STRUCTURE AND PINNING CENTERS IN MGB_2 BULKS, WIRES, THIN FILMS AND MT-YBCO

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Abstract. The structure and composition of MgB_2-based materials (wires, bulks, and thin films) prepared at different pressure (0.1 MPa - 2 GPa) – temperature (600 - 1050 °C) conditions and MT-YBCO oxidized in the gas flow at 440 °C under ambient pressure and under hydrostatic 16 MPa pressure at 800 °C witch demonstrated high critical current densities, j_c, were analyzed by X-ray, JAMP–9500F Auger spectrometer (after removing the oxidized layers at the sample surfaces by Ar ion etching performed directly in the vacuum chamber of microscope) and TEM. Regularly distributed inhomogeneities connected with Mg, B and admixture O content variation on the nanolevel were observed in all types of the MgB_2-based materials and are responsible for pinning. In MT-YBCO such defects as twins, dislocations and staking faults to high extent are responsible for pinning. Their densities are strongly correlated with the distances between dispersed Y_2BaCuO_5 inclusions. The correlations between the character of the materials inhomogeneities which can be pinning centers and the attained superconducting characteristics are discussed. The superconducting matrices of magnesium diboride bulks with AlB_2 structures contain some oxygen in their unite cells what has been shown experimentally by X-ray and Auger study and supported by ab-inito simulation.

1. Introduction

Magnezium diboride wires and bulks are promising for many different applications, for example, fault current limiters, magnetic resonance imaging, superconducting magnetic energy storage devices, transformers, electrical motors and generators, cryogenic pumps, adiabatic demagnetization refrigerators, magnetic separators, magnetic levitation transport and bearings, magnets for high-energy physics. Lightweight superconducting wires can be used for aviation and space applications and for powerful offshore wind generators, etc. Magnesium diboride wires and bulks compete to some extend with YBCO coated conductors and melt-textured ceramics. The working temperature of magnesium diboride can be chosen near liquid hydrogen or neon (20-30 K). It is easily produced and comparatively cheap, but prone to quenching during pulsed magnetization. This problem has to be solved in order not to restrict the material´s wide spread application. The working temperature of YBCO-based materials can be higher (e.g. around the temperature of liquid nitrogen, 77 K, or somewhat lower), but their production is much more expensive and complicated and the problems with ac losses and appropriate optimal twisting are not solved. A big risk of quenching and damaging powerful magnets is existing for coated conductors as well.

Many scientists are working on the improvement of the characteristics of MgB_2 –based materials and MT-YBCO and studying the positive effect of oxygen in their structures on superconducting characteristics.

2. Experimental procedure and sample preparation

Monofilamentary MgB_2 strands of round (0.83 mm in diameter) and quadratic (0.73×0.73 mm) shapes were fabricated by Hyper Tech Research Inc. The strand architecture consists of a Monel outer sheath and a Nb barrier surrounding the powder mixture. The starting powders were non doped and C-doped boron from Specialty Materials Inc. (SMI) or Pavezyum. The boron powders from Specialty Materials Inc. were mostly amorphous with a particle size of 10–100 nm. The C-doped powders contained 2 mol.%C. The MgB_2 bulk samples were prepared in MgB_2 stoichiometry (at the Institute for Superhard Materials NASU) without and with carbon addition. The high pressure (2 GPa)-high temperature(600 and 1050 ºC) synthesis was performed in contact with pre-compacted hexagonal boron nitride powder in the recessed-anvil-type high pressure apparatus.

MT-YBCO after melt texturing was oxygenated at 440 ºC in O_2 flow for 14 days and at 800 ºC, 16 MPa for 3 days.

3. Results and conclusions

Despite magnesium diboride has a comparatively simple unit cell which contains only two elements, it is quite difficult to synthesize a uniform material and practically impossible to synthesize or sinter magnesium diboride without oxygen impurities. It is impossible to identify one main technological factor which will guarantee a high superconducting performance of magnesium diboride.

The study of different types of wires produced from boron without and with additions of carbon or using different initial types of boron allowed us to understand which factors are of primary importance for attaining high superconducting performance. First of all it is very important to obtain a stoichiomentry of matrix phase close to MgB_2 and a high density of the wire core. A significant deviation of the main superconducting phase from MgB_2 stoichiometry (i.e. Mg excess or deficiency) leads to a reduction of the critical current density, J_c, as well as a very non-uniform distribution of the elements. While regularly repeated nano– or micro-inhomogeneties in the material structure, can be the reason of J_c increase if their concentration is rather high. The wire with a round-shaped highly dense core (with a composition of its matrix phase near $MgB_{1.8\text{-}2.4}O_{0.04\text{-}0.71}C_{0.12\text{-}0.16}$) prepared from C-doped boron and with mostly homogeneously distributed (on the macrolevel) B, C, Mg, and O demonstrated the best superconducting characteristics: $J_c(20\text{ K}, 2\text{ T}) = 10^5$ A/cm^2 and $J_c(20\text{ K}, 6\text{ T}) = 2.7\times10^3$ A/cm ^{2}, $J_c(4.2\text{ K}, 5\text{ T}) = 1.6\times10^5$ A/cm^2, $J_c(4.2\text{ K}, 15\text{ T}) = 2\times10^3$ A/cm ^{2} and B_{irr} (20 K) = 8 T, B_{irr} (12.5 K) = 15 T. The resolution of the used microscope was not enough to reveal the regularly repeated nano-inhomogeneties. Bulk magnesium diboride of Type 2 synthesized from the boron with carbon additions and regularly repeated inhomogeneties demonstrated $J_c(10\text{ K}, 10\text{ T}) = 4\times10^3$ A/cm ^{2} and $J_c(20\text{ K}, 6\text{ T}) = 4\times10^3$ A/cm ^{2}.

The critical current density, J_c, at 77 K of melt textured $YBa_2Cu_3O_{7-x}$ (MT-YBCO) oxygenated under 16 MPa at 800 ºC (the details of the manufacturing conditions are described in [1]), which is given for comparison, is rather high, but anisotropic. At 77 K in the *ab* plane $j_c = 9\times10^4$ A/cm^2 (in a zero magnetic field), $H_{irr} = 9.7$ T; in the direction of the *c*-axis $j_c = 4\times10^4$ A/cm^2 (in the zero magnetic field), and in the magnetic field of 10 T j_c exceeds 2×10^3 A/cm^2. It has been shown that the J_c of the fully oxygenated MT-YBCO (up to $YBa_2Cu_3O_{6.9\text{-}7}$) depends to a high extend on the twin density (J_c increases with the twin density). The effect of dislocations is much smaller. The twin density is higher if the distance between the Y_2BaCuO_5 inclusions is smaller.

It has been shown experimentally that the stoichiometry of a superconducting magnesium diboride having AlB_2 structure with a high level of superconducting properties (transition temperature to superconducting state, critical current density, upper critical magnetic field, and field of irreversibility) is close to $MgB_{1.75}O_{0.25}$. The ab-inito simulation confirmed the possibility of the existence of solid substitution solutions (boron to oxygen) and the energy benefit of such stoichiometry, as well as the fact that the impurity oxygen with the high probability is included in each second plane of boron of the elemental atomic cell of magnesium diboride, while every second hexagonal plane of boron of the same unite cell remains unchanged.

References

[1] Prikhna T. A., Rabier J., Proult A., et al., *Supercond. Sci. Technol.*, 2004, 17, 515–519.