

Ultrafast Metal-Insulator and Charge-Ordering Transitions in Correlated Transition Metal Compounds

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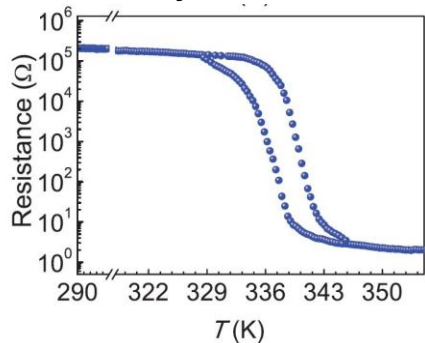
Outline:

1. Metal-to-insulator phase transitions in VO_2
2. Ultrafast photo-induced phase transitions in 1T-TaS_2
3. New development of RF-compressed ultrafast electron microscope at MSU

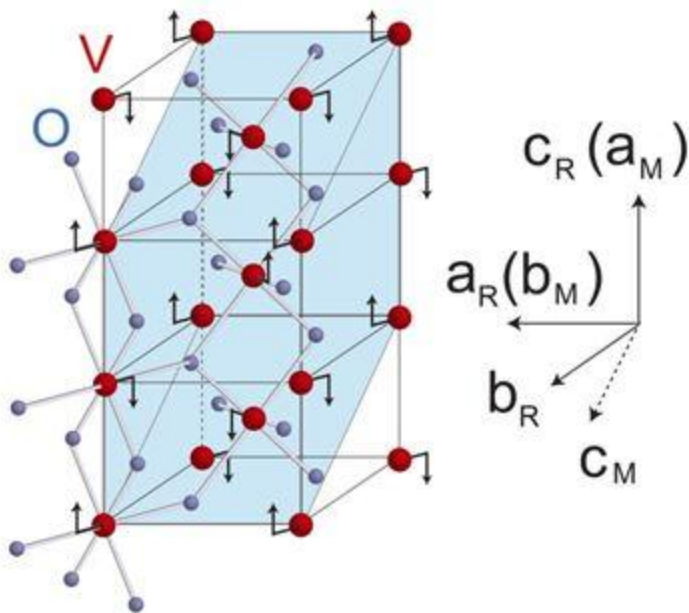
VO₂, a prototypical example of strongly correlated electron system

- Metal-to-Insulator Transition (MIT)

F. J. Morin, Phys. Rev. Lett. 3, 34 (1959)



- Structural Phase Transition



Peierls or Mott Insulator ?

- ❖ Peierls band theory

J. B. Goodenough, J. Sol. Stat. Chem., 3, 490 (1971)

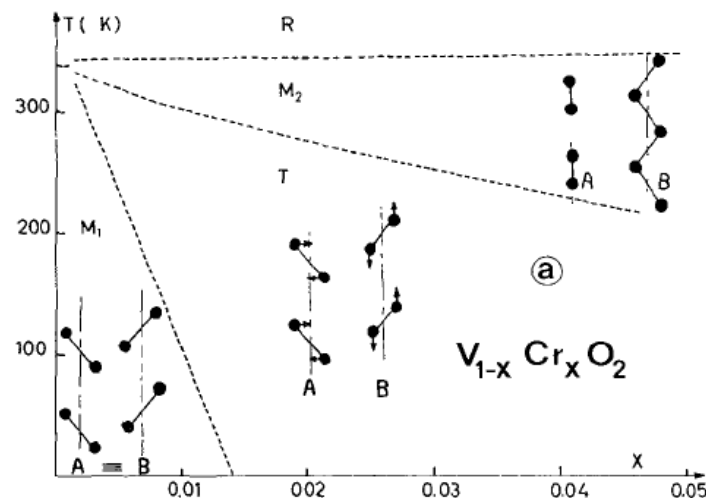
- ❖ Mott-Hubbard model

A. Zylbersztein and N. F. Mott, Phys. Rev. B., 11, 4383 (1974)

- ❖ Recent dynamical mean-field theory

S. Biermann, et al., Phys. Rev. Lett., 94, 026404 (2005)

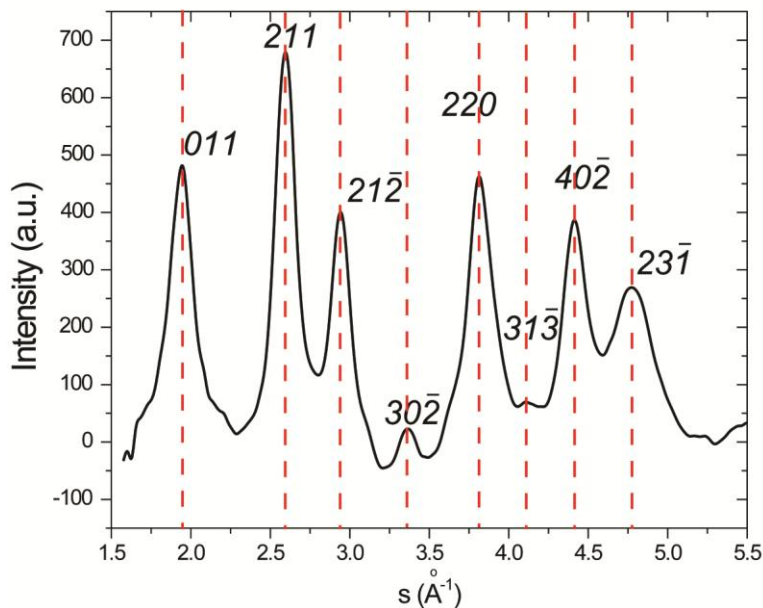
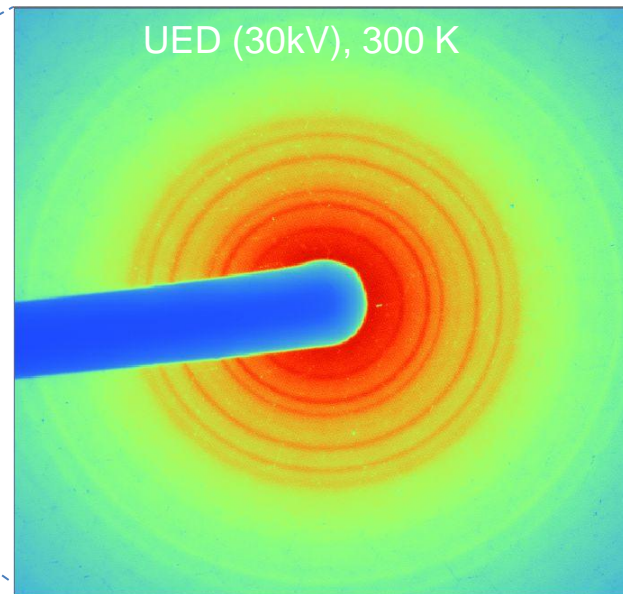
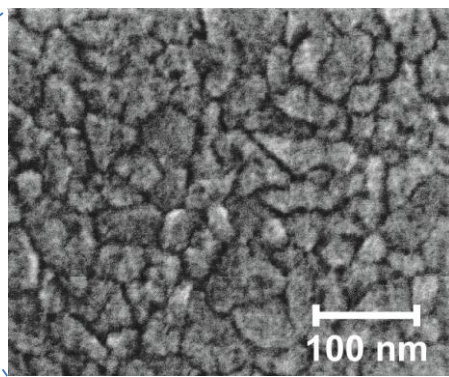
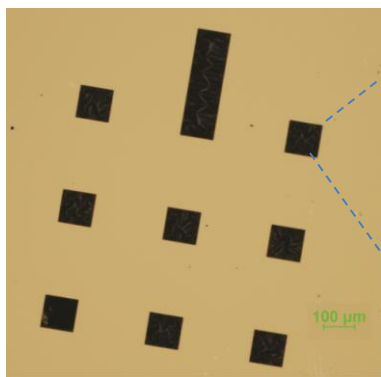
C. Weber, et al., Phys. Rev. Lett., 108, 256402 (2012)



J. P. Pouget and H. Launois, Journal De Physique, C4, 49 (1976)

Cooperative electronic and structural phase transitions in VO_2 thin film

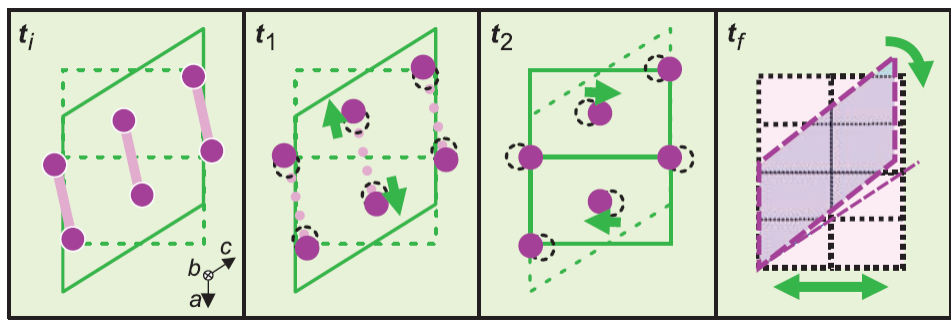
VO_2 thin film deposited on Si membrane



Atomic movements

V atom position in VO₂
 ● Monoclinic
 ○ Rutile

Unpublished result

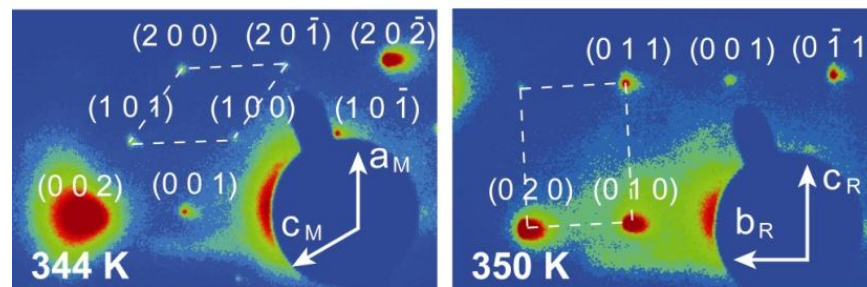
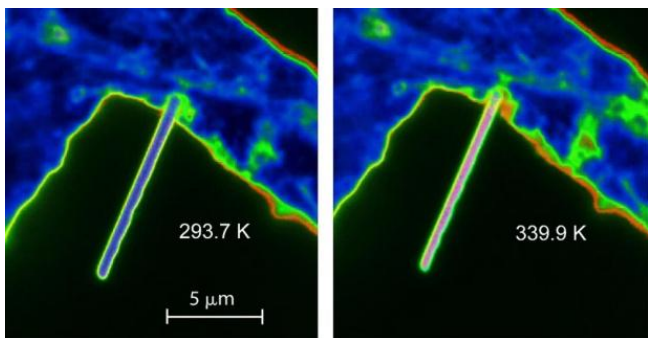


P. Baum, D-Sh Yang, A. H. Zewail, Science 318, 788 (2007)

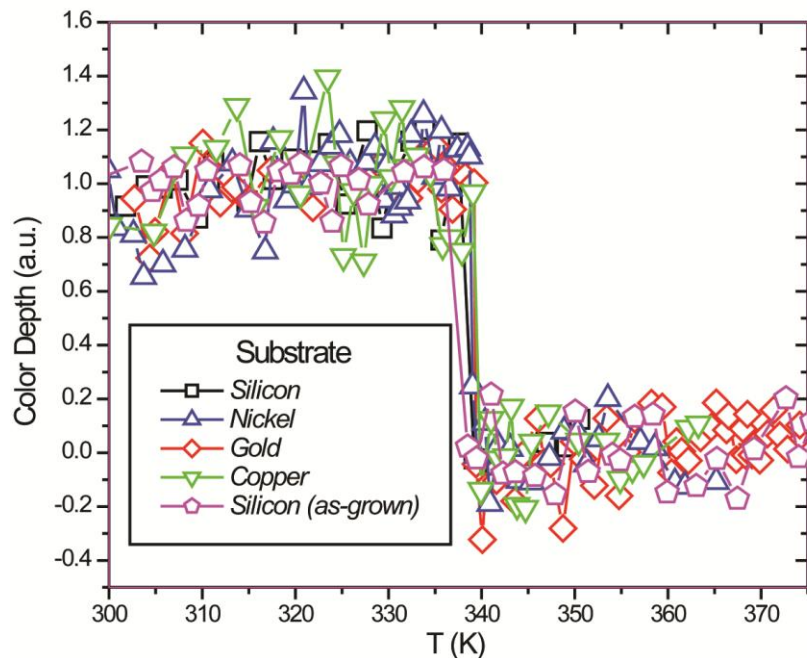
Phase transition occurs in several steps

Decoupling of electronic and structural phase transitions in VO_2

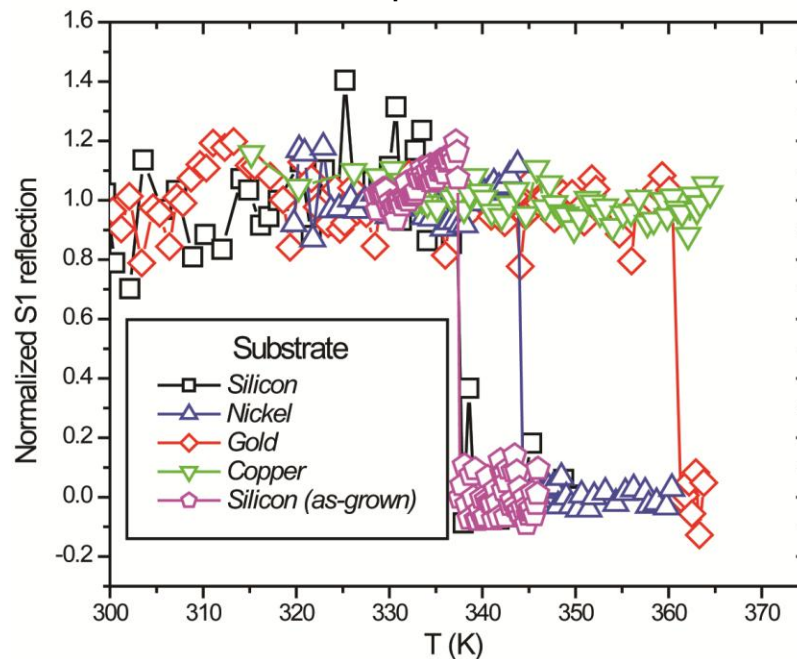
Single-crystal VO_2 nanobeam placed on different substrates



Metal-to-insulator transition



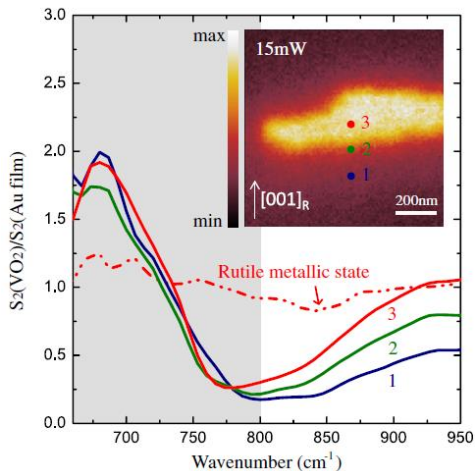
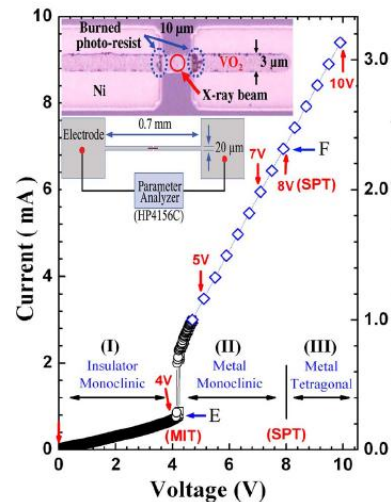
Structural phase transition



Decoupling of electronic and structural phase transitions in VO₂

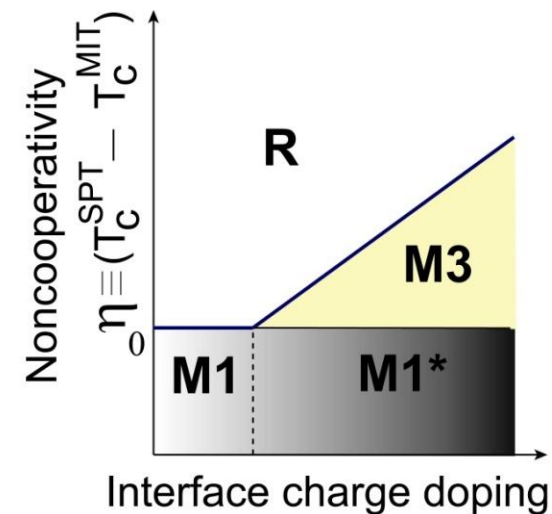
- ❖ Micrometer X-ray diffraction
- ❖ Thin film VO₂
- ❖ Electrically induced phase transition

B. Kim, et al., Phys. Rev. B, 77, 235401 (2008)



- ❖ Scanning near-field optical microscope
- ❖ Strained thin film VO₂
- ❖ Near-IR optical pump heating

M. K. Liu, et al., Phys. Rev. Lett. 111, 096602 (2013)



Interplay between Peierls and Mott physics

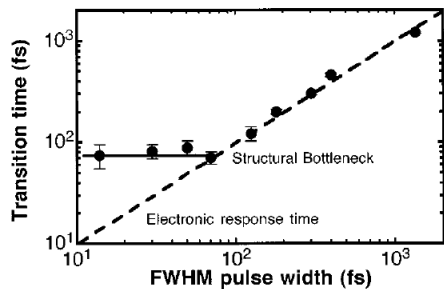
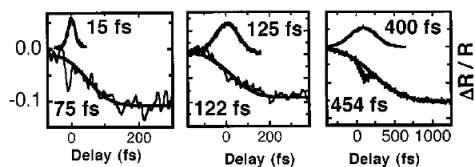
V-V dimerization and strong electron-electron correlation:

Coexist, cooperative, or competing?

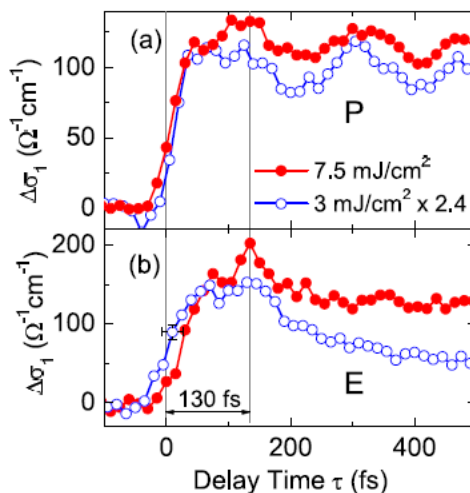
➤ *Metallic monoclinic M3 state, decoupling of electronic phase transition and structural phase transition*

Mott physics nature of the insulating gap

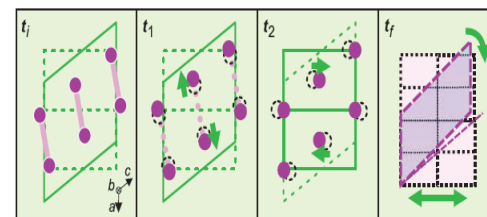
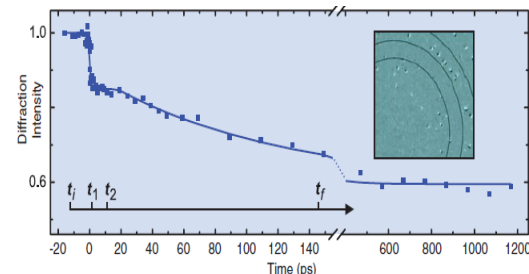
➤ *Cooperative dissolution of insulating gap and V-V dimerization*



A. Cavalleri, et al.,
Phys. Rev. B., 70, 161102(R) (2004)



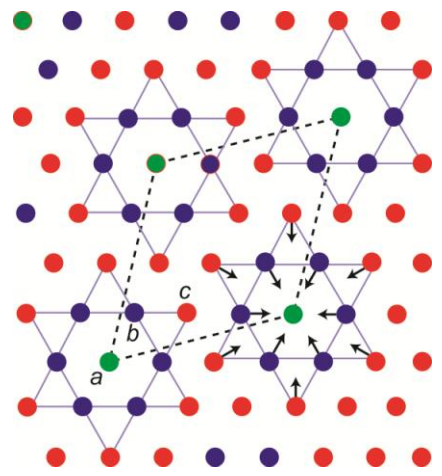
C. Kubler, et al.,
Phys. Rev. Lett., 99, 116401 (2007)



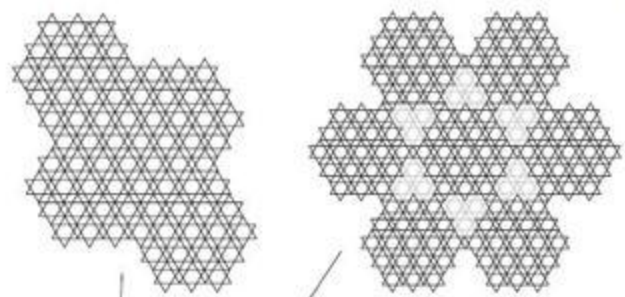
P. Baum, et al. and A. H. Zewail
Science, 318, 788 (2007)

Metal-insulator transition associated with charge-ordering in 1T-TaS₂

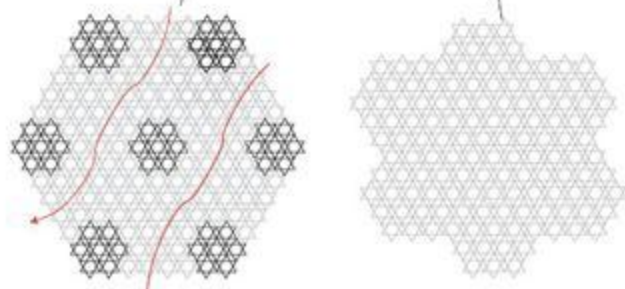
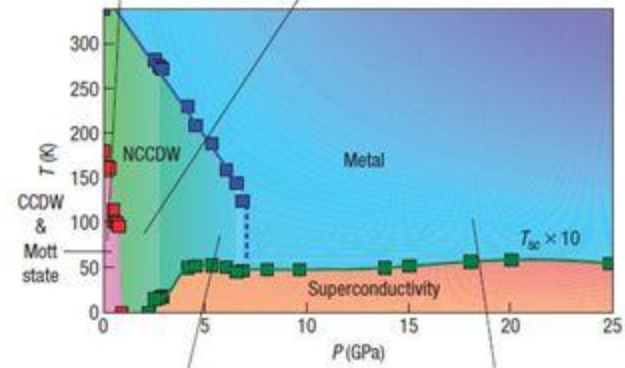
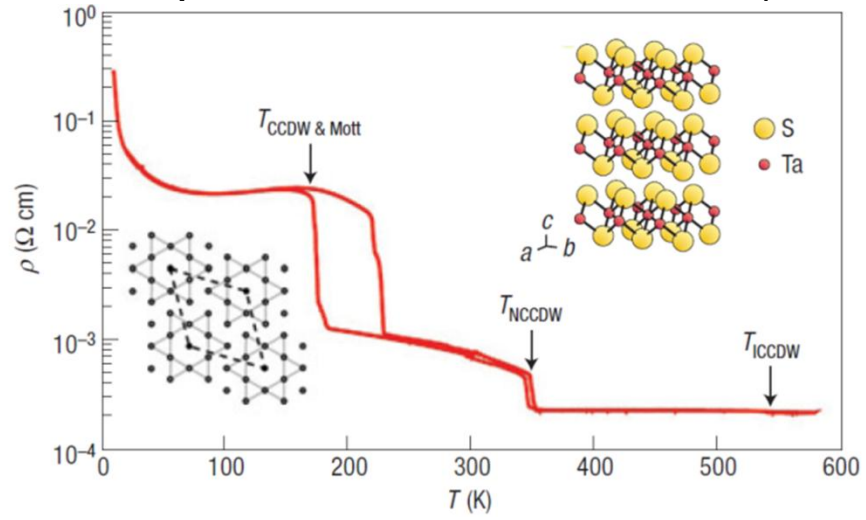
PLD in 1T-TaS₂



B. Sipos et al., Nat. Mat. 7, 960 (2008).

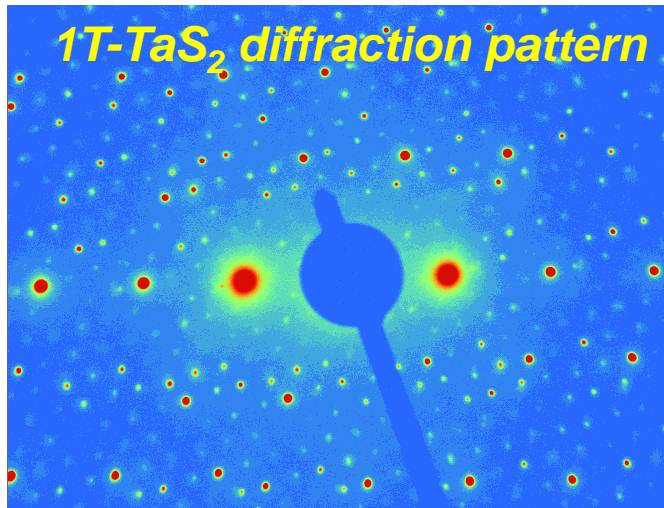


B. Sipos et al., Nat. Mat. 7, 960 (2008)



... 255 (1975)

Photo-induced CDW melting observed by ultrafast electron diffraction



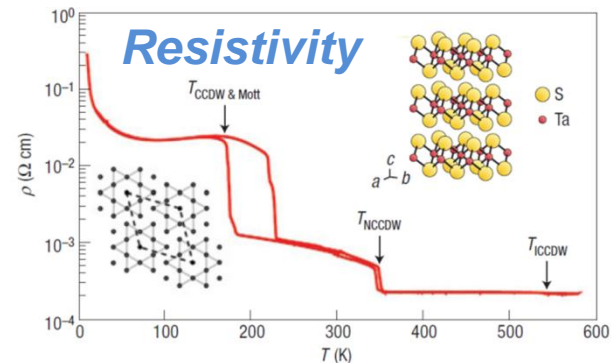
*Ultrafast Electron
Crystallography with high
energy electrons (~30 keV)
can track the dynamics of
long-range ordering
(amplitude and period) and
the short range fluctuations
of lattice.*

Unpublished results

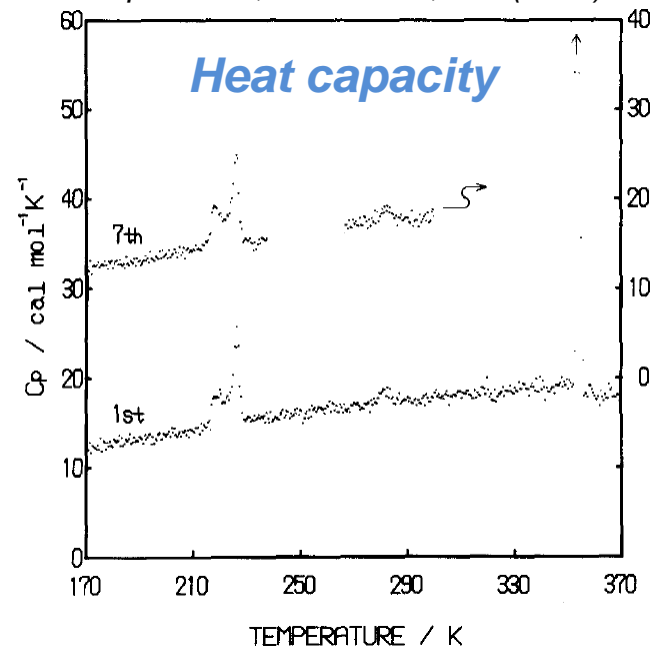
1T-TaS₂ phase transitions mapped by ultrafast crystallography

Structure dynamics

Unpublished result



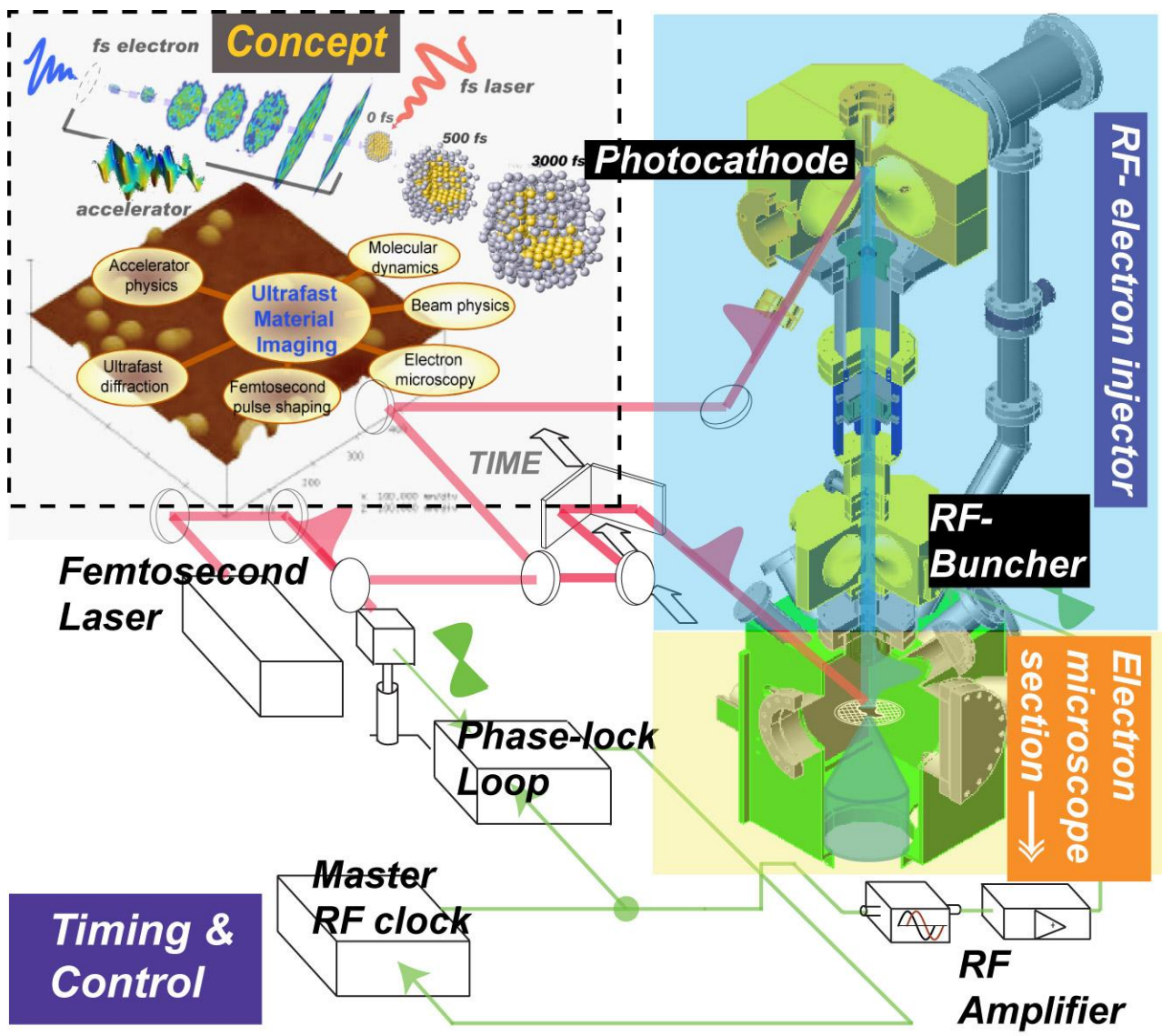
B. Sipos et al., Nat. Mat. 7, 960 (2008).



A. Suzuki et al., Sol. Stat. Comm. 53, 201(1985).

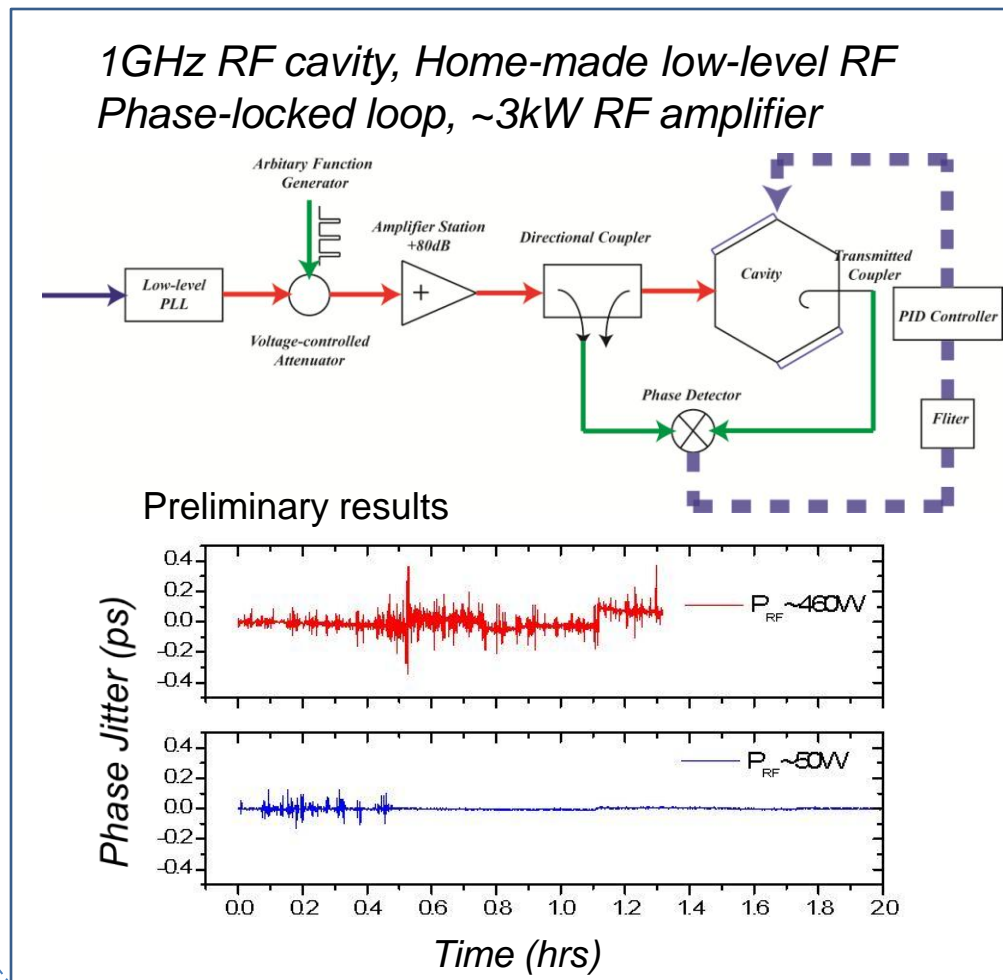
Electronic and structural phase transitions are correlated but manifest differently due to different driving mechanisms.

Development of ultrafast electron microscope at MSU



Development of ultrafast electron microscope at MSU

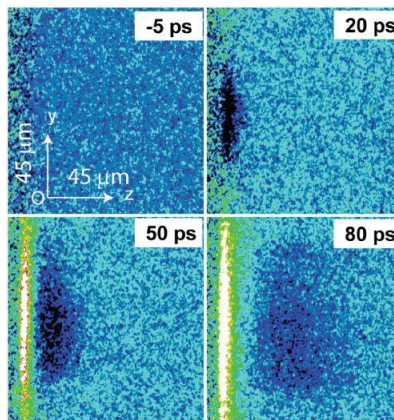
Spatial and temporal confocus of high-brightness electron pulse



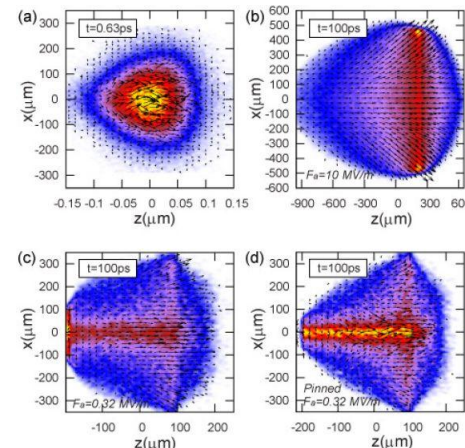
Development of ultrafast electron microscope at MSU

Spatial and temporal confocus of high-brightness electron pulse

Imaging electron gun and camera for beam characterization



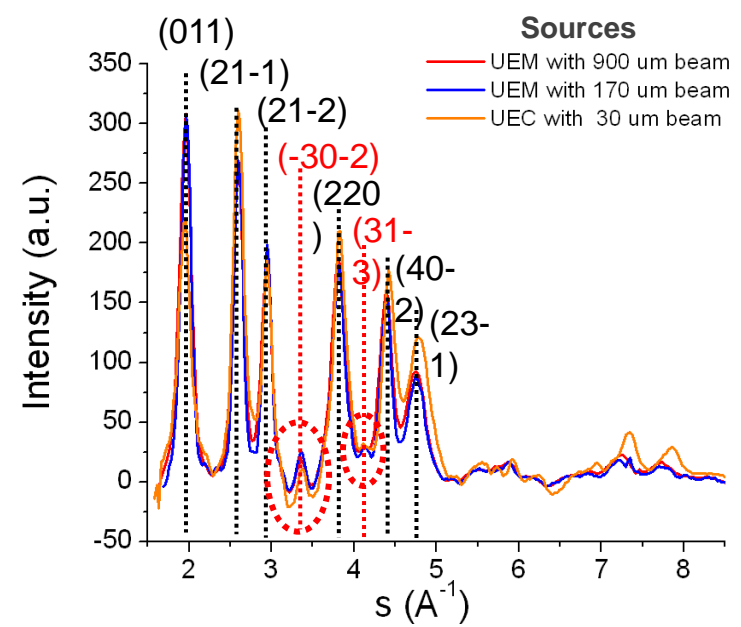
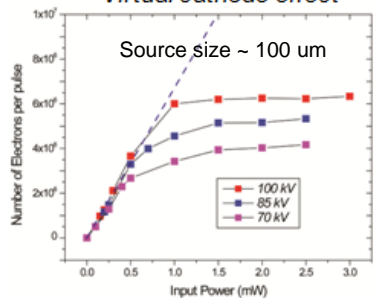
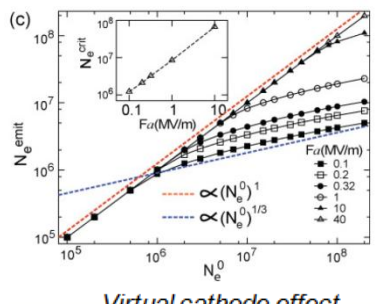
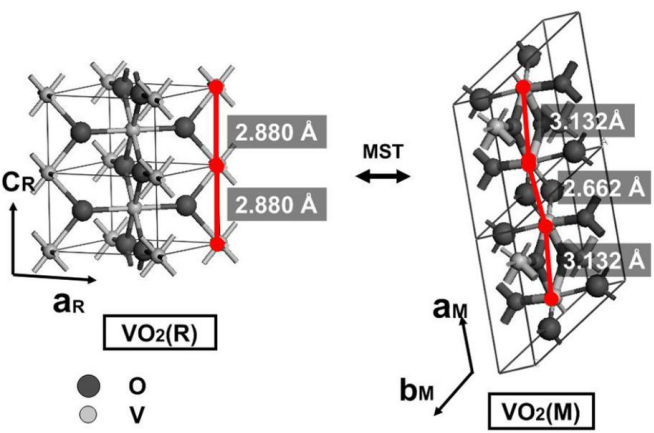
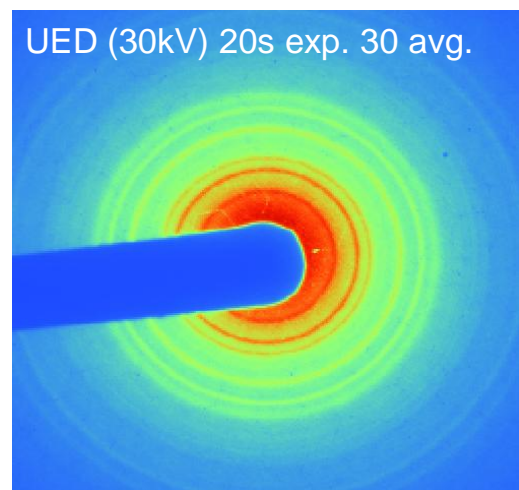
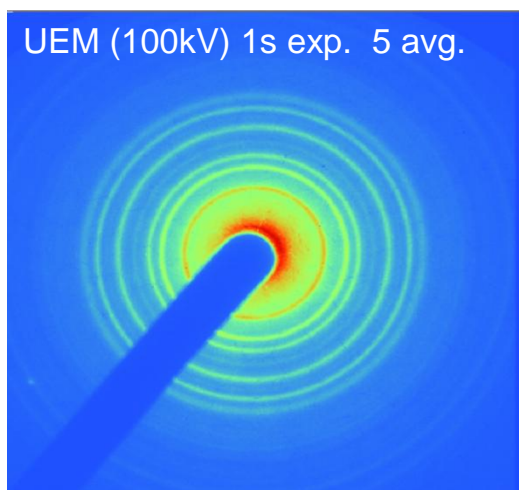
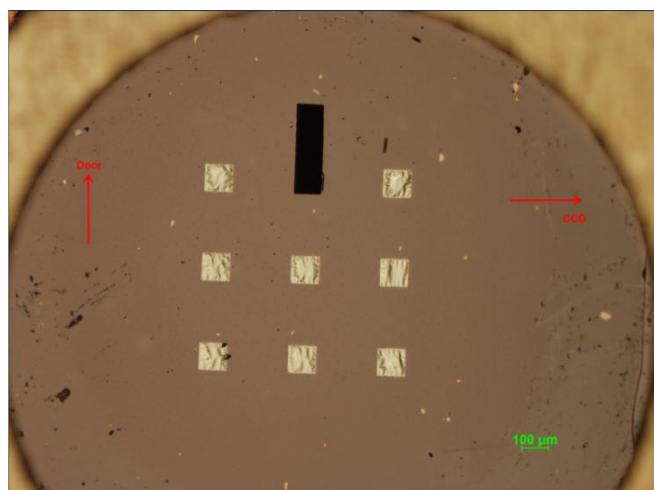
Zhensheng Tao, et al., *J. Appl. Phys.* 111, 044316 (2012)



Jenni Portman, et al., accepted by *Appl. Phys. Lett* (2013)

Electron diffraction

VO₂ film sample : insulator (<68°C, Monoclinic) to Metal (>68°C, Rutile)



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[UEM Project Collaborators](#)

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