Real-Time Observation of Slowed Charge-Density Wave Dynamics in Thinned 1T-TaS_2

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The dynamical response of charge-density wave (CDW) materials offers a promising path to implement active devices, such as non-volatile memories and oscillators. 1T-tantalum disulfide is a transition-metal dichalcogenide with rich CDW transitions that may be thermally or electrically driven, and which may also proceed via hidden, intermediate, states with strongly non-equilibrium character. Overall, the rich interplay of effects that can arise in this material provides a broad landscape for the development of electronic devices based upon CDW manipulation.

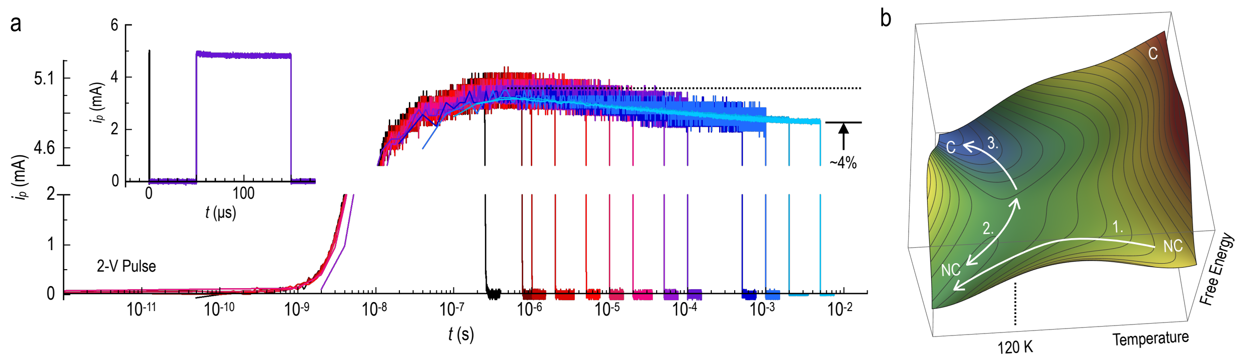

Fig. 1. (a) Transient currents of varying duration (250 ns – 5 ms) in a 1T-TaS_2 crystallite at 3 K. The slow transient response seen here, on ms time scales, reflects the dynamics of CDW ordering. (b) Proposed free-energy contour, with distinct energy minima for the different CDW phases. C: commensurate CDW. NC: nearly commensurate CDW.

In this work, we use transient electrical pulsing to investigate the kinetics of CDW ordering in thin (<100 nm) crystals of 1T-tantalum disulfide (1T-TaS_2). The sub-nanosecond resolution of our measurements [1] enables us to distinguish a fast response of the material that appears consistent with the onset of self-heating, from much slower transient-current variations that occur on times orders of magnitude longer than this (Fig. 1(a)). These latter variations appear consistent with slow configurational changes in the CDW state, which, due to the thin nature of the 1T-TaS_2, can be distinguished from the much faster dynamics of Joule heating. Our results, which are supported by detailed thermal modeling of these materials, point to the existence of a complex free-energy space for the thinned material (Figure 1(b)), whose multi-valley structure governs the resulting thermal and field-driven dynamics. In the analysis of systems that exhibit resistive switching, it is common to emphasize the competition of thermally and field-driven processes, highlighting the role of one of these mechanisms over the other. Our work reveals a more nuanced picture; while current-driven Joule heating may stabilize quickly (on a time of a few tens of nanoseconds), transitions to new metastable states require much longer times. In a sense, the system must be held at some elevated "annealing temperature", for an extended period, to induce transitions between these states. The discovery of these very different mechanisms (Joule heating *vs*. thermal annealing) will be important for efforts to implement active devices that utilize the CDW states of thinned 1T-TaS_2.

References

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[2] S. Yin, K. He, B. Barut, M. D. Randle, R. Dixit, J. Nathawat, D. Adinehloo, V. Perebeinos, J. E. Han, and J. P. Bird, Advanced Physics Reports, *under review* (*revision submitted*).