

Microwave-Assisted Unidirectional Superconductivity in Al-InAs Nanowire-Al Junctions under Magnetic Fields

Haitian Su

Beijing Academy of Quantum Information Sciences

The work addresses the enhancement of the superconducting diode effect (SDE) and the emergence of unidirectional superconductivity (USC) in Al-InAs nanowire-Al junctions under microwave irradiation and magnetic fields. The SDE describes asymmetric critical currents in superconducting systems. Recently, the SDE has received considerable interest. When one of the critical currents is zero, it is called the ideal SDE. To go further, when both critical currents lie on the same side of zero, it is called USC. Two theoretical studies have investigated the enhancement effect of microwaves on the SDE and the causes of USC emergence. However, there is a dearth of experimental studies. We have conducted relevant experimental research and obtained some novel results.

Our research is based on Josephson junctions. The simple structure of this device can facilitate more extensive research, and our experiments have good reproducibility. The results of our work are summarized briefly as follows: (a) USC has been observed for the first time in a semiconductor Josephson junction; (b) The enhancement effect of microwave irradiation on the SDE under different magnetic fields was studied systematically; (c) The simulation results of the RSJ model cannot explain the experimental results well, suggesting that nonequilibrium transport may play a role in this periodically driven system.

Ultrafast giant enhancement of second harmonic generation in a strongly correlated cobaltite

Yuchen Cui

Beijing Academy of Quantum Information Sciences

We report the observation of ultrafast photoinduced giant enhancement of optical second harmonic generation (SHG) in $\text{YbBaCo}_4\text{O}_7$ cobaltite. Upon femtosecond pumping at energies above the band gap, the system exhibits an ultrafast enhancement in SHG intensity, reaching up to 60 % higher than the unperturbed value, then decays into a metastable state maintaining the enhancement. A pure electronic process sets in within the first 200 femtoseconds and is accompanied by a pronounced anisotropic amplification of second-rank optical tensors. We propose this anomalous SHG enhancement originates from ultrafast electronic band renormalization owing to dynamical modification of multi-electron correlations. In stark contrast to conventional asymmetric systems where SHG is typically suppressed upon photoexcitation, our experimental findings shed a new light on ultrafast optical control nonlinear properties in emerging quantum materials.

Robustness and real-space chiral rotation of flat bands in twisted trilayer graphene moiré quasicrystals

Chenyue Hao

Beijing Normal University

Moiré structures formed by twisting three layers of graphene with two independent twist angles present an ideal platform for studying correlated quantum phenomena, as an infinite set of angle pairs is predicted to exhibit flat bands. Moreover, the two mutually incommensurate moiré patterns among the twisted trilayer graphene (TTG) can form highly tunable moiré quasicrystals [1]. This enables us to extend correlated physics in periodic moiré crystals to quasiperiodic systems. However, direct local characterization of the structure of the moiré quasicrystals and of the resulting flat bands are still lacking, which is crucial to fundamental understanding and control of the correlated moiré physics. Here, we demonstrate the existence of flat bands in a series of alternating twisted trilayer graphene (ATG) with various twist angle pairs. Our direct spatial mappings, supported by theoretical calculations, reveal that the localization of the flat bands exhibits distinct symmetries in different regions of the moiré quasicrystals.

Moreover, through a systematic real-space investigation comparing flat-band states across four representative graphene moiré systems, we directly observe that ultra-small twist-angle helical trilayer graphene (HTG) unveils distinct C_{3z} -symmetric electronic states localized at certain moiré sites within the flat-band regime, distinguishing it from other moiré systems. Spatial mapping of the C_{3z} -symmetric pattern reveals a chiral rotation that varies as a function of energy. Theoretical simulations reveal that this chiral rotation arises from the variation in the intrinsic characteristics of discrete low-energy minibands. Our results demonstrate that real-space electronic textures—previously overlooked—can partially reveal the intrinsic disparities among different flat bands, highlighting that systematic exploration of flat bands across moiré systems is critical for deciphering the origins of distinct correlated phases.

References:

- [1] Uri, A. et al., Nature 620, 762–767, (2023).
- [2] Hao, C.-Y. et al., Nat. Commun. 15, 8437 (2024).
- [3] Hao, C.-Y. et al., Phys. Rev. B 108, 125429, (2023).
- [4] Zhen, Q., Hao, C.-Y. et al., Phys. Rev. Lett. 129, 076803 (2022).
- [5] Liu, Y.-W., Hao, C.-Y. et al., Phys. Rev. Applied 17, 034013 (2022).
- [6] Hao, C.-Y. et al., Phys. Rev. Lett. (under review).

Emergence of exotic quantum states of Dirac fermions under anisotropic potentials

Huiying Ren

Beijing Normal University

The type of confined quasiparticles significantly affects the properties of the quantum confined systems. In the realm of quantum confinement, early research focused primarily on the quantum confinement behavior of traditional Schrödinger fermions. However, with the continuous deepening of research on two-dimensional materials such as graphene, quantum-confined Dirac fermions have gradually attracted researchers' interest due to the emergence of exotic quantum states. In this report, we achieve controllable construction of confined Dirac fermion systems (i.e., graphene quantum dots, GQDs) by precisely inserting 1T' -phase WSe₂ nanoscale islands at the interfaces of graphene/WSe₂ heterostructures via scanning tunneling microscope (STM) lithography¹. Furthermore, by triggering local phase transitions in interfacial WSe₂ islands or generating one dimensional (1D) domain boundaries within them, we have achieved nanoscale-precise control over the anisotropy of the confining potential in GQDs². Building on the anisotropic confining potential we constructed^{1,2}, we have performed a series of in-depth studies. In the elliptical potential, we achieved the first realization of orbital hybridization in artificial atoms and directly visualized the hybridized orbitals in real space³. In the quasi-1D potential, we explicitly uncover two density waves with different velocities induced by electron-electron interactions—an observation attributed to real-space spin-charge separation⁴. In the anisotropic atomic collapse potential, we observed the anisotropic atomic collapse state, and pioneered the study of the effects of inter-orbital angular momentum scatterings on quantum phases and quasiparticle interference⁵.

References:

1. Y.-N. Ren[#], M.-H. Zhang[#], X.-F. Zhou[#], Q. Zheng[#], **H.-Y. Ren**, L. He, *Phys. Rev. B* **110**, 125416 (2024).
2. **H.-Y. Ren**[#], Y. Mao[#], Y.-N. Ren, Q.-F. Sun, L. He, *ACS Nano* **19**, 1352–1360 (2025).
3. Y. Mao[#], **H.-Y. Ren**[#], X.-F. Zhou[#], Y.-H. Xiao, Y.-C. Zhuang, Y.-N. Ren, L. He, Q.-F. Sun, *Nature* **639**, 73–78 (2025).
4. **H.-Y. Ren**[#], Y.-N. Ren[#], Q. Zheng[#], J.-Q. He, L. He, *Phys. Rev. B* **108**, L081408 (2023).
5. **H.-Y. Ren**[#], Y.-C. Zhuang[#], W.-X. Zhao, Y.-N. Ren, Q.-F. Sun, L. He, *Phys. Rev. Lett.* under review.

Intrinsic heavy Wigner crystal formed by transferred 4f electrons

Zhongjie Wang
复旦大学

As a quintessential quantum matter, realizing robust Wigner crystals and achieving their angstrom-scale imaging remain formidable challenges. Here, we devise an original charge-transfer-crystallization strategy to realize intrinsic electron solid made of 4f-electrons. The highly localized and correlated nature of 4f electrons gives rise to a heavy Wigner crystal characteristic of record-high density ($2.02 \times 10^{13}/\text{cm}^2$) and melting temperature (>60 K). Q-plus atomic force microscopy and Kelvin probe force microscopy are employed to directly image the Wigner crystal, by which the sub-unit-cell localization and electrostatic influence of Wigner electron are accurately determined. Moreover, the collective tunneling is captured, underlining the quantum nature of Wigner crystal. Our discovery presents the 4f system as a tunable platform with the charge-transfer degree of freedom to study 2D many-body correlation of heavy electrons.

First-principles study on the carrier-phonon scattering mechanisms in boron-based semiconductors

Zirui He

Fudan University

Boron-based semiconductors, which cover layered van der Waals systems (h-BN) and zinc-blende structures (c-BN, c-BP, c-BAs, c-BSb, etc.), are scientifically intriguing materials for investigating electrical transport properties. Theoretical insights into the dominant scattering mechanisms governing carrier mobility are critical for optimising their electronic and optoelectronic applications. Our *ab initio* studies reveal that acoustic deformation potential (ADP) scattering has a considerable effect for all materials covered in this study. Meanwhile, material-specific deviations are observed. In c-BN, piezoelectric (PE) scattering dominates at room temperature. In specific h-BN stacking polytypes (e.g., AA' and AB), optical deformation potential (ODP) scattering mediated by inter-layer shear vibration modes contributes significantly to electron scattering. Furthermore, at elevated temperatures, polar optical phonon (POP) scattering (also known as Fröhlich interaction) becomes substantial for both electrons and holes especially in BN, whilst ODP scattering becomes enhanced for hole scattering. Therefore, the occurrence and relative strength of different scattering mechanisms are determined by various intrinsic properties (e.g., symmetry, band structure, dielectric constant, polarity, etc.) and extrinsic factors (e.g., temperature). For example, our calculations show that c-BAs has both high electron and hole mobilities at room temperatures, which can be attributed to its small effective masses, small PE constant, low polarity, high longitudinal optical (LO) phonon energy, and large dielectric constant. Regarding h-BN, we find that the AB' polytype has appreciably higher electron mobility compared with AA' and AB polytypes, which is due to the different band structures modulated by their stacking sequences. These findings are expected to provide useful guidelines for the discovery and design of novel high-mobility semiconductors for future applications.

References

- [1] P. Giannozzi, O. Baseggio, P. Bonfà, et al., Quantum ESPRESSO toward the exascale, J. Chem. Phys. **152**, 154105 (2020).
- [2] H. Lee, S. Poncé, K. Bushick, et al., Electron-phonon physics from first principles using the EPW code, npj Comput. Mater. **9**, 156 (2023).
- [3] Z. He, A.-A. Sun, and S.-P. Gao, Electron-phonon scattering and stacking sequences in hexagonal boron nitride: An *ab initio* study, Phys. Rev. B **108**, 165108 (2023).
- [4] Z. He, M. Chen, and S.-P. Gao, Carrier mobility and carrier-phonon scattering mechanisms in zinc-blende boron-V compound semiconductors, Phys. Rev. B **112**, 075111 (2025).

Research on the Macromolecular Crowding Effect of Methylcellulose

座山 刘

College of Physics, Guizhou University

The crowded intracellular environment affects biochemical reactions, protein behavior, and enzyme activity. While methylcellulose is commonly used to study macromolecular crowding in vitro, how it interacts with nucleic acids remains unclear. Using magnetic tweezers with the Bell model and van't Hoff analysis, we examined how methylcellulose crowding influences DNA hairpin stability. By varying methylcellulose concentration, temperature, and viscosity, we measured DNA hairpin folding/unfolding dynamics. Higher methylcellulose concentrations increased the hairpin's mechanical stability, slowing unfolding while slightly accelerating folding. This shifted the equilibrium toward the folded state. Temperature-dependent measurements at fixed crowding concentrations revealed negative entropy and enthalpy changes, with entropy being the dominant factor. This indicates methylcellulose affects DNA hairpins primarily through excluded volume effects.

Keywords: macromolecular crowding, magnetic tweezers, methylcellulose, DNA hairpin, van't Hoff analysis, entropy

References

- [1] Hong F, Schreck J S, Šulc P. Understanding DNA interactions in crowded environments with a coarse-grained model[J]. *Nucleic acids research*, 48(19): 10726-10738(2020).
- [2] M. A. Mourão, J. B. Hakim, S. Schnell, Connecting the dots: The effects of macromolecular crowding on cell physiology, *Biophys. J.* 107, 2761 (2014).
- [3] Miyazaki M, Chiba M, Eguchi H, et al. Cell-sized spherical confinement induces the spontaneous formation of contractile actomyosin rings in vitro[J]. *Nature cell biology*, 17(4): 480-489(2015).
- [4] Liang T, Yang C, Song X, et al. Quantification of macromolecule crowding at single-molecule level[J]. *Physical Review E*, 108(1): 014406(2023).
- [5] Hsuan-Lei Sung and David J. Nesbitt. Effects of Molecular Crowders on Single-Molecule Nucleic Acid Folding: Temperature-Dependent Studies Reveal True Crowding vs Enthalpic Interactions. *J. Phys. Chem. B* 2021, 125, 13147-13157
- [6] Joan Camunas-Soler^{1,2}, Maria Manosal^{1,2}, Silvia Frutos^{1,2}, Judit Tulla-Puche³, Fernando Albericio³ and Felix Ritort^{1,2,*}. Single-molecule kinetics and footprinting of DNA bis-intercalation: the paradigmatic case of Thiocoraline. *Nucleic Acids Research*, 2015, Vol. 43, No. 5 2767 - 2779.
- [7] Loren Stagg, Shao-Qing Zhang, Margaret S. Cheung, and Pernilla Wittung-Stafshede. Molecular-crowding effects on single-molecule RNA folding/unfolding thermodynamics and kinetics. *Proc Natl Acad Sci USA* 111 (23) 8464-8469.

Hybridization versus Hund–A comparison of two pairing mechanisms in $\text{La}_3\text{Ni}_2\text{O}_7$

Jiangfan Wang
杭州师范大学

Recent experiments on bulk and thin film bilayer nickelate high- T_c superconductors urge for clarification of their pairing mechanism. Debates exist on whether the hybridization or the Hund's coupling between the nickel $d_{x^2-y^2}$ and d_{z^2} orbitals plays a primary role in driving the superconductivity. We study the Hund scenario and make comparisons with the hybridization scenario using the same dynamic Schwinger boson approach. Our calculations reveal several key features of the Hund-driven superconductivity, including an isotropic s-wave gap, a lower maximum T_c , and Fermi liquid normal states, that differ from the hybridization-driven mechanism. We attribute these differences to their distinct low-energy dynamics. Comparison with recent experiments suggests that the Hund scenario alone is not enough to explain the bilayer nickelate superconductivity in both bulk and thin films.

Exactly Solvable Mobility Edges for Phonons in One-Dimensional Quasiperiodic Chains

Yizhi Hu

哈尔滨工业大学（深圳）

There has been a long-standing debate about the observability of phonon localization. Mobility edges, the boundaries between extended and localized states, can greatly facilitate the observation of phonon localization if their positions are analytically solvable. However, to date, no reports have been made about analytical mobility edges in phonon systems. In this talk, we would like to present an investigation of phonon localization and mobility edges in one-dimensional phonon systems with deterministic quasiperiodic mass modulation, leveraging the Aubry-André-Harper model. Mobility edges, are theoretically derived and numerically validated, paving the way for the experimental observation of phonon localization.

Giant Tunneling Magnetoresistance Based on Spin-Valley-Mismatched Ferromagnetic Metals

Kun Yan

哈尔滨工业大学（深圳）

Half metals, which are amenable to perfect spin filtering, can be utilized for high-magnetoresistive devices. However, available half metals are very limited. Here, we demonstrate that materials with intrinsic spin-valley-mismatched (SVM) states can be used to block charge transport, resembling half metals and leading to giant tunneling magnetoresistance. As an example, by using first-principles transport calculations, we show that ferromagnetic 1T-VSe₂, 1T-VS₂, and 2H-VS₂ are such spin-valley-mismatched metals, and giant magnetoresistance of more than 99% can be realized in spin-valve van der Waals (vdW) junctions using these metals as electrodes. Owing to the intrinsic mismatch of spin states, the central-layer materials for the vdW junctions can be arbitrary nonmagnetic materials, in principle. Our research provides clear physical insights into the mechanism for high magnetoresistance and opens new avenues for the search and design of high-magnetoresistance devices.