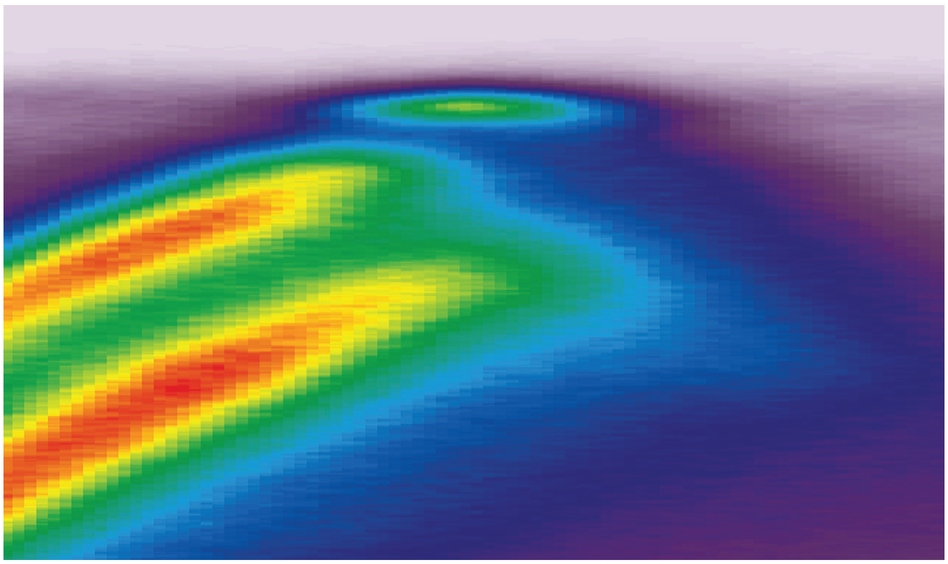
ADVANCED LIGHT SOURCE

MATERIALS SCIENCES

The Flat Band in Magic-Angle Graphene Visualized



Nanofocused angle-resolved photoemission spectroscopy (nanoARPES) of twisted bilayer graphene, performed at the MAESTRO beamline at the ALS, shows a flat electronic band near the Fermi level (boundary between light and dark purple regions).

Scientific Achievement

At the Advanced Light Source (ALS), researchers visualized flat band structures associated with exotic electronic phases in stacked graphene layers offset from each other by a "magic angle."

Significance and Impact

The work corroborates theoretical predictions and discusses a new flexible testbed to study correlation effects that are leading to topological phases and superconductivity.

Graphene with a twist

Graphene consists of a single sheet of carbon atoms that form a hexagonal lattice resembling chicken wire. One of the many fascinating properties of graphene is its extremely high electron mobility. The charge carriers in the system act as if they are massless—a condition signified by linear (cone-shaped) electronic band structures.

When two graphene layers are stacked on top of each other, the electronic bands are modified through interlayer coupling and orbital mixing, resulting in parabolic band structures. It's also possible to tune the material's behavior by introducing a small twist angle between the two layers. Due to the mismatch between the offset hexagonal lattices, the twist produces a moiré-patterned superlattice that can also affect electronic properties, depending on the twist angle.

Magic-angle moiré

It has been theorized that, at a twist angle of about 1° (the "magic angle"), twisted bilayer graphene (tBLG) will exhibit flattened electronic bands near the charge-neutrality point (where upper and lower bands meet). An implication of this flat band structure is a high density of states, which has been known to provide a platform for emergent electronic phases involving strong (correlated) electron interactions. For example, magic-angle tBLG can host both strongly correlated insulating and superconducting states that can be controlled by doping the material with charge carriers using an applied gate voltage.

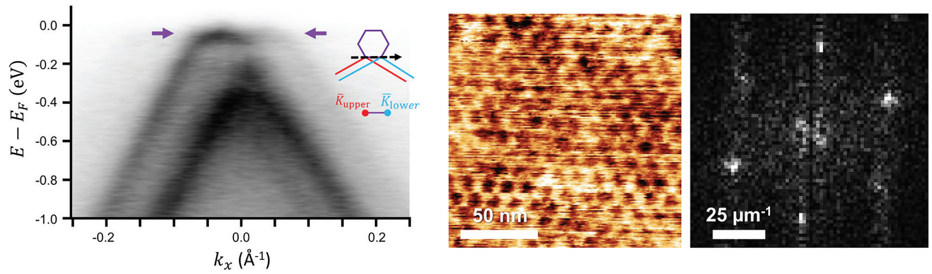
In general, magic-angle tBLG has been shown to exhibit a rich phase diagram at low temperature, making it a promising, relatively simple system for the study of exotic phenomena such as unconventional superconductivity, topological phases, and orbital magnetism. Although the implications of flat band dispersions have been widely reported, flat bands in tBLG had never before been directly visualized experimentally.

MAESTRO resolves the flat bands

In this work, the researchers used nanofocused angle-resolved photoemission spectroscopy (nanoARPES) at ALS Beamline 7.0.2 (MAESTRO) to probe tBLG samples for evidence of the flat bands, which are difficult to resolve using other methods. Moreover, the high spatial resolution of the nanoARPES beamline is crucial in light of the micron-sized effective sample area, along with the inhomogeneity and local variations in the twist angle that are known to occur in fabricated tBLG samples. Following the nanoARPES experiment, the magic-angle twist of the sample was verified by measuring the periodicity of the moiré superlattice as imaged by scanning impedance microwave microscopy (sMIM).

Toward a future "twistronics"

The measurements demonstrated the existence of the predicted flat bands in magic-angle tBLG near the charge-neutrality point at room temperature. In particular, the results provided direct evidence that the localized electronic states associated with the moiré geometry are responsible for the observed exotic behaviors. Future efforts will involve detailed nanoARPES studies of other flat band structures induced by moiré superlattices in related van der Waals heterostructure systems, including observations of electronic behavior at different doping levels induced by in situ electrostatic gating. Overall, the direct visualization enabled by the nanoARPES capability at MAESTRO should help researchers gain a more quantitative understanding of moiré-based physics, or "twistronics," in magic-angle tBLG and other materials.



Left: A nanoARPES spectrum along momentum cut that passes the K points of both graphene layers. The flat band is observed near the Fermi level (purple arrows). Center: The moiré lattice formed in tBLG as probed by sMIM. Right: A fast Fourier transform of the image on the left allowed determination of a ~0.96° twist angle.

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Publication: M.I.B. Utama, R.J. Koch, K. Lee, N. Leconte, H. Li, S. Zhao, L. Jiang, J. Zhu, K. Watanabe, T. Taniguchi, P.D. Ashby, A. Weber-Bargioni, A. Zettl, C. Jozwiak, J. Jung, E. Rotenberg, A. Bostwick, and F. Wang, "Visualization of the flat electronic band in twisted bilayer graphene near the magic angle twist," *Nat. Phys.*, doi:10.1038/s41567-020-0974-x (2020).

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Funding: U.S. Department of Energy, Office of Science, Basic Energy Sciences program (DOE BES); Ministry of Education, Culture, Sports, Science and Technology, Japan; Japan Science and Technology Agency; Korean National Research Foundation; Korean Ministry of Science and ICT; Korea Institute of Science and Technology Information; and Samsung Science and Technology Foundation. Operation of the ALS is supported by DOE BES.Operation of the ALS is supported by DOE BES.

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