Study on the control of vortex pinning in high-Tc bulk cuprates

Abstract

We focus on immobilizing magnetic vortices in type-II superconductor — a problem that has plagued scientists trying to engineer real-world applications for decades. The key original finding is that we discovered a method to stabilize magnetic vortices in a wide range of magnetic fields by creating a geometric pinning landscape, i.e. the grid-like nanowalls, in the melt-textured Gd-Ba-Cu-O bulk superconductor. This discovery favor to promotion of the large-scale applications of high temperature superconductors as well as the understanding of the "vortex lattice/pinning landscape" puzzle. Following this key original finding, other fundamental findings include: (1) clarified for the first time two key factors that serve the peak effect; (2) proposed and proved for the first time an efficient in-field pinning model; (3) found for the first time the complementary melting growth and was summarized as the two-steps solidification; (4) proposed and proved a recrystallization mechanism for achieving nano-sized inclusions; (5) clarified the pinning mechanism of the additions of $BaTiO_3$, TiO_2 and BaO_2; (6) found a new efficient dilute addition of ferroelectric $BaTiO_3$; (7) proposed a scenario of how to explain the evolutions of peak effect both in changed magnetic fields and temperatures; (8) found a method on the control of the trapped flux profile; (9) clarified the key factors in making of hybrid magnet with bulks and tapes. The arrangement of this thesis is as follows.

In **chapter 1**, a brief review of the development of superconductivity was given which includes several basic relevant theories and materials. In particular, theories and considerations relevant to the vortex pinning were summarized which include what is the vortex pinning, how to trap vortices, types of vortex pinning as well as current development on the control of vortex pinning. The basic relationship between current-carrying ability and vortex pinning was given. The peak effect was discussed too. We also summarized the development of the melt processing techniques. A prototype application of the type-II superconductor was described based on the bulk HTS synchronous motor made by our laboratory. Last, the motivation of the present work was given.

In **chapter 2**, characterizations techniques such as SQUID, SEM, TG-DTA, XRD, etc were summarized briefly. Synthesis methods of the relevant materials and general process of the top seeded melt growth were described. We also explored the optimal growth parameters involved in both hot and cold seeding method. Especially, we found a method on the control of the trapped flux profile.

In **chapter 3**, the detailed dilute addition effect of $BaTiO_3$ was discussed. Interestingly, two optimized doping levels were found: one is 0.1 mol.% and the other is 0.3 mol.%. These two doping levels show different pinning behaviours. The possible pinning mechanisms were discussed. We proposed a view point that the composition of the doping related precipitations change with changing of growth conditions as well as doping levels.

In **chapter 4**, the detailed dilute doping effect of TiO_2 was described first. Then a comparative study was performed by employing the additions of $BaTiO_3$, TiO_2 and BaO_2, by which a recrystallization of fine inclusions was proposed. Further, based on the aligned peaks in the $J_c - B$ diagram, the hypothesis of the possible geometrical arrangements of fine inclusions was proposed and discussed which was confirmed by the direct observation of the microstructure described in chapter 5. Issues related to in-field pinning were discussed.

In **chapter 5**, we put the "vortex lattice/pinning landscape" puzzle boils down to the task of "stabilizing tunable vortex lattice with only one pinning landscape" and proposed that the most effective pinning may arise from the geometrical arrangement of superconducting defects. The three dimensional one should be arranged semi-continuously in some way. The present understanding of the vortex pinning posed by the three dimensional geometric defect array is never achieved in type-II superconductor whether in bulks, tapes or wires. We obtained for the first time a semi-continuous geometric pinning landscape, i.e. the grid-like nanowalls, which were achieved by inserting nanoparticles into the neatly arranged grain boundaries in textured Gd-Ba-Cu-O bulk superconductor. In contrast to the sharp peaks in the critical current posed by the simple defect array in thin film, strikingly enhanced critical current sustained by nanowalls has been achieved in a wide range of magnetic fields since the grid-like nanowall provides variable spatial periodicities for matching with the variable vortex lattice induced by external fields. This finding highlights the key parameters on the control of vortex pinning in high magnetic field. The present grid-like nanowalls shows great potentials on boosting the large-scale applications of high-T_c superconductor. Another original finding is that we discovered a method of making geometric defect array by exploiting the detailed ripening process of sub-grains, which can be summarized as the "two-steps solidification" procedure. Thanks to the addition of $BaTiO_3$, inserting nanoparticles into GBs has been achieved elaborately in the second step of the "two-steps solidification" procedure.

In **chapter 6**, superimposed effect of bulks and tapes was studied. Key factors involved in the hybrid magnet assembled with bulks and tapes were clarified. The possible practical strategies on the improvement of trapped flux as well as thermal conductance were discussed.

In **chapter 7**, we give a summary of the main findings of this thesis. Possible future perspectives for promotion of current-carrying ability were discussed.

Our study opens a new perspective on engineering of pinning landscape and provides a new basis on the control of vortex pinning. We believe that our contribution will be benefit to boost the large-scale applications of type-II superconductor.