# Flowermon: A superconducting qubit based on twisted cuprate van der Waals heterostructures

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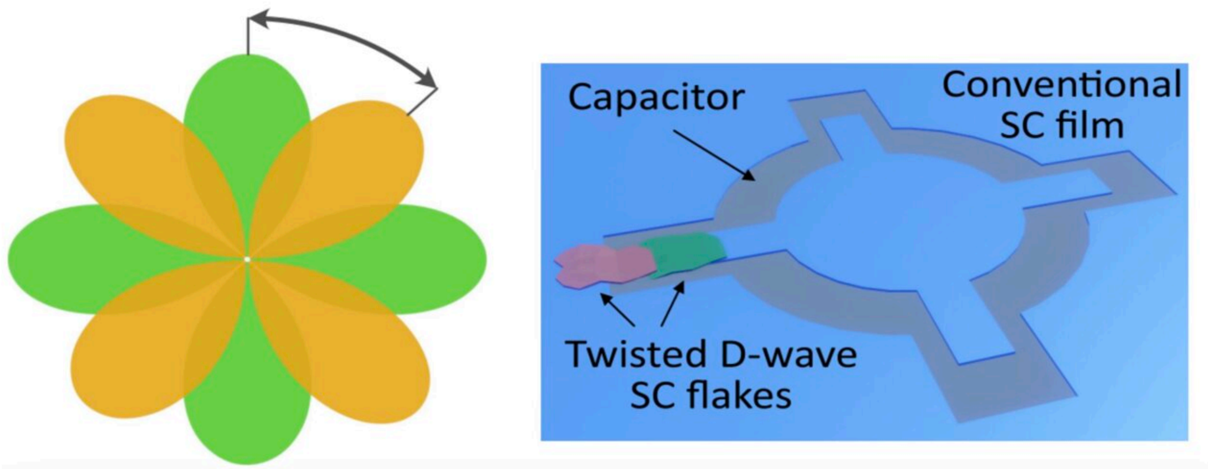


Right: Design of the flowermon qubit with a single d-wave junction shunted by a large capacitor. Left: Structure of the order parameter for twisting angles close to 45°. Credit: Brosco et al

Quantum technology could outperform conventional computers on some advanced optimization and computational tasks. In recent years, physicists have been working to identify new strategies to create quantum systems and promising qubits (i.e., basic units of information in quantum computers).

Researchers at the Institute for Complex Systems of CNR (Consiglio Nazionale delle Ricerche), Max Planck Institute for Chemical Physics of Solids, and other institutes worldwide have recently introduced a new superconducting and capacitively shunted qubit, which they dubbed "flowermon." This qubit, introduced in *Physical Review Letters*, is based on twisted cuprate van der Waals heterostructures.

"The project came about by a nice chance, during an attempt to combine the languages of our different expertise in conversation," Uri Vool, co-author of the paper, told Phys.org. "The initial motivation was the recent work of our collaborator Nicola Poccia, who was able to achieve a 'twisted van der Waals heterostructure' where they can control the angle between individual layers in the novel cuprate superconductor BSCCO without ruining its unique properties.

"Nicola Poccia asked Valentina Brosco and I if this could be used in any way as a qubit or device for quantum technology. Initially I was quite skeptical, but this led to several brainstorming sessions between Valentina and I that eventually converged on the idea presented in our paper."

Most experiments aimed at creating quantum superconducting circuits have employed conventional and extensively studied superconducting materials, such as aluminum or niobium. Around the year 2000, however, some theoretical physicists explored the idea of introducing noise-protected superconducting circuits that leverage the unique symmetry of unconventional superconductors.

As realizing this idea in experimental settings appeared unfeasible at the time, these theoretical works were abandoned for several years. The recent study by Vool, Poccia, Brosco and their colleagues brings this idea back to create a new superconducting qubit.

"As superconducting circuits developed, there were several proposals to create circuits with protection from noise by designing the circuit elements in a way that achieves a symmetry," Vool said. "These ideas are very interesting, but experimental implementation was always challenging as imperfections, e.g., in the relative inductance of the circuit elements or the applied flux in the loop they form broke the symmetry and degraded their performance.

"In the flowermon, we noticed that a simple circuit using a twisted van der Waals cuprate heterostructure also provides this protection, which comes from the symmetry of the material itself and not the circuit placement."

The unique structure and properties of the flowermon, the qubit introduced by this research team, can greatly enhance the robustness of a superconducting circuit, as it removes the need for tuning or flux. Building on previous research efforts focusing on protected circuits, Vool and his colleagues demonstrated the potential of materials with an inherent symmetry for creating quantum superconducting systems.

"Our work shows that using materials with inherent symmetry as opposed to engineered symmetry yields a robust qubit that doesn't require fine-tuning," Vool explained. "The flowermon modernizes the old idea of using unconventional superconductors for protected quantum circuits and combines it with new fabrication techniques and a new understanding of superconducting circuit coherence."

The new qubit introduced by the researchers is essentially comprised of a single BSCCO van der Waals Josephson junction. This junction has a twisting angle of around 45°, shunted by a large capacitor and a read-out superconducting resonator.

"Despite its simplicity, the unique twisted d-wave nature of the order parameter allows the flowermon to encode information in parity-preserving eigenstates," Valentina Brosco, co-author of the paper, said. "Ideally, this brings orders of magnitude improvement in the relaxation time over the well-known transmon. Furthermore, the control over the twisting angle demonstrated in the experiment, suggests that, contrary to what happens in standard d-wave junctions, in the flowermon quasi-particle induced dissipation is exponentially suppressed."

The flowermon's simple design leverages the complex and peculiar features of Josephson tunneling between two thin flakes of BSCCO with a relative twisting angle.

A further advantage of the new qubit is its distinctive spectral structure, which enables the manipulation of circuit quantum electrodynamics (cQED) and read-out schemes.

"I think the flowermon yields an excellent illustration of the emerging functionalities achievable through the integration of complex materials and heterostructures in quantum devices, particularly within the realm of superconducting circuits," Brosco said. "What I found extremely interesting and fascinating is that the strength of the flowermon circuit is built-in the many-body wavefunction that leads to a current-phase relation with a dominant two Copper pair tunneling term."

In contrast with other parity-protected qubits that are realized through complex circuit engineering, the flowermon relies on naturally occurring physical mechanisms. The reported robustness of this unique design could inspire other physicists to explore the potential of twisted van der Waals cuprate heterostructures for creating superconducting circuits.

"The idea behind the flowermon can be extended in several directions: searching for different superconductors or junctions yielding similar effects, exploring the possibility to realize novel quantum devices based on the flowermon," Brosco said. "These devices would combine the benefits of quantum materials and coherent quantum circuits or using the flowermon or related design to investigate the physics of complex superconducting heterostructures."

Vool, Brosco, and their collaborators now plan to conduct additional theoretical and experimental studies. In their theoretical work, they plan to address various aspects of the circuit they introduced.

Notably, the flowermon circuit opens a new possible route for broadening the understanding of unconventional superconductors using quantum circuits. This is highly relevant, as the properties of these materials remain one of the biggest mysteries in condensed matter physics.

"This is only the first simple concrete example of utilizing the inherent properties of a material to make a new quantum device, and we hope to build on it and find additional examples, eventually establishing a field of research that combines complex material physics with quantum devices," Vool added.

"Experimentally, there is still quite a lot of work towards implementing this proposal. We are currently fabricating and measuring hybrid superconducting circuits which integrate these van der Waals superconductors, and hope to utilize these circuits to better understand the material, and eventually design and measure protected hybrid superconducting circuits to make them into real useful devices."

**More information:** Valentina Brosco et al, Superconducting Qubit Based on Twisted Cuprate Van der Waals Heterostructures, *Physical Review Letters* (2024). DOI: 10.1103/PhysRevLett.132.017003. On *arXiv*: DOI: 10.48550/arxiv.2308.00839

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