ISSN 1674-1056
http://cpb.iphy.ac.cn
http://iopscience.iop.org/cpb
中国物理 B
Chinese Physics
中国物理 Chinese Physics B

Emerging properties of two-dimensional twisted bilayer materials

Yang Cheng(程阳), Chen Huang(黄琛), Hao Hong(洪浩), Zixun Zhao(赵子荀), Kaihui Liu(刘开辉)
Citation: Chin. Phys. B . 2019, 28(10): 107304 . **doi:** 10.1088/1674-1056/28/10/107304
Journal homepage: http://cpb.iphy.ac.cn; http://iopscience.iop.org/cpb

What follows is a list of articles you may be interested in

Energy band alignment at Cu_2O/ZnO heterojunctions characterized by *in situ* x-ray photoelectron spectroscopy

Yan Zhao(赵妍), Hong-Bu Yin(尹泓卜), Ya-Jun Fu(符亚军), Xue-Min Wang(王雪敏), Wei-Dong Wu(吴卫东)
Chin. Phys. B . 2019, 28(8): 087301 . **doi:** 10.1088/1674-1056/28/8/087301

Analysis of displacement damage effects on bipolar transistors irradiated by spallation neutrons

Yan Liu(刘岩), Wei Chen(陈伟), Chaohui He(贺朝会), Chunlei Su(苏春垒), Chenhui Wang(王晨辉), Xiaoming Jin(金晓明), Junlin Li(李俊霖), Yuanyuan Xue(薛院院)
Chin. Phys. B . 2019, 28(6): 067302 . **doi:** 10.1088/1674-1056/28/6/067302

Room-temperature infrared photodetectors with hybrid structure based on two-dimensional materials

Tiande Liu(刘天德), Lei Tong(童磊), Xinyu Huang(黄鑫宇), Lei Ye(叶镭)
Chin. Phys. B . 2019, 28(1): 017302 . **doi:** 10.1088/1674-1056/28/1/017302

A facile and efficient dry transfer technique for two-dimensional Van der Waals heterostructure

Li Xie(谢立), Luojun Du(杜罗军), Xiaobo Lu(卢晓波), Rong Yang(杨蓉), Dongxia Shi(时东霞), Guangyu Zhang(张广宇)
Chin. Phys. B . 2017, 26(8): 087306 . **doi:** 10.1088/1674-1056/26/8/087306

Au and Ti induced charge redistributions on monolayer WS_2

Zhu Hui-Li, Yang Wei-Huang, Wu Ya-Ping, Lin Wei, Kang Jun-Yong, Zhou Chang-Jie
Chin. Phys. B . 2015, 24(7): 077301 . **doi:** 10.1088/1674-1056/24/7/077301

ISSN 1674-1056

CPB
Chinese Physics B

Volume 28 October 2019 Number 10

TOPICAL REVIEW

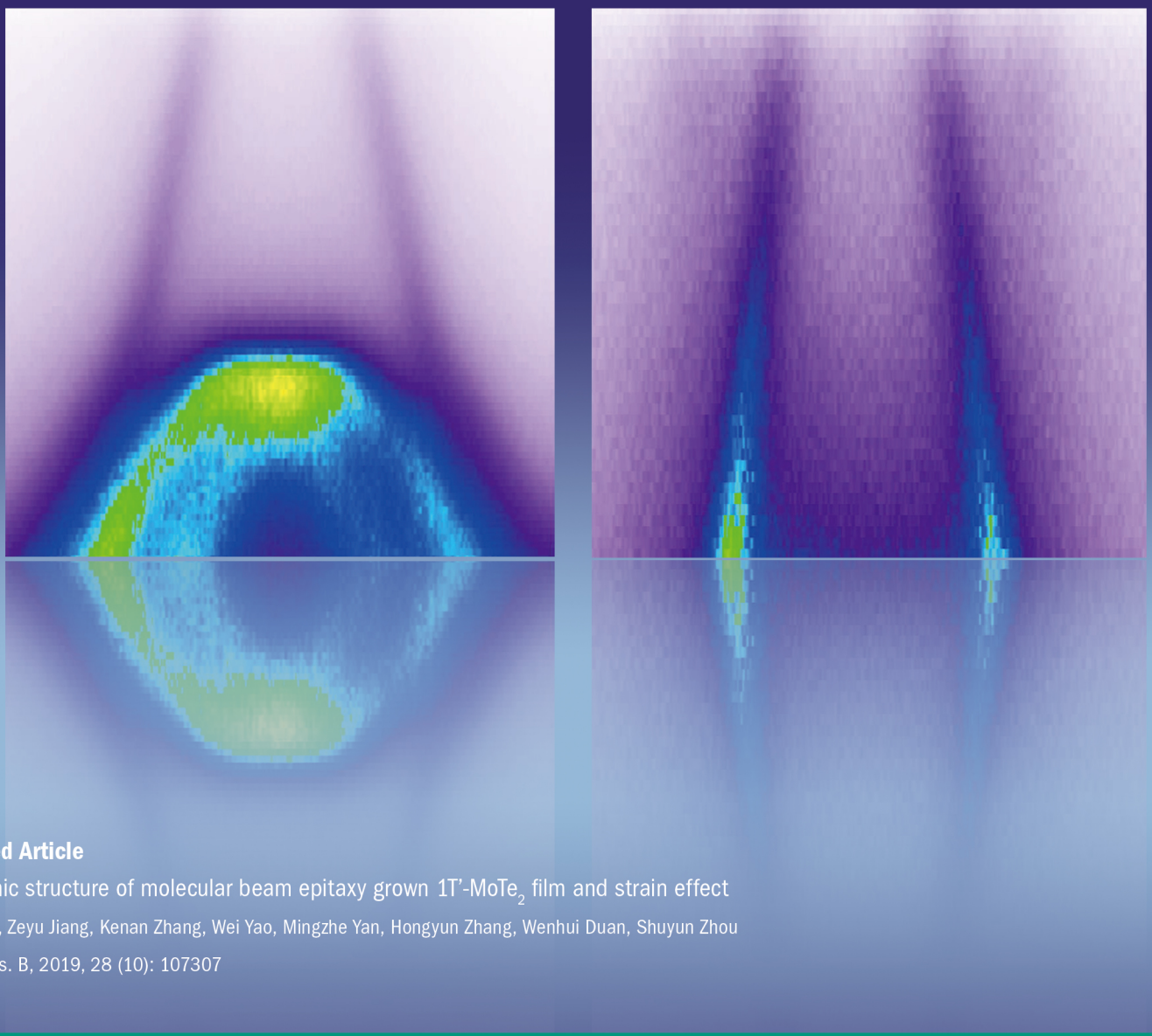
- CALYPSO structure prediction methodology and its applications to materials discovery

SPECIAL TOPIC

- A celebration of the 100th birthday of Kun Huang
- 110th Anniversary of Lanzhou University
- Strong-field atomic and molecular physics

A series Journal of the Chinese Physical Society Distributed by IOP Publishing

iopscience.org/cpb | **cpb.iphy.ac.cn**



Featured Article

Electronic structure of molecular beam epitaxy grown 1T'-$MoTe_2$ film and strain effect

Xue Zhou, Zeyu Jiang, Kenan Zhang, Wei Yao, Mingzhe Yan, Hongyun Zhang, Wenhui Duan, Shuyun Zhou

Chin. Phys. B, 2019, 28 (10): 107307

CHINESE PHYSICAL SOCIETY | IOP Publishing

Chinese Physics B

Volume 28 Number 10 October 2019

TOPICAL REVIEW — CALYPSO structure prediction methodology and its applications to materials discovery

103104 Cluster structure prediction via CALYPSO method
Yonghong Tian, Weiguo Sun, Bole Chen, Yuanyuan Jin and Cheng Lu

106104 Discovery of superhard materials via CALYPSO methodology
Shuangshuang Zhang, Julong He, Zhisheng Zhao, Dongli Yu and Yongjun Tian

106105 The CALYPSO methodology for structure prediction
Jian Lv, Pengyue Gao and Yanchao Wang

106106 Pressure-induced new chemistry
Jianyan Lin, Xin Du and Guochun Yang

106107 Geoscience material structures prediction via CALYPSO methodology
Andreas Hermann

106201 High-pressure electrides: From design to synthesis
Biao Wan, Jingwu Zhang, Lailei Wu and Huiyang Gou

107104 The role of CALYPSO in the discovery of high-T_c hydrogen-rich superconductors
Wenwen Cui and Yinwei Li

107306 Recent progress on the prediction of two-dimensional materials using CALYPSO
Cheng Tang, Gurpreet Kour and Aijun Du

TOPICAL REVIEW — A celebration of the 100th birthday of Kun Huang

104202 Unconventional phase transition of phase-change-memory materials for optical data storage
Nian-Ke Chen and Xian-Bin Li

107304 Emerging properties of two-dimensional twisted bilayer materials
Yang Cheng, Chen Huang, Hao Hong, Zixun Zhao and Kaihui Liu

107502 Electrical transport and optical properties of Cd_3As_2 thin films
Yun-Kun Yang, Fa-Xian Xiu, Feng-Qiu Wang, Jun Wang and Yi Shi

SPECIAL TOPIC — A celebration of the 100th birthday of Kun Huang

106802 Charge trapping memory device based on the Ga_2O_3 films as trapping and blocking layer
Bing Bai, Hong Wang, Yan Li, Yunxia Hao, Bo Zhang, Boping Wang, Zihang Wang, Hongqi Yang, Qihang Gao, Chao Lü, Qingshun Zhang and Xiaobing Yan

107501 Magnetoresistance hysteresis in topological Kondo insulator SmB_6 nanowire
Ling-Jian Kong, Yong Zhou, Hua-Ding Song, Da-Peng Yu and Zhi-Min Liao

JUST FOR AUTHORS
— Chinese Physics B

(*Continued on the Bookbinding Inside Back Cover*)

107504 Two-dimensional XSe_2 (X = Mn, V) based magnetic tunneling junctions with high Curie temperature
Longfei Pan, Hongyu Wen, Le Huang, Long Chen, Hui-Xiong Deng, Jian-Bai Xia and Zhongming Wei

107801 Optoelectronic properties analysis of silicon light-emitting diode monolithically integrated in standard CMOS IC
Yanxu Chen, Dongliang Xu, Kaikai Xu, Ning Zhang, Siyang Liu, Jianming Zhao, Qian Luo, Lukas W. Snyman and Jacobus W. Swart

TOPICAL REVIEW — 110th Anniversary of Lanzhou University

107105 A review of current research on spin currents and spin–orbit torques
Xiao-Yu Feng, Qi-Han Zhang, Han-Wen Zhang, Yi Zhang, Rui Zhong, Bo-Wen Lu, Jiang-Wei Cao and Xiao-Long Fan

SPECIAL TOPIC — 110th Anniversary of Lanzhou University

100501 Enhancing von Neumann entropy by chaos in spin–orbit entanglement
Chen-Rong Liu, Pei Yu, Xian-Zhang Chen, Hong-Ya Xu, Liang Huang and Ying-Cheng Lai

100502 Experimental investigation of the fluctuations in nonchaotic scattering in microwave billiards
Runzu Zhang, Weihua Zhang, Barbara Dietz, Guozhi Chai and Liang Huang

107103 Benchmarking the simplest slave-particle theory with Hubbard dimer
Wei-Wei Yang, Hong-Gang Luo and Yin Zhong

SPECIAL TOPIC — Strong-field atomic and molecular physics

103201 Asymmetric structure of atomic above-threshold ionization spectrum in two-color elliptically polarized laser fields
Xu-Cong Zhou, Shang Shi, Fei Li, Yu-Jun Yang, Jing Chen, Qing-Tian Meng and Bing-Bing Wang

103202 Role of the dressed and bound states on below-threshold harmonic generation of He atom
Jian-Wei Zhou, Zhi-Hong Jiao, Peng-Cheng Li and Xiao-Xin Zhou

RAPID COMMUNICATION

104211 Characterize and optimize the four-wave mixing in dual-interferometer coupled silicon microrings
Chao Wu, Yingwen Liu, Xiaowen Gu, Shichuan Xue, Xinxin Yu, Yuechan Kong, Xiaogang Qiang, Junjie Wu, Zhihong Zhu and Ping Xu

106103 Structural and electronic properties of transition-metal chalcogenides Mo_5S_4 nanowires
Ming-Shuai Qiu, Huai-Hong Guo, Ye Zhang, Bao-Juan Dong, Sajjad Ali and Teng Yang

107307 Electronic structure of molecular beam epitaxy grown 1T′-$MoTe_2$ film and strain effect
Xue Zhou, Zeyu Jiang, Kenan Zhang, Wei Yao, Mingzhe Yan, Hongyun Zhang, Wenhui Duan and Shuyun Zhou

TO-BE FOR AUTHORS
— CHINESE PHYSICS B

107401 Robust two-gap strong coupling superconductivity associated with low-lying phonon modes in pressurized Nb_5Ir_3O superconductors
Bosen Wang, Yaoqing Zhang, Shuxiang Xu, Kento Ishigaki, Kazuyuki Matsubayashi, Jin-Guang Cheng, Hideo Hosono and Yoshiya Uwatoko

108704 Influence of matrigel on the shape and dynamics of cancer cells
Teng Ye and Feng Qiu

GENERAL

100201 Compact finite difference schemes for the backward fractional Feynman–Kac equation with fractional substantial derivative
Jiahui Hu, Jungang Wang, Yufeng Nie and Yanwei Luo

100202 Exact solutions of a (2+1)-dimensional extended shallow water wave equation
Feng Yuan, Jing-Song He and Yi Cheng

100203 Lump-type solutions of a generalized Kadomtsev–Petviashvili equation in (3+1)-dimensions
Xue-Ping Cheng, Wen-Xiu Ma and Yun-Qing Yang

100301 Time evolution of angular momentum coherent state derived by virtue of entangled state representation and a new binomial theorem
Ji-Suo Wang, Xiang-Guo Meng and Hong-Yi Fan

100302 Boundary states for entanglement robustness under dephasing and bit flip channels
Hong-Mei Li, Miao-Di Guo, Rui Zhang and Xue-Mei Su

100303 Manipulating transition of a two-component Bose–Einstein condensate with a weak δ-shaped laser
Bo Li, Xiao-Jun Jiang, Xiao-Lin Li, Wen-Hua Hai and Yu-Zhu Wang

100304 Topological phases of a non-Hermitian coupled SSH ladder
J S Liu, Y Z Han and C S Liu

100401 Optimal estimation of the amplitude of signal with known frequency in the presence of thermal noise
Jie Luo, Jun Ke, Yi-Chuan Liu, Xiang-Li Zhang, Wei-Ming Yin and Cheng-Gang Shao

100701 Photoactivation experiment of ^{197}Au(γ, n) performed with 9.17-MeV γ-ray from ^{13}C(p, γ)^{14}N
Yong-Le Dang, Fu-Long Liu, Guang-Yong Fu, Di Wu and Nai-Yan Wang

ATOMIC AND MOLECULAR PHYSICS

103101 Interface properties and electronic structures of aromatic molecules with anhydride and thio-functional groups on Ag (111) and Au (111) substrates
Wei-Qi Yu, Hong-Jun Xiao and Ge-Ming Wang

103102 Elastic properties of anatase titanium dioxide nanotubes: A molecular dynamics study
Kang Yang, Liang Yang, Chang-Zhi Ai, Zhao Wang and Shi-Wei Lin

JUST FOR AUTHORS

103103 Theoretical investigation of the pressure broadening D_1 and D_2 lines of cesium atoms colliding with ground-state helium atoms
Moussaoui Abdelaziz, Alioua Kamel, Allouche Abdul-rahman and Bouledroua Moncef

103105 *Ab initio* investigation of excited state dual hydrogen bonding interactions and proton transfer mechanism for novel oxazoline compound
Yu-Sheng Wang, Min Jia, Qiao-Li Zhang, Xiao-Yan Song and Da-Peng Yang

103203 Selection of right-circular-polarized harmonics from p orbital of neon atom by two-color bicircular laser fields
Chang-Long Xia, Yue-Yue Lan, Qian-Qian Li and Xiang-Yang Miao

103204 Helicity of harmonic generation and attosecond polarization with bichromatic circularly polarized laser fields
Jun Zhang, Tong Qi, Xue-Fei Pan, Jing Guo, Kai-Guang Zhu and Xue-Shen Liu

ELECTROMAGNETISM, OPTICS, ACOUSTICS, HEAT TRANSFER, CLASSICAL MECHANICS, AND FLUID DYNAMICS

104201 Dynamic and inner-dressing control of four-wave mixing in periodically-driven atomic system
Yuan-Yuan Li, Li Li, Yun-Zhe Zhang and Lei Zhang

104203 Proof-of-principle experimental demonstration of quantum secure imaging based on quantum key distribution
Yi-Bo Zhao, Wan-Li Zhang, Dong Wang, Xiao-Tian Song, Liang-Jiang Zhou and Chi-Biao Ding

104204 Numerical investigation on coherent mid-infrared supercontinuum generation in chalcogenide PCFs with near-zero flattened all-normal dispersion profiles
Jie Han, Sheng-Dong Chang, Yan-Jia Lyu and Yong Liu

104205 Second-order interference of two independent photons with different spectra
Yu Zhou, Jian-Bin Liu, Huai-Bin Zheng, Hui Chen, Fu-Li Li and Zhuo Xu

104206 Polymer/silica hybrid waveguide Y-branch power splitter with loss compensation based on $NaYF_4$:Er^{3+}, Yb^{3+} nanocrystals
Yue-Wu Fu, Tong-He Sun, Mei-Ling Zhang, Xu-Cheng Zhang, Fei Wang and Da-Ming Zhang

104207 Properties of multi-Gaussian Schell-model beams carrying an edge dislocation propagating in oceanic turbulence
Da-Jun Liu, Yao-Chuan Wang, Gui-Qiu Wang, Hong-Ming Yin and Hai-Yang Zhong

104208 Extraordinary transmission and reflection in $\mathcal{PT}$-symmetric two-segment-connected triangular optical waveguide networks with perfect and broken integer waveguide length ratios
Jia-Ye Wu, Xu-Hang Wu, Xiang-Bo Yang and Hai-Ying Li

104209 Low insertion loss silicon-based spatial light modulator with high reflective materials outside Fabry–Perot cavity
Li-Fei Tian, Ying-Xin Kuang, Zhong-Chao Fan and Zhi-Yong Li

JUST FOR AUTHORS

104210 Multi-objective strategy to optimize dithering technique for high-quality three-dimensional shape measurement
Ning Cai, Zhe-Bo Chen, Xiang-Qun Cao and Bin Lin

104212 Single event upset on static random access memory devices due to spallation, reactor, and monoenergetic neutrons
Xiao-Ming Jin, Wei Chen, Jun-Lin Li, Chao Qi, Xiao-Qiang Guo, Rui-Bin Li and Yan Liu

104301 Theoretical framework for geoacoustic inversion by adjoint method
Yang Wang and Xiao-Feng Zhao

104601 Evolution of real contact area during stick-slip movement observed by total reflection method
Zhijun Luo, Baojiang Song, Jingyu Han and Shaoze Yan

104701 Stabilized seventh-order dissipative compact scheme for two-dimensional Euler equations
Jia-Xian Qin, Ya-Ming Chen and Xiao-Gang Deng

104702 Numerical simulation on dynamic behaviors of bubbles flowing through bifurcate T-junction in microfluidic device
Liang-Yu Wu, Ling-Bo Liu, Xiao-Tian Han, Qian-Wen Li and Wei-Bo Yang

PHYSICS OF GASES, PLASMAS, AND ELECTRIC DISCHARGES

105201 Construction of an H_α diagnostic system and its application to determine neutral hydrogen densities on the Keda Torus eXperiment
Junfeng Zhu, Tao Lan, Ge Zhuang, Tijian Deng, Jie Wu, Hangqi Xu, Chen Chen, Sen Zhang, Jiaren Wu, Yiming Zu, Hong Li, Jinlin Xie, Ahdi Liu, Zixi Liu, Zhengwei Wu, Hai Wang, Xiaohui Wen, Haiyang Zhou, Chijin Xiao, Weixing Ding and Wandong Liu

105202 The inverse Bremsstrahlung absorption in the presence of Maxwellian and non-Maxwellian electrons
Mehdi Sharifian, Fatemeh Ghoveisi, Leila Gholamzadeh and Narges Firouzi Farrashbandi

CONDENSED MATTER: STRUCTURAL, MECHANICAL, AND THERMAL PROPERTIES

106101 Defects and electrical properties in Al-implanted 4H-SiC after activation annealing
Yi-Dan Tang, Xin-Yu Liu, Zheng-Dong Zhou, Yun Bai and Cheng-Zhan Li

106102 First principles study of interactions of oxygen–carbon–vacancy in bcc Fe
Yuan You, Mu-Fu Yan, Ji-Hong Yan, Gang Sun and Chao Wang

106301 Physical properties of ternary thallium chalcogenes Tl_2MQ_3 (M = Zr, Hf; Q = S, Se, Te) via *ab-initio* calculations
Engin Ateser, Oguzhan Okvuran, Yasemin Oztekin Ciftci, Haci Ozisik and Engin Deligoz

106401 Phosphine-free synthesis of $FeTe_2$ nanoparticles and self-assembly into tree-like nanoarchitectures
Hongyu Wang, Min Wu, Yixuan Wang, Hao Wang, Xiaoli Huang and Xinyi Yang

JUST FOR AUTHORS

106701 Expansion dynamics of a spherical Bose–Einstein condensate
Rui-Zong Li, Tian-You Gao, Dong-Fang Zhang, Shi-Guo Peng, Ling-Ran Kong, Xing Shen and Kai-Jun Jiang

106801 Highly reliable and selective ethanol sensor based on α-Fe_2O_3 nanorhombs working in realistic environments
Wenjun Yan, Xiaomin Zeng, Huan Liu, Chunwei Guo, Min Ling and Houpan Zhou

CONDENSED MATTER: ELECTRONIC STRUCTURE, ELECTRICAL, MAGNETIC, AND OPTICAL PROPERTIES

107101 Electronic properties of size-dependent $MoTe_2/WTe_2$ heterostructure
Jing Liu, Ya-Qiang Ma, Ya-Wei Dai, Yang Chen, Yi Li, Ya-Nan Tang and Xian-Qi Dai

107102 Hubbard model on an anisotropic checkerboard lattice at finite temperatures: Magnetic and metal–insulator transitions
Hai-Di Liu

107301 Negative transconductance effect in p-GaN gate AlGaN/GaN HEMTs by traps in unintentionally doped GaN buffer layer
Mei Ge, Qing Cai, Bao-Hua Zhang, Dun-Jun Chen, Li-Qun Hu, Jun-Jun Xue, Hai Lu, Rong Zhang and You-Dou Zheng

107302 Optical response of an inverted InAs/GaSb quantum well in an in-plane magnetic field
Xiaoguang Wu

107303 Observation of hopping transitions for delocalized electrons by temperature-dependent conductance in silicon junctionless nanowire transistors
Yang-Yan Guo, Wei-Hua Han, Xiao-Song Zhao, Ya-Mei Dou, Xiao-Di Zhang, Xin-Yu Wu and Fu-Hua Yang

107305 Enhanced spin-dependent thermopower in a double-quantum-dot sandwiched between two-dimensional electron gases
Feng Chi, Zhen-Guo Fu, Liming Liu and Ping Zhang

107503 Magnetic vortex gyration mediated by point-contact position
Hua-Nan Li, Zi-Wei Fan, Jia-Xin Li, Yue Hu and Hui-Lian Liu

107802 Cascaded plasmonic nanorod antenna for large broadband local electric field enhancement
Dou Zhang, Zhong-Jian Yang and Jun He

107803 Photoluminescence properties of blue and green multiple InGaN/GaN quantum wells
Chang-Fu Li, Kai-Ju Shi, Ming-Sheng Xu, Xian-Gang Xu and Zi-Wu Ji

INTERDISCIPLINARY PHYSICS AND RELATED AREAS OF SCIENCE AND TECHNOLOGY

108101 Effect of AlN coating on hydrogen permeability and surface structure of VT6 alloy by vacuum arc ion plating
Zi-Yi Ding

JUST FOR AUTHORS
— Chinese Physics B

108102 Effect of sintering temperature on luminescence properties of borosilicate matrix blue–green emitting color conversion glass ceramics
Qiao-Yu Zheng, Yang Li, Wen-Juan Wu, Ming-Ming Shi, Bo-Bo Yang and Jun Zou

108103 Flexible rGO/Fe_3O_4 NPs/polyurethane film with excellent electromagnetic properties
Wei-Qi Yu, Yi-Chen Qiu, Hong-Jun Xiao, Hai-Tao Yang and Ge-Ming Wang

108201 Parameter identification and state-of-charge estimation approach for enhanced lithium-ion battery equivalent circuit model considering influence of ambient temperatures
Hui Pang, Lian-Jing Mou and Long Guo

108501 Analysis of non-uniform hetero-gate-dielectric dual-material control gate TFET for suppressing ambipolar nature and improving radio-frequency performance
Hui-Fang Xu, Jian Cui, Wen Sun and Xin-Feng Han

108502 Opto-electromechanically induced transparency in a hybrid opto-electromechanical system
Hui Liu, Li-Guo Qin, Li-Jun Tian and Hong-Yang Ma

108503 Designing of spin filter devices based on zigzag zinc oxide nanoribbon modified by edge defect
Bao-Rui Huang, Fu-Chun Zhang, Yan-Ning Yang, Zhi-Yong Zhang and Wei-Guo Wang

108701 Quantitative heterogeneity and subgroup classification based on motility of breast cancer cells
Ling Xiong, Yanping Liu, Ruchuan Liu, Wei Yuan, Gao Wang, Yi He, Jianwei Shuai, Yang Jiao, Xixiang Zhang, Weijing Han, Junle Qu and Liyu Liu

108702 Theory and method of dual-energy x-ray grating phase-contrast imaging
Feng Rong, Yan Gao, Cui-Juan Guo, Wei Xu and Wei Xu

108703 Benefit community promotes evolution of cooperation in prisoners' dilemma game
Jianwei Wang, Jialu He, Fengyuan Yu, Wei Chen, Rong Wang and Ke Yu

108901 Theoretical analyses of stock correlations affected by subprime crisis and total assets: Network properties and corresponding physical mechanisms
Shi-Zhao Zhu, Yu-Qing Wang and Bing-Hong Wang

JUST FOR AUTHORS
— CHINESE PHYSICS B

Chinese Physics B (中国物理 B)

Published monthly in hard copy by the Chinese Physical Society and online by IOP Publishing, Temple Circus, Temple Way, Bristol BS1 6HG, UK

Institutional subscription information: 2019 volume

For all countries, except the United States, Canada and Central and South America, the subscription rate per annual volume is UK£974 (electronic only) or UK£1063 (print + electronic).

Delivery is by air-speeded mail from the United Kingdom.

Orders to:

Journals Subscription Fulfilment, IOP Publishing, Temple Circus, Temple Way, Bristol BS1 6HG, UK

For the United States, Canada and Central and South America, the subscription rate per annual volume is US$1925 (electronic only) or US$2100 (print + electronic). Delivery is by transatlantic airfreight and onward mailing.

Orders to: IOP Publishing, P. O. Box 320, Congers, NY 10920-0320, USA

© **2019** Chinese Physical Society and IOP Publishing Ltd

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted in any form or by any means, electronic, mechanical, photocopying, recording or otherwise, without the prior written permission of the copyright owner.

Supported by the China Association for Science and Technology and Chinese Academy of Sciences

Editorial Office: Institute of Physics, Chinese Academy of Sciences, P. O. Box 603, Beijing 100190, China

Tel: (86 - 10) 82649026 or 82649519, Fax: (86 - 10) 82649027, E-mail: cpb@aphy.iphy.ac.cn

主管单位: 中国科学院
主办单位: 中国物理学会和中国科学院物理研究所
主　　编: 欧阳钟灿
出　　版: 中国物理学会
印刷装订: 北京科信印刷有限公司
编　　辑: Chinese Physics B 编辑部
国内发行: Chinese Physics B 出版发行部
国外发行: IOP Publishing Ltd
发行范围: 公开发行

国际统一刊号: ISSN 1674–1056
国内统一刊号: CN 11–5639/O4
编辑部地址: 北京 中关村 中国科学院物理研究所内
通 讯 地 址: 100190 北京 603 信箱
电　　话: (010) 82649026, 82649519
传　　真: (010) 82649027
"Chinese Physics B"网址:
http://cpb.iphy.ac.cn
http://iopscience.iop.org/journal/1674-1056

Published by the Chinese Physical Society

Advisory Board

Prof. Academician Chen Jia-Er(陈佳洱) School of Physics, Peking University, Beijing 100871, China
Prof. Academician Feng Duan(冯端) Department of Physics, Nanjing University, Nanjing 210093, China
Prof. Academician T. D. Lee(李政道) Department of Physics, Columbia University, New York, NY 10027, **USA**
Prof. Academician Samuel C. C. Ting(丁肇中) LEP3, CERN, CH-1211, Geneva 23, **Switzerland**
Prof. Academician C. N. Yang(杨振宁) Institute for Theoretical Physics, State University of New York, **USA**
Prof. Academician Yang Fu-Jia(杨福家) Department of Nuclear Physics, Fudan University, Shanghai 200433, China
Prof. Academician Zhou Guang-Zhao (Chou Kuang-Chao)(周光召) China Association for Science and Technology, Beijing 100863, China
Prof. Academician Wang Nai-Yan(王乃彦) China Institute of Atomic Energy, Beijing 102413, China
Prof. Academician Liang Jing-Kui(梁敬魁) Institute of Physics, Chinese Academy of Sciences, Beijing 100190, China

Editor-in-Chief

Prof. Academician Ouyang Zhong-Can(欧阳钟灿) Institute of Theoretical Physics, Chinese Academy of Sciences, Beijing 100190, China

JUST FOR AUTHORS — CHINESE PHYSICS B

Associate Editors

Prof. Academician Zhao Zhong-Xian(赵忠贤)	Institute of Physics, Chinese Academy of Sciences, Beijing 100190, China
Prof. Academician Yang Guo-Zhen(杨国桢)	Institute of Physics, Chinese Academy of Sciences, Beijing 100190, China
Prof. Academician Zhang Jie(张杰)	Chinese Academy of Sciences, Beijing 100864, China
Prof. Academician Xing Ding-Yu(邢定钰)	Department of Physics, Nanjing University, Nanjing 210093, China
Prof. Academician Shen Bao-Gen(沈保根)	Institute of Physics, Chinese Academy of Sciences, Beijing 100190, China
Prof. Academician Gong Qi-Huang(龚旗煌)	School of Physics, Peking University, Beijing 100871, China
Prof. Academician Xue Qi-Kun(薛其坤)	Department of Physics, Tsinghua University, Beijing 100084, China
Prof. Sheng Ping(沈平)	The Hong Kong University of Science & Technology, Kowloon, Hong Kong, China

Editorial Board

Prof. David Andelman	School of Physics and Astronomy Tel Aviv University, Tel Aviv 69978, Israel
Prof. Academician Chen Xian-Hui(陈仙辉)	Department of Physics, University of Science and Technology of China, Hefei 230026, China
Prof. Cheng Jian-Chun(程建春)	School of Physics, Nanjing University, Nanjing 210093, China
Prof. Chia-Ling Chien	Department of Physics and Astronomy, The Johns Hopkins University, Baltimore, MD 21218, USA
Prof. Dai Xi(戴希)	Institute of Physics, Chinese Academy of Sciences, Beijing 100190, China
Prof. Ding Jun(丁军)	Department of Materials Science & Engineering, National University of Singapore, Singapore 117576, Singapore
Prof. Masao Doi	Toyota Physical and Chemical Research Institute, Yokomichi, Nagakute, Aichi 480-1192, Japan
Prof. Fang Zhong(方忠)	Institute of Physics, Chinese Academy of Sciences, Beijing 100190, China
Prof. Feng Shi-Ping(冯世平)	Department of Physics, Beijing Normal University, Beijing 100875, China
Prof. Academician Gao Hong-Jun(高鸿钧)	Institute of Physics, Chinese Academy of Sciences, Beijing 100190, China
Prof. Gu Chang-Zhi(顾长志)	Institute of Physics, Chinese Academy of Sciences, Beijing 100190, China
Prof. Gu Min(顾敏)	Royal Melbourne Institute of Technology (RMIT University), GPO Box 2476, Melbourne, VIC 3001, Australia
Prof. Academician Guo Guang-Can(郭光灿)	School of Physical Sciences, University of Science and Technology of China, Hefei 230026, China
Prof. Academician He Xian-Tu(贺贤土)	Institute of Applied Physics and Computational Mathematics, Beijing 100088, China
Prof. Werner A. Hofer	Stephenson Institute for Renewable Energy, The University of Liverpool, Liverpool L69 3BX, UK
Prof. Hong Ming-Hui(洪明辉)	Department of Electrical and Computer Engineering, National University of Singapore, Singapore 117576, Singapore
Prof. Hu Gang(胡岗)	Department of Physics, Beijing Normal University, Beijing 100875, China
Prof. Jiang Hong-Wen(姜弘文)	Department of Physics and Astronomy, University of California, Los Angeles, CA 90095, USA
Prof. Jiang Ying(江颖)	School of Physics, Peking University, Beijing 100871, China
Prof. Jin Xiao-Feng(金晓峰)	Department of Physics, Fudan University, Shanghai 200433, China
Prof. Robert J. Joynt	Physics Department, University of Wisconsin-Madison, Madison, USA
Prof. Jaewan Kim	Korea Institute for Advanced Study, School of Computational Sciences, Hoegiro 85, Seoul 02455, Korea
Prof. Li Ru-Xin(李儒新)	Shanghai Institute of Optics and Fine Mechanics, Chinese Academy of Sciences, Shanghai 201800, China
Prof. Li Xiao-Guang(李晓光)	Department of Physics, University of Science and Technology of China, Hefei 230026, China
Assits. Prof. Liu Chao-Xing(刘朝星)	Department of Physics, Pennsylvania State University, PA 16802-6300, USA
Prof. Liu Xiang-Yang(刘向阳)	Department of Physics, Xiamen University, Xiamen 361005, China
Prof. Liu Ying(刘荧)	Department of Physics and Astronomy, Shanghai Jiao Tong University, Shanghai 200240, China
Prof. Long Gui-Lu(龙桂鲁)	Department of Physics, Tsinghua University, Beijing 100084, China
Prof. Lv Li(吕力)	Institute of Physics, Chinese Academy of Sciences, Beijing 100190, China
Prof. Ma Xu-Cun(马旭村)	Department of Physics, Tsinghua University, Beijing 100084, China
Prof. Antonio H. Castro Neto	Physics Department, Faculty of Science, National University of Singapore, Singapore 117546, Singapore
Prof. Nie Yu-Xin(聂玉昕)	Institute of Physics, Chinese Academy of Sciences, Beijing 100190, China
Prof. Niu Qian(牛谦)	Department of Physics, University of Texas, Austin, TX 78712, USA
Prof. Academician Ouyang Qi(欧阳颀)	School of Physics, Peking University, Beijing 100871, China

Prof. Academician Pan Jian-Wei(潘建伟) Department of Modern Physics, University of Science and Technology of China, Hefei 230026, China

Prof. Amalia Patane School of Physics and Astronomy, The University of Nottingham, NG7 2RD, UK

Prof. Qian Lie-Jia(钱列加) Department of Physics and Astronomy, Shanghai Jiao Tong University, Shanghai 200240, China

Prof. J. Y. Rhee Department of Physics, Sungkyunkwan University, Suwon, Korea

Prof. Shen Jian(沈健) Department of Physics, Fudan University, Shanghai 200433, China

Prof. Shen Yuan-Rang(沈元壤) Lawrence Berkeley National Laboratory, Berkeley, CA 94720, USA

Prof. Shen Zhi-Xun(沈志勋) Stanford University, Stanford, CA 94305-4045, USA

Prof. Academician Sun Chang-Pu(孙昌璞) Beijing Computational Science Research Center, China Academy of Engineering Physics, Beijing 100094, China

Prof. Sun Xiao-Wei(孙小卫) Department of Electrical and Electronic Engineering, Southern University of Science and Technology, Shenzhen 518055, China

Prof. Sun Xiu-Dong(孙秀冬) Department of Physics, Harbin Institute of Technology, Harbin 150001, China

Prof. Michiyoshi Tanaka Research Institute for Scientic Measurements, Tohoku University, Katahira 2-1-1, Aoba-ku 980, Sendai, Japan

Prof. Tong Li-Min(童利民) Department of Optical Engineering, Zhejiang University, Hangzhou 310027, China

Prof. Tong Penger(童彭尔) Department of Physics, The Hong Kong University of Science and Technology, Kowloon, Hong Kong, China

Prof. Wang Bo-Gen(王伯根) School of Physics, Nanjing University, Nanjing 210093, China

Prof. Wang Kai-You(王开友) Institute of Semiconductors, Chinese Academy of Sciences, Beijing 100083, China

Prof. Wang Wei(王炜) School of Physics, Nanjing University, Nanjing 210093, China

Prof. Wang Ya-Yu(王亚愚) Department of Physics, Tsinghua University, Beijing 100084, China

Prof. Wang Yu-Peng(王玉鹏) Institute of Physics, Chinese Academy of Sciences, Beijing 100190, China

Prof. Wang Zhao-Zhong(王肇中) Laboratory for Photonics and Nanostructures (LPN) CNRS–UPR20, Route de Nozay, 91460 Marcoussis, France

Prof. Academician Wang Wei-Hua(汪卫华) Institute of Physics, Chinese Academy of Sciences, Beijing 100190, China

Prof. Wei Su-Huai(魏苏淮) Beijing Computational Science Research Center, China Academy of Engineering Physics, Beijing 100094, China

Prof. Wen Hai-Hu(闻海虎) Department of Physics, Nanjing University, Nanjing 210093, China

Prof. Wu Nan-Jian(吴南健) Institute of Semiconductors, Chinese Academy of Sciences, Beijing 100083, China

Prof. Academician Xia Jian-Bai(夏建白) Institute of Semiconductors, Chinese Academy of Sciences, Beijing 100083, China

Prof. Academician Xiang Tao(向涛) Institute of Physics, Chinese Academy of Sciences, Beijing 100190, China

Prof. Academician Xie Si-Shen(解思深) Institute of Physics, Chinese Academy of Sciences, Beijing 100190, China

Prof. Academician Xie Xin-Cheng(谢心澄) Department of Physics, Peking University, Beijing 100871, China

Prof. Academician Xu Zhi-Zhan(徐至展) Shanghai Institute of Optics and Fine Mechanics, Chinese Academy of Sciences, Shanghai 201800, China

Assist. Prof. Xu Cen-Ke(许岑珂) Department of Physics, University of California, Santa Barbara, CA 93106, USA

Prof. Academician Ye Chao-Hui(叶朝辉) Wuhan Institute of Physics and Mathematics, Chinese Academy of Sciences, Wuhan 430071, China

Prof. Ye Jun(叶军) Department of Physics, University of Colorado, Boulder, Colorado 80309-0440, USA

Prof. Yu Ming-Yang(郁明阳) Theoretical Physics I, Ruhr University, D-44780 Bochum, Germany

Prof. Academician Zhan Wen-Long(詹文龙) Chinese Academy of Sciences, Beijing 100864, China

Prof. Zhang Fu-Chun(张富春) Kavli Institute for Theoretical Sciences, University of Chinese Academy of Sciences, Beijing 100190, China

Prof. Zhang Xiang(张翔) NSF Nanoscale Science and Engineering Center (NSEC), University of California, Berkeley, CA 94720, USA

Prof. Zhang Yong(张勇) Electrical and Computer Engineering Department, The University of North Carolina at Charlotte, Charlotte, USA

Prof. Zhang Zhen-Yu(张振宇) International Center for Quantum Design of Functional Materials, University of Science and Technology of China, Hefei 230026, China

Prof. Zeng Hao(曾浩) Department of Physics, University at Buffalo, SUNY, Buffalo, NY 14260, USA

Prof. Zheng Bo(郑波) Physics Department, Zhejiang University, Hangzhou 310027, China

Prof. Zhou Xing-Jiang(周兴江) Institute of Physics, Chinese Academy of Sciences, Beijing 100190, China

Prof. Academician Zhu Bang-Fen(朱邦芬) Department of Physics, Tsinghua University, Beijing 100084, China

Editorial Staff

Wang Jiu-Li(王久丽) (Editorial Director) Cai Jian-Wei(蔡建伟) Zhai Zhen(翟振)

JUST FOR AUTHORS — CHINESE PHYSICS B

TOPICAL REVIEW — A celebration of the 100th birthday of Kun Huang

Emerging properties of two-dimensional twisted bilayer materials*

Yang Cheng(程阳)†, Chen Huang(黄琛)†, Hao Hong(洪浩)†, Zixun Zhao(赵子荀), and Kaihui Liu(刘开辉)‡

State Key Laboratory for Mesoscopic Physics, Academy for Advanced Interdisciplinary Studies, School of Physics, Peking University, Beijing 100871, *China*

(Received 18 August 2019; revised manuscript received 25 August 2019; published online 28 August 2019)

Recent studies in van der Waals coupled two-dimensional (2D) bilayer materials have demonstrated a new freedom for material engineering by the formation of moiré pattern. By tuning the twist angle between two layers, one can modulate their electronic band structures and therefore the associated electrical transport and optical properties, which are distinct from the original ones of each individual layer. These new properties excite great passion in the exploration of new quantum states and possible applications of 2D bilayers. In this article, we will mainly review the prevailing fabrication methods and emerging physical properties of twisted bilayer materials and lastly give out a perspective of this topic.

Keywords: two-dimensional materials, twist angle, moiré potential, interlayer coupling

PACS: 73.40.Lq, 73.61.–r, 74.78.Fk, 78.67.–n **DOI:** 10.1088/1674-1056/ab3e46

1. Introduction

The concept of 2D materials is prevailing accompanied with the discovery of graphene,[1,2] which opens up a new field of material science. 2D materials have many unique physical properties, such as the Dirac cone band structure of monolayer graphene, valley-selective polarized light absorption of transition metal dichalcogenide (TMD), great insulation of hexagonal boron nitride (hBN), and so on.[3–5] Benefitting from the abundance of 2D monolayers, the heterostructures, built by different layer stacking, form a new big family. In sharp contrast to conventional bulk materials, lack of dangling bonds at the surface greatly facilitates the building of heterostructures without further consideration of the lattice mismatch. When one layer is stacked on another forming bilayer, their different lattice vectors can lead to the formation of superlattice, and the electrons in the system will feel an additional potential called moiré periodic potential (Fig. 1). Also, surface-exposed electronic states and quantum confinement significantly enhance the interlayer electronic coupling. The moiré periodic potential and enhanced electronic coupling not only tune the intrinsic behavior of the component layers, but also bring many novel physical properties appearing at the interface such as Mott-insulator state, unconventional superconductivity, and moiré excitons.[6–11] Furthermore, these two mechanisms bring us a new approach to engineering the properties of 2D bilayer materials by tuning the interfacial twist angle. With interfacial twist angle tuning, real-space rotation introduces the evolution of moiré pattern and moiré periodic potential, reciprocal-space rotation introduces band alignment change and finally tunes the interlayer coupling.

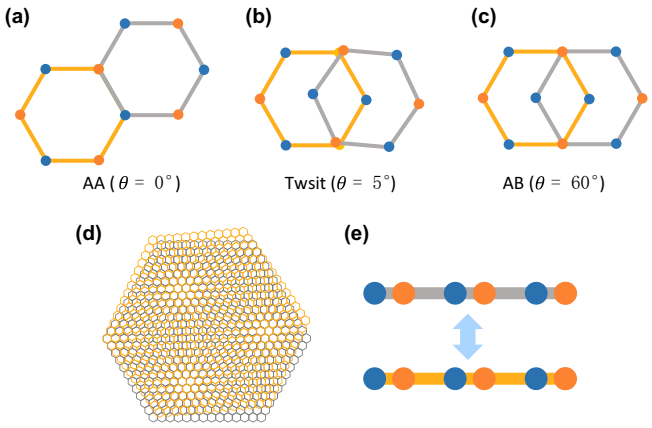


Fig. 1. Moiré patterns and enhanced interlayer coupling in 2D twisted bilayer materials. (a)–(c) Configurations of AA stacking/twisted/AB stacking hexagonal lattice bilayers. (d) Schematics of moiré patterns of 5° twisted bilayer graphene. (e) Schematics of interlayer couping in 2D twisted bilayer materials.

In this review, we discuss the topic of the 2D twisted bilayer materials, particularly concentrating on how the twist angle determines the physical properties. First, we summarize different methods to fabricate twisted bilayers under different conditions. Then, three typical material systems are discussed: twisted bilayer graphene, graphene/hBN heterostructures, and TMD bilayers. At last, we give our perspectives on the study and applications of 2D twisted bilayer materials.

*Project supported by the National Key R&D Program of China (Grant Nos. 2016YFA0300903 and 2016YFA0300804), National Equipment Program of China (Grant No. ZDYZ2015-1), Beijing Graphene Innovation Program, China (Grant No. Z181100004818003), Beijing Municipal Science & Technology Commission, China (Grant No. Z181100004218006), Bureau of Industry and Information Technology of Shenzhen, China (Graphene platform contract No. 201901161512), and the Key R&D Program of Guangdong Province, China (Grant No. 2019B010931001).

†These authors contributed equally to this work.

‡Corresponding author. E-mail: khliu@pku.edu.cn

© 2019 Chinese Physical Society and IOP Publishing Ltd

2. Fabrication of 2D twisted bilayer materials

Fabrication is the first and most fundamental step in material science research. Mainly two challenges exist in the fabrication process of 2D twisted bilayer materials: accurately controlling interfacial twist angle and building clean interface. Generally, if we do not care much about the accuracy of the twist angle, crude methods can satisfy our demands. Common wet transfer or dry transfer method can be used to fabricate twisted bilayer, where polymer is used to pick up one layer from its substrate and stack the layer on another. However, in this way the interface is not clean enough.[12–15] As shown in Fig. 2(a), direct chemical vapor deposition (CVD) method can also be used to grow TMD bilayers with different twist angles.[16] In this process, twisted bilayer (non $0°/60°$ twist angle) is a by-product of high-symmetry-stacking heterostructures. The value of the twist angle can be obtained directly according to their relative geometry. Although CVD method can guarantee the clean interface, it gives random twist angle which is uncontrollable. Figure 2(b) illustrates the process used to fabricate magic-angle twisted bilayer graphene.[17] The maximum magic angle is less than $1.1°$,[18] so the fabrication process must be more delicate. The so-called 'tear & stack' technique, first proposed by Kim *et al.*,[19] is essentially a modified dry transfer method used for twist angle control. Independently, utilizing the strong van der Waals interaction between hBN and graphene, Cao *et al.* tore half of one piece of monolayer graphene vertically from the substrate, and then rotated the substrate by the largest magic angle with an accuracy of about $0.1°$. At last they stacked the first half on the remaining monolayer to form twisted bilayer and picked it up from the substrate. In this process, hBN was used instead of polymer to obtain a cleaner interface compared to common dry transfer method.[20]

In contrast to the methods mentioned above, twisted graphene/hBN heterostructures can be fabricated in other ways as reported, and such methods allow one to regulate the twist angle after fabrication. As shown in Fig. 2(c), utilizing the weak friction between hBN and graphene, atomic force microscope (AFM) tip can be used to control the twist angle of the heterostructures mechanically.[21,22] In this process, graphene is placed on top of hBN with a large twist angle to avoid disturbance. Then the graphene layer is etched into a Hall bar with oxygen plasma for electronic measurements, and a preshaped hBN flake is transferred onto the graphene. Thus AFM tip can rotate the preshaped flake to control the twist angles after fabrication. In addition, utilizing the potential difference among heterostructures with different twist angles, thermal annealing is also adopted as shown in Fig. 2(d).[21,23]

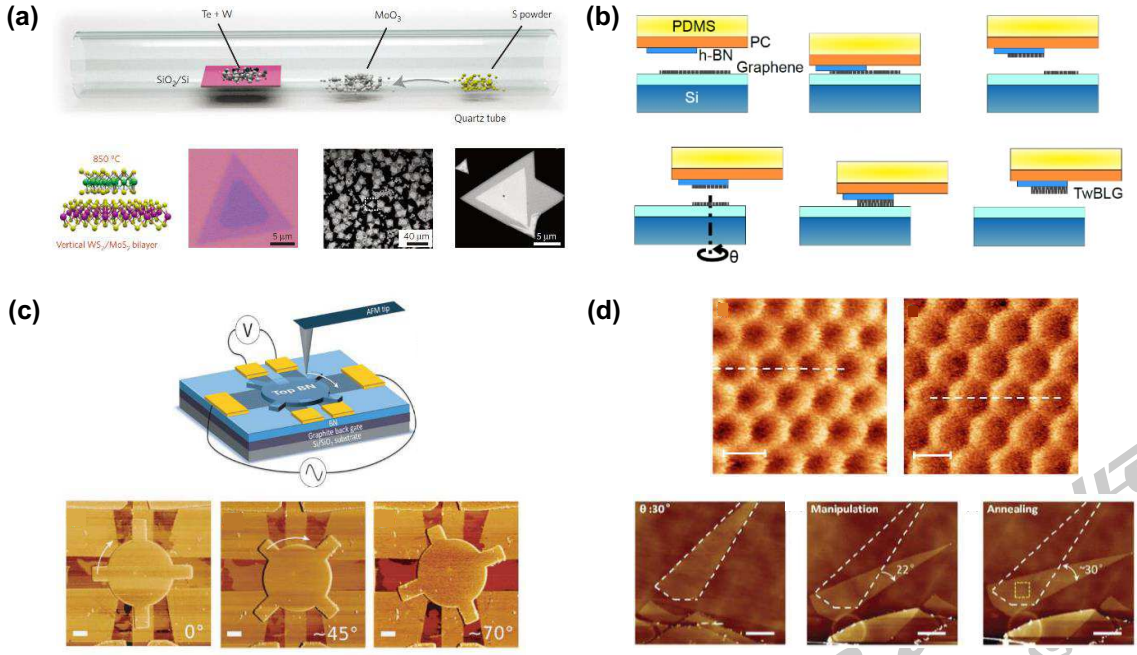


Fig. 2. Fabrication methods. (a) Top: illustration of CVD growth of vertical WS_2/MoS_2 bilayers. Bottom: schematic illustration, optical image, and scanning electron microscopy image of vertical WS_2/MoS_2 bilayers. Reprinted with permission from Ref. [16]. Copyright 2016, Nature Publishing Group. (b) Schematic illustration of 'tear & stack' technique, which is essentially a modified dry transfer method to fabricate clean interface with accurate twist angle. Reprinted with permission from Ref. [17]. Copyright 2016, American Physical Society. (c) Schematic illustration and AFM images of the twist-angle-tunable graphene/hBN heterostructures. Reprinted with permission from Ref. [22]. Copyright 2018, American Association for the Advancement of Science. (d) Top: AFM images of graphene/hBN heterostructures before (left) and after (right) annealing. Bottom: AFM images of graphene/hBN heterostructures. They are obtained initially (left), after AFM tip control (middle), and after long-time annealing (right), respectively. Reprinted with permission from Ref. [23]. Copyright 2016, Nature Publishing Group. Reprinted with permission from Ref. [21]. Copyright 2016, American Physical Society.

3. Physical properties of 2D twisted bilayer materials

3.1. Twisted bilayer graphene

Monolayer graphene is a 2D Dirac semimetal with many unique properties, such as massless Dirac fermion, high carrier mobility, and wide-spectrum light absorption compared to the conventional materials.[24] As for common intrinsic Bernal stacked bilayer graphene (AB stacking), the bandgap remains zero while the fermion becomes massive.[3] However, when taking the twist angle into consideration, new physical phenomena have been found and investigated in twisted bilayer graphene.

3.1.1. New van Hove singularities

As shown in Fig. 3(a), it has been reported that within a broad range (from 1° to 10°) of twist angles, two robust new van Hove singularities arise owing to the hybridization of the energy bands of these two layers.[25–27] The energy level of the two van Hove singularities can be obtained by scanning tunneling spectroscopy (STS), while the experimental results of the energy separation between them (ΔE) accord with the theoretical prediction (based on the continuum model)[28,29]

$$\Delta E = 2\hbar v_{\mathrm{F}} \Gamma K \sin\frac{\theta}{2} - 2t_{\theta}, \tag{1}$$

where v_{F} is the Fermi velocity of monolayer graphene, ΓK is the wave vector of the Dirac point in reciprocal space of graphene, θ is the twist angle, and t_{θ} is the amplitude of the main Fourier component of the interlayer potential. The effect of such band structure can also be observed in optical spectroscopy, like absorption spectra, angle-resolved Raman imaging, and angle-tunable photoluminescence with resonant 2-photon excitation.[30–33] The van Hove singularity boosts the density of states of materials, and thus provides a strong light–matter interaction in twisted bilayer graphene. It has been reported that twisted bilayer graphene can enhance the signal in ultrafast photodetection utilizing this property.[34]

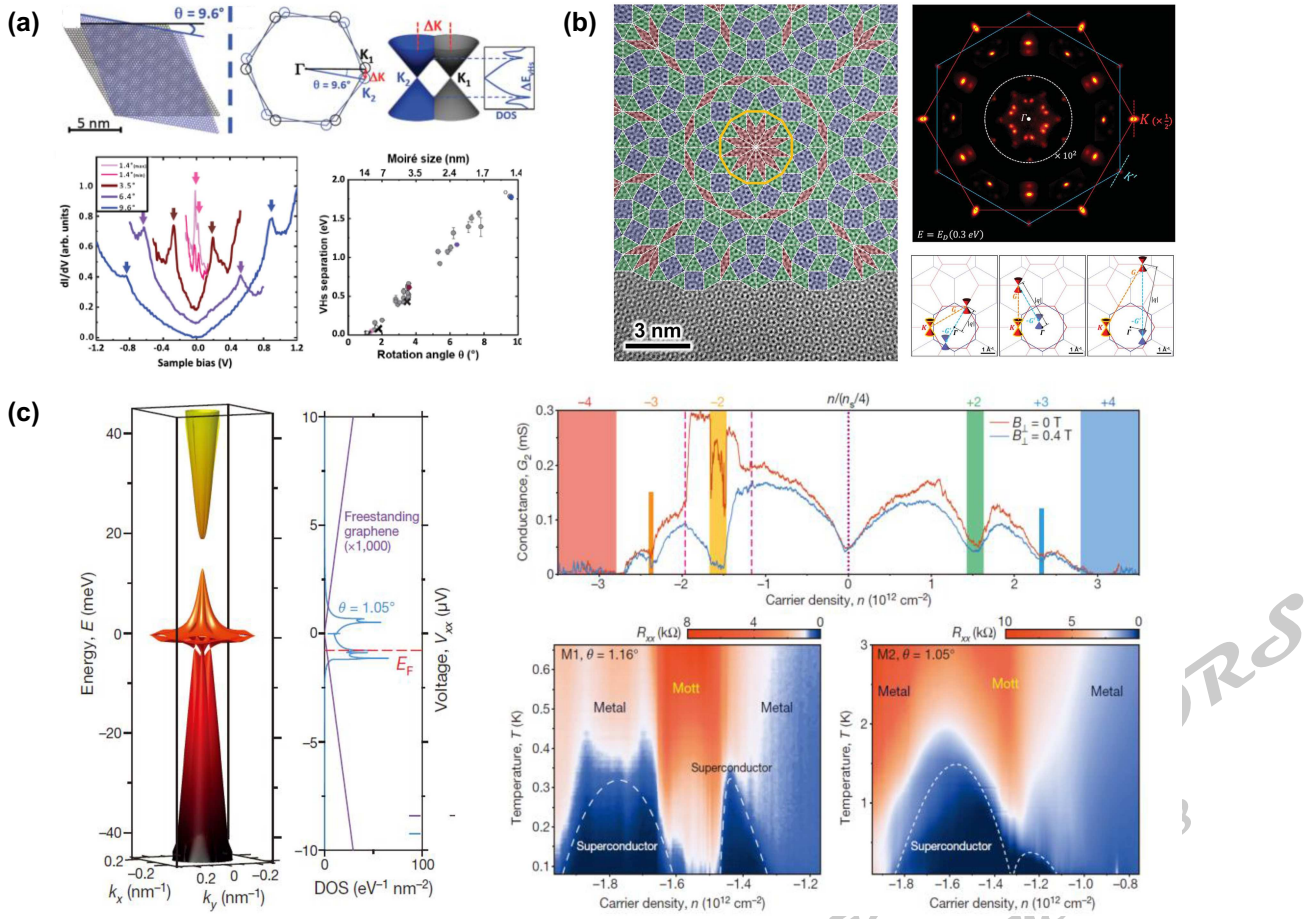


Fig. 3. Physical properties of twisted bilayer graphene. (a) Schematic illustration and STS results of the new van Hove singularities of twisted bilayer graphene. The interlayer interaction leads to the formation of van Hove singularities, and they correspond to the two peaks in STS measurements. The relation between the singularity energy separation and the twist angle is also shown. Reprinted with permission from Ref. [27]. Copyright 2012, American Physical Society. (b) Left, calculated band structure and density of states of twisted bilayer graphene with twist angle $\theta = 1.05°$. Top right, two-probe longitudinal conductance results of twisted bilayer graphene with twist angle $\theta = 1.16°$. Insulating states have been marked by background color. Bottom right, four-probe longitudinal resistance results of two twisted bilayer graphene samples with twist angles $\theta = 1.05°$ and $\theta = 1.16°$. Reprinted with permission from Ref. [7]. Copyright 2018, Nature Publishing Group. (c) Left: illustration of quasicrystal twisted bilayer graphene. Top right: ARPES results of quasicrystal twisted bilayer graphene. Bottom right: illustration of Umklapp scattering process, which is responsible for the extra scattering points in the ARPES. Reprinted with permission from Ref. [51]. Copyright 2018, American Association for the Advancement of Science.

3.1.2. Magic angle and flat band

In 2010, Morell *et al.* predicted the occurrence of flat bands (simultaneously, zero Fermi velocity at Dirac point) in twisted bilayer graphene using tight-binding calculations, which probably means the existence of strong electron–electron interaction.[35] In 2011, Bistritzer *et al.* solved the continuum Dirac model for twisted bilayer graphene and also found a flat band for a series of the so-called magic angles,[18] which was partly (only for the largest twist angle) convinced in 2015 using STS by Yin *et al.*[36] Later, Cao *et al.* successfully realized the material system and made various electrical measurements on it.[6,7] At first, they found that the conductance of twisted bilayer graphene becomes zero with the moiré band half-filled and attributed this to the formation of a Mott insulator, which can be explained in rough as the consequence of the split of the moiré band caused by the repulsion of the two electrons in the same orbital state with different spins (Hubbard model).[37,38] Then they made more careful measurements (four-probe resistance R_{xx}) and observed an unconventional superconducting state whose doping density is slightly away from the lower Mott-insulator state (Fermi level $E_F < 0$) with the critical temperature below 1.7 K. The band structure, the two-probe conductance results, and the four-probe resistance results are shown in Fig. 3(c). As they have pointed out, such tunable system offers a brand-new platform to study unconventional superconductivity, which has attracted many researchers to do related work on it (e.g., a superconducting state is also observed at a twist angle slightly larger than 1.1° under higher pressure).[39–48]

3.1.3. Graphene quasicrystal

The twist angles mentioned above are mostly small angles. As for large twist angles, the interaction between two layers is usually weak.[49,50] Ahn *et al.* fabricated twisted bilayer graphene with a twist angle of exactly 30°, which forms a graphene quasicrystal with dodecagonal quasicrystalline order and anomalous interlayer interaction is found by angle-resolved photoemission spectra of the system.[51] Extra scattering points owing to Umklapp scattering process of the two layers are shown in Fig. 3(b). Yao *et al.* have also reported successful growth of such graphene quasicrystal and investigated the emergence of mirrored Dirac cones.[52] They identified that these mirrored Dirac cones are a consequence of the interlayer interaction showing its importance in the incommensurate structure which had been overlooked before.

3.1.4. Other emerging properties

In addition to the band structure of electrons, electron–phonon coupling is also a fundamental interaction that affects a broad range of phenomena in condensed matter physics, such as electron mobility, and is responsible for conventional superconductivity.[53] In multilayer structures, the interaction can involve intralayer electron–phonon interaction or interlayer electron–phonon interaction (Figs. 4(a) and 4(b)). Eliel *et al.* reported the ability of Raman spectroscopy to probe and distinguish interlayer and intralayer interactions in graphene-

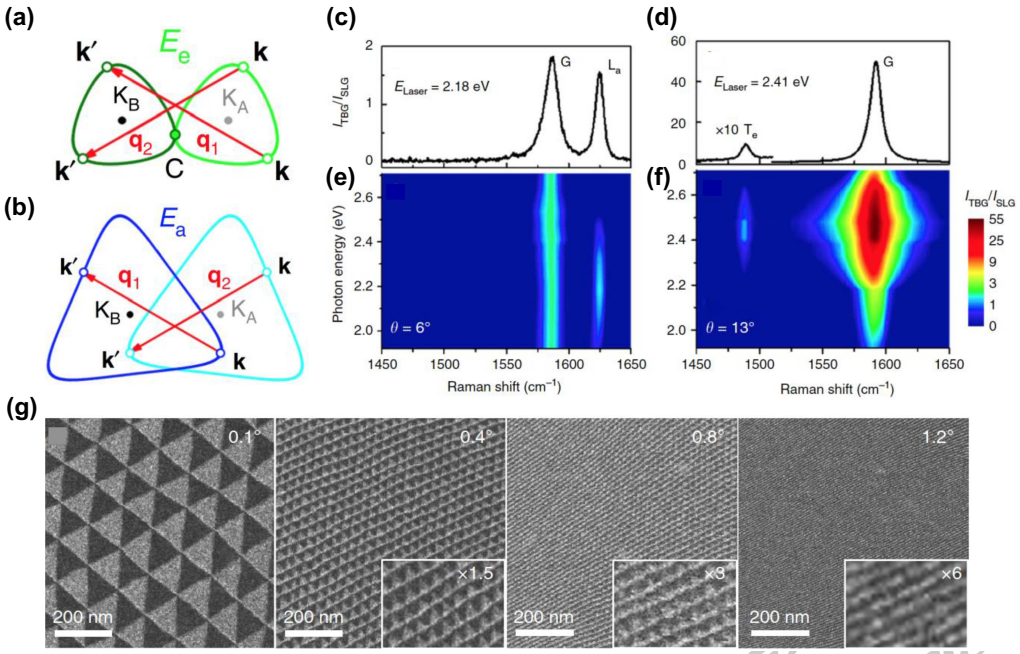


Fig. 4. Electron–phonon coupling and atomic reconstruction in 2D twisted bilayer materials. (a) and (b) Schematics of interlayer electron–phonon process where a phonon with momentum $\hbar q_1$ connects the states k and k' of different layer (a) and intralayer electron–phonon process where both states k and k' are from the same layer. (c) and (d) Raman spectra of twisted bilayer graphene with $\theta = 6°$ and 13° measured with the 2.18 eV and 2.41 eV laser lines, respectively. The vertical coordinate corresponds to the ratio of the peak intensities of the Raman spectra in twisted bilayer graphene and monolayer graphene. (c) The peak around 1620 cm^{-1} is called L_a and stems from intralayer electron–phonon scattering process and (d) the peak at 1480 cm^{-1} is called T_e and stems from the interlayer electron–phonon scattering process. (e) and (f) Excitation Raman maps of twisted bilayer graphene with $\theta = 6°$ (e) and 13° (f) measured under different laser energy excitations. Reprinted with permission from Ref. [54]. Copyright 2019, Nature Publishing Group. (g) TEM dark-field images of twisted bilayer graphene with different twist angles obtained by selecting diffraction peak ($g = 10\bar{1}0$). Different contrast stands for different stacking order (AB/BA). Reprinted with permission from Ref. [45]. Copyright 2019, Nature Publishing Group.

based heterostructures.[54] As shown in Figs. 4(c) and 4(d), they measured Raman spectra in two samples of twisted bilayer graphene with twist angles $\theta = 6^\circ$ and 13° recorded with the 2.18 eV and 2.41 eV laser lines, respectively. The frequencies of these phonons depend on the twisting angle θ.[55–63] In addition, they made multiple-excitation Raman measurements using multiple laser lines and found that the results show different dependence on the incident photon energy (Figs. 4(e) and 4(f)). Bilayer graphene and graphene/hBN samples with different twist angles also show similar results.

The theoretical results of twisted bilayer graphene mentioned above are all based on a common assumption that the lattice structure of either layer does not change significantly despite the interlayer interaction. However, Yoo *et al.* reported that this is not the case.[45] In Fig. 4(g), the transmission electron microscope (TEM) dark-field images are obtained by selecting the diffraction peak from a series of twisted bilayer graphene samples with multiple twist angles. In these images, different contrasts stand for totally different stacking order (AB/BA) domains, and for the twisted bilayer graphene sample with 0.1° twist angle, the sharp boundaries indicate the existence of atomic reconstruction, in contrast to the relatively continuous distribution of stacking order if not reconstructed. As the twist angle increases, the boundaries become blurry, which represents the weakening of interlayer interaction. Based on this discovery, they recalculated the band structure of twisted bilayer graphene with small twist angles and found that a simple moiré band description breaks down and the secondary Dirac bands appear when the twist angle $\theta < \theta_c$ ($\theta_c \approx 1^\circ$).

3.2. Graphene/hBN heterostructures

The study of graphene/hBN heterostructures became popular after Dean *et al.* pointed out that hBN can be an appealing substrate for graphene, fairly avoiding various factors which will decrease the quality of graphene in contrast to the standard SiO_2 substrate.[64] The experimental results indicate that the coupling between graphene and hBN is generally weak for the band structure of graphene. In 2013, several papers were published discussing the transport properties of graphene/hBN heterostructures, and they particularly concentrated on the so-called Hofstadter butterfly[65] induced by the moiré periodic potential and an external magnetic field, as shown in Fig. 5(a).[66–68] However, despite the crucial role

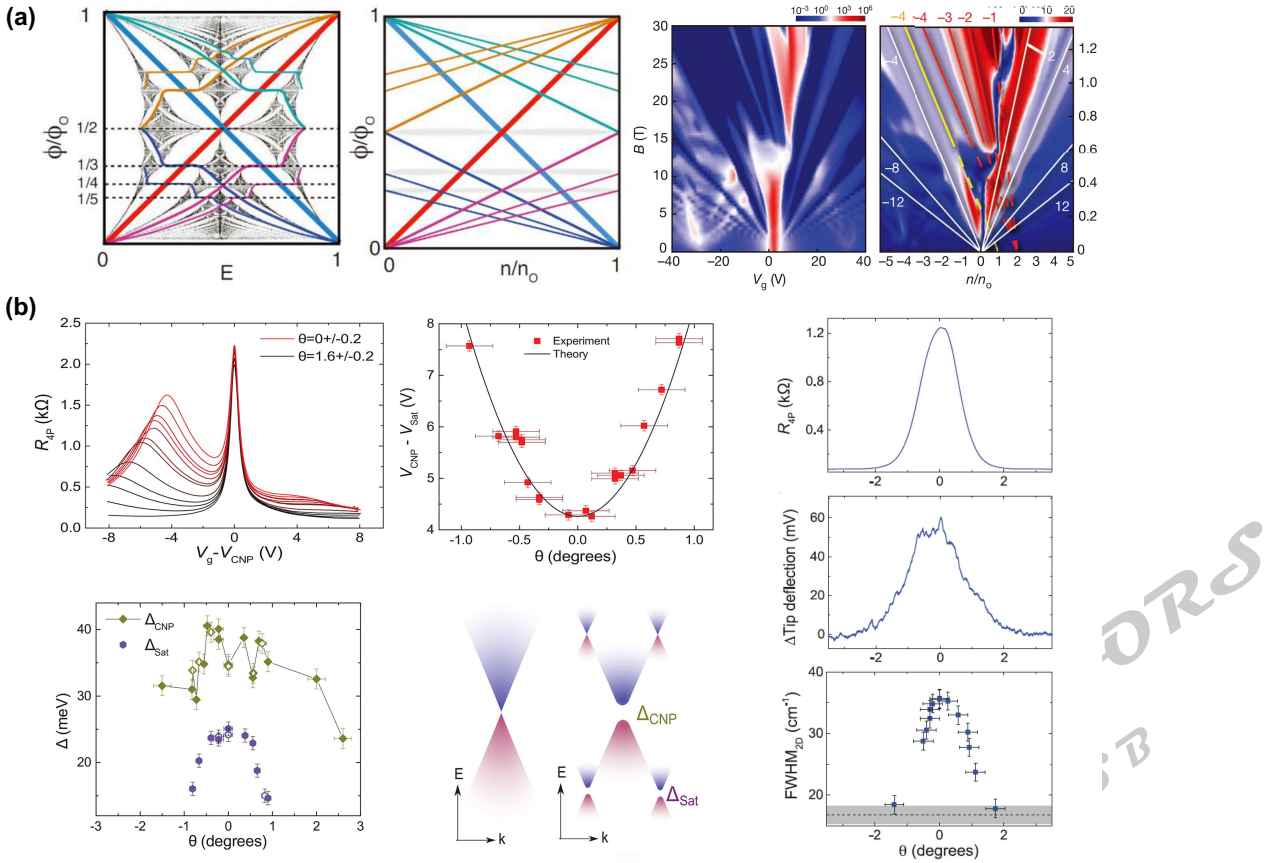


Fig. 5. Physical properties of graphene/hBN heterostructures. (a) Left, normalized Hofstadter butterfly spectrum for square lattice in a magnetic field. Middle, density-field diagrams of such system. Colored lines stand for constant chemical potential for both two above. Right, transport measurement results of graphene/hBN heterostructures. The slope of each line has been marked in the figure. Reprinted with permission from Ref. [68]. Copyright 2013, Nature Publishing Group. (b) Top left, four-probe resistance as a function of gate voltage (V_g) results. A satellite peak locates away from charge neutrality point and indicates an extra energy gap. Bottom left, energy gap as a function of twist angle. Top middle, satellite peak position as a function of twist angle. Bottom middle, illustration of energy gap. Right, four-probe resistance (R_{4P}), tip deflection (reflection of friction force), and full width at half maximum of the 2D peak ($FWHM_{2D}$) in Raman spectroscopy as a function of twist angle at a carrier density of -1.9×10^{12} cm^{-2}. Reprinted with permission from Ref. [22]. Copyright 2018, Nature Publishing Group.

which moiré pattern plays in the realization of the Hofstadter butterfly, the twist angle, an important factor to tune the moiré periodic potential was not introduced then. This can be attributed to the reasons below. Firstly, the realization of the Hofstadter butterfly demands a large periodicity, and thus the twist angle cannot be larger than 2° for graphene/hBN heterostructures. Most importantly, the method to precisely regulate the twist angle after fabrication had not been proposed then. In 2016, AFM tip was introduced and thus the properties of the heterostructures with respect to the twist angle were studied, as shown in Fig. 5(b) (the fabrication method has been illustrated in Fig. 2(d)).[22] In their experiments, large twist angles exhibit weak coupling between layers accounting for the so-called superlubricity which has also been investigated in other 2D systems,[69–72] while for small twist angles, the interlayer interaction opens a small bandgap at the doping density where locates the satellite peak of the longitudinal resistance. The satellite peak has been reported before as the consequence of the moiré potential, and thus the bandgap significantly depends on the twist angle. In addition, the Raman intensity of the 2D peak, and mechanical properties measured by the AFM tip exhibit similar dependence on the twist angle as well. Despite all this, further investigations are still demanded to explain these experimental results.

3.3. TMD bilayers

After the discovery of graphene, the appearance of TMD materials markedly broadens the 2D materials with diverse physical properties.[73–76] Most TMD materials are semiconductors whose bandgaps cover the range from near-infrared to visible region with strong light–matter interaction, the degenerate exciton transitions at the K and K' valleys in the momentum space with broken inversion symmetry in TMD materials offer a new platform for exploring spin and valley physics, TMD materials have several phases which can be tuned by electric field, pressure, or light.[77–79]

3.3.1. Electronic and mechanical coupling in twisted MoS_2 bilayer

Liu *et al.* investigated photoluminescence and Raman spectra of 44 MoS_2 bilayers with different twist angles (Figs. 6(a) and 6(b)).[80] They reported that the A exciton recombination photoluminescence peak position (peak I in Fig. 6(c)) remains the same for all bilayers with different twist angles, but photoluminescence intensity decreases significantly compared with the monolayer one. For the bilayer case, a lower-energy peak appears (peak II in Fig. 6(c)), which corresponds to an indirect bandgap recombination resulting from the interlayer electronic coupling. They found that the indirect bandgap varies with twist angle. AA/AB stacking bilayers have smaller bandgap than that of twist ones, indicating stronger interlayer electronic coupling. In addition, Raman spectra of MoS_2 monolayer and bilayers with different twist angles have been investigated to identify the effective interlayer mechanical coupling, that is, larger separation between two Raman peaks ($\omega_A - \omega_E$) means stronger coupling strength (Fig. 6(d)). This twist-angle-dependent coupling is attributed

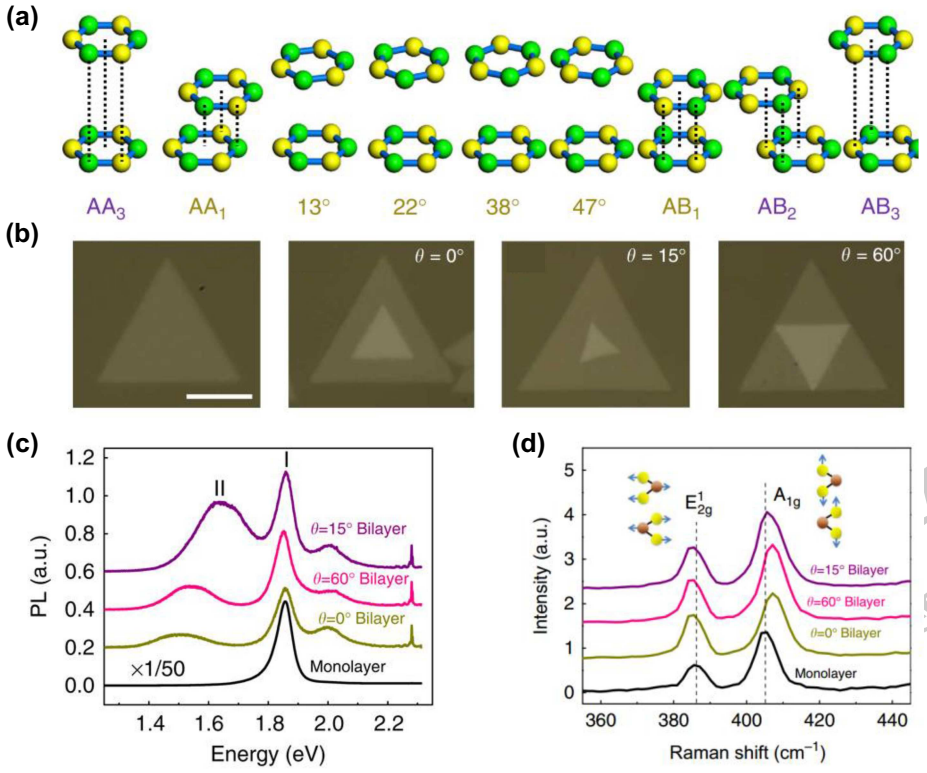


Fig. 6. Electronic and mechanical coupling in twisted MoS_2 bilayer. (a) Schematics of MoS_2 bilayers with different stacking configurations. Green spheres are Mo atoms; yellow sphere are S atoms. (a) Optical images of a MoS_2 monolayer and twisted bilayers with different twist angles. (c) Photoluminescence and (d) Raman spectra of MoS_2 monolayer and bilayers with different twist angles. Reprinted with permission from Ref. [80]. Copyright 2014, Nature Publishing Group.

to the varied interlayer distance in van der Waals coupled 2D atomic-layered materials due to steric effect: the increase of the interlayer distance will weaken the coupling strength. From their experimental results, AA or AB stacking MoS_2 bilayer has stronger electronic and mechanical coupling than the twist angles ones. This conclusion is also suitable for other TMD bilayers.[81–83]

3.3.2. Stacking-independent ultrafast charge transfer in twisted TMD heterostructures

TMD heterostructures are of particular interests because many of them form type II heterojunctions, which facilitate the efficient separation of photoexcited electrons and holes and therefore exhibit great potential in the applications of photodetectors, photovoltaics, and sensors. This separation in MoS_2/WS_2 bilayers could take place within 50 fs upon photoexcitation due to strong interlayer coupling.[84–86] As the interlayer coupling in 2D heterostructure materials varies with interlayer twist angles, Ji *et al.* have investigated how the interlayer charge transfer in MoS_2/WS_2 bilayers evolves with different stacking configurations (Fig. 7(a)).[87] In Fig. 7(b), two obvious peaks in MoS_2/WS_2 bilayers photoluminescence spectra correspond to direct A-exciton transitions from MoS_2 (peak I) and WS_2 (peak II), respectively. Intensity of Peak I in the heterostructures is $1/5$ of that in MoS_2 monolayer indicating strong interlayer electronic coupling and efficient electron–hole separation. The transient absorption spectra of MoS_2 and MoS_2/WS_2 bilayers with different twist angles are shown in Fig. 7(c). Interestingly, they observed that the rise time of MoS_2/WS_2 bilayers with different twist angles only varies slightly, suggesting that the charge transfer time is robust and stacking independent. This robust ultrafast charge transfer is contrary to time-dependent density functional theory simulations and naive thinking that stronger interlayer coupling induces faster charge transfer.[88] In Fig. 7(d), scanning transmission electron microscopy (STEM) image of an AA stacking MoS_2/WS_2 bilayer indicates that in addition to the energy-favourable AA_1 stacking, there exists high-energy stacking of AA_3 due to interlayer stretching and shifting. The existence of multiple parallel charge transfer channels results in the robust ultrafast stacking-independent charge transfer, as the measured charge transfer time is mainly determined by the fastest channel (Fig. 7(e)). Same results have also be reported by Zhu *et al.*[89]

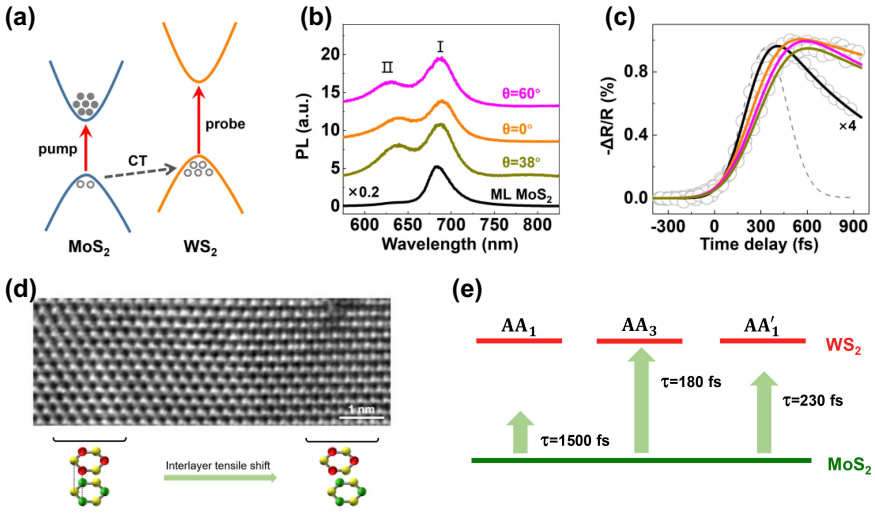


Fig. 7. Stacking-independent ultrafast charge transfer in TMD heterostructures. (a) Band alignment of MoS_2/WS_2 bilayers. After pumping MoS_2 A-exciton with ultrafast laser, the electron remains in MoS_2 while the hole will transfer to a lower energy at WS_2, resulting in an efficient electron–hole separation. (b) Photoluminescence spectra of MoS_2 monolayer and MoS_2/WS_2 bilayers. The two obvious peaks in MoS_2/WS_2 bilayers correspond to direct A-exciton transitions from MoS_2 (peak I) and WS_2 (peak II), respectively. (c) Transient absorption spectra of MoS_2/WS_2 bilayers by selectively probing with a higher energy light at WS_2 A-exciton resonance. (d) TEM image of an AA stacking MoS_2/WS_2 bilayer. In addition to the energy-favorable AA_1 stacking, there exists high-energy state of AA_3 stacking due to interlayer stretching and shifting. (e) Schematic of charge transfer process at the interface of AA stacking MoS_2/WS_2 bilayers, where multi-channels coexist. The apparent transfer time is mainly determined by the fastest channel. Reprinted with permission from Ref. [87]. Copyright 2017, American Chemical Society.

3.3.3. Moiré phonons in twisted MoS_2 bilayer

In TMD bilayers, there exists a moiré periodic potential as well, so electron–phonon coupling and phonon–phonon interactions can be affected. Lin *et al.* discovered that the moiré periodic potential in twisted MoS_2 bilayer can modify the properties of phonons in its MoS_2 monolayer constituent to generate Raman modes related to moiré phonons.[90] They measured the Raman spectra in the region of 50–425 cm^{-1} of the twisted MoS_2 bilayers with twist angles ranging from 9° to 49° under the excitation energy $E = 2.54$ eV. Apart from those modes observed in all twisted MoS_2 bilayers independent of θ like longitudinal acoustic (LA) and transverse acoustic (TA) modes, they observed seven series of θ-dependent Raman modes (Figs. 8(a) and 8(b)). It can be attributed to that there are seven moiré phonons in the twisted MoS_2 bilayer. These phonons originate from the phonons in monolayer constituents with the basic vectors of moiré reciprocal lattices folded onto the zone center due to the modulation of

the periodic moiré potentials (Figs. 8(c) and 8(d)). Due to the weak interlayer coupling in twisted MoS_2 bilayer, the phonon dispersions of the monolayer constituents can be probed by the θ-dependent frequency of moiré phonons. In addition, all these moiré phonons exhibit a mirror behavior with regard to $\theta = 30°$.

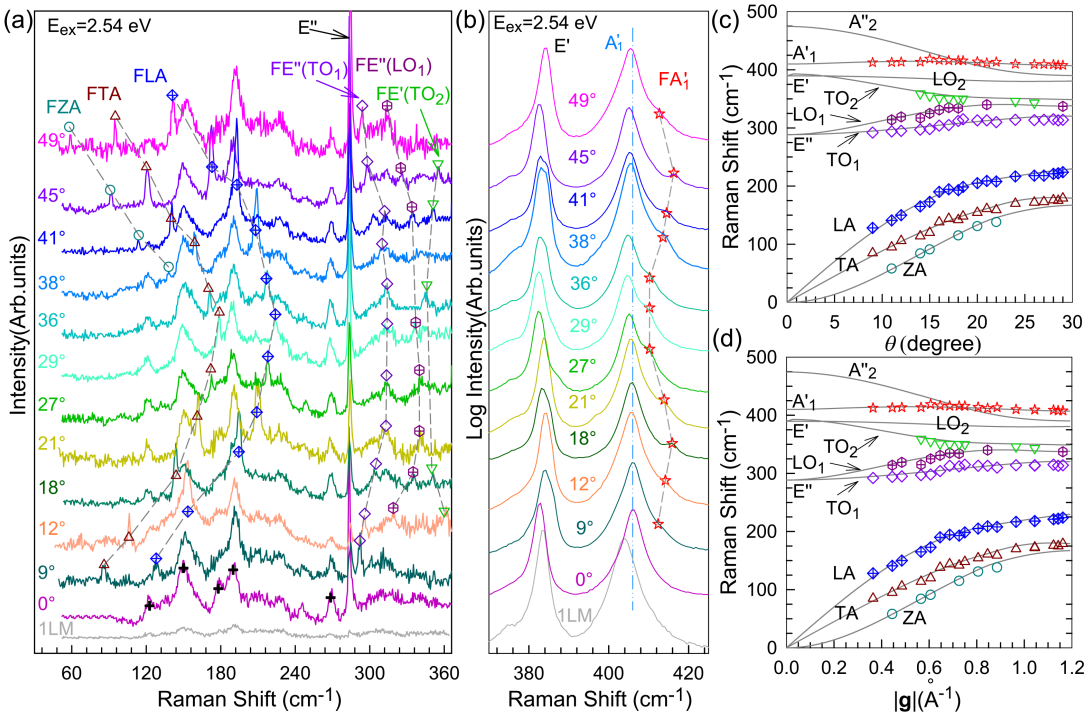


Fig. 8. Moiré phonons in twisted MoS_2 bilayer. (a) and (b) Raman spectra of twisted MoS_2 bilayer in the regions of (a) 50–365 cm^{-1} and (b) 370–425 cm^{-1}. The Raman modes in different phonon branches are represented by different shapes and color symbols. The Raman spectra of monolayer MoS_2 and 3R-bilayer MoS_2 ($\theta = 0°$) are plotted for comparison. (c) and (d) The comparison of calculated and experimental frequencies of moiré phonons dependent on θ (c) and $|g|$ (d), $|g|$ is the magnitude of the basic vector of the moiré reciprocal lattices. Reprinted with permission from Ref. [90]. Copyright 2018, American Chemical Society.

3.3.4. Moiré excitons in twisted TMD heterostructures

Exciton is the particle-like entity that formed by an electron bound to a hole.[91] Moiré excitons are excitons whose energy levels are quantized arising from the lateral confinement imposed by the deep moiré potential.[8,11] Jin *et al.* reported experimental observation of moiré excitons in WSe_2/WS_2 bilayers.[8] The optical photograph and schematic diagram are shown in Figs. 9(a) and 9(b), and the WSe_2/WS_2 bilayers are encapsulated in thin hBN layers for protection. The twist angle is identified by the STEM image in Fig. 9(c), which shows a uniform triangular lattice pattern with a well-defined periodicity of about 8 nm. In the WSe_2/WS_2 bilayers with near-zero twist angle, WSe_2 A exciton state splits to three prominent peaks (labelled as I, II, and III, respectively) corresponding to distinct moiré exciton states, while only a single resonance peak appears in large twist angle heterostructures (Fig. 9(d)). They found that the gate-dependent behaviors of these moiré exciton states are distinct from that of the A exciton in WSe_2 monolayers and WSe_2/WS_2 bilayers with large twist angles (Fig. 9(e)). These phenomena can be fully described by a theoretical model in which the moiré periodic potential (250 meV) is much stronger than the exciton kinetic energy (8 meV) and generates multiple flat exciton minibands. Other three groups also reported the observation of moiré excitons in TMD heterostructures at the same time.[9–11] These observations provide a promising platform for exploring several theoretical proposals related to quantum photonics, such as topological

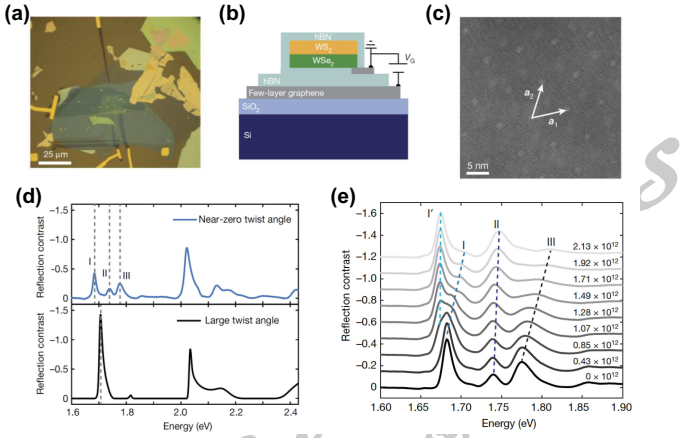


Fig. 9. Moiré excitons in twisted TMD heterostructures. (a) and (b) Optical microscopy image (a) and side-view illustration (b) of a representative heterostructure with a near-zero twist angle. (c) A zoomed-in image of atomic-resolution STEM of near-zero twist angle WSe_2/WS_2 bilayers showing the moiré superlattice. The two superlattice vectors are labelled. (d) Reflection contrast spectrum of near-zero twist angle WSe_2/WS_2 bilayers (top) compared to a large twist angle one (bottom). (e) Reflection contrast spectra in the range between 1.6 eV and 1.8 eV of the WSe_2. A exciton upon electron doping. The electron concentration is noted for each spectrum in units of cm^{-2}. Reprinted with permission from Ref. [8]. Copyright 2019, Nature Publishing Group.

excitons, giant spin–orbit coupling, and entangled photon sources.

4. Conclusion and perspectives

As introduced above, engineering physical properties of 2D bilayers by interfacial twist angle has become a hot topic in recent years. This is mainly achieved by two mechanisms, tuning interlayer coupling and moiré periodic potential by tuning the twist angle. Although various novel physics have been found in the 2D heterostructure family, many of them such as the unconventional superconductivity and stacking-independent ultrafast interfacial charge transfer still demand deeper understanding. Also, developing a universal approach to continuously tuning the twist angle and thereby modulating their physical properties is required. At last, massive production of clean interface with accurate twist angle and large-area single crystal is the main challenge for the real applications based on 2D heterostructure family, which should be on the schedule to be explored.

References

[1] Novoselov K S, Geim A K, Morozov S V, Jiang D, Zhang Y, Dubonos S V, Grigorieva I V and Firsov A A 2004 *Science* **306** 666

[2] Novoselov K S, Jiang D, Schedin F, Booth T J, Khotkevich V V, Morozov S V and Geim A K 2005 *Proc. Natl. Acad. Sci. U. S. A.* **102** 10451

[3] Geim A K 2009 *Science* **324** 1530

[4] Wang Q H, Kalantar-Zadeh K, Kis A, Coleman J N and Strano M S 2012 *Nat. Nanotechnol.* **7** 699

[5] Novoselov K S, Mishchenko A, Carvalho A and Neto A H C 2016 *Science* **353** aac9439

[6] Cao Y, Fatemi V, Demir A, Fang S, Tomarken S L, Luo J Y, Sanchez-Yamagishi J D, Watanabe K, Taniguchi T, Kaxiras E, Ashoori R C and Jarillo-Herrero P 2018 *Nature* **556** 80

[7] Cao Y, Fatemi V, Fang S, Watanabe K, Taniguchi T, Kaxiras E and Jarillo-Herrero P 2018 *Nature* **556** 43

[8] Jin C H, Regan E C, Yan A M, Utama M I B, Wang D Q, Zhao S H, Qin Y, Yang S J, Zheng Z R, Shi S Y, Watanabe K, Taniguchi T, Tongay S, Zettl A and Wang F 2019 *Nature* **569** E7

[9] Alexeev E M, Ruiz-Tijerina D A, Danovich M, Hamer M J, Terry D J, Nayak P K, Ahn S, Pak S, Lee J, Sohn J I, Molas M R, Koperski M, Watanabe K, Taniguchi T, Novoselov K S, Gorbachev R V, Shin H S, Fal'ko V I and Tartakovskii A I 2019 *Nature* **567** 81

[10] Seyler K L, Rivera P, Yu H Y, Wilson N P, Ray E L, Mandrus D G, Yan J Q, Yao W and Xu X D 2019 *Nature* **567** 66

[11] Tran K, Moody G, Wu F C, Lu X B, Choi J, Kim K, Rai A, Sanchez D A, Quan J M, Singh A, Embley J, Zepeda A, Campbell M, Autry T, Taniguchi T, Watanabe K, Lu N S, Banerjee S K, Silverman K L, Kim S, Tutuc E, Yang L, MacDonald A H and Li X Q 2019 *Nature* **567** 71

[12] Liu Y, Weiss N O, Duan X D, Cheng H C, Huang Y and Duan X F 2016 *Nat. Rev. Mater.* **1** 16042

[13] Hong H, Zhang J C, Zhang J, Qiao R X, Yao F R, Cheng Y, Wu C C, Lin L, Jia K C, Zhao Y C, Zhao Q, Gao P, Xiong J, Shi K B, Yu D P, Liu Z F, Meng S, Peng H L and Liu K H 2018 *J. Am. Chem. Soc.* **140** 14952

[14] Lin L, Zhang J C, Su H S, Li J Y, Sun L Z, Wang Z H, Xu F, Liu C, Lopatin S, Zhu Y H, Jia K C, Chen S L, Rui D R, Sun J Y, Xue R W, Gao P, Kang N, Han Y, Xu H Q, Cao Y, Novoselov K S, Tian Z Q, Ren B, Peng H L and Liu Z F 2019 *Nat. Commun.* **10** 1912

[15] Jia K C, Zhang J C, Lin L, Li Z Z, Gao J, Sun L Z, Xue R W, Li J Y, Kang N, Luo Z T, Rummeli M H, Peng H L and Liu Z F 2019 *J. Am. Chem. Soc.* **141** 7670

[16] Gong Y J, Lin J H, Wang X L, Shi G, Lei S D, Lin Z, Zou X L, Ye G L, Vajtai R, Yakobson B I, Terrones H, Terrones M, Tay B K, Lou J, Pantelides S T, Liu Z, Zhou W and Ajayan P M 2014 *Nat. Mater.* **13** 1135

[17] Cao Y, Luo J Y, Fatemi V, Fang S, Sanchez-Yamagishi J D, Watanabe K, Taniguchi T, Kaxiras E and Jarillo-Herrero P 2016 *Phys. Rev. Lett.* **117** 116804

[18] Bistritzer R and MacDonald A H 2011 *Proc. Natl. Acad. Sci. U. S. A.* **108** 12233

[19] Kim K, Yankowitz M, Fallahazad B, Kang S, Movva H C P, Huang S Q, Larentis S, Corbet C M, Taniguchi T, Watanabe K, Banerjee S K, LeRoy B J and Tutuc E 2016 *Nano Lett.* **16** 5968

[20] Wang L, Meric I, Huang P Y, Gao Q, Gao Y, Tran H, Taniguchi T, Watanabe K, Campos L M, Muller D A, Guo J, Kim P, Hone J, Shepard K L and Dean C R 2013 *Science* **342** 614

[21] Wang D M, Chen G R, Li C K, Cheng M, Yang W, Wu S, Xie G B, Zhang J, Zhao J, Lu X B, Chen P, Wang G L, Meng J L, Tang J, Yang R, He C L, Liu D H, Shi D X, Watanabe K, Taniguchi T, Feng J, Zhang Y B and Zhang G Y 2016 *Phys. Rev. Lett.* **116** 126101

[22] Ribeiro-Palau R, Zhang C J, Watanabe K, Taniguchi T, Hone J and Dean C R 2018 *Science* **361** 690

[23] Woods C R, Withers F, Zhu M J, Cao Y, Yu G, Kozikov A, Ben Shalom M, Morozov S V, van Wijk M M, Fasolino A, Katsnelson M I, Watanabe K, Taniguchi T, Geim A K, Mishchenko A and Novoselov K S 2016 *Nat. Commun.* **7** 10800

[24] Lin K X, Li D S, Ye Y, J W G, Y Z G and Z W 2018 *Acta. Phys. Sin.* **67** 246802 (in Chinese)

[25] Li G H, Luican A, Lopes dos Santos J M B, Castro Neto A H, Reina A, Kong J and Andrei E Y 2010 *Nat. Phys.* **6** 109

[26] Yan W, Liu M X, Dou R F, Meng L, Feng L, Chu Z D, Zhang Y F, Liu Z F, Nie J C and He L 2012 *Phys. Rev. Lett.* **109** 126801

[27] Brihuega I, Mallet P, Gonzalez-Herrero H, de Laissardiere G T, Ugeda M M, Magaud L, Gomez-Rodriguez J M, Yndurain F and Veuillen J Y 2012 *Phys. Rev. Lett.* **109** 196802

[28] Lopes dos Santos J M B, Peres N M R and Castro A H 2007 *Phys. Rev. Lett.* **99** 256802

[29] Lopes dos Santos J M B, Peres N M R and Castro Neto A H 2012 *Phys. Rev. B* **86** 155449

[30] Havener R W, Zhuang H, Brown L, Hennig R G and Park J 2012 *Nano Lett.* **12** 3162

[31] Kim K, Coh S, Tan L Z, Regan W, Yuk J M, Chatterjee E, Crommie M F, Cohen M L, Louie S G and Zettl A 2012 *Phys. Rev. Lett.* **108** 246103

[32] Havener R W, Liang Y F, Brown L, Yang L and Park J 2014 *Nano Lett.* **14** 3353

[33] Patel H, Huang L J, Kim C J, Park J and Graham M W 2019 *Nat. Commun.* **10** 1445

[34] Yin J B, Wang H, Peng H, Tan Z J, Liao L, Lin L, Sun X, Koh A L, Chen Y L, Peng H L and Liu Z F 2016 *Nat. Commun.* **7** 10699

[35] Morell E S, Correa J D, Vargas P, Pacheco M and Barticevic Z 2010 *Phys. Rev. B* **82** 121407

[36] Yin L J, Qiao J B, Zuo W J, Li W T and He L 2015 *Phys. Rev. B* **92** 081406

[37] Mott N F 1990 *Met.-insulator Transitions* (2 Edn.) (London: Talor and Francis) pp. 123–130

[38] Imada M, Fujimori A and Tokura Y 1998 *Rev. Mod. Phys.* **70** 1039

[39] Kim K, DaSilva A, Huang S, Fallahazad B, Larentis S, Taniguchi T, Watanabe K, Leroy B J, MacDonald A H and Tutuc E 2017 *Proc. Natl. Acad. Sci. U. S. A.* **114** 3364

[40] Po H C, Zou L J, Vishwanath A and Senthil T 2018 *Phys. Rev. X* **8** 031089

[41] Wu F C, MacDonald A H and Martin I 2018 *Phys. Rev. Lett.* **121** 257001

[42] Liu C C, Zhang L D, Chen W Q and Yang F 2018 *Phys. Rev. Lett.* **121** 217001

[43] Xu C K and Balents L 2018 *Phys. Rev. Lett.* **121** 087001

[44] Gonzalez J and Stauber T 2019 *Phys. Rev. Lett.* **122** 026801

[45] Yoo H, Engelke R, Carr S, Fang S A, Zhang K, Cazeaux P, Sung S H, Hoyden R, Tsen A W, Taniguchi T, Watanabe K, Yi G C, Kim M, Luskin M, Tadmor E B, Kaxiras E and Kim P 2019 *Nat. Mater.* **18** 448

[46] Jia Y T , Zhao J F , Zhang S J , Yu S, Dai G Y , Li W M , Duan L, Zhao G Q , Wang X C and Zheng X 2019 *Chin. Phys. Lett.* **36** 087401

[47] Qinyan G, Dingyu X and Jian S 2019 *Chin. Phys. Lett.* **36** 097401

[48] Liu Z, Li Y and Yang Y F 2019 *Chin. Phys. B* **28** 77103

[49] Shallcross S, Sharma S, Kandelaki E and Pankratov O A 2010 *Phys. Rev. B* **81** 165105

[50] Rozhkov A V, Sboychakov A O, Rakhmanov A L and Nori F 2016 *Phys. Rep.* **648** 1

[51] Ahn S J, Moon P, Kim T H, Kim H W, Shin H C, Kim E H, Cha H W, Kahng S J, Kim P, Koshino M, Son Y W, Yang C W and Ahn J R 2018 *Science* **361** 782

[52] Yao W, Wang E Y, Bao C H, Zhang Y O, Zhang K A, Bao K J, Chan C K, Chen C Y, Avila J, Asensio M C, Zhu J Y and Zhou S Y 2018 *Proc. Natl. Acad. Sci. USA* **115** 6928

[53] Bardeen J, Cooper L N and Schrieffer J R 1957 *Phys. Rev.* **108** 1175

[54] Eliel G S N, Moutinho M V O, Gadelha A C, Righi A, Campos L C, Ribeiro H B, Chiu P W, Watanabe K, Taniguchi T, Puech P, Paillet M, Michel T, Venezuela P and Pimenta M A 2018 *Nat. Commun.* **9** 1221

[55] Gupta A K, Tang Y J, Crespi V H and Eklund P C 2010 *Phys. Rev. B* **82** 241406

[56] Righi A, Costa S D, Chacham H, Fantini C, Venezuela P, Magnuson C, Colombo L, Bacsa W S, Ruoff R S and Pimenta M A 2011 *Phys. Rev. B* **84** 241409

[57] Carozo V, Almeida C M, Ferreira E H M, Cancado L G, Achete C A and Jorio A 2011 *Nano Lett.* **11** 4527

[58] Righi A, Venezuela R, Chacham H, Costa S D, Fantini C, Ruoff R S, Colombo L, Bacsa W S and Pimenta M A 2013 *Solid State Commun.* **175–176** 13

[59] Carozo V, Almeida C M, Fragneaud B, Bede P M, Moutinho M V O, Ribeiro-Soares J, Andrade N F, Souza A G, Matos M J S, Wang B, Terrones M, Capaz R B, Jorio A, Achete C A and Cancado L G 2013 *Phys. Rev. B* **88** 085401

[60] Wang Y N, Su Z H, Wu W, Nie S, Xie N, Gong H Q, Guo Y, Lee J H, Xing S R, Lu X X, Wang H Y, Lu X H, McCarty K, Pei S S, Robles-Hernandez F, Hadjiev V G and Bao J M 2013 *Appl. Phys. Lett.* **103** 123101

[61] Woods C R, Britnell L, Eckmann A, Ma R S, Lu J C, Guo H M, Lin X, Yu G L, Cao Y, Gorbachev R V, Kretinin A V, Park J, Ponomarenko L A, Katsnelson M I, Gornostyrev Y N, Watanabe K, Taniguchi T, Casiraghi C, Gao H J, Geim A K and Novoselov K S 2014 *Nat. Phys.* **10** 451

[62] Dai S Y, Xiang Y and Srolovitz D J 2016 *Nano Lett.* **16** 5923

[63] Kim N Y, Jeong H Y, Kim J H, Kim G, Shin H S and Lee Z 2017 *ACS Nano* **11** 7084

[64] Dean C R, Young A F, Meric I, Lee C, Wang L, Sorgenfrei S, Watanabe K, Taniguchi T, Kim P, Shepard K L and Hone J 2010 *Nat. Nanotechnol.* **5** 722

[65] Hofstadter D R 1976 *Phys. Rev. B* **14** 2239

[66] Hunt B, Sanchez-Yamagishi J D, Young A F, Yankowitz M, LeRoy B J, Watanabe K, Taniguchi T, Moon P, Koshino M, Jarillo-Herrero P and Ashoori R C 2013 *Science* **340** 1427

[67] Ponomarenko L, Gorbachev R, Yu G, Elias D, Jalil R, Patel A, Mishchenko A, Mayorov A, Woods C and Wallbank J 2013 *Nature* **497** 594

[68] Dean C R, Wang L, Maher P, Forsythe C, Ghahari F, Gao Y, Katoch J, Ishigami M, Moon P, Koshino M, Taniguchi T, Watanabe K, Shepard K L, Hone J and Kim P 2013 *Nature* **497** 598

[69] Li S Z, Li Q Y, Carpick R W, Gumbsch P, Liu X Z, Ding X D, Sun J and Li J 2016 *Nature* **539** 541

[70] Li H, Wang J H, Gao S, Chen Q, Peng L M, Liu K H and Wei X L 2017 *Adv. Mater.* **29** 1701474

[71] Song Y M, Mandelli D, Hod O, Urbakh M, Ma M and Zheng Q S 2018 *Nat. Mater.* **17** 894

[72] Ying Z, Deng A L, Lyu B S, Wang L L, Taniguchi T, Watanabe K and Shi Z W 2019 *Chin. Phys. B* **28** 028102

[73] Mak K F, Lee C, Hone J, Shan J and Heinz T F 2010 *Phys. Rev. Lett.* **105** 136805

[74] Splendiani A, Sun L, Zhang Y B, Li T S, Kim J, Chim C Y, Galli G and Wang F 2010 *Nano Lett.* **10** 1271

[75] Qiu D Y, da Jornada F H and Louie S G 2013 *Phys. Rev. Lett.* **111** 216805

[76] Xu X D, Yao W, Xiao D and Heinz T F 2014 *Nat. Phys.* **10** 343

[77] Keum D H, Cho S, Kim J H, Choe D H, Sung H J, Kan M, Kang H, Hwang J Y, Kim S W, Yang H, Chang K J and Lee Y H 2015 *Nat. Phys.* **11** 482

[78] Cho S, Kim S, Kim J H, Zhao J, Seok J, Keum D H, Baik J, Choe D H, Chang K J, Suenaga K, Kim S W, Lee Y H and Yang H 2015 *Science* **349** 625

[79] Sie E J, Nyby C M, Pemmaraju C D, Park S J, Shen X Z, Yang J, Hoffmann M C, Ofori-Okai B K, Li R K, Reid A H, Weathersby S, Mannebach E, Finney N, Rhodes D, Chenet D, Antony A, Balicas L, Hone J, Devereaux T P, Heinz T F, Wang X J and Lindenberg A M 2019 *Nature* **565** 61

[80] Liu K H, Zhang L M, Cao T, Jin C H, Qiu D A, Zhou Q, Zettl A, Yang P D, Louie S G and Wang F 2014 *Nat. Commun.* **5** 4966

[81] Rigos A F, Hill H M, Li Y L, Chernikov A and Heinz T F 2015 *Nano Lett.* **15** 5033

[82] Huang S X, Liang L B, Ling X, Puretzky A A, Geohegan D B, Sumpter B G, Kong J, Meunier V and Dresselhaus M S 2016 *Nano Lett.* **16** 1435

[83] Wang K, Huang B, Tian M, Ceballos F, Lin M W, Mahjouri-Samani M, Boulesbaa A, Puretzky A A, Rouleau C M, Yoon M, Zhao H, Xiao K, Duscher G and Geohegan D B 2016 *ACS Nano* **10** 6612

[84] Ceballos F, Bellus M Z, Chiu H Y and Zhao H 2014 *ACS Nano* **8** 12717

[85] Hong X P, Kim J, Shi S F, Zhang Y, Jin C H, Sun Y H, Tongay S, Wu J Q, Zhang Y F and Wang F 2014 *Nat. Nanotechnol.* **9** 682

[86] Song Z P , Zhu H O , Shi W T , Sun D L and Ruan S C 2018 *Chin. Phys. Lett.* **35** 127801

[87] Ji Z H, Hong H, Zhang J, Zhang Q, Huang W, Cao T, Qiao R X, Liu C, Liang J, Jin C H, Jiao L Y, Shi K B, Meng S and Liu K H 2017 *ACS Nano* **11** 12020

[88] Zhang J, Hong H, Lian C, Ma W, Xu X Z, Zhou X, Fu H X, Liu K H and Meng S 2017 *Adv. Sci.* **4** 1700086

[89] Zhu H M, Wang J, Gong Z Z, Kim Y D, Hone J and Zhu X Y 2017 *Nano Lett.* **17** 3591

[90] Lin M L, Tan Q H, Wu J B, Chen X S, Wang J H, Pan Y H, Zhang X, Cong X, Zhang J, Ji W, Hu P A, Liu K H and Tan P H 2018 *ACS Nano* **12** 8770

[91] Eisenstein J P and MacDonald A H 2004 *Nature* **432** 691

JUST FOR AUTHORS — CHINESE PHYSICS B

Chinese Physics B

Volume 28 Number 10 October 2019

TOPICAL REVIEW — CALYPSO structure prediction methodology and its applications to materials discovery

103104 Cluster structure prediction via CALYPSO method
Yonghong Tian, Weiguo Sun, Bole Chen, Yuanyuan Jin and Cheng Lu

106104 Discovery of superhard materials via CALYPSO methodology
Shuangshuang Zhang, Julong He, Zhisheng Zhao, Dongli Yu and Yongjun Tian

106105 The CALYPSO methodology for structure prediction
Jian Lv, Pengyue Gao and Yanchao Wang

106106 Pressure-induced new chemistry
Jianyan Lin, Xin Du and Guochun Yang

106107 Geoscience material structures prediction via CALYPSO methodology
Andreas Hermann

106201 High-pressure electrides: From design to synthesis
Biao Wan, Jingwu Zhang, Lailei Wu and Huiyang Gou

107104 The role of CALYPSO in the discovery of high-T_c hydrogen-rich superconductors
Wenwen Cui and Yinwei Li

107306 Recent progress on the prediction of two-dimensional materials using CALYPSO
Cheng Tang, Gurpreet Kour and Aijun Du

TOPICAL REVIEW — A celebration of the 100th birthday of Kun Huang

104202 Unconventional phase transition of phase-change-memory materials for optical data storage
Nian-Ke Chen and Xian-Bin Li

107304 Emerging properties of two-dimensional twisted bilayer materials
Yang Cheng, Chen Huang, Hao Hong, Zixun Zhao and Kaihui Liu

107502 Electrical transport and optical properties of Cd_3As_2 thin films
Yun-Kun Yang, Fa-Xian Xiu, Feng-Qiu Wang, Jun Wang and Yi Shi

SPECIAL TOPIC — A celebration of the 100th birthday of Kun Huang

106802 Charge trapping memory device based on the Ga_2O_3 films as trapping and blocking layer
Bing Bai, Hong Wang, Yan Li, Yunxia Hao, Bo Zhang, Boping Wang, Zihang Wang, Hongqi Yang, Qihang Gao, Chao Lü, Qingshun Zhang and Xiaobing Yan

107501 Magnetoresistance hysteresis in topological Kondo insulator SmB_6 nanowire
Ling-Jian Kong, Yong Zhou, Hua-Ding Song, Da-Peng Yu and Zhi-Min Liao

JUST FOR AUTHORS
— Chinese Physics B

(*Continued on the Bookbinding Inside Back Cover*)

107504 Two-dimensional XSe_2 (X = Mn, V) based magnetic tunneling junctions with high Curie temperature
Longfei Pan, Hongyu Wen, Le Huang, Long Chen, Hui-Xiong Deng, Jian-Bai Xia and Zhongming Wei

107801 Optoelectronic properties analysis of silicon light-emitting diode monolithically integrated in standard CMOS IC
Yanxu Chen, Dongliang Xu, Kaikai Xu, Ning Zhang, Siyang Liu, Jianming Zhao, Qian Luo, Lukas W. Snyman and Jacobus W. Swart

TOPICAL REVIEW — 110th Anniversary of Lanzhou University

107105 A review of current research on spin currents and spin–orbit torques
Xiao-Yu Feng, Qi-Han Zhang, Han-Wen Zhang, Yi Zhang, Rui Zhong, Bo-Wen Lu, Jiang-Wei Cao and Xiao-Long Fan

SPECIAL TOPIC — 110th Anniversary of Lanzhou University

100501 Enhancing von Neumann entropy by chaos in spin–orbit entanglement
Chen-Rong Liu, Pei Yu, Xian-Zhang Chen, Hong-Ya Xu, Liang Huang and Ying-Cheng Lai

100502 Experimental investigation of the fluctuations in nonchaotic scattering in microwave billiards
Runzu Zhang, Weihua Zhang, Barbara Dietz, Guozhi Chai and Liang Huang

107103 Benchmarking the simplest slave-particle theory with Hubbard dimer
Wei-Wei Yang, Hong-Gang Luo and Yin Zhong

SPECIAL TOPIC — Strong-field atomic and molecular physics

103201 Asymmetric structure of atomic above-threshold ionization spectrum in two-color elliptically polarized laser fields
Xu-Cong Zhou, Shang Shi, Fei Li, Yu-Jun Yang, Jing Chen, Qing-Tian Meng and Bing-Bing Wang

103202 Role of the dressed and bound states on below-threshold harmonic generation of He atom
Jian-Wei Zhou, Zhi-Hong Jiao, Peng-Cheng Li and Xiao-Xin Zhou

RAPID COMMUNICATION

104211 Characterize and optimize the four-wave mixing in dual-interferometer coupled silicon microrings
Chao Wu, Yingwen Liu, Xiaowen Gu, Shichuan Xue, Xinxin Yu, Yuechan Kong, Xiaogang Qiang, Junjie Wu, Zhihong Zhu and Ping Xu

106103 Structural and electronic properties of transition-metal chalcogenides Mo_5S_4 nanowires
Ming-Shuai Qiu, Huai-Hong Guo, Ye Zhang, Bao-Juan Dong, Sajjad Ali and Teng Yang

107307 Electronic structure of molecular beam epitaxy grown 1T′-$MoTe_2$ film and strain effect
Xue Zhou, Zeyu Jiang, Kenan Zhang, Wei Yao, Mingzhe Yan, Hongyun Zhang, Wenhui Duan and Shuyun Zhou

TO-BE FOR AUTHORS
— CHINESE PHYSICS B

107401 Robust two-gap strong coupling superconductivity associated with low-lying phonon modes in pressurized Nb_5Ir_3O superconductors
Bosen Wang, Yaoqing Zhang, Shuxiang Xu, Kento Ishigaki, Kazuyuki Matsubayashi, Jin-Guang Cheng, Hideo Hosono and Yoshiya Uwatoko

108704 Influence of matrigel on the shape and dynamics of cancer cells
Teng Ye and Feng Qiu

GENERAL

100201 Compact finite difference schemes for the backward fractional Feynman–Kac equation with fractional substantial derivative
Jiahui Hu, Jungang Wang, Yufeng Nie and Yanwei Luo

100202 Exact solutions of a (2+1)-dimensional extended shallow water wave equation
Feng Yuan, Jing-Song He and Yi Cheng

100203 Lump-type solutions of a generalized Kadomtsev–Petviashvili equation in (3+1)-dimensions
Xue-Ping Cheng, Wen-Xiu Ma and Yun-Qing Yang

100301 Time evolution of angular momentum coherent state derived by virtue of entangled state representation and a new binomial theorem
Ji-Suo Wang, Xiang-Guo Meng and Hong-Yi Fan

100302 Boundary states for entanglement robustness under dephasing and bit flip channels
Hong-Mei Li, Miao-Di Guo, Rui Zhang and Xue-Mei Su

100303 Manipulating transition of a two-component Bose–Einstein condensate with a weak δ-shaped laser
Bo Li, Xiao-Jun Jiang, Xiao-Lin Li, Wen-Hua Hai and Yu-Zhu Wang

100304 Topological phases of a non-Hermitian coupled SSH ladder
J S Liu, Y Z Han and C S Liu

100401 Optimal estimation of the amplitude of signal with known frequency in the presence of thermal noise
Jie Luo, Jun Ke, Yi-Chuan Liu, Xiang-Li Zhang, Wei-Ming Yin and Cheng-Gang Shao

100701 Photoactivation experiment of ^{197}Au(γ, n) performed with 9.17-MeV γ-ray from ^{13}C(p, γ)^{14}N
Yong-Le Dang, Fu-Long Liu, Guang-Yong Fu, Di Wu and Nai-Yan Wang

ATOMIC AND MOLECULAR PHYSICS

103101 Interface properties and electronic structures of aromatic molecules with anhydride and thio-functional groups on Ag (111) and Au (111) substrates
Wei-Qi Yu, Hong-Jun Xiao and Ge-Ming Wang

103102 Elastic properties of anatase titanium dioxide nanotubes: A molecular dynamics study
Kang Yang, Liang Yang, Chang-Zhi Ai, Zhao Wang and Shi-Wei Lin

JUST FOR AUTHORS

103103 Theoretical investigation of the pressure broadening D_1 and D_2 lines of cesium atoms colliding with ground-state helium atoms
Moussaoui Abdelaziz, Alioua Kamel, Allouche Abdul-rahman and Bouledroua Moncef

103105 *Ab initio* investigation of excited state dual hydrogen bonding interactions and proton transfer mechanism for novel oxazoline compound
Yu-Sheng Wang, Min Jia, Qiao-Li Zhang, Xiao-Yan Song and Da-Peng Yang

103203 Selection of right-circular-polarized harmonics from p orbital of neon atom by two-color bicircular laser fields
Chang-Long Xia, Yue-Yue Lan, Qian-Qian Li and Xiang-Yang Miao

103204 Helicity of harmonic generation and attosecond polarization with bichromatic circularly polarized laser fields
Jun Zhang, Tong Qi, Xue-Fei Pan, Jing Guo, Kai-Guang Zhu and Xue-Shen Liu

ELECTROMAGNETISM, OPTICS, ACOUSTICS, HEAT TRANSFER, CLASSICAL MECHANICS, AND FLUID DYNAMICS

104201 Dynamic and inner-dressing control of four-wave mixing in periodically-driven atomic system
Yuan-Yuan Li, Li Li, Yun-Zhe Zhang and Lei Zhang

104203 Proof-of-principle experimental demonstration of quantum secure imaging based on quantum key distribution
Yi-Bo Zhao, Wan-Li Zhang, Dong Wang, Xiao-Tian Song, Liang-Jiang Zhou and Chi-Biao Ding

104204 Numerical investigation on coherent mid-infrared supercontinuum generation in chalcogenide PCFs with near-zero flattened all-normal dispersion profiles
Jie Han, Sheng-Dong Chang, Yan-Jia Lyu and Yong Liu

104205 Second-order interference of two independent photons with different spectra
Yu Zhou, Jian-Bin Liu, Huai-Bin Zheng, Hui Chen, Fu-Li Li and Zhuo Xu

104206 Polymer/silica hybrid waveguide Y-branch power splitter with loss compensation based on $NaYF_4$:Er^{3+}, Yb^{3+} nanocrystals
Yue-Wu Fu, Tong-He Sun, Mei-Ling Zhang, Xu-Cheng Zhang, Fei Wang and Da-Ming Zhang

104207 Properties of multi-Gaussian Schell-model beams carrying an edge dislocation propagating in oceanic turbulence
Da-Jun Liu, Yao-Chuan Wang, Gui-Qiu Wang, Hong-Ming Yin and Hai-Yang Zhong

104208 Extraordinary transmission and reflection in $\mathcal{PT}$-symmetric two-segment-connected triangular optical waveguide networks with perfect and broken integer waveguide length ratios
Jia-Ye Wu, Xu-Hang Wu, Xiang-Bo Yang and Hai-Ying Li

104209 Low insertion loss silicon-based spatial light modulator with high reflective materials outside Fabry–Perot cavity
Li-Fei Tian, Ying-Xin Kuang, Zhong-Chao Fan and Zhi-Yong Li

JUST FOR AUTHORS

104210 Multi-objective strategy to optimize dithering technique for high-quality three-dimensional shape measurement
Ning Cai, Zhe-Bo Chen, Xiang-Qun Cao and Bin Lin

104212 Single event upset on static random access memory devices due to spallation, reactor, and monoenergetic neutrons
Xiao-Ming Jin, Wei Chen, Jun-Lin Li, Chao Qi, Xiao-Qiang Guo, Rui-Bin Li and Yan Liu

104301 Theoretical framework for geoacoustic inversion by adjoint method
Yang Wang and Xiao-Feng Zhao

104601 Evolution of real contact area during stick-slip movement observed by total reflection method
Zhijun Luo, Baojiang Song, Jingyu Han and Shaoze Yan

104701 Stabilized seventh-order dissipative compact scheme for two-dimensional Euler equations
Jia-Xian Qin, Ya-Ming Chen and Xiao-Gang Deng

104702 Numerical simulation on dynamic behaviors of bubbles flowing through bifurcate T-junction in microfluidic device
Liang-Yu Wu, Ling-Bo Liu, Xiao-Tian Han, Qian-Wen Li and Wei-Bo Yang

PHYSICS OF GASES, PLASMAS, AND ELECTRIC DISCHARGES

105201 Construction of an H_α diagnostic system and its application to determine neutral hydrogen densities on the Keda Torus eXperiment
Junfeng Zhu, Tao Lan, Ge Zhuang, Tijian Deng, Jie Wu, Hangqi Xu, Chen Chen, Sen Zhang, Jiaren Wu, Yiming Zu, Hong Li, Jinlin Xie, Ahdi Liu, Zixi Liu, Zhengwei Wu, Hai Wang, Xiaohui Wen, Haiyang Zhou, Chijin Xiao, Weixing Ding and Wandong Liu

105202 The inverse Bremsstrahlung absorption in the presence of Maxwellian and non-Maxwellian electrons
Mehdi Sharifian, Fatemeh Ghoveisi, Leila Gholamzadeh and Narges Firouzi Farrashbandi

CONDENSED MATTER: STRUCTURAL, MECHANICAL, AND THERMAL PROPERTIES

106101 Defects and electrical properties in Al-implanted 4H-SiC after activation annealing
Yi-Dan Tang, Xin-Yu Liu, Zheng-Dong Zhou, Yun Bai and Cheng-Zhan Li

106102 First principles study of interactions of oxygen–carbon–vacancy in bcc Fe
Yuan You, Mu-Fu Yan, Ji-Hong Yan, Gang Sun and Chao Wang

106301 Physical properties of ternary thallium chalcogenes Tl_2MQ_3 (M = Zr, Hf; Q = S, Se, Te) via *ab-initio* calculations
Engin Ateser, Oguzhan Okvuran, Yasemin Oztekin Ciftci, Haci Ozisik and Engin Deligoz

106401 Phosphine-free synthesis of $FeTe_2$ nanoparticles and self-assembly into tree-like nanoarchitectures
Hongyu Wang, Min Wu, Yixuan Wang, Hao Wang, Xiaoli Huang and Xinyi Yang

JUST FOR AUTHORS

106701 Expansion dynamics of a spherical Bose–Einstein condensate
Rui-Zong Li, Tian-You Gao, Dong-Fang Zhang, Shi-Guo Peng, Ling-Ran Kong, Xing Shen and Kai-Jun Jiang

106801 Highly reliable and selective ethanol sensor based on α-Fe_2O_3 nanorhombs working in realistic environments
Wenjun Yan, Xiaomin Zeng, Huan Liu, Chunwei Guo, Min Ling and Houpan Zhou

CONDENSED MATTER: ELECTRONIC STRUCTURE, ELECTRICAL, MAGNETIC, AND OPTICAL PROPERTIES

107101 Electronic properties of size-dependent $MoTe_2/WTe_2$ heterostructure
Jing Liu, Ya-Qiang Ma, Ya-Wei Dai, Yang Chen, Yi Li, Ya-Nan Tang and Xian-Qi Dai

107102 Hubbard model on an anisotropic checkerboard lattice at finite temperatures: Magnetic and metal–insulator transitions
Hai-Di Liu

107301 Negative transconductance effect in p-GaN gate AlGaN/GaN HEMTs by traps in unintentionally doped GaN buffer layer
Mei Ge, Qing Cai, Bao-Hua Zhang, Dun-Jun Chen, Li-Qun Hu, Jun-Jun Xue, Hai Lu, Rong Zhang and You-Dou Zheng

107302 Optical response of an inverted InAs/GaSb quantum well in an in-plane magnetic field
Xiaoguang Wu

107303 Observation of hopping transitions for delocalized electrons by temperature-dependent conductance in silicon junctionless nanowire transistors
Yang-Yan Guo, Wei-Hua Han, Xiao-Song Zhao, Ya-Mei Dou, Xiao-Di Zhang, Xin-Yu Wu and Fu-Hua Yang

107305 Enhanced spin-dependent thermopower in a double-quantum-dot sandwiched between two-dimensional electron gases
Feng Chi, Zhen-Guo Fu, Liming Liu and Ping Zhang

107503 Magnetic vortex gyration mediated by point-contact position
Hua-Nan Li, Zi-Wei Fan, Jia-Xin Li, Yue Hu and Hui-Lian Liu

107802 Cascaded plasmonic nanorod antenna for large broadband local electric field enhancement
Dou Zhang, Zhong-Jian Yang and Jun He

107803 Photoluminescence properties of blue and green multiple InGaN/GaN quantum wells
Chang-Fu Li, Kai-Ju Shi, Ming-Sheng Xu, Xian-Gang Xu and Zi-Wu Ji

INTERDISCIPLINARY PHYSICS AND RELATED AREAS OF SCIENCE AND TECHNOLOGY

108101 Effect of AlN coating on hydrogen permeability and surface structure of VT6 alloy by vacuum arc ion plating
Zi-Yi Ding

JUST FOR AUTHORS
— Chinese Physics B

108102 Effect of sintering temperature on luminescence properties of borosilicate matrix blue–green emitting color conversion glass ceramics
Qiao-Yu Zheng, Yang Li, Wen-Juan Wu, Ming-Ming Shi, Bo-Bo Yang and Jun Zou

108103 Flexible rGO/Fe_3O_4 NPs/polyurethane film with excellent electromagnetic properties
Wei-Qi Yu, Yi-Chen Qiu, Hong-Jun Xiao, Hai-Tao Yang and Ge-Ming Wang

108201 Parameter identification and state-of-charge estimation approach for enhanced lithium-ion battery equivalent circuit model considering influence of ambient temperatures
Hui Pang, Lian-Jing Mou and Long Guo

108501 Analysis of non-uniform hetero-gate-dielectric dual-material control gate TFET for suppressing ambipolar nature and improving radio-frequency performance
Hui-Fang Xu, Jian Cui, Wen Sun and Xin-Feng Han

108502 Opto-electromechanically induced transparency in a hybrid opto-electromechanical system
Hui Liu, Li-Guo Qin, Li-Jun Tian and Hong-Yang Ma

108503 Designing of spin filter devices based on zigzag zinc oxide nanoribbon modified by edge defect
Bao-Rui Huang, Fu-Chun Zhang, Yan-Ning Yang, Zhi-Yong Zhang and Wei-Guo Wang

108701 Quantitative heterogeneity and subgroup classification based on motility of breast cancer cells
Ling Xiong, Yanping Liu, Ruchuan Liu, Wei Yuan, Gao Wang, Yi He, Jianwei Shuai, Yang Jiao, Xixiang Zhang, Weijing Han, Junle Qu and Liyu Liu

108702 Theory and method of dual-energy x-ray grating phase-contrast imaging
Feng Rong, Yan Gao, Cui-Juan Guo, Wei Xu and Wei Xu

108703 Benefit community promotes evolution of cooperation in prisoners' dilemma game
Jianwei Wang, Jialu He, Fengyuan Yu, Wei Chen, Rong Wang and Ke Yu

108901 Theoretical analyses of stock correlations affected by subprime crisis and total assets: Network properties and corresponding physical mechanisms
Shi-Zhao Zhu, Yu-Qing Wang and Bing-Hong Wang

JUST FOR AUTHORS
— CHINESE PHYSICS B