Keeping bulk magnesium diboride superconducting at higher current densities

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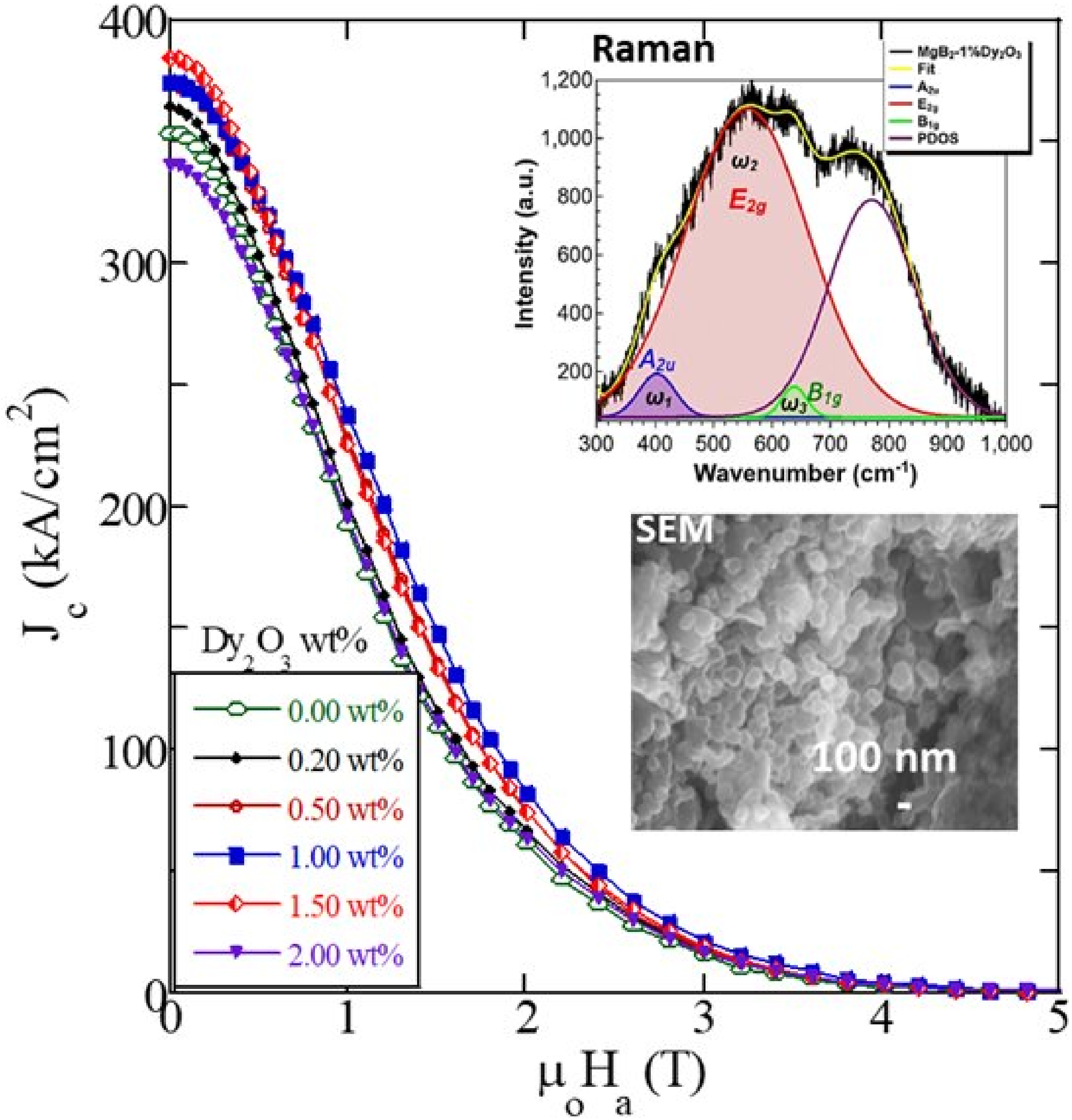

The low and high field critical current density of bulk MgB_2 superconductors can be improved by a combination of optimum processing temperature and controlled addition (1Wt%) of Dy_2O_3 and amorphous nanometer-sized boron precursor, finds a new study by researchers from SIT, Japan. Credit: Muralidhar Miryala from SIT, Japan

Superconductors—wondrous materials whose resistance drop to zero below a critical temperature—show much promise to meet the growing energy demand of the global population. With potential applications in magnetic resonance imaging, nuclear magnetic resonance, magnetic drug delivery, fault current limiters, transportation (Maglev trains), and cables, there is much motivation for discovering and developing high-temperature superconductors.

In this regard, magnesium diboride (MgB_2), a high-temperature superconductor, has received much attention owing to its low cost, light weight, and easy fabricability. It is posited that MgB_2 has the potential to replace conventional niobium-based superconductors in practical engineering applications. However, bulk MgB_2 suffers from the long-standing problem of an insufficient critical current density (the current density above which it is no longer superconducting) at high magnetic fields. This, in turn, greatly limits its large-scale applications.

To address this issue, researchers have tried adding external elements in controlled quantities, a process known as "doping," during the synthesis of bulk MgB_2, with little to no success. As Prof. Muralidhar Miryala from Shibaura Institute of Technology (SIT), Japan states, "So far, researchers have tried improving the critical current density of bulk MgB_2 by doping with silicon carbide, other carbon sources, silver, transition metals etc. However, further improvement of the critical current density of MgB_2 is crucial for several industrial applications."

Not all hope is lost, however. Prof. Miryala's team managed to show that sintering MgB_2 at around 800°C for 3 hours in an argon environment can lead to a superior superconducting performance. This was linked to the formation of an optimum microstructure at such processing conditions, which was revealed to play a major role in the superconductivity of MgB_2.

In a recent study published first on July 7, 2022, in *Advanced Engineering Materials*, Prof. Miryala's team made another breakthrough. They found that combining optimum sintering conditions with controlled addition of nanometer-sized amorphous boron and dysprosium oxide (Dy_2O_3) enhanced the high-field critical current density (J_c) of MgB_2 as well as its self-field. The study included Prof. M.S. Ramachandra Rao of Indian Institute of Technology Madras (IITM), India, who provided support for the global project based learning (gPBL) program at IITM , and contributions from K. Kitamoto, A. Sai Srikanth, and M. Masato from SIT, D. Dhruba from IITM.

What was remarkable about Dy_2O_3 as a dopant was that it had almost no effect on the superconducting transition temperature of MgB_2 (which remained stable at around 38 K).

Additionally, Dy_2O_3 addition led to the formation of DyB_4 nanoparticles, enhancing further flux pinning at MgB_2 nano grain boundaries. Further, use of nano boron precursor helped to create MgB_2 nano grains with exceptional grain-boundary flux pinning. As a result, a superior critical current density was achieved.

Using amorphous nanoboron as the starting ingredient, the team quantified the precise amount of Dy_2O_3 that needed to be added to significantly improve J_c in bulk MgB_2 superconductors. By analyzing the structure and composition with techniques such as X-ray diffraction and Raman spectroscopy, and the superconducting properties of doped bulk

MgB_2, they found the ideal Dy_2O_3 doping range to be 0.5-1.5%.

With these findings, the team is excited about the future prospects of MgB_2. "These results demonstrate the potential of Dy_2O_3 doping alongside nanoboron precursors in realizing bulk MgB_2 for practical superconducting applications," says Prof. Miryala. "Our research adds to the existing literature on ways to improve J_c and could pave the way for real-life bulk superconductors, which are a beacon for sustainable technologies."

More information: Muralidhar Miryala et al, Enhancing Critical Current Density of Bulk MgB 2 via Nanoscale Boron and Dy 2 O 3 Doping, *Advanced Engineering Materials* (2022). DOI: 10.1002/adem.202200487

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