Chinese Physics Letters

RESEARCH HIGHLIGHT

Timing a Photo-induced Metastable State in the Natural Heterostructure $4H_b$-TaS_2

Cite as: Yanfeng Guo. 2026 *Chin. Phys. Lett.* **43** 100710

DOI CSTR

Recommended Articles

Photodoping-Modified Charge Density Wave Phase Transition in WS_2/1T-TaS_2 Heterostructure

Rui Wang, Jianwei Ding, Fei Sun, Jimin Zhao, and Xiaohui Qiu
Chin. Phys. Lett. **41**, (2024)

Coexisting Commensurate Pair Density Waves in 6R-TaS_2

Hongqin Xiao, Yuxuan He, Ke Zhu, Yuhan Ye, Yumeng Li, Lijing Huang, Pucen Xiong, Haitao Yang, Geng Li, and Hong-Jun Gao
Chin. Phys. Lett. **43**, 060713 (2026)

Robust Floquet-Induced Gap in Irradiated Graphite

Fei Wang, Xuanxi Cai, Wanying Chen, Jinxi Lu, Tianshuang Sheng, Xiao Tang, Jiansong Li, Hongyun Zhang, and Shuyun Zhou
Chin. Phys. Lett. **43**, 050705 (2026)

Ultrafast Melting of Charge-Density-Wave Order and a Transient Metastable State in $4H_b$-TaS_2

Lingxiao Gu *et al*.
Chin. Phys. Lett. , (2026)

Charge Density Wave Induced Second-Harmonic Generation in 1T-$TaSe_2$

Zhao-Zhe Chen, Chang-Hua Li, Hai-Xia Zhu, Yan-Peng Qi, and Si Xiao
Chin. Phys. Lett. **43**, 080404 (2026)

Revealing Light-Induced Charge Density Wave Melting and Carrier Redistribution in 1T-$TiSe_2$

Wanying Chen, Haoyuan Zhong, Changhua Bao, Fei Wang, Xuanxi Cai, Chenxia Yun, Hao Teng, Zhiyi Wei, and Shuyun Zhou
Chin. Phys. Lett. **42**, 017101 (2025)

A series journal of Chinese Physical Society distributed by IOP Publishing

Chinese Physics Letters

Chin. Phys. Lett. **43** 100710 (2026)

RESEARCH HIGHLIGHT

DOI: 10.1088/0256-307X/43/10/100710
CSTR: 32039.14.0256-307X.43.10.100710

Timing a Photo-induced Metastable State in the Natural Heterostructure $4H_b$-TaS_2

Yanfeng Guo(郭艳峰)[1,2,*]

[1]State Key Laboratory of Quantum Functional Materials, School of Physical Science and Technology, ShanghaiTech University, Shanghai 201210, China
[2]ShanghaiTech Laboratory for Topological Physics, ShanghaiTech University, Shanghai 201210, China

[*]Corresponding author. Email: guoyf@shanghaitech.edu.cn

Ultrafast research on quantum materials is moving beyond whether light can melt an ordered phase to harder questions: what state emerges afterward, why does it persist, and what determines its lifetime? The van der Waals heterostructures offer a promising platform because layer sequence and interlayer coupling can reshape correlated phases and their relaxation. In a recent *Express Letter*, Gu *et al.* investigate $4H_b$-TaS_2, a natural heterostructure of correlated 1T-TaS_2 (T) and superconducting 1H-TaS_2 (H) layers [1]. Using time- and angle-resolved photoemission spectroscopy (TRARPES), they observe sub-picosecond charge-density-wave (CDW) gap suppression followed by a slower electronic reconstruction, making the recovery lifetime a probe of the interlayer environment.

The TaS_2 family provides an instructive comparison. In bulk 1T-TaS_2, optical or electrical excitation can generate a hidden metallic state that persists for exceptionally long times at low temperature [2]. Its stability has been linked to CDW domain topology and out-of-plane stacking, including changes in interlayer dimerization. In $4H_b$-TaS_2, Star-of-David order survives within each T layer, but the intervening H layers interrupt direct T-T stacking and may introduce additional screening and relaxation channels. The material therefore tests whether local CDW melting alone can stabilize a long-lived reconstruction or whether prolonged retention requires three-dimensional rearrangement between adjacent T layers.

A key innovation is direct access to the unoccupied electronic structure. Earlier photoemission studies identified a CDW-related feature near the Fermi level on the T termination but did not connect it to an unoccupied electron-like dispersion or track its ultrafast evolution [3]. By transiently populating states above the Fermi level, Gu *et al.* resolve a band edge approximately 0.01 eV above it and extract a CDW gap of about 0.26 eV at 0.8 mJ·cm^{-2}. The 205-nm probe preferentially samples the T termination because its 6.05-eV photon energy exceeds the reported T-termination work function of 5.7 eV but remains below the H-termination value of 6.2 eV. This selectivity allows the gap dynamics to be inferred from two spectral features rather than from occupied-state intensity alone.

The measurements first reveal prompt CDW melting. At 1.2 mJ·cm^{-2}, the resolvable gap nearly closes within 0.15 ps and remains strongly suppressed beyond 0.3 ps. This response approaches the 113-fs experimental resolution and occurs within roughly one quarter of the period of the 2.4-THz CDW amplitude mode. With increasing fluence, the mode softens, broadens, and loses amplitude. The sub-cycle gap response and mode renormalization support a displacive-excitation mechanism, in which photoexcitation shifts the lattice potential before the ions complete a full oscillation. This scenario is summarized schematically in Fig. 1. The apparent collapse may combine gap filling from reduced CDW coherence with gap narrowing from suppression of the order-parameter amplitude. Accordingly, $F_c \approx 1.4$ mJ·cm^{-2} is an operational crossover, where two fitted peaks become unresolved, rather than a thermodynamic phase boundary.

A slower response emerges after the hot carriers decay. Above approximately the same fluence range, occupied spectral weight between the Fermi level and −0.2 eV remains enhanced for at least 25 ps, while recovery develops a slow component of about 50 ps. This persistence supports describing the response as a transient metastable electronic state, although TRARPES alone cannot establish a distinct free-energy minimum. Nonetheless, the sequence of prompt gap suppression, coherent-mode weakening, and long-lived spectral-weight redistribution separates initial CDW melting from the subsequent recovery pathway.

The delayed response resembles the persistent hidden state of bulk 1T-TaS_2, but important differences remain. ARPES cannot determine whether $4H_b$-TaS_2 develops the same CDW domain pattern, stacking configuration, or microscopic state, and similar fluence scales for gap suppression and delayed reconstruction do not prove causality. A bulk 1T-TaS_2 reference measured on the same platform exhibited a persistent hidden state, making cumulative heating an unlikely sole explanation for the sub-100-ps lifetime in $4H_b$-TaS_2, although the preparation protocols were not fully matched. Interrupted T-T stacking is therefore a plausible contributor to the shorter lifetime, but not a uniquely established mechanism. Electronic and phononic relaxation through the H layers and the role of the H-layer CDW remain unresolved [4].

These uncertainties reinforce the study's broader significance. Nonequilibrium research is shifting from discovering photoinduced phases to identifying the variables that govern their formation and retention. Layer sequence, dielectric screening, stacking constraints, and phonon relaxation may serve as control parameters alongside pump fluence, photon energy, and polarization. Natural heterostructures are valuable because their interfaces are atomically registered, but $4H_b$-TaS_2 is not a passive stack. Charge transfer and layer-dependent CDWs mean that the H layers may modify both the equilibrium electronic structure and T-layer relaxation.

Future experiments could directly test this interlayer interpretation. Ultrafast electron or X-ray diffraction could identify changes in CDW coherence, domain walls, or local stacking [5]. TRARPES with broader momentum coverage and improved layer sensitivity could detect a transient Fermi surface and distinguish T-layer recovery from energy transfer into H layers. Comparisons among TaS_2 polytypes, tuned crystals, and artificial 1T/1H stacks could quantify how lifetime depends on interlayer coupling, while selective electronic or phononic excitation could test whether the state is accessible with less heating. Measurements below the approximately 3 K superconducting transition could also reveal how the metastable CDW reconstruction interacts with superconductivity.

Gu *et al.* show that the recovery of a correlated state can encode a

Received 7 September 2026; accepted 11 September 2026; published 30 September 2026
© 2026 Chinese Physical Society and IOP Publishing Ltd. All rights, including for text and data mining, AI training, and similar technologies, are reserved.

Check for updates

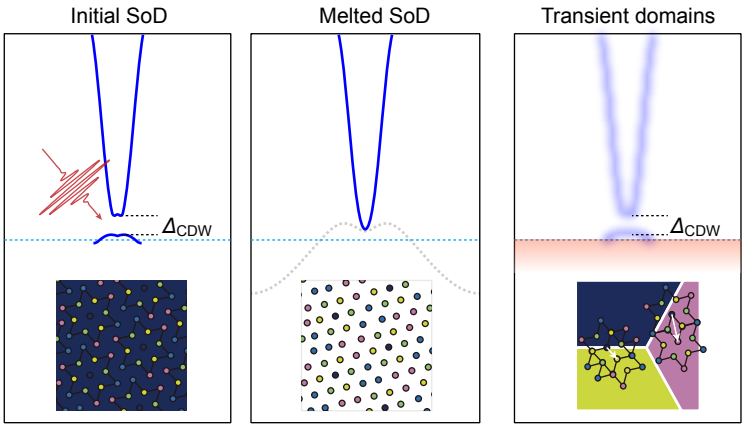

Fig. 1. Schematic of photo-induced CDW evolution in $4H_b$-TaS_2. From left to right: initial Star-of-David (SoD) ordered state, sub-picosecond melted CDW state, and a possible transient domain configuration inferred from the TRARPES results as a plausible microscopic scenario. This sequence illustrates the ultrafast gap collapse, coherent-mode weakening, and the structural context for the subsequent ~50-ps slow recovery.

material's vertical architecture. More broadly, heterostructure design may control not only equilibrium phases but also the accessibility, lifetime, and recovery pathways of nonequilibrium quantum states.

References

[1] Gu L, Meng F, Yang W, Wang S, Liu H, Huang J, Liu J, Chen D, Duan S, Qian D, Lei H, and Zhang W 2026 *Chin. Phys. Lett.* **43** 090707
[2] Stojchevska L, Vaskivskyi I, Mertelj T, Kusar P, Svetin D, Brazovskii S, and Mihailovic D 2014 *Science* **344** 177
[3] Almoalem A, Gofman R, Nitzav Y, Mangel I, Feldman I, Koo J, Mazzola F, Fujii J, Vobornik I, Sánchez-Barriga J, Clark O J, Plumb N C, Shi M, Yan B, and Kanigel A 2024 *npj Quantum Mater.* **9** 36
[4] Yang F Z, Zhang T T, Meng F Y, Lei H C, Nelson C, Cai Y Q, Vescovo E, Said A H, Lozano P M, Fabbris G, and Miao H 2025 *Phys. Rev. B* **111** L041101
[5] Vogelgesang S, Storeck G, Horstmann J G, Diekmann T, Sivis M, Schramm S, Rossnagel K, Schäfer S, and Ropers C 2018 *Nat. Phys.* **14** 184