Scientists create 'virtual sorting nanomachines' using electron beams to manipulate graphene oxide

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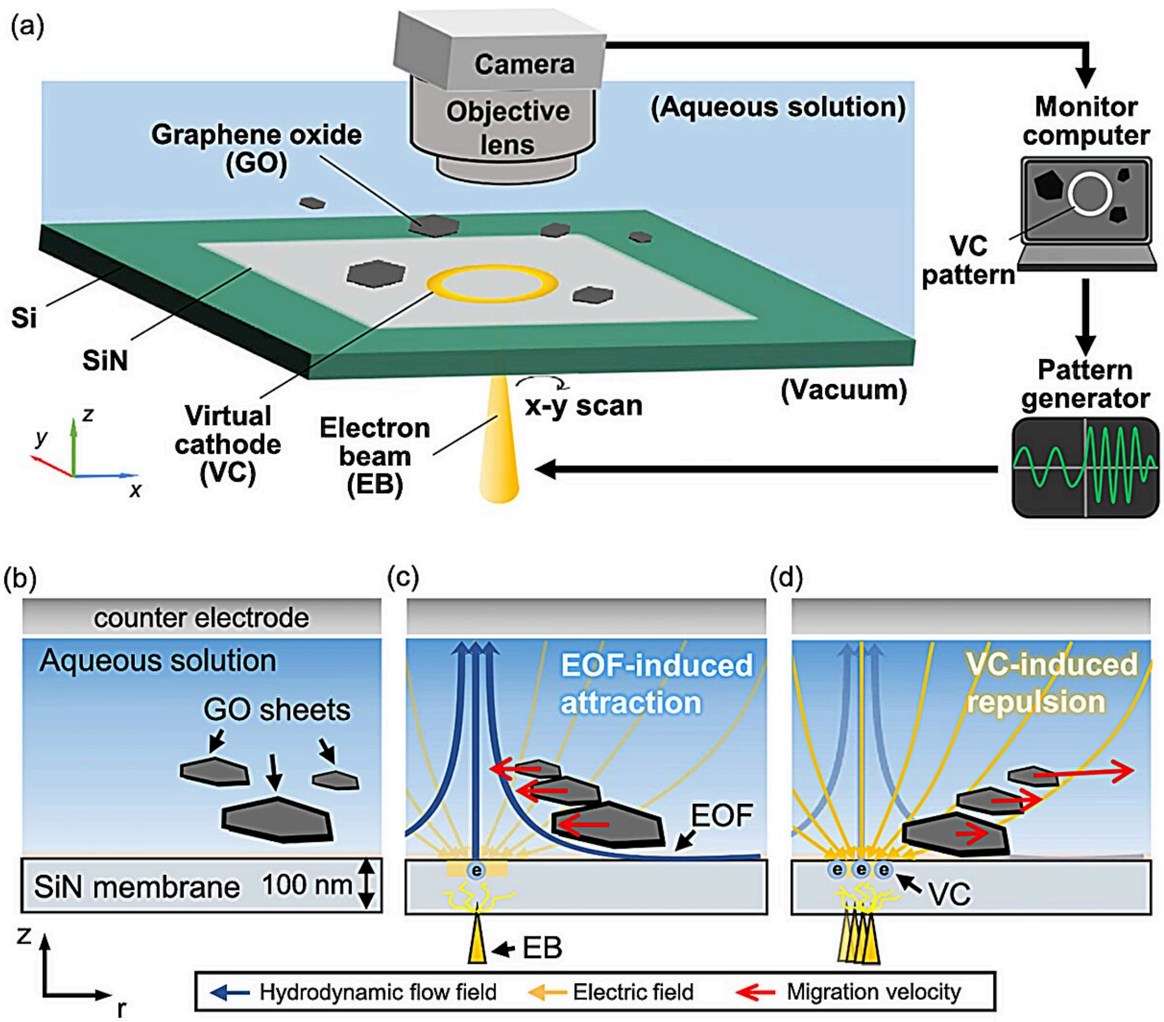

Overview of dynamic graphene oxide sorting: (a) The system uses electron beams on silicon nitride membranes to create electric field patterns that generate opposing forces on graphene oxide sheets. (b) Starting state with graphene oxide sheets in a solution. (c) Middle step showing sheets pulled toward the pattern by electroosmotic flow. (d) Final stage where different-sized sheets move away from the pattern at different speeds due to electrophoretic repulsion forces. Smaller sheets move faster because of their higher surface charge-to-mass ratio. Credit: Sasaki and Hoshino, 2025

Researchers at Nagoya University in Japan have developed an interface that creates "virtual sorting nanomachines" without the need to manufacture actual devices.

By projecting electron beams onto thin silicon nitride membranes, they generated programmable electric fields that function like microfluidic devices—systems that move very small amounts of fluids through microscopic channels. This allows them to move and sort nanomaterials by size at any desired location and time.

The findings are published in the journal *Colloids and Surfaces A: Physicochemical and Engineering*.

The scientists used graphene oxide (GO), a carbon material just one atom thick. Its properties and cellular interactions vary by sheet size, making size-sorting methods important. Traditional methods need complex prefabricated microfluidic devices with fixed structures.

The new method removes this limitation by creating temporary, programmable electric field patterns that can be instantly moved or reconfigured. This enables precise sorting of GO sheets, which can then capture pollutants, solvents, and biomolecules based on their size-dependent properties.

When electric field patterns are projected onto a solution with GO sheets, two forces work simultaneously but in opposite directions: an electroosmotic flow pulls the sheets toward the pattern, and an electrophoretic repulsion force pushes them away. This movement occurs because of the difference in the ratio of surface charge to mass between GO sheets of different sizes.

Smaller GO sheets have less total charge, but they also have significantly less mass and volume. This gives them a higher surface charge-to-mass ratio, causing them to move faster when repelled by the electric field. The researchers measured the speeds of different-sized GO sheets (5–50 μm^2) and found that as sheet size decreases, repulsion speed increases proportionally.

This allowed them to separate the sheets by size at specific locations and create virtual sorting nanomachines that appear on demand and do not require complex prefabricated microfluidic devices.

The researchers were able to improve control over the graphene sheets by changing the electric field patterns. For example, they made different ring patterns that periodically change to improve the separation of various-sized sheets and created moving semi-circle patterns to push the sheets in different directions in the solution.

"This research represents a paradigm shift in nanomaterial processing," Ph.D. student and lead author Ken Sasaki commented. "Instead of building complex microfluidic devices, we can now program virtual nanomachines that appear and function on demand. This allows material-free manufacturing where mechanical work is performed by programmable force fields."

Professor Takayuki Hoshino from the Department of Micro-Nano Mechanical Science and Engineering at Nagoya University highlighted that this technology has significant potential for environmental remediation and health care applications.

"For example, if an industrial spill occurs, this technology could be developed for on-site deployment to sort GO sheets for optimal removal of contaminants, rather than transporting materials to a facility first," he explained.

More information: Ken Sasaki et al, Size fractionation of graphene oxide sheets by electron beam-addressing localized electrophoresis, *Colloids and Surfaces A: Physicochemical and Engineering Aspects* (2025). DOI: 10.1016/j.colsurfa.2025.137056

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