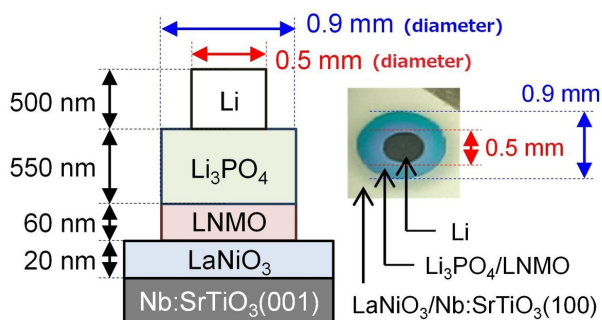


# Expanding the limits of Li-ion batteries—electrodes for all-solid-state batteries

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The batteries were made by stacking various layers via thin-film deposition methods. The LNMO/Li<sub>3</sub>PO<sub>4</sub> interface showed spontaneous migration of Li ions and had an unprecedentedly low resistance. Credit: ACS *Applied Materials & Interfaces*

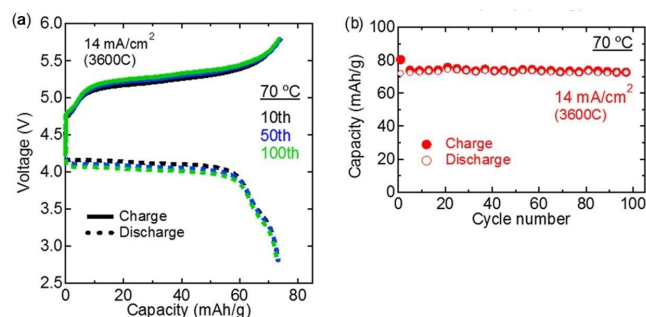
Scientists at Tokyo Institute of Technology have addressed one of the major disadvantages of all-solid-state batteries by developing batteries with a low resistance at their electrode/solid electrolyte interface. The fabricated batteries showed excellent electrochemical properties that greatly surpass those of now ubiquitous Li-ion batteries, thereby demonstrating the promise of all-solid-state battery technology and its potential to revolutionize portable electronics.

Many consumers are familiar with rechargeable lithium ion batteries, which have developed over the last few decades, and are now common in all sorts of electronic devices. Despite their broad use, scientists and engineers believe that traditional Li-ion battery technology is already nearing its full potential and new types of batteries are needed.

All-solid-state batteries are a new type of Li-ion battery, and have been shown to be potentially safer and more stable energy storage devices with

higher energy densities. However, the use of such batteries is limited due to a major disadvantage—their resistance at the electrode/solid electrolyte [interface](#) is too high, hindering fast charging and discharging.

Scientists from Tokyo Institute of Technology and Tohoku University, led by Professor Taro Hitosugi, fabricated all-solid-state batteries with extremely low interface resistance using Li(Ni<sub>0.5</sub>Mn<sub>1.5</sub>)O<sub>4</sub> (LNMO), by fabricating and measuring their batteries under ultrahigh vacuum conditions, ensuring that the electrolyte/electrode interfaces were free of impurities.



The (a) charge-discharge curves and the (b) cycling performance plot show that the performance of the fabricated all-solid-state batteries did not degrade after repeated use, demonstrating their excellent stability and the total reversibility of the reactions involved in charging/discharging. Credit: ACS *Applied and Materials & Interfaces*

The structure of these all-solid-state batteries is shown in Figure 1. After fabrication, the electrochemical properties of these batteries were characterized to shed light on Li-ion distribution around the interface. X-ray diffraction and Raman

spectroscopy were used for analyzing the crystal structure of the thin films comprising the batteries. Spontaneous migration of Li ions was found to occur from the  $\text{Li}_3\text{PO}_4$  layer to the LNMO layer, converting half the LNMO to  $\text{Li}_2\text{NMO}$  at the  $\text{Li}_3\text{PO}_4/\text{LNMO}$  interface. The reverse migration occurs during the initial charging process to regenerate LNMO.

The resistance of this interface, verified using electrochemical impedance spectroscopy, was  $7.6 \text{ } \Omega \text{ cm}^2$ , two orders of magnitude smaller than that of previous LNMO-based all-solid-state batteries, and even smaller than that of liquid-electrolyte-based Li-ion batteries using LNMO. These batteries also displayed fast charging and discharging, managing to charge/discharge half the battery within just one second. Moreover, the cyclability of the battery was also excellent, showing no degradation in performance even after 100 charge/discharge cycles (see Figure 2).

$\text{Li}(\text{Ni}_{0.5}\text{Mn}_{1.5})\text{O}_4$  is a promising material to increase the energy density of a [battery](#), because the material provides a higher voltage. The research team hopes that these results will facilitate the development of high-performance all-solid-state batteries, which could revolutionize modern portable electronic devices and electric cars.

**More information:** Hideyuki Kawasoko et al, Extremely Low Resistance of  $\text{Li}_3\text{PO}_4$  Electrolyte/ $\text{Li}(\text{Ni}_{0.5}\text{Mn}_{1.5})\text{O}_4$  Electrode Interfaces, *ACS Applied Materials & Interfaces* (2018). [DOI: 10.1021/acsami.8b08506](https://doi.org/10.1021/acsami.8b08506)

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