KYUSHU UNIVERSITY

Public Relations Office, Kyushu University
744 Motooka Nishi-ku Fukuoka, 819-0395
TEL: +81-92-802-2443 FAX: +81-92-802-2139
E-MAIL: koho@jimu.kyushu-u.ac.jp
URL: https://www.kyushu-u.ac.jp

PRESS RELEASE (2025/09/02)

Boosting fuel cell efficiency with water vapor

Hydration doubles oxide-ion conductivity in $Ba_7Nb_4MoO_{20}$, a promising material for low-temperature solid oxide fuel cells

Hydration significantly boosts ion conductivity in $Ba_7Nb_4MoO_{20}$, a promising ceramic electrolyte candidate for low-temperature solid oxide fuel cells. But its origin and mobile ionic species were unresolved issues. Researchers at Institute of Science Tokyo, in collaboration with Kyushu University, found that exposure to water vapor enhances oxide-ion mobility by increasing interstitial oxygen ions, nearly doubling the oxide-ion conductivity at 500 °C. The findings of this study could advance the development of efficient and durable fuel cells for clean energy applications.

Fuel cells generate electricity by combining hydrogen and oxygen, producing only water as a byproduct. Once used to provide power and drinking water for space missions, fuel cells are now being explored as a source of low-emission energy. Fuel cells are classified by the type of electrolyte used; each type has specific advantages and drawbacks. One category includes solid oxide fuel cells and proton ceramic fuel cells, which use ceramics as electrolytes. These fuel cells operate at high temperatures—as high as 1,000 °C—eliminating the need for expensive precious metal catalysts. However, high temperatures also accelerate material degradation; therefore, it is crucial to develop highly conductive electrolytes at lower temperatures.

A recent study led by Professor Masatomo Yashima at Institute of Science Tokyo (Science Tokyo), Japan, in collaboration with researchers from Imperial College London and Professor Hiroshige Matsumoto of Kyushu University's International Institute for Carbon-Neutral Energy Research (I^2CNER), highlights $Ba_7Nb_4MoO_{20}$ as a promising electrolyte material. The team found that the material's oxide-ion conductivity and diffusivity significantly improved when exposed to water vapor, offering a pathway toward more efficient, lower-temperature fuel cells. The findings were published online on July 18, 2025, in the *Journal of Materials Chemistry A*, where the paper was selected as a HOT Paper in honor of its impact and contribution.

Yashima says, "A new 'smart material' has been discovered that enhances the oxygen-ion mobility within ceramics while absorbing water."

$Ba_7Nb_4MoO_{20}$ is a hexagonal perovskite-related oxide where oxide ions (O^{2-}) migrate through the interstitial sites in an oxygen-deficient cubic close packed (CCP) layer in its crystal structure. Materials exhibiting this interstitialcy diffusion mechanism have shown high ionic conductivity under both wet and dry conditions. However, the impact of hydration on O^{2-} transport and conductivity of $Ba_7Nb_4MoO_{20}$ was not well understood.

To solve this problem, the researchers synthesized $Ba_7Nb_4MoO_{20}$ pellets and investigated their transport properties under dry and wet conditions at different temperatures. They measured the electromotive force using both oxygen and vapor water concentration cells to assess the contributions of O^{2-} and H^+ to the electrical conductivity. They also performed tracer diffusion experiments to track the diffusion of oxide ions within the material.

When exposed to water vapor, the material's conductivity increased significantly compared to dry air, and the O^{2-} was identified as the dominant charge carrier. At 500 °C, the oxygen diffusivity nearly doubled, and the material's total conductivity in humid air (5.3×10^{-4} S cm^{-1}) was more than twice that in dry conditions (2.5×10^{-4} S cm^{-1}).

This behavior was attributed to an increase in interstitial oxygen atoms due to the absorption of water vapor. Using molecular dynamics simulations with neural network potential, the researchers found that the hydration introduces additional O^{2-} ions, which occupy interstitial sites and form $(Nb/Mo)_2O_9$ dimers within the lattice. The disappearance and reforming of the dimers enhance O^{2-} mobility, improving the material's O^{2-} conductivity.

This study addresses a key knowledge gap in interstitial oxygen conductors by revealing how hydration enhances O^{2-} conductivity and mobility in $Ba_7Nb_4MoO_{20}$. These findings could lead to the development of more durable and efficient fuel cells that operate at lower temperatures, helping to overcome a major barrier to their wider adoption.

"Understanding O^{2-} and H^+ conduction in ceramic oxide-ion, proton, and dual-ion conductors is vital for clean energy," says Yashima. "This breakthrough in materials science is expected to greatly advance the development of ion conductors, which are essential for clean energy technologies such as fuel cells and steam electrolysis cells. These technologies are key components for building a sustainable next-generation society and achieving the United Nations Sustainable Development Goals."

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For more information about this research, see " Hydration-Driven Enhancement of Interstitialcy Oxide-Ion Diffusion," Yuichi Sakuda, Mudasir A. Yatoo, Bhuvaneshwari Manivannan, Vediyappan Veeramani[3], Junko Habasaki, Stephen J. Skinner, Hiroshige Matsumoto, and Masatomo Yashima *Journal of Materials Chemistry A*, https://doi.org/10.1039/D5TA04728E

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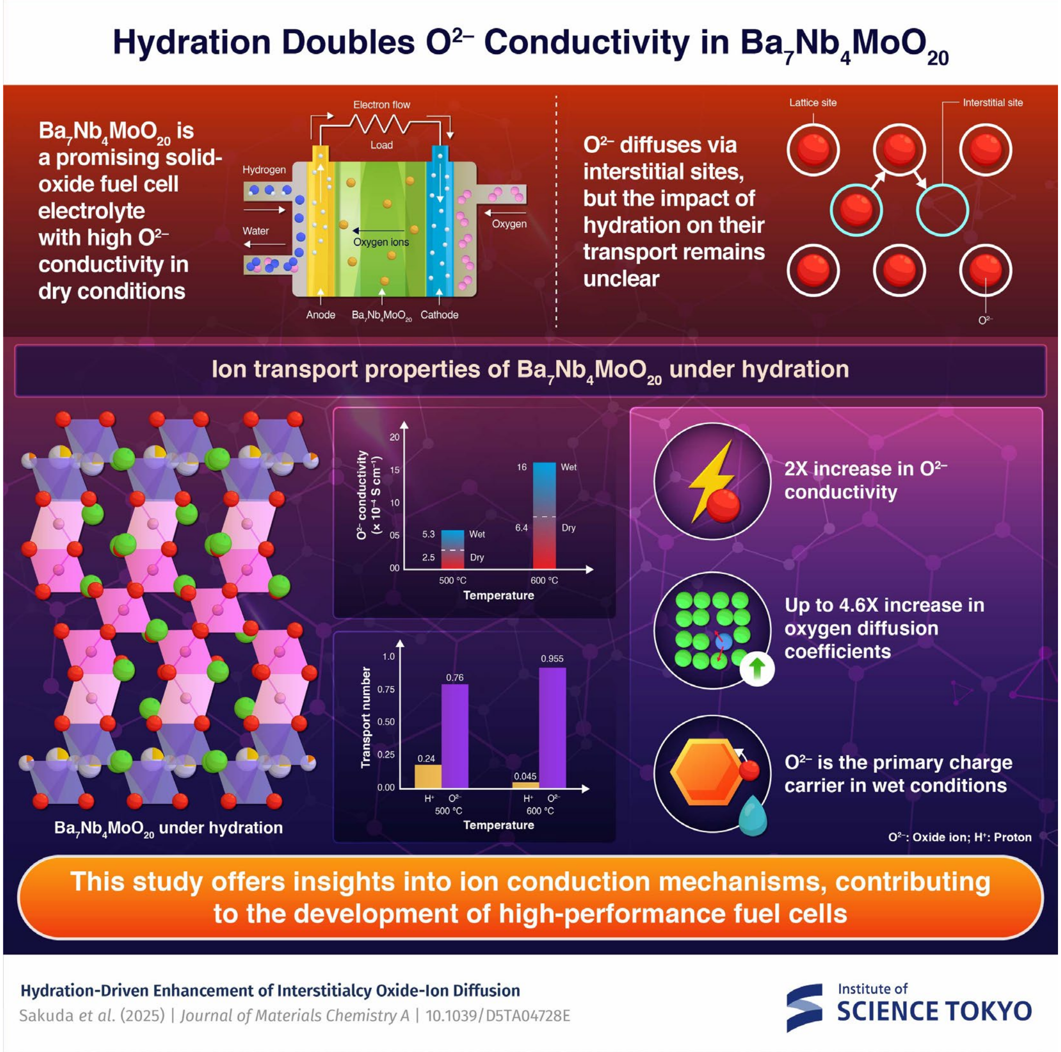

Fig. 1. Hydration-enhanced ion transport in $Ba_7Nb_4MoO_{20}$. $Ba_7Nb_4MoO_{20}$, a ceramic electrolyte with potential for low-temperature fuel cells, becomes nearly twice as conductive when exposed to water vapor at 500 °C. The improvement is driven by enhanced oxide-ion mobility in the material and could lead to more efficient and durable fuel cells. (Institute of Science Tokyo)

[Contact]
Hiroshige Matsumoto, Professor
International Institute for Carbon-Neutral Energy Research Advanced Energy Conversion Systems Thrust
Tel: +81-92-802-6705
E-mail: matsumoto@i2cner.kyushu-u.ac.jp