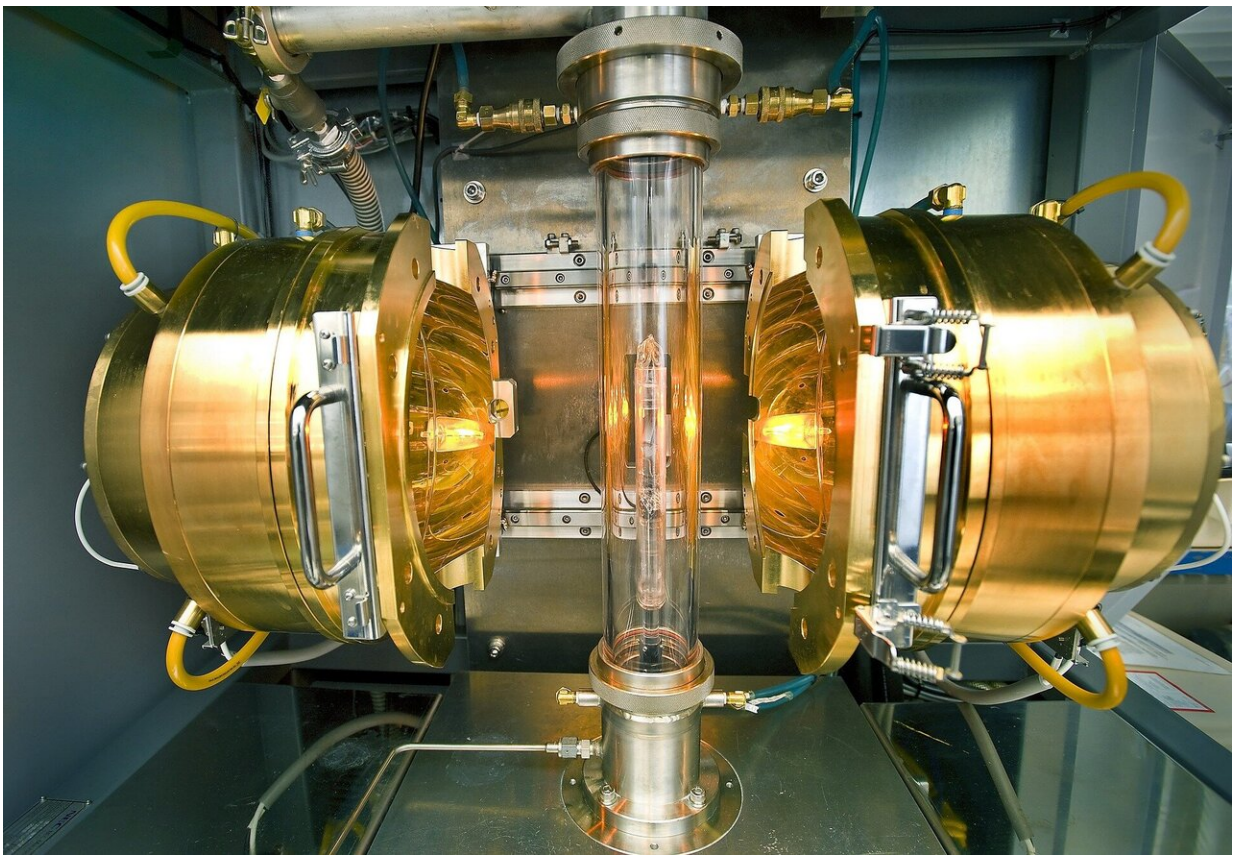
A simple way to control superconductivity: Twisting atomically thin layers fine-tunes properties

March 20 2025



Credit: CC0 Public Domain

Scientists from the RIKEN Center for Emergent Matter Science

(CEMS) and collaborators have discovered a new way to control superconductivity—an essential phenomenon for developing more energy-efficient technologies and quantum computing—by simply twisting atomically thin layers within a layered device.

By adjusting the twist angle, they were able to finely tune the "superconducting gap," which plays a key role in the behavior of these materials. The research is published in *Nature Physics*.

The superconducting gap is the energy threshold required to break apart Cooper pairs—bound electron pairs that enable superconductivity at low temperatures. Having a larger gap allows superconductivity to persist at higher, more accessible temperatures, and tuning the gap is also important for optimizing Cooper pair behavior at the nanoscale, contributing to the high functionality of quantum devices.

To date, efforts to control the superconducting gap have largely focused on "real space," in the physical position of particles. However, achieving control in momentum space—a different mapping that shows the energy state of the system—has remained elusive. Fine-tuning the gap in momentum space is crucial for the next generation of superconductors and quantum devices.

In an effort to achieve this, the group began working with ultrathin layers of niobium diselenide, a well-known superconductor, deposited on a graphene substrate. Using advanced imaging and fabrication techniques, such as spectroscopic imaging, scanning tunneling microscopy and molecular beam epitaxy, they precisely adjusted the twist angle of the layers.

This modification produced measurable changes in the superconducting gap within momentum space, unlocking a novel "knob" for precisely tuning superconducting properties.

According to Masahiro Naritsuka of CEMS, the first author of the paper, "Our findings demonstrate that twisting provides a precise control mechanism for superconductivity by selectively suppressing the superconducting gap in targeted momentum regions.

"One surprising discovery was the emergence of flower-like modulation patterns within the superconducting gap that do not align with the crystallographic axes of either material. This underscores the unique role of twisting in shaping superconducting properties."

Tetsuo Hanaguri of CEMS, the last author, added, "In the short term, our research deepens the understanding of superconducting systems and inter-layer interactions, advancing the design of superconductors with tailored properties. In the long term, it lays the foundation for developing energy-efficient technologies, quantum computing, and beyond.

"Next steps involve investigating whether magnetic layers can be integrated into the structure to enable both spin and momentum selectivity. These advances could unlock new research opportunities and pave the way for developing innovative materials and devices."

More information: Masahiro Naritsuka et al, Superconductivity controlled by twist angle in monolayer $NbSe_2$ on graphene, *Nature Physics* (2025). DOI: 10.1038/s41567-025-02828-6

Provided by RIKEN