discussed here are generic to all samples with a normal state susceptibility above a threshold value (Roy and Chaddah 1997a, 1998). We shall also present our similar comparative studies on $Bi_2Sr_2CaCu_2O_8$ (hereafter referred to as Bi-2212), where the Bragg-glass to vortex-glass transition concomitant with the onset of peak effect is second-order or at most weakly first-order (Khaykovich *et al* 1996).

2. Isothermal variation of magnetic field

Before proceeding with the anomalous peak effect, we wish to record two striking features of $CeRu_2$ that have not yet been addressed in detail in literature. First, addition of magnetic dopants at Ce site raises T_C as well as H_{C2} (Wilhelm and Hillenbrand 1971; Roy and Coles 1990). Second, the M–H curve just below H_{C2} is reversible but approaches the normal state magnetization from above (Yagasaki *et al* 1993; Roy and Coles 1994; Nakama *et al* 1995). Both these features are anomalous and understanding them may tell us more about the microscopics of superconductivity in $CeRu_2$.

Figure 1 shows a typical M–H curve of $CeRu_2$ (this data is on a 5% Nd-doped sample at 4·5 K). There are two distinct regions of irreversible magnetization; a low-field region I (below 7 kOe) and a high-field region II (around 30 kOe). Roy *et al* (1998d) have argued that while the irreversibility and concomitant metastability in region I, like that of other hard type-II superconductors (including Bi-2212), is akin to that of spin-glasses, the metastability in region II is akin to that of random-field Ising systems. The main characteristics underlying this differentiation are (i) $M_{FC} > M_{eq}$ in region I, while $M_{FC} < M_{eq}$ in region II; and (ii) dM_{FC}/dt is negative in region I but positive in region II.

*Author for correspondence