Spatial imaging of electrically driven charge density wave phase transitions in 1T-TaS_2

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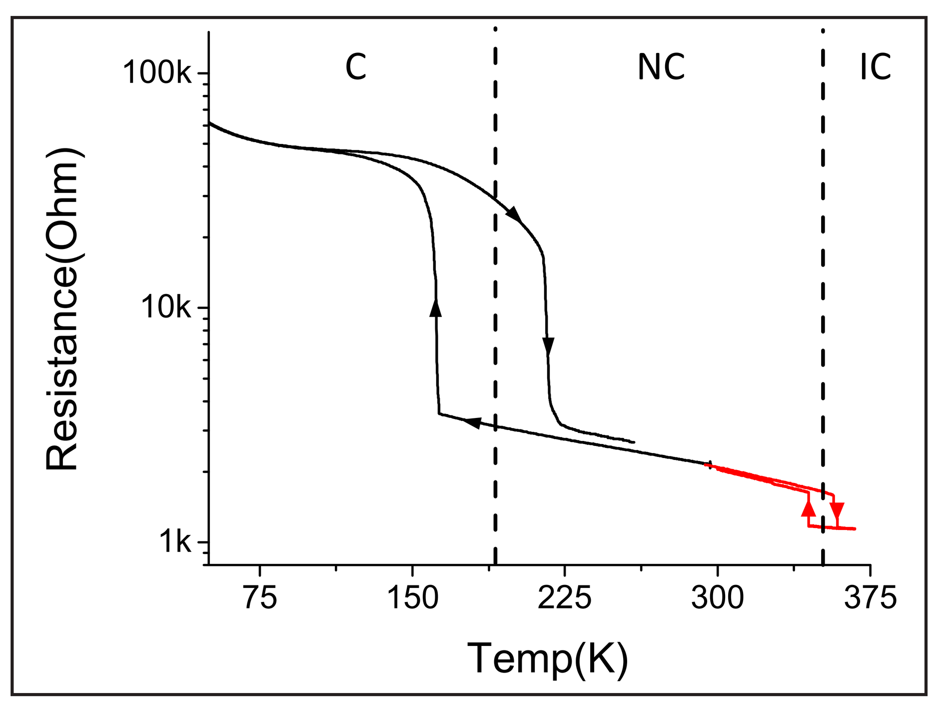
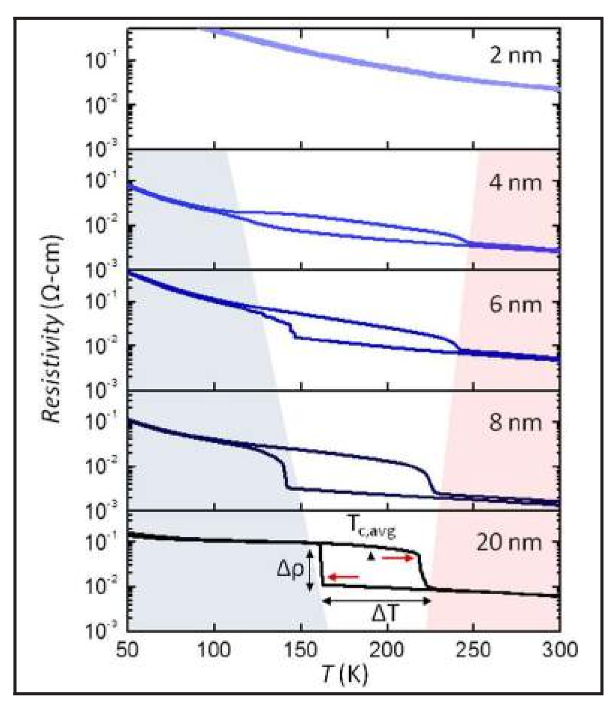
Introduction

- The discovery of graphene by Novosolov and Geim in 2004 initiated the study of 2D materials in the ultrathin limit [1].
- Scanning tunnelling microscopy (STM) is an ideal tool for studying atomically flat surfaces.
- We aim to study electrically driven charge density wave (CDW) phase transitions in ultrathin 1T-TaS_2 using STM.

Metal-insulator transitions in 1T-TaS_2

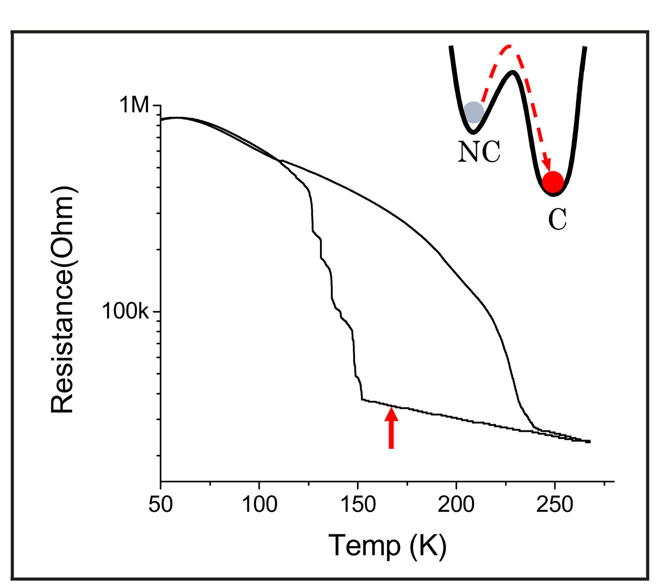


(a)



(b)

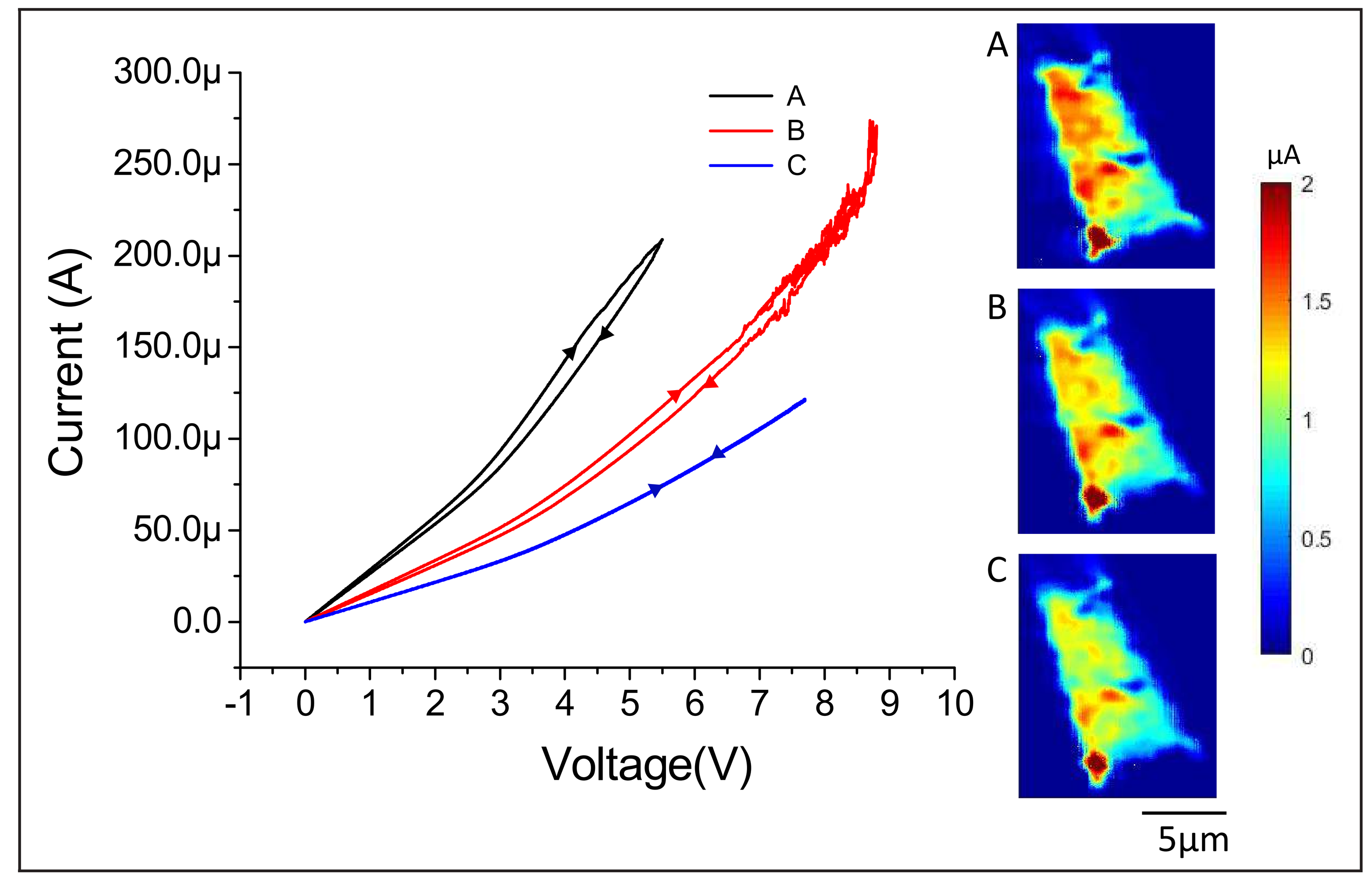
1T-TaS_2 is a semi-metal in which electrons at the Fermi surface cluster to give rise to a modulation in the electron density at the atomic scale. The arrangement of these clusters with respect to the underlying lattice manifests as multiple metal-to-insulator transitions as a function of temperature (a). Three distinct phases are identifiable: Incommensurate (IC): 360 K and above, nearly commensurate (NC): 360 K to 160 K, and commensurate (C): 160 K and below. It has been shown before that the NC-C phase transition becomes more metastable as the thickness of the material is reduced. This effect can be seen in the widening of the hysteresis in a plot of resistance vs. temperature (b) [2].



- In thin samples it is possible to drive the material from the NC phase towards the C phase by passing current through the sample.

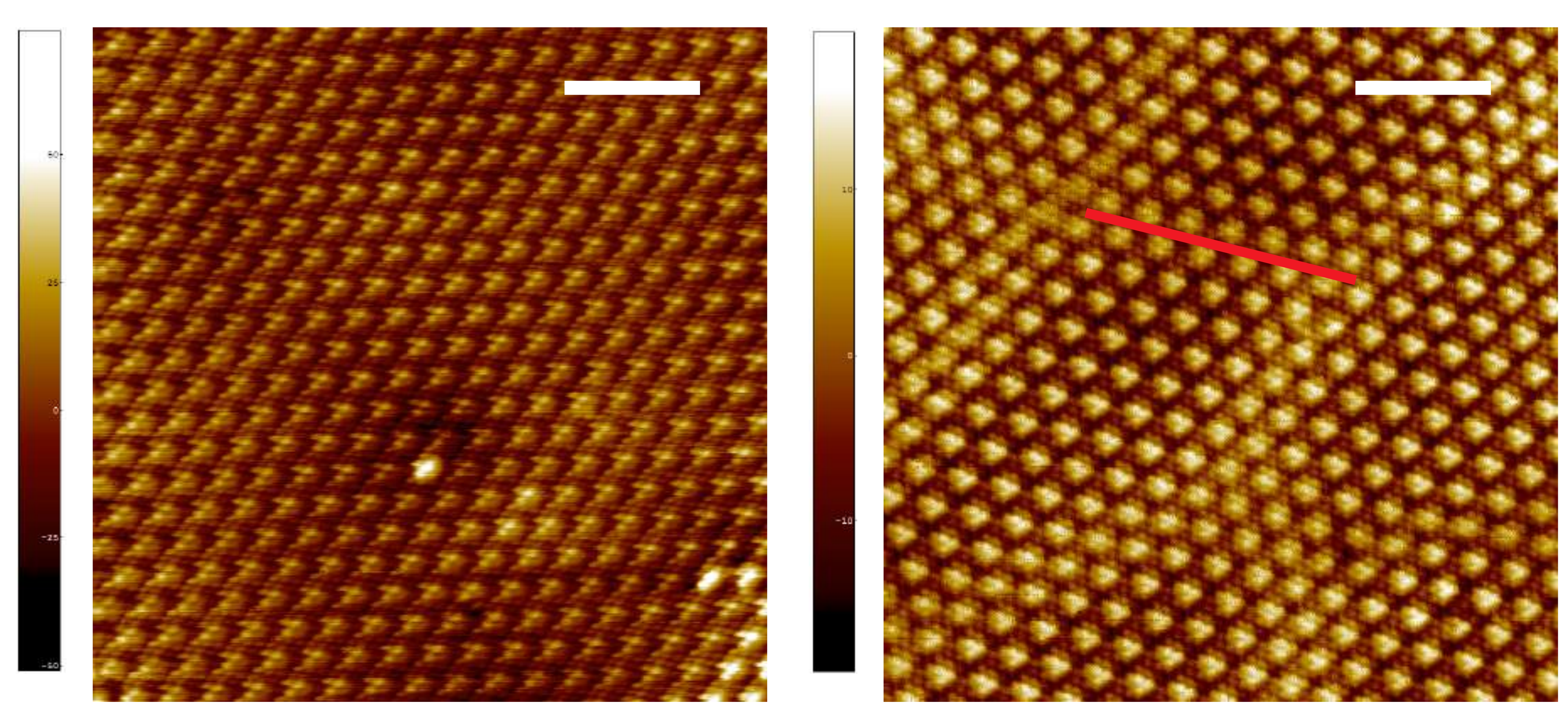
Electrical driving of NC-C phase transition

- Photocurrent maps of electrically driven phase transition help to visualize the electrical driving at a mesoscopic scale.



STM imaging of 1T-TaS_2 phase transitions

- STM gives information regarding changes at the atomic scale.

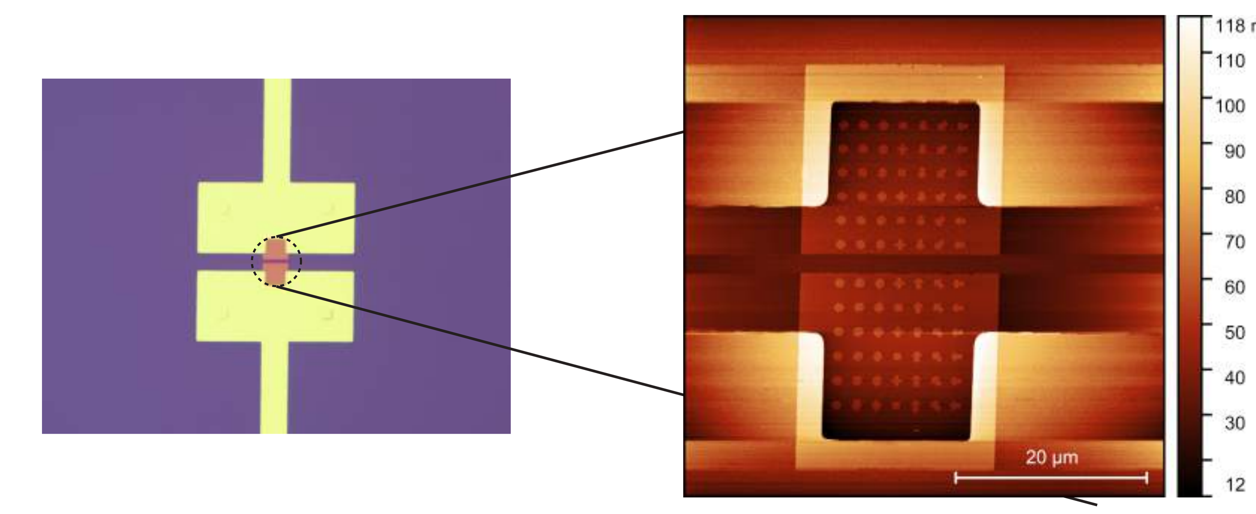


(a) (b)

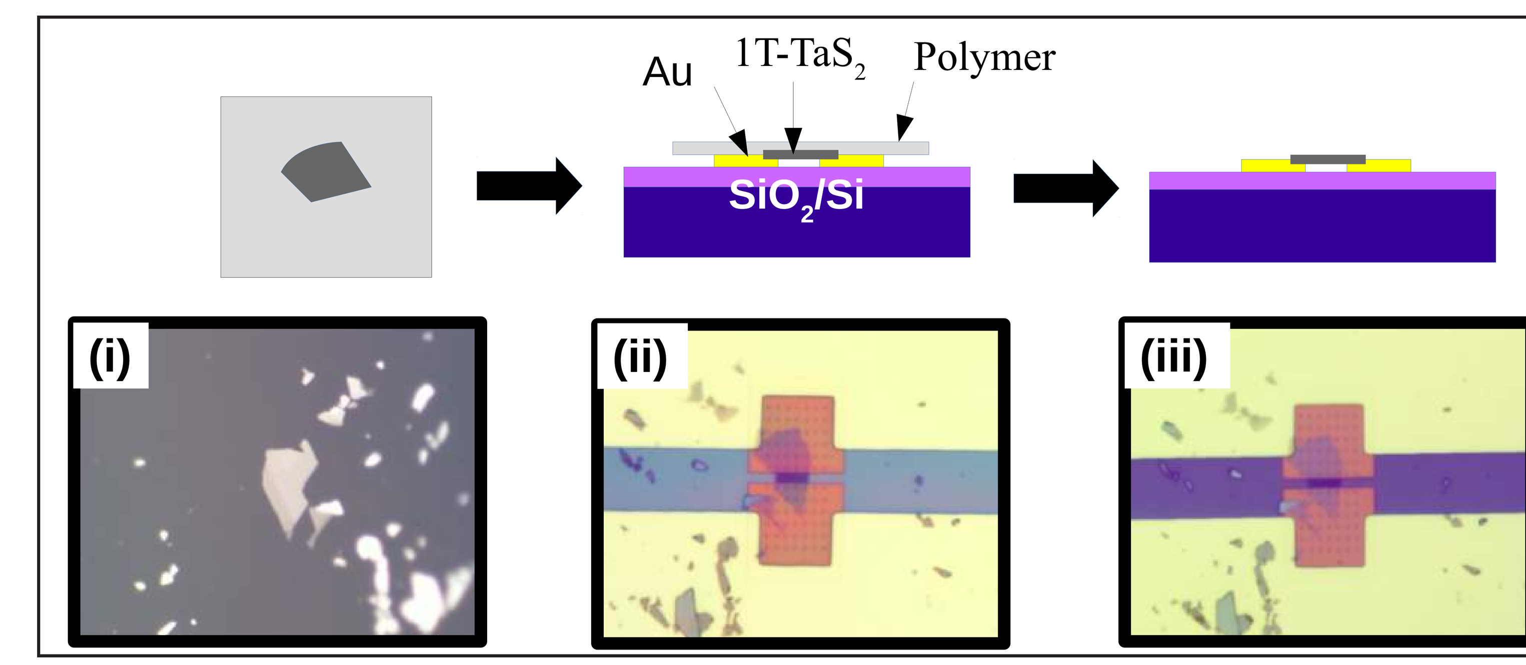
STM images of bulk 1T-TaS_2 in the C phase at 77 K (a) and the NC phase at 200 K (b) (scale bar = 4 nm). The arrangement of charge density wave "stars" in the C phase is highly uniform, while in the NC phase domains of C phase are separated by a period of dis-commensuration (e.g. along the red line in (b)).

Electrode design and sample preparation

- An electrode design with sub-micron markers allow us to locate an ultrathin flake in the STM.



- The electrodes were fabricated using electron beam lithography and imaged using atomic force microscopy.



- A polymer-based exfoliation and transfer technique is used to fabricate the samples.

Outlook

- The study of electrically driven metal-insulator phase transitions at an atomic scale will help in improving the understanding of this phase transition in 1T-TaS_2.
- Electrical control of this phase transition has possible applications as memristor devices.

Acknowledgement

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[1] Novoselov et al. *Science*, 2004, **306**, 666.
[2] Tsen et al. *PNAS*, 2015, **112**, 15054.

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