The Influence of *Ex Situ* MgB$_2$ Barrier and HIP on the $I_c$ Anisotropy in Double Core MgB$_2$/Cu Wires

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The effect of large $I_c$ anisotropy reductions in MgB$_2$/Cu sheathed wire is presented. The measurements of the critical current in rising magnetic field up to 14 T at 4.2 K were performed. Due to the application of the high isostatic pressure process to the copper sheathed MgB$_2$ wires with the *ex situ* MgB$_2$ homo barrier around the *in situ* core the anisotropy for such wires was very small and approached to less than 2% at magnetic field over 4 T. The presented geometry and technology show several advantages in their practical applications.

PACS numbers:

1. Introduction

The majority of the MgB$_2$ [1] wires are performed with iron based or Cu–Ni alloys type clad, often with the chemical barrier made of expensive niobium or titanium. A disadvantage of such barriers is very high costs of its difficult plastic deformation as wires or tapes, and also considerable high electric resistance and low thermal conductivity of the sheath. Such problems have been resolved by use of copper composite cladding and the *ex situ* barrier (pat. US 12/098/475) [2]. However, the use of the copper type clad causes many technological problems. The strong reactivity of Mg with Cu causes the immediate formation of the Cu$_2$Mg or CuMg$_2$ phases, even at low annealing temperature and also causes degradations of MgB$_2$ amount in a core. The rapid creation of these eutectic phases can considerably diminish the critical parameters of superconducting wires. High chemical reactivity of Cu especially with Mg can be strongly limited by using *ex situ* chemical barrier and high isostatic pressure (HIP) heat treatment [2, 3]. However, considerably small presence of low temperature eutectic phases causes substantial increase of the critical current in MgB$_2$ wires obtained by HIP at temperatures below the melting temperature of Mg. In addition, application of several nano tens average size grains obtained (by mechanical alloying, MA, or self-propagating high-temperature synthesis, SHS methods) increase critical current density and lower the annealing temperature (by HIP) eliminating the reaction between Cu and Mg. The dense MgB$_2$ homo-barrier increases itself the active superconducting cross-section of the wire, which is not a case in conductors with Nb, Fe or Ti barrier.

2. Samples preparation

The wires were prepared from commercial grade of powders in the Institute of High Pressure Physics of Polish Academy of Sciences, by hot HIP (hot isostatic pressing) in high argon pressure medium [4]. The precursors of *in situ* powders were obtained by MA partially made in IFW Dresden and IHPP Warsaw and SHS method elaborated in IHPP Warsaw. The samples A and B consist of the *in situ* material Mg+2B+8at.%nSiC+5at.%MgH$_2$ and the *ex situ* barriers consist of MgB$_2$+8%nD. Both materials were finally CIP-ed in the rubber mould at 0.3 GPa and the samples A and B were annealed at the same temperature 700°C under Ar pressure of 0.33 GPa. The sample A was annealed 30 min and the sample B 15 min (Fig. 2).

3. Experimental

The critical current $I_c$ of the wires was measured by a four-probe resistive method with 1 $\mu$V/cm criterion used, for the samples of the length equal to about 25 mm. The wire diameter used for examination was 1.1 mm. All measurements were made at 4.2 K. Maximum measurement current was 150 A. Steady magnetic fields was generated by the Bitter-type magnet with maximum field up to 14 T. The critical transport current was measured by use of current change in constant magnetic field. The critical current measurements were made in the perpendicular...
magnetic field and the parallel magnetic field applied to the wire.

4. Results and discussions

The $I_c$ critical current anisotropy with increasing magnetic field and the parallel magnetic field applied to the wire.

In our experiments we have used the commercial ex situ type of powders with considerably large grains size to see the worse conditions of the anisotropy arise, so the overall $I_c$ level was also low, but the mechanism of anisotropy creating was minimized due to the isostatic conditions of HIP sintering and ex/in situ technology applied in copper alloys.

In Fig. 4 similar HIP effect on the specially prepared in situ and ex situ fine powder is presented. The uniformity and the high density of the HIP-ed material are presented (1 GPa argon gas medium, 720°C, and 15 min). The highest known $I_c$ results for such high dense homogeneous wires will be presented at ASC 2010 Conference, Washington.

The wires A and the $B$ presented at this work have also low anisotropies from 2% to 4%.
The authors in articles [6, 7] have described the physical properties and the chemical properties of the ex situ MgB$_2$ barrier with the barrier prepared from commercial or coarse grains short time milled. They have not defined the anisotropy effect of these types of wires after HIP.

In earlier article [8] we had presented results of similar anisotropy level reduced in in situ MgB$_2$ with ex situ MgB$_2$ barrier in iron shield. This wire has had low anisotropy in a range from 3 to 5%. The scaled pinning force on magnetic field of our Cu shield wires determines dominant of pinning mechanism as the grain boundary mechanism [9, 10]. The evaluated from scaling process parameter $p$ is close to 0.5 and appropriate $q$ parameter is almost equal to 2 — all suggested the dominant grains boundary pinning (Fig. 2). On the basis of Fig. 3 one can certify that the structure of the HIP-ed wire is very homogeneous and dense. Any cracks and voids are formed in in situ MgB$_2$ material, and the connection between ex situ MgB$_2$ barrier and in situ MgB$_2$ core is very good.

5. Conclusion

Our investigations proved that in situ MgB$_2$/Cu wires with even commercial grade grains size ex situ MgB$_2$ barrier, which were HIP-ed at severe pressure conditions result in MgB$_2$ highly homogeneous dense and stress free material. This allowed creating the uniform MgB$_2$ homogeneous material in the whole cross-section of the wire and making possible to obtain homogeneous distribution on grain boundary pinning. The homogeneous distribution of pinning in grains boundary allowed to obtain very low anisotropy.

Further work must be performed in optimization of the ex situ barrier grains size distribution and the method of densification to avoid the local grains condensation caused by the different surfaces properties of grains.

Acknowledgments

We are very grateful to Mrs. Anna Kario from IFW Dresden for performing the part of MA in situ powder for preparation of the ex/in situ/Cu type wires designated for HIP process.

References