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1. Introduction

Most of the present applications of superconducting materials utilize metallic low- T_c (LTS) materials. Their good mechanical properties, the advanced technology, and the excellent electrical performance at low temperatures provide a solid basis for a well-established market. High temperature superconductors (HTS) have, however, enough potential to be strong competitors to LTS. Their main advantage is certainly the T_c above liquid nitrogen temperature and very high irreversibility field. Besides their excellent properties in many directions, a big reserve is still in technology optimization, in a theoretical understanding of the HTS superconductivity and flux dynamics in these materials. This plays in favor of HTS and will certainly lead to a continuous improvement of their position on the market.

A special interest is here devoted to pinning in bulk (RE)Ba₂Cu₃O_{7- δ} (RE-123) superconductors. Most applications of these materials utilize the peak effect (PE). While the character of relevant pinning is well known being identified with a point-like pinning disorder, the actual sources of this kind of pinning and the mechanisms of interaction with magnetic flux are still a matter of controversial discussions.

2. Peak effect

The peak effect manifests itself in a variety of appearances, in dependence of the actual pinning distribution, field, and temperature. In clean single crystals, the secondary peak can be completely suppressed. With increasing number of pins, a weak peak first appears close to irreversibility field and then with a further increase of disorder, the peak shifts to lower fields and becomes increasingly robust [1-3]. At lower fields and becomes increasingly robust [1-3]. At a weak disorder, the peak develops a rather complicated behavior. It shifts with decreasing temperature first to lower fields, then goes through a minimum and then only starts to shift to higher fields, as commonly observed in strongly pinned samples. During all this process, its width and height continuously increase which manifests the role of increasing effective pinning as thermal activation decreases. This rather complex behavior results in a complicated vortex phase diagram (see Figure 1). Transport measurements in clean samples show a sharp first order phase transition that was identified as a vortex melting line. This phase transition disappears

just around the point where the peak first appears. To the same point also goes the irreversibility line at high fields that is believed to be vortex glass melting line, second order phase transition. The so-called multi-critical point is sometimes also associated with the depinning line predicted by the collective pinning theory [4].

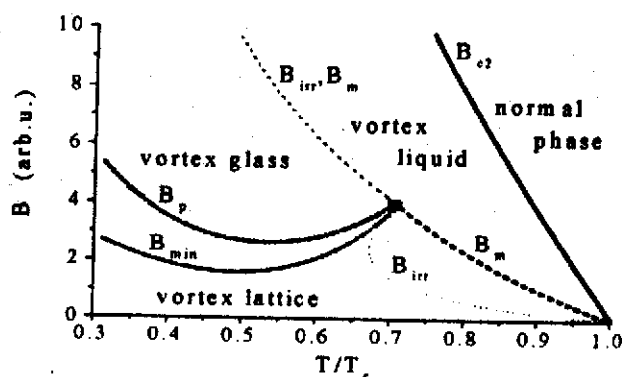


Figure 1. B-T diagram in a superconductor with weak pinning according to Nishizaki et al. [3].

With increasing pinning disorder, the multi-critical point shifts along the melting line to lower fields and disappears finally close to T_c (see Figure 2). In the samples with a strong pinning disorder, the vortex phase diagram is simpler than that shown in Figure 1: In terms of the same scenario, the vortex lattice below the peak transforms with increasing temperature to vortex glass that melts finally to vortex liquid. Above the peak, the vortex lattice phase is missing. Although this picture is certainly qualitatively correct, the details and, especially, the relation to peak effect is still not fully clear. E. g. the difference of irreversibility and melting lines in Figure 1 below the multi-critical point might result from different effective field sweep rate used, the melting line being determined from transport measurements and irreversibility line from magnetic hysteresis experiment.

While the clean and weakly pinned samples help in a study of the elementary processes of flux dynamics in HTS, for applications is important the limit of strong pinning indicated in Fig. 2. by the bottom curve. This graph indicates that the increasing pinning disorder results in an increase of the peak height but at the same time in a decrease of the secondary peak position. Note that this behavior was theoretically predicted by Kramer

long ago [5]. A similar tendency was also observed in the experiments with increasing oxygen deficiency [1-3] or with a disorder produced by electron irradiation [6]. The increase of the secondary peak and its shift to lower fields seem to be a general feature. If so, an appropriate regime would be required for each particular application. There are, however, a number of factors involved in the final material performance and it seems that a certain freedom for manipulation with the "scissors" of the $B_p(T)$ and $B_{ir}(T)$ curves shown in Figure 2 is still left. The actual position of these two curves depends on the material and its technological treatment. This is also documented by variation

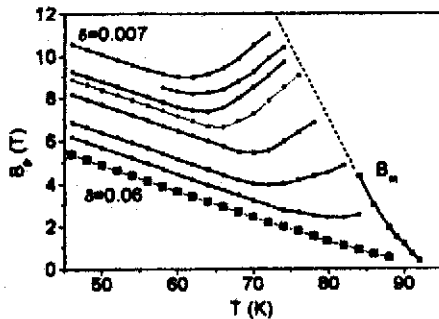


Figure 2. Development of the second peak position and multi-critical point with increasing oxygen deficiency in $YBa_2Cu_3O_{7-d}$ single crystal [2].

of free parameters in fitting functions for normalized $J_c(B)$ or $F_p(B)$ dependencies in either the classical Kramer's form [5],

$$J_c(B) \propto b^p(1-b)^q,$$

with $b=B/B_{ir}$, or in the exponentially decaying function [7]

$$J_c(B) \propto b \exp[(1-b^n)/n].$$

Both these functions give practically same fit [8] but the exponents vary in a rather broad range, which shows that even in the normalized form the relative position of the peak with respect to irreversibility field is not firm. Similar evidence also comes from the variation in the exponent of the commonly accepted temperature dependence of $B_{ir} \propto (1-T/T_c)^\alpha$.

While "properly" contaminated single crystals still achieve higher critical currents than melt textured materials, the latter ones can be easily produced in appropriately large volumes and their superconducting performance is being continuously improved so that they become nearly equal to single crystals. Especially the last years led to a significant improvement of the technology leading to fabrication of superconducting blocks of diameter up to 8-10 cm, with the structure close to single-crystalline. In particular, the use oxygen controlled melt growth process [9] represented a significant step in preparation of good quality blocks. In addition, the progress in preparation of binary and ternary RE-123 compounds [10-12] offers the necessary diversity in manipulation of superconducting matrix properties.

A huge amount of technological efforts has been devoted to incorporation of secondary phase particles into RE-123 matrices [13-15]. The well-refined secondary phase regions most probably contribute to the enhancement of a proper variation of the RE-123 matrix properties on a microscopic scale, which is the real effective pinning agent. However, their main effect seems to appear at low fields where they co-operate in a still not clear way with self-field effects. The corresponding increase of the remnant critical current density is a good counterpart to the peak effect at intermediate fields. Moreover, this type of pinning seems to form an enhanced background on which the secondary peak sits.

A number of known or proposed alternatives of the variation in matrix properties might work as a point-like disorder. Besides the best-learned oxygen deficiency in all RE-123 materials, it is a local variation of the matrix stoichiometry in connection with RE-Ba solid solution in compounds with RE=Nd, Eu, Sm, and Gd [16]. Moreover, a formation of stacking faults in the superconducting matrix or an alternation of strain-stress conditions in vicinity of secondary phase particles was also observed.

The understanding of the mechanisms of interaction of vortex matter with pinning systems under different conditions is an important task that will help to predict limits for ideal and practically reachable pinning in HTS.

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