ADVERTISEMENT FEATURE

Sustainability-driven innovation in materials science

By bridging the gap between basic materials science and sustainable technologies, researchers at SEOUL NATIONAL UNIVERSITY are realizing new paradigms in sustainable materials, solar-driven hydrogen production and carbon dioxide capture.

For 75 years, the Department of Materials Science and Engineering (DMSE) at Seoul National University has been at the centre of South Korea's rapid growth as an industrial manufacturing and scientific powerhouse. DMSE's innovations and technological breakthroughs have significantly contributed to the country's steelmaking and semiconductor industries. And as South Korea's largest materials science hub, the department has nurtured generations of leaders in the field.

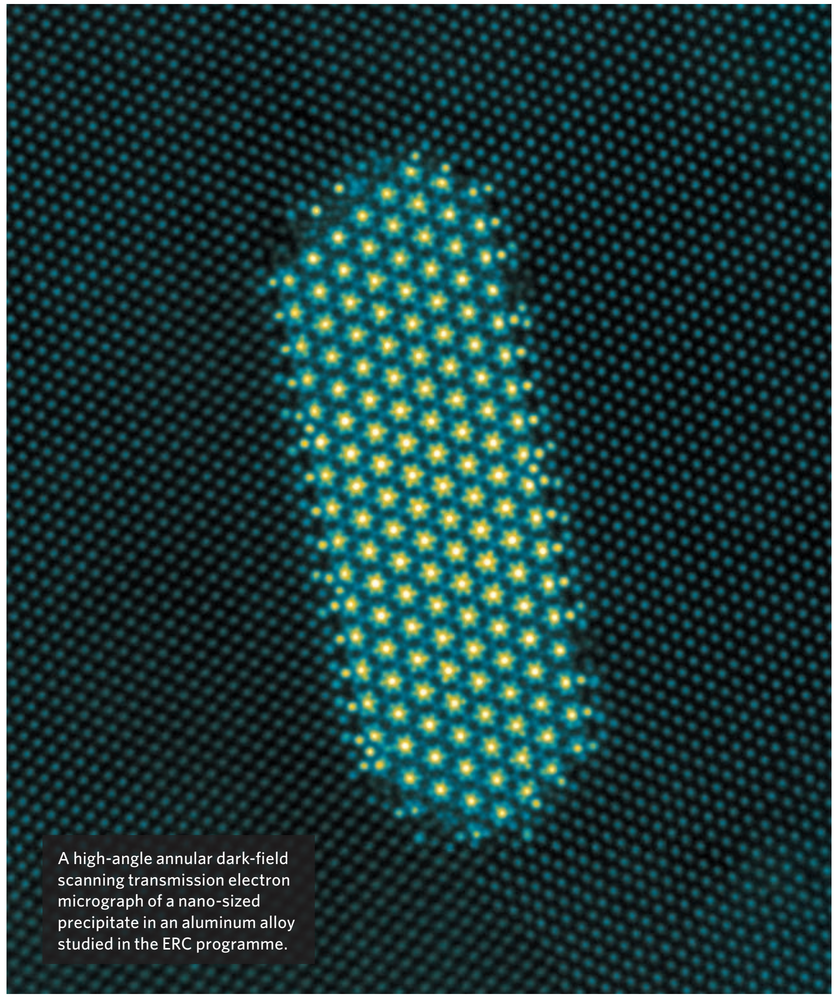
"We're now looking at process design and the development of innovative materials with a focus on reliability and sustainability to address global issues," explains Heung Nam Han, director of DMSE's Engineering Research Center (ERC, Innovative Process Design Center for Strategic Structural Materials). "By using DMSE's world-class expertise in basic materials science, state-of-the-art materials characterization and industrial engineering, we're finding new ways to reassess existing processes and create new technologies."

"OUR GOAL IS TO DIRECTLY CONVERT SOLAR ENERGY INTO HYDROGEN"

SUSTAINABLE STEEL TO SELF-HEALING METALS

The ERC is a major ongoing initiative with tens of millions of dollars in funding and dozens of partner universities, institutions and industrial leaders from South Korea and around the world.

"The status quo in many major industries on environmental and social issues such as emissions and sustainability regulation is changing rapidly," explains Han. "Companies need to be proactively developing technologies that will help them meet increasingly stringent sustainability requirements."



A high-angle annular dark-field scanning transmission electron micrograph of a nano-sized precipitate in an aluminum alloy studied in the ERC programme.

One of the ERC's biggest initiatives is a steelmaking consortium project that is building a comprehensive thermodynamic and material properties database. This will be used to simulate and optimize industrial steel-making processes, where even incremental improvements can result in huge global sustainability gains due to the enormous scale of the industry.

"Combined with a sensorized 'smart factory' and real-time process monitoring data, the platform will allow steelmakers to optimize processes for sustainability and to develop new materials systematically," says Han. "We're also taking a similar approach to develop a predictive manufacturing platform for refractory ceramics — another class of materials with promise for sustainable material applications."

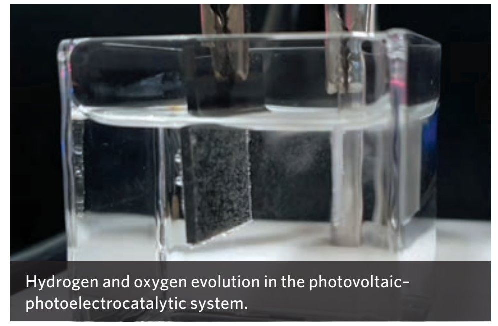
At the other end of the science-to-engineering spectrum, the translation of basic research on the electrically induced self-healing of metals is being overseen by Han. "Our research has shown that subjecting a range of metal alloys to short pulses of electric current causes them to spontaneously recrystallize or transform," Han says.

ERC researchers have experimentally shown that the microdefects that form in metals when put under strain can be 'healed' by a pulsed electric current, which causes the atoms in the crystal lattice to reorganize themselves.

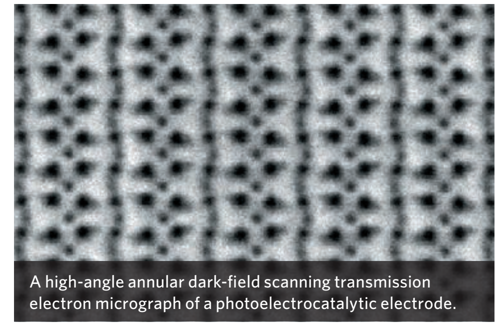
"We demonstrated this most clearly in a tensile deformation test," says Han. "We stretched a piece of 301 stainless steel under a pulsed electric current to more than eight times its original length without failure."

Ho Won Jang (left) and Jin Young Kim (right) discussing their photovoltaic–photoelectrocatalytic system with a perovskite–silcon tandem solar cell.

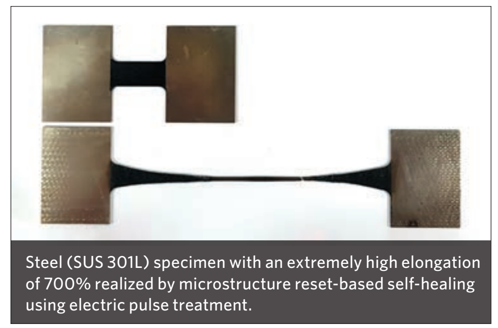
Heung Nam Han (centre) and students discussing alloy atomic structures obtained using Cs-corrected monochromated transmission electron microscopy.



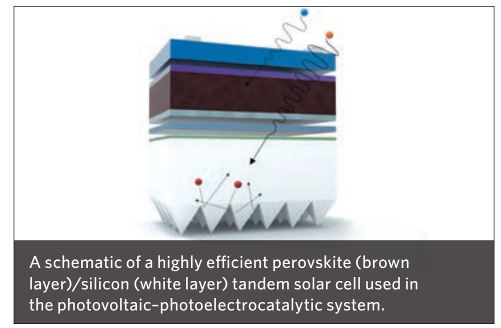
Hydrogen and oxygen evolution in the photovoltaic–photoelectrocatalytic system.



A high-angle annular dark-field scanning transmission electron micrograph of a photoelectrocatalytic electrode.



Steel (SUS 301L) specimen with an extremely high elongation of 700% realized by microstructure reset-based self-healing using electric pulse treatment.



A schematic of a highly efficient perovskite (brown layer)/silicon (white layer) tandem solar cell used in the photovoltaic–photoelectrocatalytic system.

MATERIALS: THE KEY TO HARNESSING SOLAR POWER

Hydrogen is fast becoming a central piece of the energy puzzle, but for its full potential to be realized as an efficient renewable energy carrier, we need a range of technologies that don't yet exist. Ho Won Jang, one of South Korea's leading scientists in the area of solar hydrogen production, has made a series of breakthroughs that are bringing some of these technologies closer to reality.

"Our overarching goal is to directly convert solar energy into hydrogen by splitting water," says Jang. "Our current approach is to use a photovoltaic solar cell to generate an electrical current and voltage that can, with the right catalysts, split water into hydrogen and oxygen gas — but many challenges need to be overcome."

This puzzle has two critical pieces. The first is the pair of catalysts used to evolve hydrogen and oxygen. While any pair of well-known catalysts like platinum and iridium will do the job, it has been difficult to get the voltage needed to drive the splitting reaction low enough to work with photovoltaics. This leads to the second puzzle piece — how to increase the voltage output of solar cells to a level that could drive the reaction using known catalysts.

"By finding the right pair of catalysts, we have reduced the potential needed to split water to about 1.6 volts," says Jang. "But silicon-based photovoltaic cells can only produce about 0.7 volts. So we have developed a way to stack two solar cells. With some precise fabrication and current-matching techniques, these can give an output voltage of over 1.6 volts and a high conversion efficiency of more than 29%." The setup can evolve hydrogen with a solar-to-hydrogen conversion efficiency of 20% without any external energy input.

It is a remarkable technological breakthrough that could lead to the unlimited production of hydrogen from sunlight. As with any new technology, many challenges remain, such as increasing the working life of the catalysts and lowering the cost of tandem cell fabrication. The approach has also been applied to the capture of carbon dioxide from the air using a similar setup, lighting the way to a future solar-to-fuel conversion process.

"We're sure our efforts to deal with global issues via sustainable materials science will make a big contribution to another success story with industrial and scientific partners," says Chan Park, head of DMSE. ■

Department of Materials Science and Engineering
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