Researchers Uncover Movement in Areas Where Physics Indicated None Should Exist

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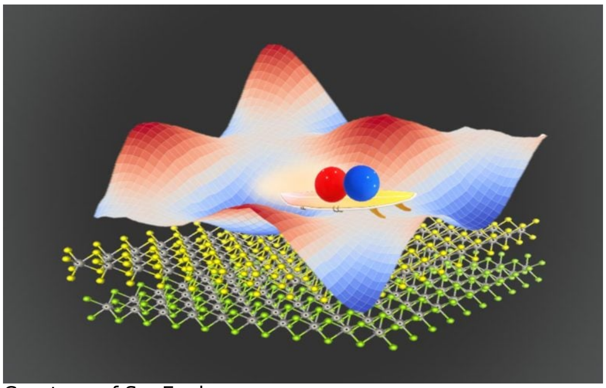

Courtesy of SynEvol
Credit: Lawrence Berkeley National Laboratory

By layering and slightly twisting two images with repeating shapes, such as squares or triangles, a moiré pattern emerges: a more prominent, wavelike design that appears to undulate across the surface. It’s a remarkable visual illusion produced by basic repetition and arrangement.

A comparable occurrence takes place at the nanoscale when researchers layer ultra-thin sheets of substances known as transition metal dichalcogenides (TMDs), which consist of mere atoms in thickness. This arrangement forms what is referred to as a moiré potential, a recurring energy structure with highs and lows between the layers. These moiré patterns can lead to unique electronic and optical properties.

Until now, moiré potentials were believed to be stationary. However, scientists at the Molecular Foundry within Lawrence Berkeley National Laboratory fou something unexpected: in layered TMDs, the moiré potential isn't fixed – it shifts, even at very low temperatures.

Their finding adds to essential understanding in materials science. It also offers potential for enhancing the stability of quantum technologies since manag moiré potentials may assist in reducing decoherence in qubits and sensors. Decoherence happens when interference leads to the loss of the quantum stat and its information. The scientists released their results in ACS Nano. This study is a component of larger initiatives at Berkeley Lab aimed at enhancing quantum information systems by collaborating within the quantum research framework, spanning theory to practical use, to create and evaluate quantum devices and to design software and algorithms.

The study was conducted by Antonio Rossi, a past postdoctoral researcher with Molecular Foundry staff scientist Alex Weber-Bargioni. Rossi returned to Berkeley Lab to work with Molecular Foundry staff scientist Archana Raja and utilize the resources in the Foundry's Imaging and Manipulation of Nanostructures facility.

Raja's laboratory emphasizes the characterization of 2D materials through ultrafast lasers and optical spectroscopy at temperatures lower than -150°C. By the layered TMD samples with a green pulsed laser, electrons are energized, prompting them to transition from their ground state to an excited state. Ene electrons create a 'hole' that carries a positive charge, leading to the formation of an electron-hole pair or exciton.

Excitons are recognized to develop in monolayer materials. Nonetheless, excitons in the two-layer system separate; electrons transition to the tungsten d layer while positively charged holes remain in the tungsten diselenide layer. Within the materials community, these unique layer-jumping excitons are refe as "interlayer excitons" or IXs.

Rossi stated, "One would anticipate the moiré valleys to function as traps." "Thus, once the exciton is inside, it's essentially confined." It feels as though y seated (in a valley), surrounded solely by the mountains. "You aren't making any progress."

Nevertheless, the team observed that IXs navigated the moiré's seascape even while being confined within it. "It requires minimal energy to set this moir in motion, so the moiré behaves just like a turbulent ocean," Rossi explained.

"We demonstrated that even in extremely low temperatures, energy and information are not as concentrated as one might assume." "This occurs due to a 'mechanical property' of the Moiré pattern," stated Raja. "There are various methods to convey energy and information across different temperatures." "T different approach to achieve that."

Collaborator Jonas Zipfel, a postdoctoral researcher in Raja's team, collaborated with Rossi to automate their measurements to gain a deeper insight into movement of the excitons. "Jonas' efforts allowed us to effortlessly gather luminescence spectra, images, and lifetime (data), which in turn helped us dete diffusivity (movement) of the excitons," stated Raja.

To facilitate the visualization of moving excitons, Johannes Lischner and Indrajit Maity from Imperial College London employed simulations to capture imag moiré potential "seascape." They were curious about its behavior at various times.

Collaborating with theorists Lischner and Maity, the research team concluded that the only sensible explanation for their findings is that the moiré potenti be in motion.

The researchers suggest that a low-temperature quasiparticle known as a phason allows the IX to shift even when it's confined. A quasiparticle is a quantu found in a crystal lattice; it possesses momentum and position, typically acting like a particle. Phasons are quasiparticles believed to be inherently found moiré potential.

"You have the (interlayer) exciton gliding over the moiré and shifting positions," Rossi remarked. He thinks the phason facilitates movement like a surfboa surfer to ride waves. "It's somewhat like transporting the exciton, in a sense."

Rossi and his team discovered that the movement of interlayer excitons within the moiré potential varies with both angle and temperature. Their moveme its peak when TMD layers are aligned parallel (when the molecules of the stacked layers orient in the same direction).

Surprisingly, when the system temperature nears zero, the movement of the interlayer excitons diminishes gradually to a value that is just above zero, in stopping entirely. Although the quantity is limited, it holds importance.

Rossi stated, "It was unexpected to discover that this movement occurs even at very low temperatures when everything is meant to be frozen."

His subsequent actions involve exploring the superconductivity in twisted bilayer graphene that could be attributed to phason quasiparticles. Rossi is pres conducting research at the Center for Nanotechnology Innovation within NEST, Institute of Technology Italy.

Raja is keen on investigating various semiconductor and moiré systems. She is also fascinated by the potential to image phasons directly. She stated, "Ou comes from the spread of the (interlayer) exciton, but we haven't exactly caught the phason in the act, yet."