Scientists use electrons to pattern light sources and wiring directly onto crystals

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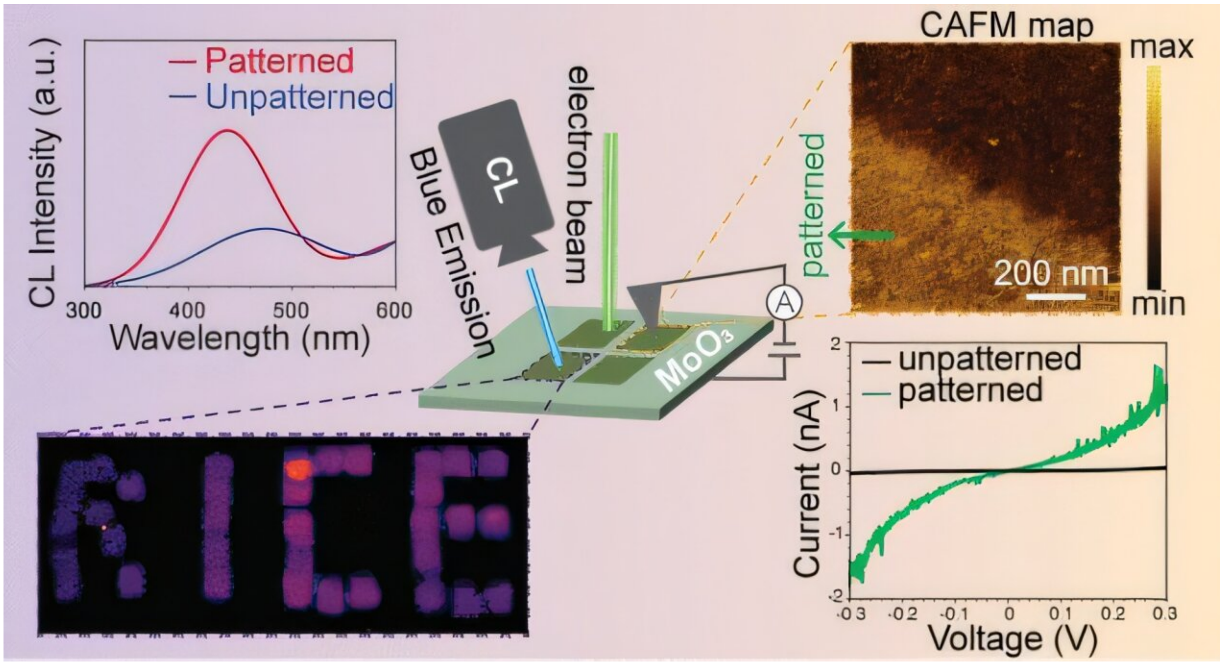
Cathodoluminescence hyperspectral mapping of a pattern spelling 'Lee' (top left); Hae Yeon Lee and Yifeng Liu (bottom left) and screen display. Credit: Jorge Vidal/Rice University

Rice University researchers used a focused electron beam to pattern device functions with submicron precision directly into an ultrathin crystal. The approach produced traces narrower than the width of a DNA helix that glow with bright blue light and conduct electricity, showing it could be used to manufacture compact on-chip wiring and built-in light sources.

"The electron beam essentially works as a nanoscale pencil," said Hae Yeon Lee, an assistant professor of materials science and nanoengineering who is a corresponding author on a study about the research published in *Nano Letters*. "This is a one-step way to draw light sources and wires at scales where control is difficult to achieve using traditional techniques like lithography."

The team worked with molybdenum oxide, a crystal made of stacked ultrathin sheets held together by weak bonds of attraction known as van der Waals forces. Unlike chemical bonds that hold atoms together in bulk three-dimensional structures, van der Waals forces act between atom-thick layers. This makes materials governed by these forces highly tunable—a quality materials scientists hope to harness for next-generation devices.

Examples of van der Waals forces at work in everyday life include the graphite in a pencil, which sheds its layers when pressed against paper; and the countless tiny folds in geckos' feet, which rely on van der Waals forces to grip walls and ceilings.



Credit: *Nano Letters* (2025). DOI: 10.1021/acs.nanolett.5c03617

"Controlling material properties is the key in engineering, and van der Waals materials are the perfect test bed for finding new ways to do so," Lee said. "This work shows we can control optical and electrical properties very precisely to pattern subwavelength features onto van der Waals materials without needing multiple, complicated steps involved with traditional techniques like lithography."

The researchers tested the idea that high-energy electrons could act like tiny hammers, knocking out oxygen atoms from the molybdenum oxide lattice. Those missing atoms—known as oxygen defects—that made the crystal both shine more brightly and carry current more easily.

"Where the electron-beam 'wrote,' blue emission grew quickly and stayed bright," said Yifeng Liu, a Rice postdoctoral researcher who is a lead author on the study. "These patterns also become hundreds of times more conductive, forming sharp built-in wires."

Because the electron beam spot is so fine, the patterns reached scales of only a few hundreds of nanometers across. That precision makes it possible to potentially integrate glowing traces and nanoscale wiring directly into chips, sensors and other devices.

Yifeng Liu (from left) and Hae Yeon Lee working on the new cathodoluminescence spectroscopy system in the Shared Equipment Authority facilities at Rice University. Credit: Jorge Vidal/Rice University

The work relied on a new cathodoluminescence spectroscopy system at Rice's Shared Equipment Authority, a facility that provides world-class research tools and expertise to researchers at Rice and beyond, making advanced experiments affordable and accessible across science and engineering.

The researchers used the instrument to both create the oxygen defects in molybdenum oxide crystals and to record the light emitted in the process, called cathodoluminescence. This allowed them to track the changes to crystal lattice in real time and characterize the emerging properties.

"We also confirmed the emergence of oxygen defects by complementary characterization techniques," Liu said. "Overall, what is exciting about this work is achieving all of these material effects simultaneously. We are not doing separate steps for optics and electronics. We are writing both at once, in one material, with really high precision."

The researchers say the method could extend beyond molybdenum oxide to other van der Waals oxides, offering a new toolkit for designing next-generation optoelectronic devices.

More information: Yifeng Liu et al, Spatial Control of Optical Emission and Conductivity in Molybdenum Oxide through Electron-Beam Irradiation, *Nano Letters* (2025). DOI: 10.1021/acs.nanolett.5c03617

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