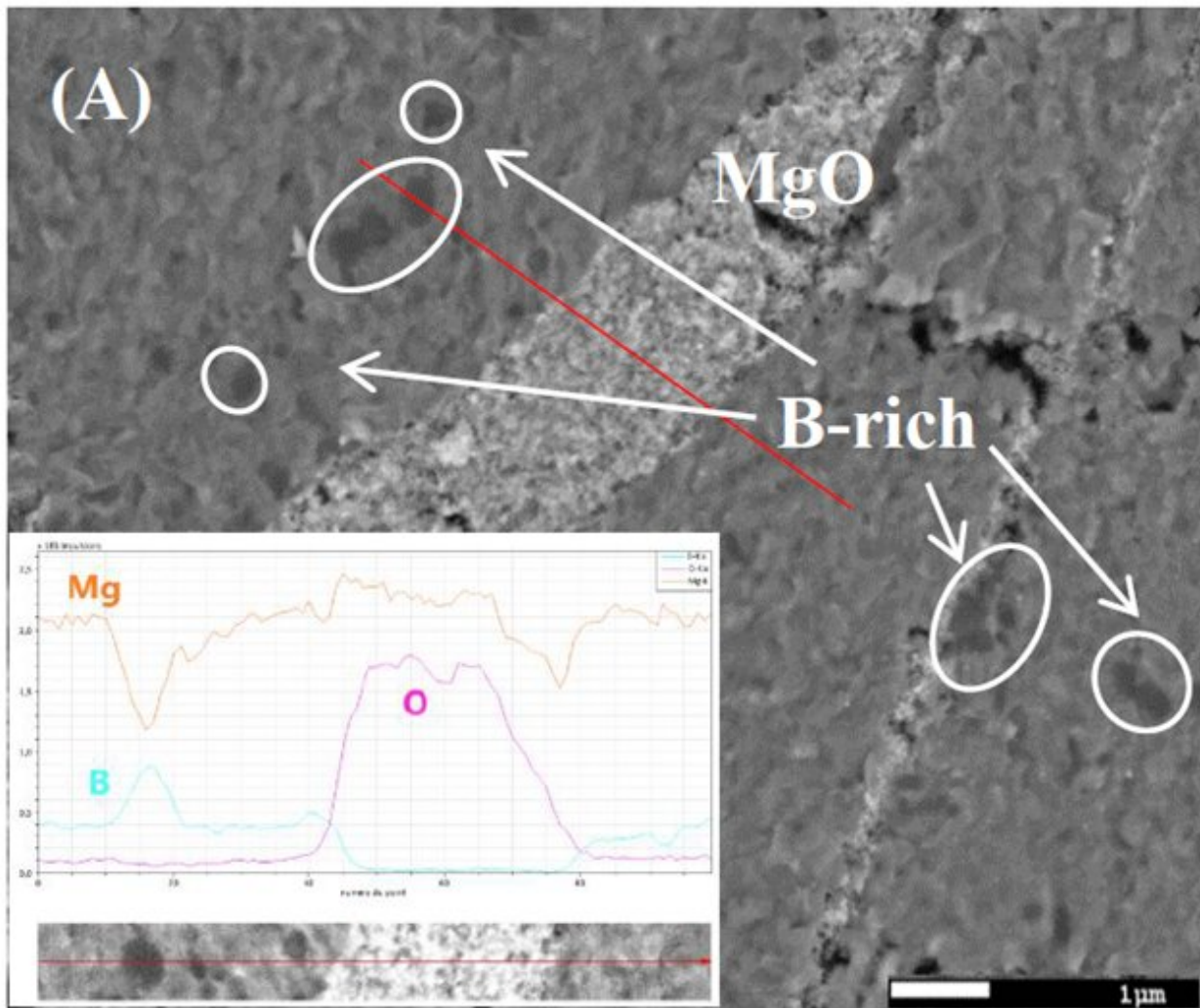


The 'dense' potential of nanostructured superconductors

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Scientists at SIT and University of Normandie developed bulk MgB_2 with promising superconductivity. This picture shows unreacted magnesium oxide and boron in the matrix of MgB_2 , and the inset shows energy dispersive x-ray

spectroscopy curves for boron, oxygen, and magnesium. Credit: Muralidhar Miryala from SIT, Japan and Prof. Jacques G. Noudem from UN, France

From superfast magnetic levitation trains and computer chips to magnetic resonance imaging (MRI) machines and particle accelerators, superconductors are electrifying various aspects of our life.

Superconductivity is an interesting property that allows materials to transfer moving charges without any resistance, below a certain critical point. This implies that superconducting materials can transfer electrical energy in a highly efficient manner without loss in the form of heat, unlike many conventional conductors.

Almost two decades ago scientists discovered superconductivity in a [new material](#)—magnesium diboride, or MgB_2 . There has been a resurgence in the of popularity MgB_2 due to its low cost, superior superconducting abilities, high critical current density (which means that compared to other materials, MgB_2 remains a semiconductor even when larger amounts of electric current is passed through it), and trapped magnetic fields arising from strong pinning of the vortices—which are cylindrical current loops or tubes of magnetic flux that penetrate a superconductor.

The intermetallic MgB_2 also allows adjustability of its properties. For instance, the critical current density values (J_c) of MgB_2 can be improved by decreasing the grain size and increasing the number of grain boundaries. Such adjustability is not observed in conventional layered superconductors.

To widen the applications of MgB_2 , however, there is a need to simplify the method of its preparation. Recently, a team of researchers embarked on a journey to do so. They fabricated a novel bulk MgB_2 via a process called spark plasma sintering (SPS).

In their recent article, published on July 27, 2022 in *Nanomaterials*, Prof. Muralidhar Miryala from Shibaura Institute of Technology (SIT), Japan, who led the group, explains that "spark plasma sintering (SPS) is a very interesting technique—it is a rapid consolidation method, where powder is turned into a dense solid."

"The [heat source](#) in this procedure is not external but is an electric current that flows across the die, causing the powder to sinter into a bulk material. The sintering kinetics can be understood and controlled better with SPS. Unlike other similar techniques, it allows grain growth control. What's more, it also has a shorter processing time!"

Prof. Miryala and Prof. Jacques G. Noudem (from the University of Normandie, France) had used this unconventional method to prepare bulk samples of MgB_2 . The resultant material had excellent superconducting properties and a density that reached 95% of what was theoretically predicted for the material. The study team included Prof. Pierre Bernstein and Yiteng Xing, who is a double degree Ph.D. student at SIT and the University of Normandie.

To synthesize the bulk MgB_2 , the team loaded two powders—magnesium and amorphous boron—into a tungsten carbide (WC) mold and sintered them using SPS at different temperatures ranging from 500–750°C, and pressure ranging from 260–300 megapascal (MPa), then cooled the formed material. The total processing time was about 100 minutes. The team then analyzed the density and the structural properties of the prepared material, using various imaging and testing methods.

Their experiments revealed that the material had a very high density of 2.46 g/cm³ and a high packing factor of 95% (indicating that the atoms in the [bulk material](#) were situated very close to each other). It also showed the presence of nano-grains and a large number of grain

boundaries.

Moreover, it did not exhibit Mg-depleted phases like MgB_4 . Electromagnetic characterization of the material showed that it exhibited an extremely high J_c of up to $6.75 \cdot 10^5$ ampere/cm² at about -253°C . This means that even at that high a current density, the bulk MgB_2 made by the team would act as a superconductor. "Its J_c was quite remarkable for pure, undoped MgB_2 ," commented Prof. Miryala.

Curious as to how the material exhibited such excellent properties, the team dug deeper. They concluded that the prepared MgB_2 's superconducting properties were due to its high density, excellent grain connectivity (due to no Mg-depleted phases), and the strong pinning of vortices availed by the presence of nano-grains and grain boundaries.

This study provided a new way to improve the properties of [superconducting materials](#) like MgB_2 . Given this material's high J_c , it can be used in liquid hydrogen-cooled technology. It is also emerging as a promising candidate for liquid hydrogen-based transportation, storage, and fuel systems.

"Global warming is one of the major threats humanity is facing today and shifting to a renewable energy economy is one of the most effective solutions to this problem. Given the material's potential use in liquid hydrogen systems and its excellent structural and superconducting properties, our work is a positive step towards the realization of greener technology," concludes Prof. Miryala.

More information: Yiteng Xing et al, High Critical Current Density of Nanostructured MgB_2 Bulk Superconductor Densified by Spark Plasma Sintering, *Nanomaterials* (2022). [DOI: 10.3390/nano12152583](https://doi.org/10.3390/nano12152583)

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