New twist on synthesis technique promises sustainable manufacturing

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The innovative research builds on Tour’s 2020 development of waste disposal and upcycling applications using flash Joule heating. Credit: James Tour's Lab/Rice University.

James Tour's lab at Rice University has developed a new method known as flash-within-flash Joule heating (FWF) that could transform the synthesis of high-quality solid-state materials, offering a cleaner, faster and more sustainable manufacturing process. The findings were published in Nature Chemistry on Aug. 8.

Traditionally, synthesizing solid-state materials has been a time-consuming and energy-intensive process, often accompanied by the production of harmful byproducts. But FWF enables gram-scale production of diverse compounds in seconds while reducing energy, water consumption and greenhouse gas emissions by more than 50%, setting a new standard for sustainable manufacturing.

The innovative research builds on Tour's 2020 development of waste disposal and upcycling applications using flash Joule heating, a technique that passes a current through a moderately resistive material to quickly heat it to over 3,000 degrees Celsius (over 5,000 degrees Fahrenheit) and transform it into other substances.

"The key is that formerly we were flashing carbon and a few other compounds that could be conductive," said Tour, the T.T. and W.F. Chao Professor of Chemistry and professor of materials science and nanoengineering. "Now we can flash synthesize the rest of the periodic table. It is a big advance."

FWF's success lies in its ability to overcome the conductivity limitations of conventional flash Joule heating methods. The team—including Ph.D. student Chi Hun "Will" Choi and corresponding author Yimo Han , assistant professor of chemistry, materials science and nanoengineering—incorporated an outer flash heating vessel filled with metallurgical coke and a semiclosed inner reactor containing the target reagents. FWF generates intense heat of about 2,000 degrees Celsius, which rapidly converts the reagents into high-quality materials through heat conduction.

This novel approach allows for the synthesis of more than 20 unique, phase-selective materials with high purity and consistency, according to the study. FWF's versatility and scalability is ideal for the production of next-generation semiconductor materials such as molybdenum diselenide (MoSe2), tungsten diselenide and alpha phase indium selenide, which are notoriously difficult to synthesize using conventional techniques.

"Unlike traditional methods, FWF does not require the addition of conductive agents, reducing the formation of impurities and byproducts," Choi said.

This advancement creates new opportunities in electronics, catalysis, energy and fundamental research. It also offers a sustainable solution for manufacturing a wide range of materials. Moreover, FWF has the potential to revolutionize industries such as aerospace, where materials like FWF-made MoSe2 demonstrate superior performance as solid-state lubricants.

"FWF represents a transformative shift in material synthesis," Han said. "By providing a scalable and sustainable method for producing high-quality solid-state materials, it addresses barriers in manufacturing while paving the way for a cleaner and more efficient future."

More information: Chi Hun 'William' Choi et al, Flash-within-flash synthesis of gram-scale solid-state materials, *Nature Chemistry* (2024). DOI: 10.1038/s41557-024-01598-7

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