量子材料中的非平衡现象

2021.4.8-11　中国·北京

会议日程

2021 年 4 月 8 日（星期四）		
中科院物理研究所M楼二楼大厅，M234报告厅外		
14:00-18:00	会议报道	
	晚餐	

2021 年 4 月 9 日（星期五）			
中科院理论所南楼 6620			
8:50-9:00	开幕式		
9:00-9:30	李玉同 中科院物理所	Novel strong Terahetz pump - ultrafast optical/x-ray/electron probe for matter dynamics	主持人： 万源
9:30-10:00	赵继民 中科院物理所	A Few Aspects on Understanding the Ultrafast Quasiparticle Dynamics of Correlated Quantum Materials	
10:00-10:30	孟胜 中科院物理所	Manipulating quantum states by photoexcitation	
10:30-10:45	茶歇		
10:45-11:15	付学文 南开大学	Developping novel 4D electron microscopy to explore hidden states in quantum materials	主持人： 向导
11:15-11:45	曾长淦 中国科学技术大学	Light-induced non-equilibrium phenomena in graphene	
11:45-12:15	吴施伟 复旦大学	碳基纳米材料的声子动力学	
	午餐		
	中科院物理所 M 楼 234 报告厅		
14:00-14:30	李建奇 中科院物理所	Charge density wave, hidden quantum state and atomic orders in layered 1T-MX_2	主持人： 曾长淦
14:30-15:00	吴东 松山湖材料实验室	Photoinduced multistage phase transitions in Ta_2NiSe_5	
15:00-15:30	孟建桥 中南大学	Temperature evolution of quasiparticle dispersion and dynamics in semimetallic 1T-$TiTe_2$ via high-resolution	

		angle-resolved photoemission spectroscopy and ultrafast optical pump-probe spectroscopy	
15:30-15:45	茶歇		
15:45-16:15	孙栋 北京大学	Anisotropic Response of Type-II Weyl Semimetal TaIrTe4 under Ultrafast Photoexcitation (线上报告)	主持人: 严以京
16:15-16:45	陆汉涛 兰州大学	The time-dependent Lanczos method in the investigations of nonequilibrium dynamics of low-dimensional correlated	
16:45-17:15	李千 清华大学	Subterahertz collective dynamics of ferroelectric polar vortices	
	晚餐		

2021 年 4 月 10 日（星期六）			
中科院物理所 M 楼 234 报告厅			
9:00-9:30	向导 上海交通大学	MeV ultrafast electron diffracton	主持人: 吴施伟
9:30-10:00	张文涛 上海交通大学	Optical manipulation of electronic dimensionality in a quantum material	
10:00-10:30	王瑄 中科院物理所	Probing nanoscale thermal transport in a GaAs/AlGaAs heterostructure	
10:30-10:45	茶歇		
10:45-11:15	储灏 The University of British Columbia	Phase-resolved Higgs response of cuprate high-T_c superconductors (线上报告)	主持人: 王楠林
11:15-11:45	董涛 北京大学	Nonlinear response of multiband superconductor MgB_2 driven by tunable THz pulse	
11:45-12:15	吴明卫 中国科学技术大学	Gauge-invariant kinetic theory of superconductivity: application to current excitation and collective modes	
	午餐		
14:00-14:30	严以京 中国科学技术大学	Nonequilibrium Statistical Quasi-Particles Dynamics Theory	主持人: 陆汉涛
14:30-15:00	郑晓 中国科学技术大学	Nonequilibrium quantum dissipative dynamics in the low temperature and strong coupling regime	
15:00-15:30	石弢 中科院理论所	Non-Gaussian variational approach to non-equilibrium problem in many-body systems	

15:30-15:45	茶歇		
15:45-16:15	周树云 清华大学	Light-tunable interlayer interaction and hybridization gap in a magnetic topological insulator	主持人: 张文涛
16:15-16:45	王熠华 复旦大学	Towards ultrafast magnetic imaging of quantum materials	
16:45-17:15	马国宏 上海大学	Formation and Dynamics of Small Polaron in Type II Dirac Semimetal $PtTe_2$ Film Probing with Transient THz Spectroscopy	
	晚餐		

2021 年 4 月 11 日（星期日）			
中科院物理所 M 楼 234 报告厅			
9:00-9:30	吴晓君 北京航空航天大学	Geneartion and manipulation of chiral terahertz waves from topological insulators and their feromagentic heterostructures	主持人: 张琦
9:30-10:00	邱红松 南京大学	Ultrafast Spin Current generation and THz emission from an Antiferromagnet at zero magnetic field	
10:00-10:30	陶镇生 复旦大学	Generation of circularly polarized broadband terahertz radiation from spintronic emitters driven by ultrafast Yb lasers(线上报告)	
10:30-10:45	茶歇		
10:45-11:15	杨鲁懿 清华大学	Unusual bandgap shift and coherent spin dynamics in hybrid organic-inorganic perovskites	主持人: 吴晓君
11:15-11:45	张春峰 南京大学	Correlated triplet pairs in tetracene oligomers indentified by transient magneto-optical spectroscopy	
11:45-12:15	赵瑾 中国科学技术大学	Real-time *GW*-BSE Investigations on Spin-Valley Exciton Dynamics in Monolayer Transition Metal Dichalcogenide	
	午餐		
14:00-14:30	盛志高 中科院强磁场科学中心	Terhertz spectroscopy studies of oxide thin films and two-dimensional materials	主持人: 张春峰
14:30-15:00	张琦 南京大学	Optical anisotropy and excitons in two-dimentional zigzag antiferromagnets	
15:00-15:30	万源 中科院物理研究所	Two-dimensional coherent spectroscopy: concepts and opportunities for strongly-correlated electronic systems	

Novel strong Terahetz pump - ultrafast optical/x-ray/electron probe for matter dynamics

Li Yutong, Liao Guoqian

(Institute of Physics, Chinese Academy of Sciences, Beijing 100190, China)

E-mail: ytli@iphy.ac.cn

Abstract

Terahertz (THz) radiation with a typical frequency range from 0.1-10 THz lies between far-infrared and microwaves in the electromagnetic spectrum. Currently energy of the THz radiation is typially less than milijous, generated with huge-sized conventional accelerators and nonlinear crystals or semiconductors pumped by optical methods. We have systematically studied strong THz radiation from solid targets driven by relativistic laser pulses at intensities above 10^{18} W/cm^2. It is found that intense laser can generate a large number of high-energy electrons in a thin foil target. When the electrons escape from the back of the target to a vacuum, the transition radiation can excite high-intensity terahertz radiation. Using intesne picosecond laser pulses, a strong terahertz pulse with an energy of up to 200 mJ was obtained experimentally, which is the highest terahertz energy obtained in the laboratory so far. Such a strong THz source can be used to study the nonlinear interaction between strong terahertz fields and matter. By coupling with the ultrafast x-ray and electron diffraction, one can probe ultrasfast dynamics of quantum matter pumped by strong THz unprecedentedly.

Keywords: ultrafast intense laser, strong THz radiation, ultrafast x-ray, ultrafast electron diffraction

References

[1] G. Q. Liao, et al., Physical Review X 10, 031062 (2020).
[2] G. Q. Liao, et al., PNAS 116, 3994 (2019).
[3] G. Q. Liao, et al., Physical Review Letters 116, 205003 (2016).
[4] G. Q. Liao, et al., Physical Review Letters 114, 255001 (2015).

A Few Aspects on Understanding the Ultrafast Quasiparticle Dynamics of Correlated Quantum Materials

ZHAO Jimin[1) 2) 3)]

1) (Beijing National Laboratory for Condensed Matter Physics, Institute of Physics, Chinese Academy of Sciences, Beijing 100190, China)

2) (School of Physical Sciences, University of Chinese Academy of Sciences, Beijing 100049, China)

3) (Songshan Lake Materials Laboratory, Dongguan, Guangdong 523808, China)

E-mail: jmzhao@iphy.ac.cn

Abstract

We have demonstrated ultrafast dynamics evidence of high-T_c superconductivity in single-layer FeSe/$SrTiO_3$, with clear identification of the SC T_c, SC gap Δ, and electron-phonon coupling (EPC) constant λ [1]. Furthermore, we observed the quasiparticle dynamics in $(Li_{0.84}Fe_{0.16})OHFe_{0.98}Se$, $Fe_{1.01}Se_{0.2}Te_{0.8}$, and $Fe_{1.05}Se_{0.2}Te_{0.8}$. Significantly, we found that almost all the optimally doped iron-based superconductors (including the FeSe-based, FeAs-based, and monolayer FeSe systems) share a universal positive correlation between T_c and the EPC strength (λ_{A1g} or λ) [2]. This result indicates that the EPC play an important role in the electron pairing. We also conceived and constructed a novel instrument that facilitates on-site in situ high pressure pump-probe ultrafast spectroscopy. With this instrument, we investigated the quasiparticle dynamics of strong correlated iridate Sr_2IrO_4, finding a unique pressure-induced phonon bottleneck effect [3].

Our results demonstrate promising venues for ultrafast optical investigation of the quantum properties of various correlated systems. I will discuss several aspects on understanding these results.

Keywords : quasiparticle dynamics, ultrafast spectroscopy, electron-phonon coupling, superconductor, quantum material.

Reference

[1] Y. C. Tian, **Jimin Zhao*** *et al.*, *Ultrafast Dynamics Evidence of High Temperature Superconductivity in Single Unit Cell FeSe on $SrTiO_3$*, **Phys. Rev. Lett.** 116, 107001 (2016).

[2] Q. Wu, **Jimin Zhao*** *et al.*, *Ultrafast Quasiparticle Dynamics and Electron-Phonon Coupling in $(Li_{0.84}Fe_{0.16})OHFe_{0.98}Se$*, **Chin. Phys. Lett. (Express Letter)** 37, 097802 (2020).

[3] Y. L. Wu, **Jimin Zhao*** *et al.*, *High-Pressure Ultrafast Dynamics in Sr_2IrO_4: Pressure-Induced Phonon Bottleneck Effect*, **Chin. Phys. Lett. (Express Letter)** 37, 047801 (2020).

Towards ultrafast magnetic imaging of quantum materials

Wang Yihua[1) 2)] Xiang Bing-ke[1)] Pan Yin-ping[1)]

1) (State Key Laboratory of Surface Physics and Department of Physics, Fudan University, Shanghai 200433, China)

2) (Shanghai Research Center for Quantum Sciences, Shanghai 201315, China)

E-mail: wangyhv@fudan.edu.cn

Abstract

Magnetic dynamics of correlated quantum materials are typically on the picosecond timescale. A direct and sensitive ultrafast magnetic probe that is capable of distinguishing the spin degree of freedom from the lattice and charge contributions is very important to these studies. In this talk, I will report our effort in developing time-resolved optical probes as well as scanning superconducting quantum interference device microscopy toward this end. I will give some preliminary result on our study of magnetic topological materials.

Keywords : ultrafast magnetic imaging, superconducting device

Developping novel 4D electron microscopy to explore hidden states in quantum materials

FU Xuewen[1)] VANACORE Giovanni Maria[2)] CARBONE Fabrizio[2)] ZHU Yimei[3)]

1) (Ultrafast Electron Microscopy Laboratory, School of Physics, Nankai University, Tianjin 300071, China)

2) (Institute of Physics, Laboratory for Ultrafast Microscopy and Electron Scattering (LUMES), École Polytechnique Fédérale de Lausanne, Station 6, Lausanne 1015, Switzerland.)

3) (Condensed Matter Physics and Material Science Department, Brookhaven National Laboratory, Upton, New York 11973, USA)

E-mail: xwfu@nankai.edu.cn

Abstract

Four-dimensional electron microscopy (4D-EM), which enables the direct observation of transient structures, morphologies and carrier transport of materials in real time and space, has attracted increasing interest to the research community due to its powerful capability in the interdisciplines of physics, chemistry, material science, and biology [1-3]. Here I will firstly give a brief introduction of 4D-EM and the state-of-the-art of its applications. Then I will present our recent development of two-color photon induced near field ultrafast electron microscopy, in which we introduced a additional fs pump laser beam with different wavelength to timely gatethe ultrafast electorn beam based a near feild assisted photon-electron coupling. By using this photon gated electrons as a probe, we improved the temporal resolution by a factor of ten for the current 4D-EM, and provide the first real space imaging of the dielectric response of a sinlge VO_2 nanowire during its insulator to metal phase transition at nanometer and tens of femtoseconds time scale [4]. After that, I will talk about our development of 4D Lorentz-phase imaging and the study of magnetization dynamics and dynamical switching of magnetic vortices in ferromagnetic Permalloy disks [5]. In addition to the in situ observation of the photon induced vortex switching process, we also revealled a lot of hidden topological magnetic states in the symetric Permalloy disks with ultrafast fs lasaer quenching. This wrok extends the application of 4D-EM to the field of magnetization dynamics.

Keywords : 4D electron microscopy, photon-electron coupling, phase transition ,magnetic vortex, magnetic switching

Reference

[1] A. Yurtsever and A. H. Zewail, *et al.*, 4D nanoscale diffraction observed by convergent-beam ultrafast electron microscopy, Science 2009, **326**: 708-712.

[2] B. Barwick and A. H. Zewail, *et al.*, Photon-induced near-field electron microscopy, Nature 2009, **462**: 902-906.

[3] A. H. Zewail, Four-dimensional electron microscopy, Science 2010, **328**: 187-193.

[4] X. Fu, F. Barantani, S. Gargiulo, *et al.*, Nanoscale-femtosecond dielectric response of Mott insulators captured by two-color near-field ultrafast electron microscopy, *Nat. Commun.,*2020, **11(1)**: 1-11.

[5] X. Fu, S. D Pollard, B. Chen, *et al.*, Optical manipulation of magnetic vortices visualized in situ by Lorentz electron microscopy, *Sci. Adv.*, 2018, **4(7)**: eaat3077.

Light-induced non-equilibrium phenomena in graphene

ZENG Changgan

Department of Physics, University of Science and Technology of China, Hefei, Anhui 230026, China

E-mail: cgzeng@ustc.edu.cn

Abstract

A wide spectrum of intriguing non-equilibrium phenomena have been discovered in optically driven quantum matters. In this talk, I will present our recent progresses on light-induced non-equilibrium phenomena in monolayer graphene in three aspects, i.e, construction of graphene superlattice by periodic optical gating [1], substantially enhanced quantum coherence by introducing electron-plasmon coupling via light illumination [2], and plasmon-assisted extraordinary transmission at the monolayer limit [3]. Collectively, these findings help to shed new light on the exploitation of emergent non-equilibrium physics in graphene and other 2D materials.

Keywords : graphene, optical gating, quantum coherence, extraordinary transmittance

Reference

[1] Qi J, Zhang H, Ji D, *et al.* Adv. Mater. 2014, **26 (22):** 3735-3740

[2] Cheng G, Qin W, Lin M, *et al.* Phys. Rev. Lett. 2017, **119 (15):** 156803

[3] Unpublished

碳基纳米材料的声子动力学

吴施伟

复旦大学物理系

E-mail: swwu@fudan.edu.cn

摘要

量子材料中电子、声子、激子等基本粒子或元激发的本征行为及对外界响应决定了物质的属性。在不同的碳材料结构中，从三维的石墨到二维的石墨烯再到一维的碳纳米管，电子、声子及其相互之间的耦合虽有共性，但各不相同。在本报告中，我将介绍我们自主发展的超快时间分辨反斯托克斯拉曼显微光谱技术，并且在石墨、单层石墨烯和单根单壁碳纳米管中声子及其与电子相互作用的动力学研究结果。通过这样的比较研究，我们的实验结果能揭示碳基纳米材料中声子在不同维度和结构中的行为，并给出高频碳基电子学器件的频率响应理论极限。

Charge density wave, hidden quantum state and atomic orders in layered 1T-MX_2

H. Wang[1,2], K. Sun[1], J.Li[1], Z.A. Li[1], H.F. Tian[1], H.X. Yang[1,2] and J.Q. Li[1,2,3※]

1) Beijing National Laboratory for Condensed Matter Physics, Institute of Physics, Chinese Academy of Sciences, Beijing 100190 China.

2)School of Physical Sciences, University of Chinese Academy of Sciences, Beijing 100049, China.

3)Songshan Lake Materials Laboratory, Dongguan, Guangdong, China

*Email： ljq@iphy.ac.cn

Abstract

Structural investigations and physical measurements on the layered transition-metal dichalcogenide (TMDs) 1T-MX_2 materials revealed a series of remarkable phenomena in correlation with structural transitions. Our study shows that notable structural features, such as CDW, the atomic ordering and micro-twinning, can be evidently introduced through chemical substitution in 1T-MX_2. It is demonstrated that the Te substitution for S in 1T-TaS_2 could destruct the CDW and yields an atomic order of metallic ions. Moreover, substitution of metal atoms in 1T-MX_2 can result in clear structural distortion with high-density twinning lamella. Several structural transitions are mostly correlated with the alterations of superconductivity and other physical properties [1-3].

A hidden (H) quantum state has been observed in 1T-$TaS_{2-x}Se_x$ with x=0 and 0.5 crystals upon an excitation with a single fs-laser pulse[4-5]. In-situ cooling TEM observations, initiated by a single fs-laser pumping with a low fluence, reveal a clear transition from a commensurate CDW phase to a new CDW order with $q_H = (1-\delta)q_C$ for the H-CDW state (δ=1/9) accompanied by an evident phase separation. An H-CDW domain relaxation then occurs, yielding a stable metallic phase under a high-fluence excitation. Furthermore, electrical resistivity measurements show that the notable drops in x=0 and 0.5 samples associated with the appearance of H-CDW states. These results potentially provide a new perspective on the photodoping mechanism for the emergence of H-CDW states in the 1T-$TaS_{2-x}Se_x$ family [2-5].

Keywords：CDW, hidden quantum state, in-situ ultrafast TEM.

Reference

[1] Manzeli S, et al., *Nat. Rev. Mater.* 2017, **2:** 17033.

[2] Sun S, J.Q.Li. et al., *Phys. Rev. B*, 2015, **92:** 224303.

[3] H.Wang et al, Europhys. Lett., 2020, **130:**47001.

[4] Sun K,J. Q. Li et al., *Sci. Adv.*, 2018,**4:** 9660.

[5]L. Stojchevska, I. Vaskivskyi, et al, *Science* 2014, **344**: 177-180

Photoinduced multistage phase transitions in Ta_2NiSe_5

Q. M. Liu[1], D. Wu[1,2], Z. A. Li[3], L. Y. Shi[1],Z. X. Wang[1],S. J. Zhang[1], T. Lin[1], T. C. Hu[1], H. F. Tian[3],J. Q. Li[3], T. Dong[1], and N. L. Wang[1,4]

1) International Center for Quantum Materials, School of Physics, Peking University, Beijing 100871, China

2) Songshan Lake Materials Laboratory, Dongguan, Guangdong 523808, China

3) Beijing National Laboratory for Condensed Matter Physics, Institute of Physics, Chinese Academy of Sciences, Beijing 100190, China

4) Collaborative Innovation Center of Quantum Matter, Beijing, China

E-mail: wudong@sslab.org.cn

Abstract

Utrafast control of material physical properties represents a rapid developing field in condensed matter physics. Yet, accessing to the long-lived photoinduced electronic states is still in its early stage, especially with respect to an insulator to metal phase transition. Here, by combing transport measurement with ultrashort photoexcitation and coherent phonon spectroscopy, we report on photoinduced multistage phase transitions in Ta_2NiSe_5. Upon excitation by weak pulse intensity, the system is triggered to a short-lived state accompanied by a structural change. Further increasing the excitation intensity beyond a threshold, a photoinduced steady new state is achieved where the resistivity drops by more than four orders at temperature 50 K. This new state is thermally stable up to at least 350 K and exhibits the lattice structure different from any of the thermally accessible equilibrium states. Transmission electron microscopy reveals an in-chain Ta atom displacement in the photoinduced new structure phase. We also found that nano-sheet samples with the thickness less than the optical penetration depth are required for attaining a complete transition.

Keywords : photoinduced phase transition, excitonic insulator, ultrafast optical spectroscopy

Reference

1. Q. M. Liu, D. Wu, Z. A. Li,*et al.* Photoinduced multistage phase transitions in Ta2NiSe5. Nature Communications (accepted), arXiv:2103.06190 (2021)

Temperature evolution of quasiparticle dispersion and dynamics in semimetallic 1T-$TiTe_2$ via high-resolution angle-resolved photoemission spectroscopy and ultrafast optical pump-probe spectroscopy

Zhu Shuangxing[1)] Zhang Chen[1)] Wu Qiyi[1)] Tang Xiaofang[2)] Liu Hao[1)] Liu Ziteng[1)] Luo Yang[1)] Song Jiaojiao[1)] Wu Fanying[1)] Zhao Yinzou[1)] Liu Shuyu[1)] Le Tian[2)] Lu Xin[2)] Ma He[3)] Liu Kaihui[3)] Yuan Yahua[1)] Huang Han[1)] He Jun[1)] Liu Haiyun[4)] Duan Yuxia[1)] Meng Jianqiao[1)5)]

1) (School of Physics and Electronics, Central South University, Changsha 410083, Hunan, China)

2) (Center for Correlated Matter and Department of Physics, Zhejiang University, Hangzhou 310058, China)

3) (State Key Laboratory for Mesoscopic Physics, Collaborative Innovation Center of Quantum Matter, School of Physics, Peking University, Beijing 100871, China)

4) (Beijing Academy of Quantum Information Sciences, Beijing 100085, China)

5) (Synergetic Innovation Center for Quantum Effects and Applications (SICQEA), Hunan Normal University, Changsha 410081, China)

E-mail: jqmeng@csu.edu.com

Abstract

High-resolution angle-resolved photoemission spectroscopy and ultrafast optical pump-probe spectroscopy were used to study semimetallic 1T -$TiTe_2$ quasiparticle dispersion and dynamics. A kink and a flat band, having the same energy scale and temperature-dependent behaviors along the Γ-M direction, were detected. Both manifested at low temperatures but blurred as temperature increased. The kink was formed by an electron-phonon coupling. And the localized flat band might be closely related to an electron-phonon coupling. Ultrafast optical spectroscopy identified multiple distinct time scales in the 10–300 K range. Quantitative analysis of the fastest decay process evidenced a significant lifetime temperature dependence at high temperatures, while this starts to change slowly below ~100 K where an anomalous Hall coefficient occurred. At low temperature, a coherent A_{1g} phonon mode with a frequency of ~4.36 THz was extracted. Frequency temperature dependence suggests that phonon hardening occurs as temperature falls and anharmonic effects can explain it. Frequency fluence dependence indicates that the phonons soften as fluence increases.

Keywords : ultrafast, iron-based superconductor, phonon

Reference

[1] Zhu X, Chen Z, Wu Q, *et al.*, Phys. Rev. B，2021，**103（12）**：115108

Manipulating quantum states by photoexcitation

Sheng Meng

Institute of Physics, Chinese Academy of Sciences, Beijing 100190, China

E-mail: smeng@iphy.ac.cn

Abstract

Photoexcitation is a powerful means in distinguishing different interactions and manipulating the states of matter, especially in complex quantum systems. Here we demonstrate photoexcitation induced ultrafast dynamics in quantum materials using time-dependent density functional theory molecular dynamics. In particular, we discover a novel mechanism which involves self-amplified exciton-phonon dynamics for the formation of charge density wave (CDW), and we predict a new collective mode induced by photoexcitation which is significantly different from thermally-induced phonon mode. We will also discuss photoinduced electronic phases in other two-dimensional materials such as black phosphorus and Weyl semimetal WTe_2. Our results provide insights from a new perspective on the coherent electron and lattice quantum dynamics in materials upon photoexcitation.

References:

1. M.X. Guan, E. Wang, P.W. You, J.T. Sun, S. Meng. Manipulating Weyl quasiparticles by orbital-selective photoexcitation in WTe2. Nature Commun. , in press (2021).

2. H. Lakhotia, H.Y. Kim, M. Zhan, S.Q. Hu, S. Meng, E. Goulielmakis. Laser picoscopy of valence electrons in solids. Nature 583, 55 (2020).

3. C. Lian, S.J. Zhang, S.Q. Hu, M.X. Guan, S. Meng. Ultrafast charge ordering by self-amplied exciton-phonon dynamics in TiSe2. Nature Commun. 11, 43 (2020).

The time-dependent Lanczos method in the investigations of nonequilibrium dynamics of low-dimensional correlated systmes

LU Hantao

School of Physical Science and Technology, Lanzhou University, Lanzhou 730000, China

E-mail: luht@lzu.edu.cn

Abstract

An exact numerical method, i.e., the time-dependent Lanczos method based on the exact diagonalization, is presented for investigating the nonequilibrium phenomena in low-dimensional correlated systems. As a demonstration, several applications to the one-dimensional extended Hubbard model are discussed, including the calculation of the time-resolved optical conductivity and single-particle spectrum, the photoinduced orders of the charge-density wave and the bond-ordered wave, and finally, the charge carrier dynamics in doped case.

Keywords: exact diagonalization, time-dependent Lanczos, one-dimensional Hubbard model, nonequilibrium dynamics

References

[1] Can Shao, Takami Tohyama, Hong-Gang Luo, and Hantao Lu, *Analysis of the time-resolved single-particle spectrum on the one-dimensional extended Hubbard model*, Phys. Rev. B, 2020, **101(4)**, 045128.

[2] Can Shao, Hantao Lu, Hong-Gang Luo, and Rubem Mondaini, *Photoinduced enhancement of bond-order in the one-dimensional extended Hubbard model*, Phys. Rev. B 2019, **100(4)**, 041114(R).

[3] Can Shao, Takami Tohyama, Hong-Gang Luo, and Hantao Lu, *Photoinduced charge carrier dynamics in Hubbard two-leg ladders and chains*, Phys. Rev. B 2019, **99(3)**, 035121.

[4] Can Shao, Takami Tohyama, Hong-Gang Luo, and Hantao Lu, *Numerical method to compute optical conductivity based on the pump-probe simulations*, Phys. Rev. B 2016, **93(19)**, 195144.

[5] Hantao Lu, Shigetoshi Sota, Hiroaki Matsueda, Janez Bonča, and Takami Tohyama, *Enhanced Charge Order in a Photoexcited One-Dimensional Strongly Correlated System*, Phys. Rev. Lett., 2012, **109(19)**, 197401 (2012).

Subterahertz collective dynamics of ferroelectric polar vortices

Qian Li（李 千）

State Key Laboratory of New Ceramics and Fine Processing, School of Materials Science and Engineering, Tsinghua University, Beijing 10084

E-mail: qianli_mse@tsinghua.edu.cn

Abstract

The recent discovery of polar vortices in $PbTiO_3/SrTiO_3$ (PTO/STO) thin-film superlattices opens up exciting opportunities to explore the structure and emergent dynamics of complex topological states of ferroelectric dipoles and potentially leads to novel electronic functionalities. Ultrafast electric fields in the form of THz laser pulses can couple with the polar vortices via dipole interaction, providing a well-defined, easy-to-model external control knob for studying the ultrafast structural dynamics of this system. We have performed a THz-pump, ultrafast X-ray diffraction probe (<100 fs temporal-resolution) study of the PTO/STO superlattice based on the hard X-ray free-electron laser at the Linac Coherent Light Source. We have observed a set of collective lattice excitations of the polar vortices and identified a novel low-energy soft vortex mode with large field tunabilities. These observations are well corroborated by the newly developed multiscale dynamical modeling based on first-principles derived atomistic potentials and Landau-Ginzburg-Devonshire phenomenological theory. In this talk, I will also give a brief introduction about structural dynamics studies based on scattering methods.

MeV ultrafast electron diffracton

Dao Xiang[1) 2) 3)]

1) (School of Physics and Astronomy, Shanghai Jiao Tong University, Shanghai 200240, China)

2) (Tsung-Dao Lee Institute, Shanghai 200240, China)

3) (Zhangjiang Institute for Advanced Study, Shanghai Jiao Tong University, Shanghai 200240, China.)

E-mail: dxiang@sjtu.edu.cn

Abstract

Historically particle accelerators are instrumental for high energy physics (accelerator based colliders) and photon science (accelerator based synchrotron light sources and free-electron lasers). Now there is growing interest in applying accelerator technology to solve the grand challenges in probing matter at ultrafast temporal and ultrasmall spatial scales. In this talk I will discuss how one can use MeV electrons produced in accelerators (e.g. photocathode radio-frequency guns) to study ultrafast dynamics at atomic scale through ultrafast electron diffraction (UED) technique. I'll focus on the principles and applications of UED. I will also report on the status of a state-of-the-art MeV UED facility at Shanghai Jiao Tong University (SJTU) which has achieved 50 fs (FWHM) resolution using the so-called double-bend achromat bunch compressor technique. The facility is expected to provide access to new sciences by producing kHz rep-rate ultrafast and ultrabright electron beams that will give researchers unparalleled power and precision in examining the fundamental nature of matter.

Keywords: Ultrafast electron diffraction, accelerator, melting, phase transition, molecular dynamics

Reference

[1] F. Qi et al., Breaking 50 femtosecond resolution barrier in MeV ultrafast electron diffraction with a double bend achromat compressor, Physical Review Letters, 124, 134803 (2020).

[2] L. Zhao et al., Femtosecond Relativistic Electron Beam with Reduced Timing Jitter from THz Driven Beam Compression, Physical Review Letters, 124, 054802 (2020).

[3] L. Zhao et al., Terahertz Oscilloscope for Recording Time Information of Ultrashort Electron Beams, Physical Review Letters, 122, 144801 (2019).

[4] L. Zhao et al., Terahertz Streaking of Few-Femtosecond Relativistic Electron Beams, Physical Review X, 8, 021061 (2018).

Optical manipulation of electronic dimensionality in a quantum material

Wentao Zhang

1) (School of Physics and Astronomy, Shanghai Jiao Tong University)

E-mail: wentaozhang@sjtu.edu.cn

Abstract

Exotic phenomenon can be achieved in quantum materials by confining electronic states into two dimensions. For example, relativistic fermions are realised in a single layer of carbon atoms, the quantized Hall effect can result from two-dimensional (2D) systems, and the superconducting transition temperature can be enhanced significantly in a one-atomic-layer material. Ordinarily, 2D electronic system can be obtained by exfoliating the layered materials, growing monolayer materials on substrates, or establishing interfaces between different materials. Herein, we use femtosecond infrared laser pulses to invert the periodic lattice distortion sectionally in a three-dimensional (3D) charge density wave material, creating macroscopic domain walls of transient 2D ordered electronic states with exotic properties. The corresponding ultrafast electronic and lattice dynamics are captured by time- and angle-resolved photoemission spectroscopy and MeV ultrafast electron diffraction. Surprisingly, a novel energy gap state, which might be a signature of light-induced superconductivity, is identified in the photoinduced 2D domain wall near the surface. Such optical modulation of atomic motion is a new path to realise 2D electronic states and will be a new platform for creating novel phases in quantum materials.

Keywords: trARPES, CDW, superconductivity, 2D electronic state, domain wall

Reference

[1] Duan S et al., arXiv:2101.08507v1

[2] Yang Y et al., Rev. Sci. Instrum. 90, 063905 (2019)

Probing nanoscale thermal transport in a GaAs/AlGaAs heterostructure

Matthew Gorfien[1)], Hailong Wang [2)], Xuan Wang [3)], Jianhua Zhao[2)], and Jianming Cao[1), 4)]

1) (Physics Department and National High Magnetic Field Laboratory, Florida State University, Tallahassee, Florida 32310, USA)

2) (State Key Laboratory of Superlattices and Microstructures, Institute of Semiconductors, Chinese Academy of Sciences,P.O. Box 912, Beijing 100083, China)

3) (Beijing National Laboratory for Condensed Matter Physics, Institute of Physics, Chinese Academy of Sciences, Beijing 100190, China)

4) Center for Ultrafast Science and Technology, Key Laboratory for Laser Plasmas (Ministry of Education) and School of Physics and Astronomy, Shanghai Jiao Tong University, Shanghai 200240, China)

E-mail: xw@iphy.ac.cn

Abstract

The drive to produce smaller, denser, and higher frequency electronics has culminated in the need for completely understanding and controlling thermal transport in devices at the nanometer scale. Here, we studied the thermal transport across a GaAs/AlGaAs interface using time-resolved Reflection High Energy Electron Diffraction. The lattice temperature change of the GaAs nanofilm was directly monitored and numerically simulated using diffusive heat equations based on Fourier's Law. The extracted thermal boundary resistances (TBRs) were found to decrease with increasing lattice temperature imbalance across the interface. The TBRs were found to agree well with the Diffuse Mismatch Model in the diffusive transport region, but showed evidence of further decrease at temperatures higher than Debye temperature, opening up questions about the mechanisms governing heat transfer at interfaces between very similar semiconductor nanoscale materials under highly non-equilibrium conditions.

Keywords : thermal transport, nanofilm, ultrafast electron diffraction, pump and probe experiment

Reference

[1] Matthew Gorfien, Hailong Wang, Long Chen, *et al.*, Nanoscale thermal transport across an GaAs/AlGaAs heterostructure interface，Structural Dynamics **7**, 025101 (2020)

Phase-resolved Higgs response of cuprate high-T_c superconductors

Hao Chu[1], Min-Jae Kim[1], Kota Katsumi[2], Sergey Kovalev[3], Robert David Dawson[1], Lukas Schwarz[1], Naotaka Yoshikawa[2], Gideok Kim[1], Daniel Putzky[1], Zhi Zhong Li[4], Hélène Raffy[4], Semyon Germanskiy[3], Jan-Christoph Deinert[3], Nilesh Awari[3], Igor Ilyakov[3], Bertram Green[3], Min Chen[3], Mohammed Bawatna[3], Georg Christiani[1], Gennady Logvenov[1], Yann Gallais[4], Alexander V. Boris[1], Bernhard Keimer[1], Andreas Schnyder[1], Dirk Manske[1], Michael Gensch[3], Zhe Wang[3], Ryo Shimano[2], Stefan Kaiser[1]

1) Max Planck Institute for Solid State Research, Heisenbergstr. 1, 70569 Stuttgart, Germany

2) Department of Physics, University of Tokyo, Hongo, Tokyo,113-0033, Japan

3) Helmholtz-Zentrum Dresden-Rossendorf, Bautzner Landstr. 400, 01328 Dresden, Germany

4) Laboratoire de Physique des Solides (CNRS UMR 8502), Bâtiment 510, Université Paris-Saclay, 91405 Orsay, France

E-mail: haochu@mail.ubc.ca

Abstract

Collective modes of the superconducting order parameter have been predicted decades ago. However, their experimental observation has been hampered by the absence of charge and magnetic dipole moments of these modes in general. Recently, time-resolved nonlinear THz techniques unveiled these modes for the first time [1]. However, a full spectroscopic characterization of these modes is still being anticipated in order to provide insights into various forms of superconductivity in a manner similar to phonon spectroscopy. In the context of the superconducting Higgs (amplitude) mode, we realized a novel way of extracting spectroscopic information using phase-resolved third harmonic generation [2]. With this technique, we discovered a new collective mode distinct from the heavily damped Higgs mode in different families of cuprates. We discuss the origin of this mode and characterize its interplay with the Higgs mode. In addition, our technique also reveals a finite pairing amplitude above T_c.

Keywords: Higgs mode, high-Tc superconductors, cuprates, nonlinear optics, THz high harmonic generation

Reference

[1] Matsunaga R. *et al.*, Higgs Amplitude Mode in the BCS Superconductors. Science, 2014, **345**, 1145

[2] Chu H. *et al.*, Phase-resolved Higgs response in superconducting cuprates. Nature Communications, 2020, **11**, 1793

Nonlinear response of multiband superconductor MgB_2 driven by tunable THz pulse

Liyu Shi, Tao Dong and Nanlin Wang

International Center For Quantum Materials (ICQM), Peking University

E-mail: taodong@pku.edu.cn

Abstract

The superconducting state can be described by a complex order parameter with spontaneously broken U(1) gauge symmetry, whose free energy is given by the Mexican-hat-like potential. The Higgs mode corresponds to the amplitude oscillation of the order parameter, while the phase mode corresponds to the longitudinal fluctuation of the order parameter. The latter is pushed up to the plasma frequency by the Anderson-Higgs mechanism. However, the presence of two SC gaps in the two bands of MgB_2 introduces a new phase mode, which is the out-of-phase mode between the two components of the gap function, called the Leggett mode. The energy scale of the Leggett mode is determined by the values of the two superconducting gaps and the coupling strength between them. Since both Higgs and Leggett modes do not carry charge or spin, they normally cannot be probed directly using linear spectroscopy. Recently, instead of linear spectroscopy the THz pump-probe and nonlinear THz transmission spectroscopy (third harmonic generation, THG) provided new routes to access the Higgs mode directly in a single-band superconductor NbN. Here we report on time-resolved linear and nonlinear terahertz spectroscopy of the two-band superconductor MgB2 with the superconducting transition temperature Tc =36 K. THG is observed below Tc by driving the system with intense narrowband THz pulses. For the pump-pulse frequencies f = 0.3, 0.4, and 0.5 THz, temperature-dependent evolution of the THG signals exhibits a resonance maximum at the temperature where 2 f = 2Δ(T), for the dirty-limit superconducting gap $2\Delta_\pi$ = 1.03 THz at 4 K. In contrast, for f = 0.6 and 0.7 THz with 2 f > $2\Delta_\pi$, the THG intensity increases monotonically with decreasing temperature. Moreover, for 2 f < $2\Delta_\pi$ the THG is found nearly isotropic with respect to the pump-pulse polarization. These results suggest the predominant contribution of the driven Higgs amplitude mode of the dirty-limit gap, pointing to the importance of scattering for observation of the Higgs mode in superconductors.

Gauge-invariant kinetic theory of superconductivity: application to current excitation and collective modes

F. Yang[1)] and M. W. Wu[1)]

1) (Hefei National Laboratory for Physical Sciences at Microscale, University of Science and Technology of China, Hefei, Anhui, 230026, China)

E-mail: mwwu@ustc.edu.cn

Abstract

Within a gauge-invariant kinetic theory, we study the electromagnetic response of superconducting states. For the s-wave case, we predict that the normal fluid is present only when the superconducting velocity is larger than a threshold. Then, it is interesting to find there exists friction between the superfluid and normal-fluid currents. Part of the superfluid becomes viscous due to this friction. Therefore, a three-fluid model, normal fluid and nonviscous and viscous superfluids, is proposed to capture electromagnetic properties. Responses of both collective Nambu-Goldstone and Higgs modes are also studied. Particularly, the second-order response exhibits interesting physics. On one hand, a finite second-order response of the Higgs mode is obtained. We reveal that this response is attributed solely to drive effect rather than the widely considered Anderson-pump effect. On the other hand, the second-order response of the Nambu-Goldstone mode, free from the influence of Anderson-Higgs mechanism, is predicted. Finally, by applying the gauge-invariant kinetic theory in d-wave superconductors, we analytically derive the energy spectra of the breathing Higgs mode and the rotating Higgs mode that is unique for d-wave order parameter. The dynamic properties of both Higgs modes, including the optical and magnetic responses as well as the negative thermal Hall signal are studied.

Keywords: nonequilibrium superconductivity, electromagnetic properties of superconductors, collective excitations in superconductors, gauge invariance

Reference

[1] F. Yang and M. W. Wu, “Gauge-invariant microscopic kinetic theory of superconductivity in response to electromagnetic fields”, Phys. Rev. B, 2018, **98:** 094507.

[2] F. Yang and M. W. Wu, “Gauge-invariant microscopic kinetic theory of superconductivity: Application to the optical response of Nambu-Goldstone and Higgs modes”, Phys. Rev. B, 2019, **100:** 104513.

[3] F. Yang and M. W. Wu, “Influence of scattering on the optical response of superconductors”, Phys. Rev. B, 2020, **102:** 144508.

[4] F. Yang and M. W. Wu, “Theory of Higgs modes in d-wave superconductors”, Phys. Rev. B, 2020, **102:** 014511.

Nonequilibrium Statistical Quasi-Particles Dynamics Theory

严以京

中国科学技术大学

Email: yanyj@ustc.edu.cn; web site: http://openquan.ustc.edu.cn

Abstract

This talk is concerned with the Dissipaton Equation of Motion (DEOM) theory for correlated system and hybrid environments that constitute statistical quasi-particles [1]. DEOM has exploited in elucidating complex Fano interferences and transport current noise spectrum, directly related to the hybrid environments dynamics [2]. As a versatile impurity solver [3], DEOM enables accurate evaluations on various strong correlation problems. These include the transient Kondo dynamics, steady-states and thermodynamics properties of model open quantum systems [4,5]. I will also present the first-principles studies on some realist molecular spintronic systems, with combining the DEOM dynamics and electronic structure methods [6].

Reference

1. Y. J. Yan, *J. Chem. Phys.* **140**, 054105 (2014); Y. J. Yan, J. S. Jin, R. X. Xu, and X. Zheng, *Front. Phys.* **11**, 110306 (2016); Y. Wang, R. X. Xu, and Y. J. Yan, *J. Chem. Phys.* **152**, 041102 (2020).

2. H. D. Zhang, R. X. Xu, X. Zheng, and Y. J. Yan, *Mol. Phys.* **116**, 780 (2018); J. S. Jin, S. K. Wang, X. Zheng, and Y. J. Yan, *J. Chem. Phys.* **142**, 234108 (2015); J. S. Jin, *Phys. Rev.* B **101**, 235144 (2020).

3. L. Z. Ye, X. L. Wang, D. Hou, R. X. Xu, X. Zheng, and Y. J. Yan, *WIREs Comp. Mol. Sci.* (2016).

4. Z. H. Li, N. H. Tong, X. Zheng, D. Hou, J. H Wei, J. Hu, and Y. J. Yan, *Phys. Rev. Lett.* **109**, 266403 (2012); X. Zheng, Y. J. Yan, and M. Di Ventra, *Phys. Rev. Lett.* **111**, 086601 (2013); D. Hou, R. L Wang, X. Zheng, N. H. Tong, J. H. Wei, and Y. J. Yan, *Phys. Rev.* B **90**, 045141 (2014).

5. H. Gong, Y. Wang, H. D. Zhang, Q. Qiao, R. X. Xu, X. Zheng, and Y. J. Yan, *J. Chem. Phys.* **153**, 154111 (2020); *J. Chem. Phys.* **153**, 214115 (2020).

6. X. L. Wang, Dong Hou, X. Zheng, and Y. J. Yan, *J. Chem. Phys.* **144**, 034101 (2016); X.L. Wang, L.Q. Yang, L. Z. Ye, X. Zheng, and Y. J. Yan, *J. Phys. Chem. Letts.* **9**, 2418 (2018).

Nonequilibrium quantum dissipative dynamics in the low temperature and strong coupling regime

ZHENG Xiao and YAN Yijing

Hefei National Laboratory for Physical Sciences at the Microscale, University of Science and Technology of China, 96 Jinzhai Road, Hefei, 230026

E-mail: xz58@ustc.edu.cn

Abstract

Dissipative dynamics of a quantum system under the influence of surrounding environment is a fundamental yet long-standing problem. It has profound implication in many fields of physics, chemistry and biology. Particularly, various fascinating phenomena emerge in the low-temperature and strong-coupling regime, where the environmental thermal fluctuations are greatly suppressed, and thus the quantum features (such as quantum coherence and quantum correlation) become prominent. However, it is extremely difficult to access the low-temperature and strong-coupling regime with conventional quantum statistical mechanics theories.

In this talk, I will report some of our recent progress in tackling the above formidable challenge. These include a series of advancements for the hierarchical equations of motion (HEOM) method [1,2], and the development of a practical stochastic equation of motion (SEOM) for fermionic environments [3,4]. These efforts have resulted in unprecedented accuracy, efficiency, and applicability for the numerical simulation of quantum dissipative dynamics in the low-temperature and strong-coupling regime.

Keywords: open quantum systems, quantum dissipation, strong electron correlation, non-Markovian effect

Reference

[1] L. Han, H.-D. Zhang, X. Zheng, and Y. J. Yan, *J. Chem. Phys.* **148,** 234108 (2018).

[2] L. Cui, H.-D. Zhang, X. Zheng, R.-X. Xu, and Y. J. Yan, *J. Chem. Phys.* **150,** 024110 (2019); H.-D. Zhang, L. Cui, H. Gong, R.-X. Xu, X. Zheng, and Y. J. Yan, *J. Chem. Phys.* **152,** 064107 (2020).

[3] L. Han, V. Chernyak, Y.-A. Yan, X. Zheng and Y. J. Yan, *Phys. Rev. Lett.* **123,** 050601 (2019).

[4] L. Han, A. Ullah, Y.-A. Yan, X. Zheng, Y. J. Yan, and V. Chernyak, *J. Chem. Phys.* **152,** 204105 (2020); A. Ullah, L. Han, Y.-A. Yan, X. Zheng, Y. J. Yan, and V. Chernyak, *J. Chem. Phys.* **152,** 204106 (2020).

Non-Gaussian variational approach to non-equilibrium problem in many-body systems

石弢

中国科学院理论物理研究所

E-mail: tshi@itp.ac.cn

Abstract

In this talk, I will talk about a new theoretical approach to non-equilibrium problem in many-body systems. By combining a decoupling transformation and the Gaussian variational ansatz, the in and out-of equilibrium physics in many-body systems are explored. This approach have been applied to study the long-term dynamical crossover in Kondo systems, the Anderson-Holstein model under ultrafast THz pulse, and the dynamical confinement-deconfinement transition in lattice gauge theories. For the short time evolution, the result agrees with that from DMRG very well. A rich variety of physics are predicted by our method in the long-term evolution, which is difficult to study by the present numerical methods.

Light-tunable interlayer interaction and hybridization gap in a magnetic topological insulator

Shuyun Zhou
Department of Physics, Tsinghua University
E-mail: syzhou@mail.tsinghua.edu.cn

Abstract

Magnetic topological insulators in the family of $MnBiTe_4/(Bi_2Te_3)_m$ have attracted extensive research interests because of the coexistence of topological properties and magnetism. Experimental observation and engineering of the electronic properties are fundamental. Here by using angle-resolved photoemission spectroscopy with micrometerscale spot and ultrafast time-resolving capability (μ-TrARPES), we reveal the electronic structures of different termination surfaces with spatial resolving capability and report the light-tunable interlayer interaction.

Keywords: Magnetic topological insulator, $MnBiTe_4/(Bi_2Te_3)$m, TrARPES, μ-TrARPES

Anisotropic Response of Type-II Weyl Semimetal TaIrTe4 under Ultrafast Photoexcitation

ZHUO Xiao[1)],LAI Jiawei[1)], YU Peng[2)3)],YU Ze[4)], MA Junchao[1)],LU Wei[5)], LIU Miao[4)6)], LIU Zheng[3)], SUN Dong[1)7)]

1)(International Center for Quantum Materials, School of Physics, Peking University, Beijing 100871, China)
2)(State Key Laboratory of Optoelectronic Materials and Technologies,, Sun Yat-sen University, Guangzhou 510275, Guangdong, China)
3)(Centre for Programmed Materials, School of Materials Science and Engineering, Nanyang Technological University, Singapore, 639798, Singapore.)
4)(Institute of Physics, Chinese Academy of Sciences, Beijing 100190, China)
5)(School of Precision Instruments and Opto-electronics Engineering, Tianjin University, NO. 92 Weijin Road, Tianjin 300072, China)
6)(Songshan Lake Materials Laboratory, Dongguan, Guangdong 523808, China)
7)(Collaborative Innovation Center of Quantum Matter, Beijing 100871, China)

E-mail: sundong@pku.edu.cn

Abstract

We perform angle-resolved transient reflection spectroscopy to study the dynamical evolution of anisotropic properties of Type-II Weyl semimetal TaIrTe4 under photo excitation. The dynamical relaxation of photoexcited carriers exhibits three exponential decay components relating to optical/acoustic phonon cooling and subsequent heat transfer to the substrate. The angle resolved measurement reveals that the anisotropy of reflectivity is reduced in the pump induced quasi-equilibrium state, suggestinga reduction of the anisotropy in dynamical conductivity in hot carrier dominated regime.Such anisotropic response is very similar to its two-dimensional layered counterparts, black phosphorus(BP) while the anisotropy of BP is enhanced in hot carrier dominated regime. These results are indispensable in designing high field, angle sensitive electronic, optoelectronic and remote sensing devices exploiting the dynamical electronic anisotropy.

Keywords: anisotropic response,TaIrTe4, ultrafast spectroscopy,black phosphorus

Reference

[1]ShaofengGe,*et al.*,Dynamical Evolution of Anisotropic Response in Black Phosphorus under Ultrafast Photoexcitation，Nano Lett. 2015, **15, 7**, 4650–4656

[2]Xuefeng Liu*et al.*,Dynamical anisotropic response of black phosphorus under magnetic field，2018 2D Mater. **5**025010

Formation and Dynamics of Small Polaron in Type II Dirac Semimetal $PtTe_2$ Film Probing with Transient THz Spectroscopy

Guohong Ma

Department of Physics, Shanghai University Shanghai 200444

E-mail: ghma@staff.shu.edu.cn

Abstract

As a newly emergent type-II Dirac semimetal, Platinum Telluride ($PtTe_2$) stands out from other 2D noble transition-metal dichalcogenides (TMDCs) for the unique band structure and novel physical properties, and has been studied extensively. However, the ultrafast response of low energy quasiparticle excitation in THz frequency remains nearly unexplored yet. In this study, we employ optical pump-THz probe spectroscopy to systematically study the photocarrier dynamics of $PtTe_2$ thin films with varying pump fluence, temperature, and film thickness. Upon photoexcitation the THz photoconductivity (PC) of $PtTe_2$ films show abrupt increase initially, while the THz PC changes into negative value in a subpicosecond time scale, followed by a prolonged recovery process that lasted a few ns. The magnitude of both positive and negative THz PC response shows strongly pump fluence dependence. We assign the unusual negative THz PC to the formation of small polaron due to the strong electron-phonon (e-ph) coupling, which is further substantiated by temperature and film thickness dependent measurements. Moreover, our investigations give a subpicosecond time scale of sequential carrier cooling and polaron formation. In addition, our experimental study demonstrates that the photoexcited generation of small polariton is a general phenomenon in topological semimetal with layered structure. We have also observed the formation of small polaron in a T_d phase $MoTe_2$ (type II Weyl semimetal) film after photoexcitation at low temperature, while the formation of polaron is absent in the 1T' phase of $MoTe_2$. Our study provides deep insights into the underlying dynamics evolution mechanisms of photocarrier in type-II Dirac/Weyl semimetal upon photoexcitation, which is crucial importance for designing $PtTe_2$-based optoelectronic devices.

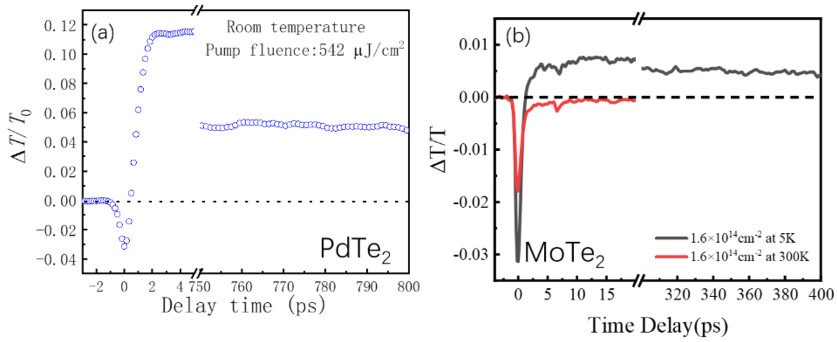

Figure 1. The transient THz transmission of 20 nm $PtTe_2$ film at room temperature (a), and 12 nm $MoTe_2$ film (b) under 780 nm pump at room temperature (red) and 5 K (black)

Geneartion and manipulation of chiral terahertz waves from topological insulators and their feromagentic heterostructures

WU Xiaojun

School of Electronic and Information Engineering, Beihang University, Beijing 100083, China

E-mail: xiaojunwu@buaa.edu.cn

Abstract

Generation and arbitrary manipulation of spin-polarized terahertz (THz) waves at the source through employing the spin properties of electrons not only manifests its appealing fundamental physics in light-matter interaction, but also providing powerful tools for investigating ultrafast THz spintronic dynamics and enabling promising applications such as THz circular dichroism spectroscopy, polarization-sensitive imaging and wireless communication. However, up to now, there are few researches on the generation of chiral THz electromagnetic waves by means of electron spin properties. This talk will present several recent progresses on generation and manipulation of chiral THz waves from topological insulators and their ferromagnetic heterostructure driven by femtosecond laser pulses. Through manipulating the pump laser polarization, sample azimuthal angle, external applied magnetic field direction, the radiated THz chirality and ellipiticity can be flexibly controlled. After comprehensive analysis of these phenomena, we attribute the chiral THz wave generation and manipulation mechanism to the engineering capability of femtosecond pulse induced photogalvanic effects and spin-to-charge conversion. Application demonstration of THz circular dichroism spectroscopy is conducted on several biomaterials, further verifying the usage feasibility of nano-film based chiral THz sources.

Keywords: Chiral THz wave, generation, manipulation, electron spin, topological insulator

Reference

[1] Xinhou Chen, Hangtian Wang, et al., Xiaojun Wu*, Adv. Photon. Research 202000099 (2021)

[2] Haihui Zhao, Xinhou Chen, et al., Xiaojun Wu*, Adv. Photon. 2, 066003 (2020)

[3] Tian Dong, Shaoxian Li, et al., Xiaojun Wu*, Adv. Funct. Mater. 2100463 (2021)

[4] Baolong Zhang, Zhenzhe Ma, Jinglong Ma, Xiaojun Wu*, et al., Laser Photonics Rev. 202000295 (2021)

Ultrafast Spin Current generation and THz emission from an Antiferromagnet at zero magnetic field

Hongsong Qiu[1†], Lifan Zhou[2†], Caihong Zhang[1], Jingbo Wu[1], Yuanzhe Tian[2], Shaodong Cheng[3], Shaobo Mi[3], Haibin Zhao[4], Qi Zhang[2], Di Wu[2*], Biaobing Jin[1*], Jian Chen[1], Peiheng Wu[1]

[1]RISE, School of Electronics Science and Engineering, Nanjing University, Nanjing, P. R. China

[2] Department of Physics, Nanjing University, Nanjing, P. R. China

[3] State Key Laboratory for Mechanical Behavior of Materials, Xi'an Jiaotong Univ., P. R. China

[4] Department of Optical Science and Engineering, Fudan University, P. R. China

E-mail: bbjin@nju.edu.cn

Abstract

Antiferromagnets (AFMs) have the potentials for high-speed processing in the terahertz (THz) range [1-3]. However, the application of the AFM is still facing heavy predicaments because of its insensitivity to external magnetic perturbation and difficulty in detection. An efficient technique to manipulate the antiferromagnetic order is the optical stimulus [4,5]. Unlike mild traditional approaches, e.g., external magnetic field or electrical currents, perturbation of phonons is always more dramatic. The microscopic mechanism can be phenomenologically represented as an effective magnetic field and therefore magneto-optics (MO) is an efficient probe of the nonequilibrium state. Besides, THz emission spectroscopy is also an appealing technique to probe spin dynamics [6], since ultrafast laser pulses induce transients in the sub-picosecond timescale and the resonant frequency of magnon in AFM usually extends to THz range. Here, we report the generation of ultrafast spin current in an AFM/HM heterostructure at zero external magnetic fields detected with THz emission spectroscopy. The THz emission is based on the inverse spin Hall effect (ISHE) in the HM layer. The THz emission sensitively depends on the sample azimuth and the distribution of the spin domains. To the best of our knowledge, it is the first time to observe the generation of spin currents from an antiferromagnet and our results possibly open a new avenue for fundamental research of AFM opto-spintronics.

Keywords: Antiferromagnet, Spin current, Terahertz Emission Spectroscopy

Reference

[1] Jungwirth T. et al., "Antiferromagnetic spintronics," Nature Nanotechnology, 2016, **11(3)**:231

[2] Kimel A. V. et al., "Inertia-driven spin switching in antiferromagnets," Nat. Phys., 2009, **5**:727

[3] Kampfrath T., et al., "Coherent terahertz control of antiferromagnetic spin waves," Nat.

Photonics, 2010, **5(1)**: 31
[4] Němec, P.et al., “Antiferromagnetic opto-spintronics,” Nat. Phys., 2018, **14(3)**: 229
[5] Satoh, T. et al., “Excitation of coupled spin-orbit dynamics in cobalt oxide by femtosecond laser pulses,” Nat. Commun., 2017, **8(1)**: 638
[6] Kampfrath T. et al., “Terahertz spin current pulses controlled by magnetic heterostructures,” Nat. Nanotechnol.,2013, **8(4)**: 256

Generation of circularly polarized broadband terahertz radiation from spintronic emitters driven by ultrafast Yb lasers

Zhensheng Tao[1)]

1) State Key Laboratory of Surface Physics and Department of Physics, Fudan University, Shanghai, China

E-mail: ZhenshengTao@fudan.edu.cn

Abstract

Terahertz (THz) emission covering the energy range of ~4 meV to 40 meV (1-10 THz) is of critical importance for quantum materials, because many resonant responses, including optical phonons, quasi-particle scattering and antiferromagnetic spin-wave gaps, all lie in this spectral range. The generation and manipulation of the circularly polarized THz radiation is essential for characterizing the magnetic properties and handedness of quantum materials. However, it has been a great challange, because of the lack of suitable polarzation control optics for THz waves. In this work, we demonstrate a broadband THz emitter established on the novel spintronic devices, in combination with metamaterial structures. Our method enables high flexibility and tunability of the circularity and handedness of the broadband THz radiation. The THz emission is driven by an ultrafast Yb laser, enabled by the efficient pulse compression under the solitary beam propagation in a nonlinear resonator. Our approach can be broadly applied to novel Yb ultrafast lasers for generating THz radiation with tunable polarizations, which exhibit advantages of high power scaling and high flexibility. This will open new possibilities for ultrafast circular dichroism spectroscopies on quantum materials.

Keywords : THz radiation, spintronics, ultrashort pulse compression

Unusual bandgap shift and coherent spin dynamics in hybrid organic-inorganic perovskites

YANG Luyi [1) 2)]

1）State Key Laboratory of Low Dimensional Quantum Physics and Department of Physics, Tsinghua University, 100084, Beijing, China

2）Frontier Science Center for Quantum Information, 100084, Beijing, China

Email: luyi-yang@mail.tsinghua.edu.cn

Abstract

Hybrid organic-inorganic perovskites have demonstrated potential applications in optoelectronic devices, such as solar cells, light emitting diodes and high energy radiation detectors. In addition, the strong spin-orbit coupling in these materials can be exploited for spintronic applications. However, direct probes of optical properties and spin dynamics in these materials are still at an early stage. In this work, we investigate the temperature dependence of the bandgap and coherent spin dynamics in two representative perovskites, that is, $MA_{0.3}FA_{0.7}PbI_3$ (pure Pb) and $MA_{0.3}FA_{0.7}Pb_{0.5}Sn_{0.5}I_3$ (mixed Pb-Sn), where MA=CH_3NH_3 and FA= $(NH_2)_2$ CH. Using both photoluminescence and optical transmittance spectra, we find that the bandgap of the mixed Pb-Sn sample exhibits an unusually large blue shift by raising the temperature from 10 to 340 K. By contrast, the pure Pb sample shows nonmonotonic and small bandgap shift with temperature. We demonstrate optical orientation and detection of spin polarization and spin coherence in both materials. Time-resolved Faraday rotation measurements reveal long spin lifetimes of electrons and holes and dephasing of spin polarization in the presence an applied magnetic field due to inhomogeneous broadening of the *g*-factors.

Keywords: hybrid organic-inorganic perovskites, optical properties, spin dynamics

Correlated triplet pairs in tetracene oligomers indentified by transient magneto-optical spectroscopy

ZHANG Chunfeng[1)]

1) (School of Physics, Nanjing University, Nanjing 210093, China)

E-mail: cfzhang@nju.edu.cn

Abstract

Singlet fission occurs in organic molecular systems with the energy of singlet state about twice of triplet state (E_{S1}~$2E_{T1}$) by converting a singlet exciton (S_1) into two free triplets (T_1+T_1). Such a process holds the potential to overcome the Shockley-Queisser efficiency limit of single-junction solar cells. The state of correlated triplet pair (TT) with different spatial separation, i.e., two triplets with spin coherence retained, has been considered as the key intermediate for singlet fission process. Neverthless, it has been chanllenging to experimentally distinguish these TT from T_1 state. By using transient magneto-optical spectroscopic methods, we show that the different TT states can be identified by using the transitient magneto-optical spectroscopy considering the different exchange interaction. We show that free-triplet generation can be significantly enhanced through the SF pathway that involves the spatially separated (T…T) state in tetracene oligmers rather than the pathway mediated by the spatially adjacent TT state, leading to a marked improvement in free triplet generation with an efficiency increase from 21% for the dimer to 85% (124%) for the trimer (tetramer).

Keywords: Singlet fission, correlated triplet pairs, transient magneto-optical spectroscopy

Reference

1. Zhiwei Wang, et al., Free-triplet generation with improved efficiency in tetracene oligomers through spatially separated triplet pair states, Nature Chemistry, DOI:10.1038/s41557-021-00665-7 (2021).

Real-time *GW*-BSE Investigations on Spin-Valley Exciton Dynamics in Monolayer Transition Metal Dichalcogenide

Xiang Jiang,[1] Qijing Zheng,[1] Zhenggang Lan,[2,3] Wissam A. Saidi,[4] Xinguo Ren,[5] and Jin Zhao[1,6,7]*

[1]ICQD/Hefei National Laboratory for Physical Sciences at Microscale, and CAS Key Laboratory of Strongly-Coupled Quantum Matter Physics, and Department of Physics, University of Science and Technology of China, Hefei, Anhui 230026, China
[2]SCNU Environmental Research Institute, Guangdong Provincial Key Laboratory of Chemical Pollution and Environmental Safety & MOE Key Laboratory of Theoretical Chemistry of Environment, South China Normal University, Guangzhou 510006, China
[3]School of Environment, South China Normal University, University Town, Guangzhou 510006, China
[4]Department of Mechanical Engineering and Materials Science, University of Pittsburgh, Pittsburgh, Pennsylvania 15261, USA
[5]Institute of Physics, Chinese Academy of Sciences, Beijing 100190, China
[6]Department of Physics and Astronomy, University of Pittsburgh, Pittsburgh, Pennsylvania 15260, USA
[7]Synergetic Innovation Center of Quantum Information & Quantum Physics, University of Science and Technology of China, Hefei, Anhui 230026, China

*Corresponding author. Email: zhaojin@ustc.edu.cn

Abstract

The valley exciton dynamics in two-dimensional transition metal dichalcogenides (TMDs) is crucial for the spin-valleytronics. However, a real-time *ab initio* method for the spin-resolved exciton dynamics is still missing. Here we develop an *ab initio* nonadiabatic molecular dynamics (NAMD) method based on *GW* plus real-time Bethe-Salpeter equation (*GW*+rtBSE-NAMD) for the spin-resolved exciton dynamics. From investigations on MoS_2, we provide a comprehensive picture of spin-valley exciton dynamics where the electron-phonon (*e-ph*) scattering, spin-orbit interaction (SOI) and electron-hole (*e-h*) interactions come into play collectively. Especially, we provide a direct evidence that *e-h* exchange interaction plays a dominant role in the fast valley depolarization within few picoseconds in excellent agreement with experiments. Moreover, there are bright-to-dark exciton transitions induced by *e-ph* scattering and SOI. Our study proves that *e-h* many-body effects are essential to understand the spin-valley exciton dynamics in TMDs and the newly developed *GW*+rtBSE-NAMD method provides a powerful tool for exciton dynamics in extended systems with time,

space, momentum, energy and spin resolution.

Reference

1. X. Jiang, Q. Zheng, Z. Lan, W. A. Saidi, X. Ren and J. Zhao*, "Real-time GW-BSE Investigations on Spin-Valley Exciton Dynamics in Monolayer Transition Metal Dichalcogenide." *Sci. Adv.*, **7**, eabf3759 (2021)

Terhertz spectroscopy studies of oxide thin films and two-dimensional materials

Long Cheng[1], Zhuang Ren[1],Zuanming Jin[2], Fuhai Su[3], Gaoting Lin[3], Lin Hu[3], Xuan Luo[3], Yuping Sun[3], and Zhigao Sheng[1]*

1) (High Magnetic Field Laboratory, HFIPS, Anhui, Chinese Academy of Sciences, Hefei 230031, China)

2) (Department of Physics, Shanghai University, Shanghai 200444, P.R. China)

3) (Institute of Solid State Physics, HFIPS, Chinese Academy of Sciences, Hefei, 230031, China)

E-mail: zhigaosheng@hmfl.ac.cn

Abstract

Terahertz (THz) generally refers to sub-millimeter electromagnetic waves with frequencies between 10^{11} and 10^{13} Hz. Benefit from its excellent spectral performance, terahertz-related technology possesses great application potential in fields of communication, sensing, national security, and especially fundamental research. Here, we will briefly introduce our recent works on the THz spectroscopy studies of two dimensional materials.

Afterwards, studies of mechanical THz modulation effect and possible THz emission in 2D materials will be presented. For the first work, a device prototype based on single-layered graphene is constructed and systematically studied and presents excellent modulation effect. For the second work, a phonon related THz oscillation in a ferromagnetic 2D materials was discovered.

Keywords : THz-TDS, two-dimensional materials, thin films, THz modulation, THz emission.

Reference

[1]. Zhuang Ren, Long Cheng, **Zhigao Sheng,*** *et al.*, "Photoinduced Broad-band Tunable Terahertz Absorber Based on a VO_2 Thin Film", ***ACS Appl. Mater. Interfaces*** 12, 43, 48811–48819 (2020).

[2]. Long Cheng, Zuanming Jin, Fuhai Su, **Zhigao Sheng***, *et al.* "Mechanical Terahertz Modulation Based on Single-Layered Graphene", ***Adv. Optical Mater.*** 6, 1700877(2018).

Optical anisotropy and excitons in two-dimentional zigzag antiferromagnets

Qi Zhang[1)]

1) (School of physics, Najing University, Nanjing 210093, China)

E-mail: zhangqi@nju.edu.cn

Abstract

Two-dimensional antiferromagnetism (2D AFM) plays an essential role in various correlated phenomena. In contrast to ferromagnetism, direct optical probing of the AFM order parameter in atomically thin samples is challenging, e.g. via magneto-optical spectroscopy, due to the lack of net magnetization. Here, we report zigzag-AFM induced optical linear dichroism (LD) in layered transition-metal thiophosphates MPS_3 (M=Fe, Ni). The observed LD is giant, at least one order of magnitude larger than those reported in other antiferromagnetic systems. We further revealed ultrafast AFM dynamics and critical slowing down behaviors in this system via ultrafast polarimetry measurements. We will also introduce our recent observation of anisotropic excitons strongly coupled to the zigzag antiferromagnetic order, as well as exciton-phonon bound states.

Our findings point to a new optical approach for the investigation and control of zigzag or stripe magnetic order in strongly correlated systems, and establishes MPS_3 as a new 2D platform for exploring 2D antiferromagnetism with strong correlations, as well as a building block for 2D heterostructures for engineering physical phenomena with time reversal symmetry breaking.

Keywords : 2D antiferromagnetism, spin-lattice coupling, excitons

Two-dimensional coherent spectroscopy: concepts and opportunities for strongly-correlated electronic systems

Yuan Wan

Institute of Physics, Chinese Academy of Sciences, Beijing 100190, China

E-mail: yuan.wan@iphy.ac.cn

Abstract

Two-dimensional coherent spectroscopy (2DCS) is a powerful experimental technique that probes the nonlinear optical response of materials. In essence, the traditional "1D" spectroscopy, which measures the linear response, reveals the excitations in a system, whereas the 2DCS unveils the interplay between these excitations. The 2DCS in the infrared frequency range has been widely used in chemistry and biology to unravel the complex structure of molecules. The advent of terahertz 2DCS makes it now possible to apply this technique to solid state systems and, in particular, strongly correlated electronic systems. In this talk, I will give an exposition to the basic concepts of the 2DCS and demonstrate theoretically its potential utilities in quantum spin systems. Specifically, I will show that the 2DCS can resolve the "spinon continuum" from the gapped fractional excitations. For the Luttinger spin liquid, the 2DCS can directly reveal the coherent propagation of the fractional excitations. Finally, I will briefly discuss some of the challenges in the development of 2DCS theory.