Effect of Oxygen Distribution in the Structure of Magnesium Diboride-Based Materials on their Superconducting Characteristics

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Devices based on the superconductor MgB$_2$ can be envisaged for many applications, as MRI, cables, electromotors, magnetic bearings and fault current limiters, etc. There are many factors which can influence the functional properties of MgB$_2$, the most important ones being: critical current density, $J_c$, trapped magnetic field, upper critical magnetic field $B_{c2}$, irreversibility field, $B_{irr}$, ac losses, rate of superconducting-normal state (S-N) transition, density, hardness and fracture toughness.

Although MgB$_2$ is a nominally oxygen-free superconductor, it is practically impossible to synthesize oxygen-free MgB$_2$-based materials even if high purity initial components and protecting atmosphere are used. However, previous studies indicated a positive role of oxygen-containing nano-inclusions as pinning centers: MgO, Mg(OH)$_2$, MgB$_2$O$_x$, MgB$_{0.6-0.8}$O$_{0.8-0.9}$ or nanolayers MgB$_{1.2-2.7}$O$_{1.8-2.5}$.

The experimental X-ray, SEM and Auger results concerning oxygen incorporation into MgB$_2$ crystal structure are supported by $ab$ initio calculations of the electronic structure, binding energy and enthalpy of formation [1, 2].

As indicated by SEM and Auger study, some oxygen is usually present in superconducting MgB$_2$-based materials (bulk, thin films, and wires). The matrices phases of bulk MgB$_2$ contain rather small amount of oxygen while the high amount of dispersed inclusions or areas with the close to MgBO composition are present in them. X-ray phase analysis with the Rietveld refinement of several highly dense magnesium diboride-based bulks (demonstrated high level of superconducting characteristics and high critical current densities, in particular) showed that the materials superconducting matrices had near MgB$_{1.75}$O$_{0.25}$ composition instead of pure MgB$_2$. Besides, a small amount of MgO was observed in the materials as well. The calculation of the enthalpy of formation proves the possibility of oxygen solubility in MgB$_2$ and shows that formation of MgB$_{1.75}$B$_{0.25}$ is favorable. The results of $ab$ initio calculations of the electronic structure and stability of the MgB$_2$ compounds with partial oxygen substitution for boron show that it is energetically preferable for oxygen atoms to ordered replace boron forming pairs or zigzag chains.

For the bulk MgB$_2$-based materials critical current densities $J_c(10 \, K)=1.2-1.0 \cdot 10^6$ A/cm$^2$ in 0-1 T field, $J_c(10 \, K)=9 \cdot 10^4$ A/cm$^2$ in 4 T field and $J_c(20 \, K)=9-7 \cdot 10^5$ A/cm$^2$ in 0-1 T field were registered. For the thin (140 nm) MgB$_2$ films in zero magnetic field of magnetometer critical current densities $J_c(10 \, K, B_{||ab})=1.8\cdot10^7$ A/cm$^2$; $J_c(10 \, K, B_{||c})=1.5\cdot10^7$ A/cm$^2$, $J_c(20 \, K, B_{||ab})=7.8\cdot10^6$ A/cm$^2$, $J_c(20 \, K, B_{||c})=6.4\cdot10^6$ A/cm$^2$ have been measured and $B_{c2}(B_{||ab})=15$ T at 22 K and $H_{irr}(B_{||a})=15$ T at 19 K were observed.
