POLYMER PARTS FOR GREENER RECHARGEABLE BATTERIES

POLYMERIC ELECTRODES promise to make RECHARGEABLE BATTERY COMPONENTS more renewable and recyclable.

Household appliances, electric vehicles and mobiles drive a doubling of the global demand for rechargeable batteries every three years or so. The Energy and Nanomaterials Unit at Waseda University in Japan is working to reduce the environmental footprint of this by replacing metal components with more renewable and recyclable polymer parts.

Minerals such as lithium are typical component materials today, explains Kenichi Oyaizu, who leads the unit. And while rechargeable battery technology is expected to reduce fossil fuel consumption, the metals in them aren't renewable, are expensive to manufacture and recycle, and can be environmentally damaging to extract.

In the 2000s, Hiroyuki Nishide at Waseda University pioneered rechargeable battery cathodes and anodes made of radical polymers, which can be chemically synthesized from organic materials, and could be made to be biodegradable or easily recyclable.

ELECTRICITY IN THE AIR

Today, Oyaizu, who studied under Nishide, leads a team strong in polymer chemistry and battery tests. In 2020, with Martin Sjödin's team from Uppsala University, in Sweden, they published on a polymer-air battery.

Rechargeable air-metal batteries have the potential for the highest possible energy density per unit mass, which is vital for creating less heavy devices, explains Oyaizu.

While rechargeable air batteries aren't yet commercially viable, polymer parts sidestep a major hurdle: dendrite formation on metal components caused by the redox reactions between air and metals. Polymer parts can also be rolled on or printed using cheap inkjet techniques. At a 0.5 voltage (V), Oyaizu and Sjödin's battery is not yet at the roughly 1.5V required for use, but it's a step forward.

BATTERY PARTS MADE OF POLYMERS COULD BE MADE RECYCLABLE.

PENDANT AND BACKBONE

Radical polymers consist of a repeating polymer sub-unit backbone with side group 'pendant' organic radicals – compounds with an unpaired electron, but stabilized by their shape. These side groups can undergo quick transitions between different oxidation states to move charge efficiently along the backbone. "Radical polymers may have an advantage over other organic electrode-active materials in terms of high-rate capabilities and robust charge storage, due to a simple one-electron redox reaction," explains Oyaizu.

Nishide's early radical polymers could achieve high charge and discharge rates. But while his devices showed promise, with good cycling lifetimes and reasonable output voltages, the electrodes had a low energy density per unit weight, and a tendency to react with or dissolve in the battery's electrolyte.

Then in 2019, a theoretical study suggested that the reactivity of organic radicals could be slowed using the electric field effects of ionic liquid electrolytes, reducing radical polymer electrode degradation and increasing output voltages. The study, led by Ekaterina I. Izgorodina from Monash University in Australia, was experimentally verified at Waseda by a doctoral student from Monash through a Joint Supervision programme.

Ionic liquids represent a promising alternative to electrolytes. Their application as electrolytes in supercapacitors has demonstrated potential for commercial viability. The ionic liquid's high-energy storage-capacity is now considered a possible game-changer for future battery technologies.

Meanwhile, Sjödin has been working with Oyaizu's group since 2015, through a Joint Appointment system that recruits key international researchers and allows them to retain their original appointments. Sjödin brought expertise in conducting redox polymer (CRP) materials and *in-situ* electrochemical studies.

CRPs are covalently attached, high-capacity redox group extensions of radical polymers, with conjugated main chains. Sjödin pioneered the first all-organic proton batteries using CRPs in 2017. "CRPs are less likely to dissolve in a battery's electrolyte than most electroactive polymers," explains Sjödin. Traditional electroactive polymers also require conductive additives, such as carbon fibres, to function as electrodes, while CRPs are naturally conductive.

However, there are constraints: the redox reactions of CRP pendant groups must occur at potentials consistent with the conjugated polymer backbone oxidization and reduction potentials in order to conduct. The alignment of these redox potentials can, in turn, be affected by the electrolyte. "Effective systems are still being identified," Sjödin explains.

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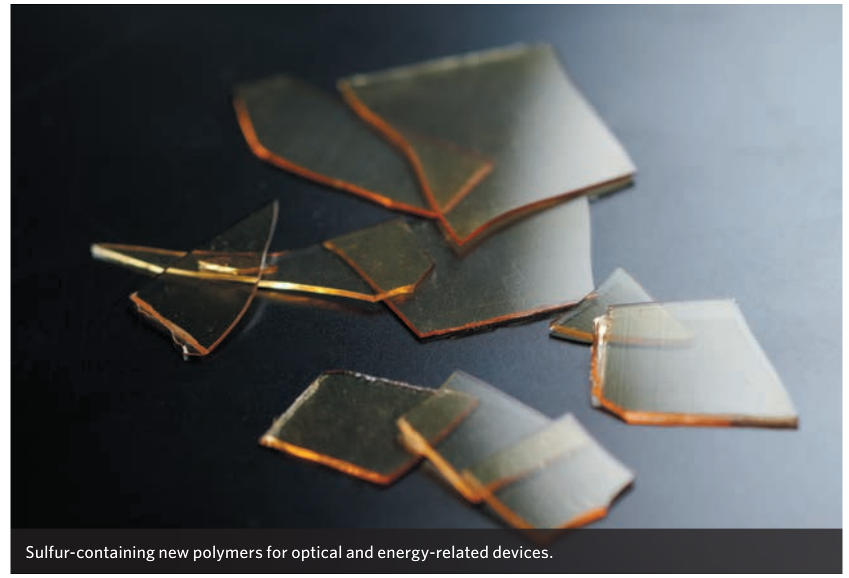
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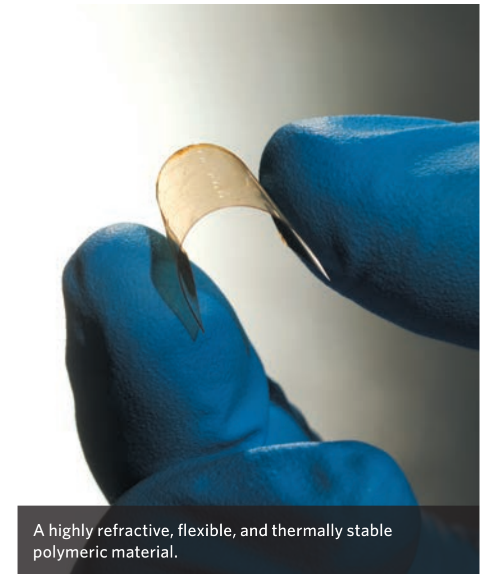
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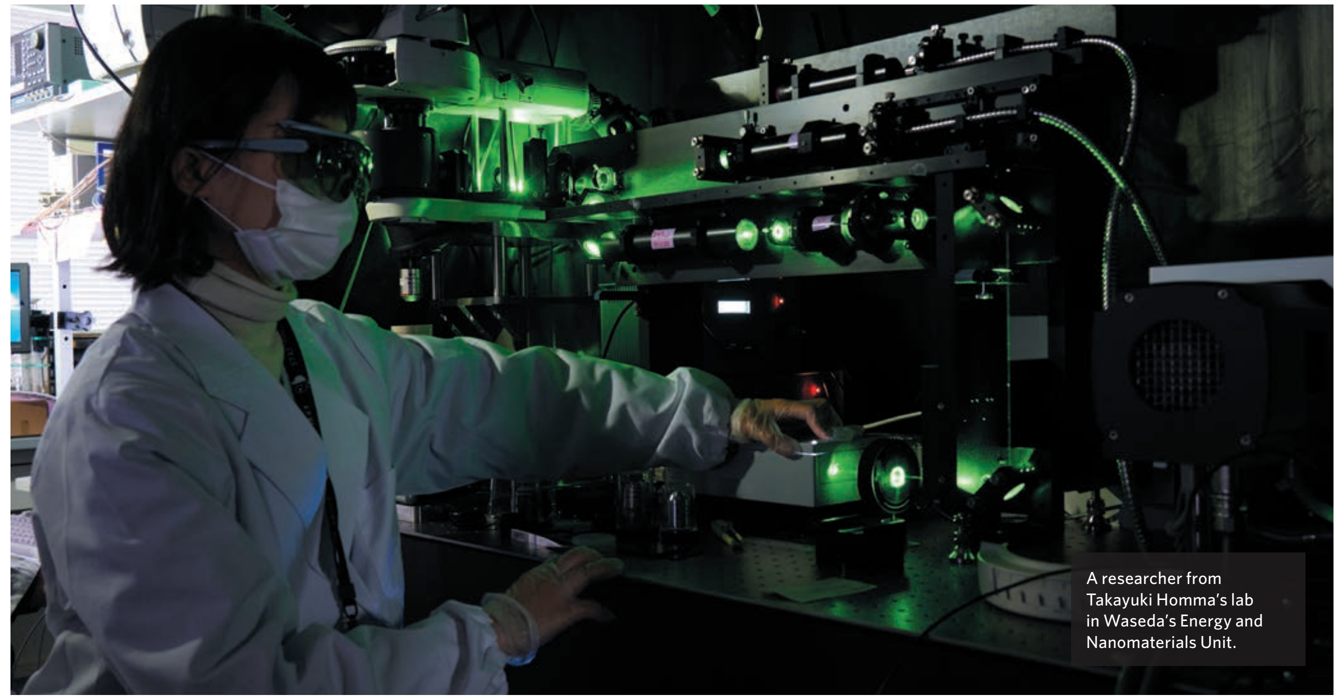
A researcher from Takayuki Homma's lab in Waseda's Energy and Nanomaterials Unit.

GREEN FIELD

Oyaizu's group is exploring ways to help Sjödin, and others, using learning algorithms that explore chemical systems relevant to organic batteries. They have already predicted the conductivity of lithium-conducting solid polymer electrolytes, and identified unexpected candidate materials.

The group has also constructed new graph representations of materials-science data that unify the outputs of different research programmes, increasing the ability of neural network algorithms to exploit otherwise disparate data sets to explore candidate battery and optical materials.

Oyaizu's unit shares researchers across half a dozen institutions abroad, and is pursuing new relationships, particularly in opto-electronic functional materials and machine learning. Connections can be made at the annual Organic Battery Days conference, which will be hosted at Waseda later this year.

The Waseda Goes Global Plan is supported by Japan's Ministry of Education, Culture, Sports, Science and Technology (MEXT). A Joint Appointment programme allows recruited researchers to retain prior appointments. This involves shared resources, joint publications and a three month minimum stay. Under a Joint Supervision programme, doctoral students benefit from supervisors and facilities across two universities. ■

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