ADVANCES IN MATERIALS SCIENCE OFFER A FUTURE OF CLEAN ENERGY

Breakthroughs in materials technology at the Wuhan University of Technology are unlocking new possibilities for CLEANER, GREENER AND MORE EFFICIENT ENERGY PRODUCTION AND STORAGE.

With the world facing a climate and energy crisis, developing novel technologies for clean, affordable and reliable power has become increasingly important. Researchers at the School of Materials Science and Engineering (MSE) at the Wuhan University of Technology have been developing key materials technologies that could shape the way we produce and store energy in the future.

The school is one of China's leading institutions for research and training in materials science and engineering, and is known for its long and significant contribution to research on construction materials in China. Today, the MSE's research covers a wide array of pioneering materials research to support China's transition to a low-carbon economy, including green building materials, efficient energy conversion and storage, smart vehicles, defence applications and future materials.

SOLAR BREAKTHROUGHS

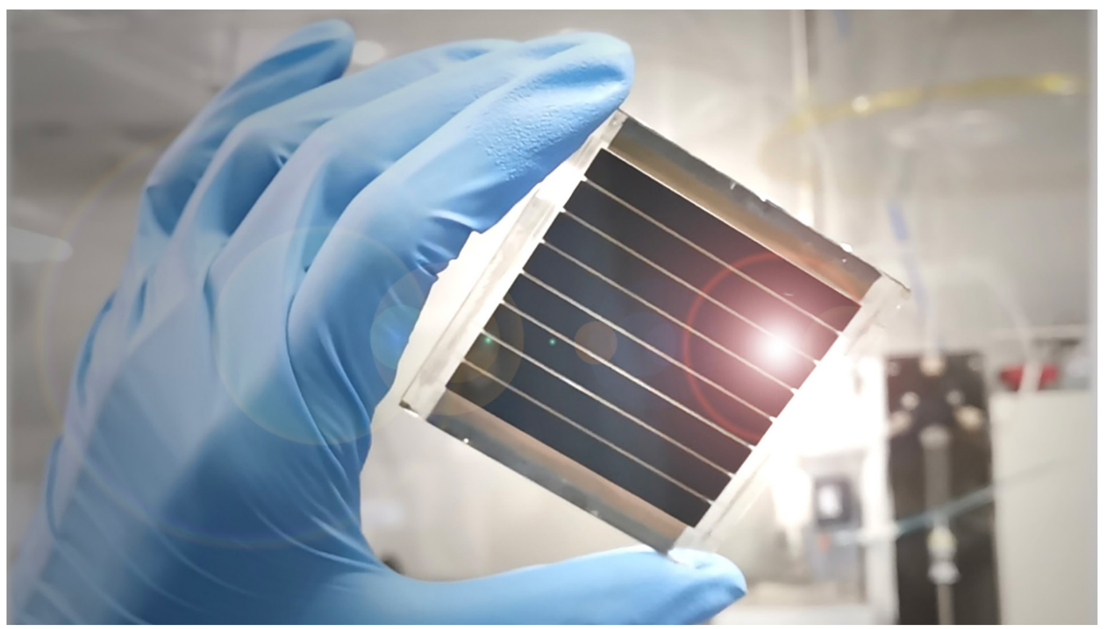
Photovoltaic (PV) solar cells are currently the fastest-growing energy source globally, with additional capacity being added at a speed unthinkable just a decade ago. The standard silicon-based solar panel, however, offers a relatively low light-to-energy conversion of less than 20%, leaving much potential for improvement. Silicon is also comparatively expensive, involving complex and energy-intensive manufacturing processes.

An alternative technology that has been extensively studied is a PV cell based on a thin film with a perovskite structure — a cubic crystalline structure that achieves the same light-to-energy conversion as silicon. Yet despite higher theoretical efficiencies than silicon of up to 31% — and much cheaper and easier fabrication — perovskite PV technology has not yet been commercially realised due to the difficulty in producing large cells, and the instability of the cells at high temperatures and under intense light conditions.

"Reducing the energy consumption of producing PV cells is currently the biggest challenge in the field of photovoltaics," explains Fuzhi Huang, who is leading MSE's PV research. "Solving this would truly enable PV to become a clean energy technology that can be used on large scales. Perovskite-based cells have good conversion efficiency, but the efficiency drops dramatically as the device area increases due to difficulty in controlling the crystallization over large areas."

Last year, in a breakthrough published in *Science*[1], Huang's team proposed a new process for preparing perovskite cells that overcomes this barrier to industrialization.

"After studying the nucleation and crystallization of perovskite materials for many years, we found that the process is intrinsically slow and resistant to forming dense uniform films," says Huang. "So instead of trying to improve that process directly, we circumvented the problem by introducing lead halide as a 'template' to first form a complex that nucleates quickly and easily as a uniform dense film. A subsequent heating step then induces a chemical reaction that forms the perovskite film and eliminates the complexing agent."



▲ **Fuzhi Huang has fabricated a perovskite solar cell mini module with efficiency of close to 20%.**

Using this approach, Huang's team demonstrated fabrication of 10 x 10 cm perovskite-based PV cells with efficiency of close to 20% and much improved thermal and light stability. Huang notes that this technology is now ready to be applied for PV cell production, although work continues on further improving efficiency and stability.

ENERGY STORAGE ON A CHIP

Turning to much smaller scales, a research group led by MSE's chair professor, Liqiang Mai, is focusing on energy storage in miniaturized devices such as sensors and implants. These devices could include an energy-harvesting element such as solar PV cell or thermoelectric converter, but the collected energy then needs to be stored. By studying the detailed physics of an electrochemical field-effect transistor (FET), Mai's team has developed an energy storage scheme, known as the Mai-Yan model, that could be implemented in microchip form[2].

"Our team designed and constructed the first nanowire electrochemical energy storage device in 2010," says Mai. "Recently, we developed a way to measure the electronic transport in this structure in real time, which led to the discovery of new ways to increase the energy storage capacity of this field-effect device by more than three times."

A FET is the basis of modern electronics, in which an electrical current applied to a 'gate' terminal controls the flow of current between two adjacent 'source' and 'drain' terminals. Mai's research has shown that a charge can be stored in these devices electrochemically for future use.

▲ **Liqiang Mai leads a team to synthesize nanowire materials for electrochemical energy storage devices.**

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"This research provides a new idea for energy storage chips that could be used in a wide range of devices, such as vehicle networking, smart agriculture, medical wireless monitoring and the Internet of Things," says Mai. "Funded by the National Key Research and Development Program of China , we are now focusing on optimizing electrode materials, the electrolyte, diaphragm modification, and device assembly, as well as collaborating with scientists in electrical engineering, bioengineering and other related fields on potential applications."

INNOVATION POTENTIAL

MSE's Qingjie Zhang — another chair professor at MSE and a member of the Chinese Academy of Sciences — has been spearheading research on thermal-to-electric energy conversion in small-scale power generation devices. Thermoelectric materials convert heat to electrical current, and are often used to harvest energy from waste heat. Improving the performance of these materials could open a range of new applications that make efficient use of available energy, but advances have been slow.

By analysing the detailed physics of the thermoelectric conversion process, Zhang's team has devised a way to modify and control the transport of both electrons and phonons (energetic vibrations) through the design of nano-structures in nanocomposite materials. The breakthrough, reported in *Nature*[3], is expected to lead to significant improvements in thermoelectric performance.

MSE's materials research is not limited to energy. Zhengyi Fu — a chair professor at MSE and a member of the Chinese Academy of Engineering — has been leading an international team to conduct research on high-performance ceramics and multifunctional composites. Inspired by structure formation processes in nature, Fu's team looks to synthesize materials with the idea of 'bioprocessing-inspired fabrication'.

Based on a detailed analysis of the chemomechanical mechanisms of collagen mineralization, his team has revealed that the bone formation process provides an exciting concept for enhancing the mechanical properties of hybrid materials through the control of internal stresses, similar to concrete that is pre-stressed by steel fibres[4]. Fu is investivating the use of this finding to produce ceramic materials.

Advances in materials science have driven the development of civilization and society for thousands of years, since humans shaped the first tools, fashioned the first mud huts and smelted the first copper.

Today, materials science is helping solve global energy and climate challenges, while contributing to many other fundamental aspects of society. The MSE is making breakthroughs that promise to keep it at the forefront of this exciting field. ■

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