Metal-Insulator Transition in VO_2

5/13/10

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Introduction

- Background: band theory, Mott insulators
- Analysis of MIT in VO_2 by infrared spectroscopy (Qazilbash et al, 2007)
- Electrical oscillations induced by the VO_2 MIT (Kim et al, 2010)

Background

- Band Theory: models interaction of electrons with ions in a lattice. Yields valence band, conduction band, band gap.
- Mott Insulator: accounting for the Coulomb repulsion when two electrons occupy the same site can lead to further band splitting
- Hubbard Model: accounts for tunneling, better models the MIT.

Metal-Insulator Transition in VO_2

- Occurs at T~340K
- Conductivity increases drastically
- Lattice structure changes from monoclinic to rutile tetragonal.
- How uniform is this transition?
- Does the MIT coincide exactly with the structural transition?

Conductivity vs. Frequency at various temperatures

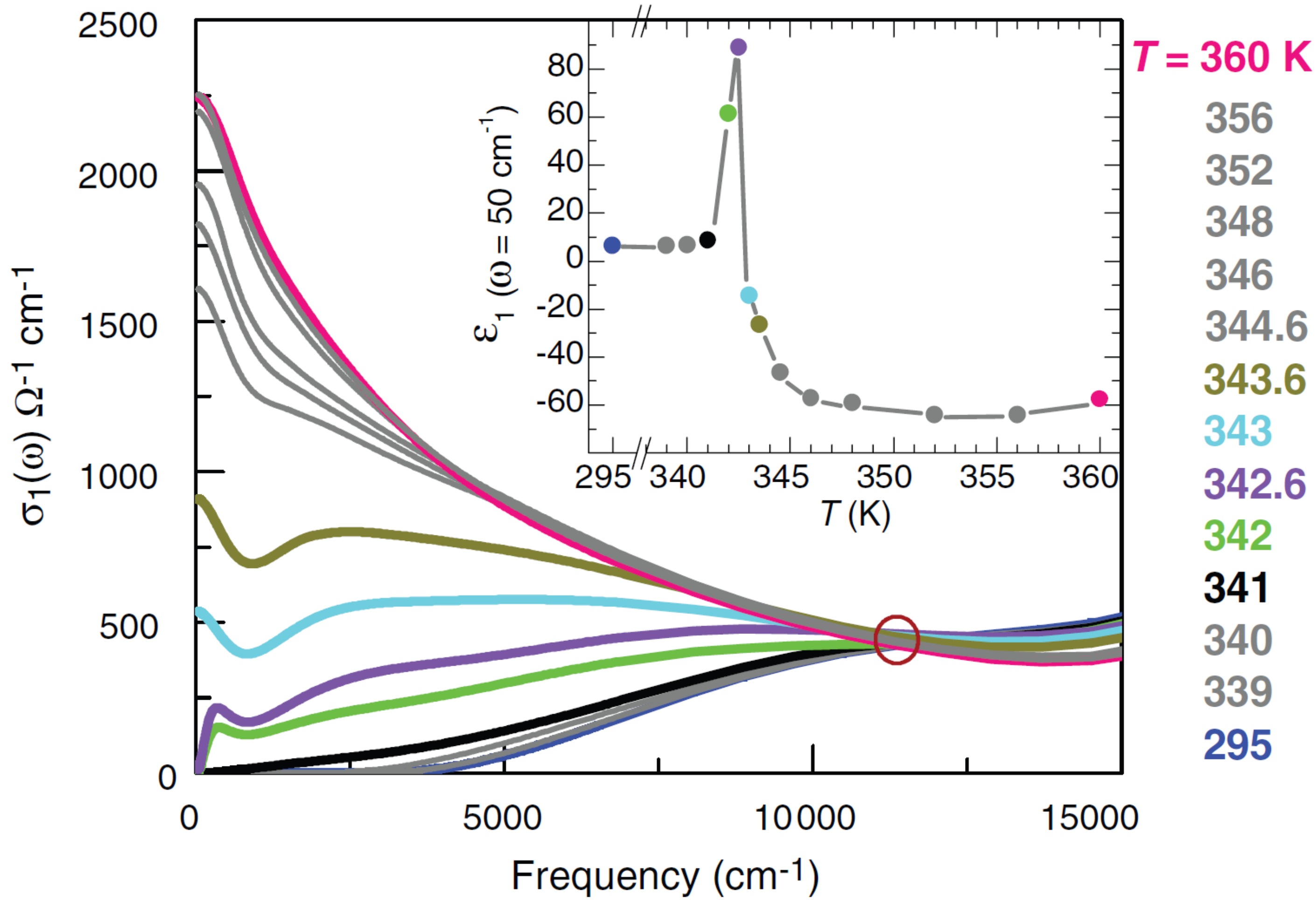


Fig. 1. The real part of the optical conductivity $\sigma_1(\omega) = \frac{\omega\varepsilon_2(\omega)}{4\pi}$ of VO_2 is plotted as a function of frequency for various representative temperatures. The open circle denotes the isosbestic (equal conductivity) point for all spectra. (**Inset**) The temperature dependence of the real part of the dielectric function ε_1 in the low-frequency limit ($\omega = 50$ cm^{-1}).

Qazilbash, et al, 2007

Percolative MIT

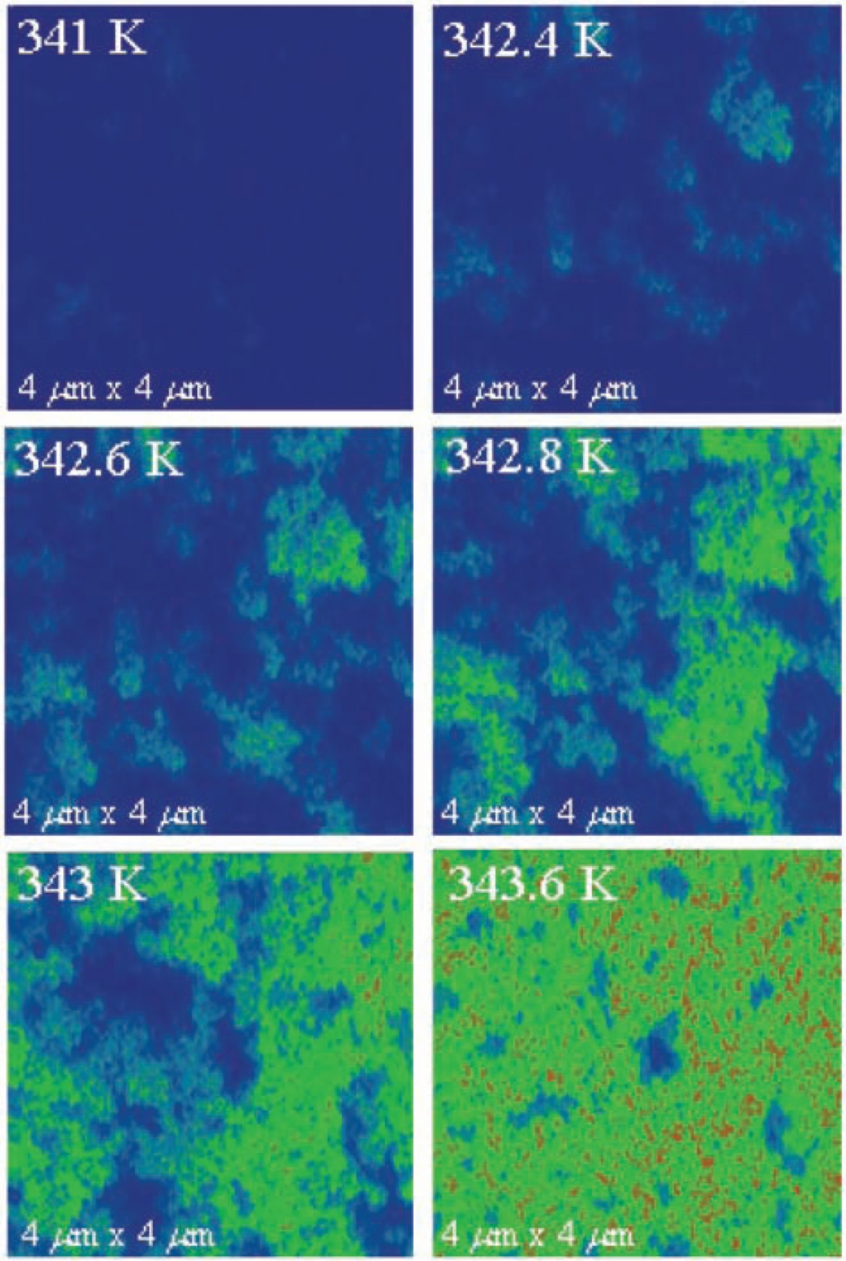


Fig. 2. Images of the near-field scattering amplitude over the same 4-μm-by-4-μm area obtained by s-SNIM operating at the infrared frequency ω = 930 cm^{-1}. These images are displayed for representative temperatures in the insulator-to-metal transition regime of VO_2 to show percolation in progress. The metallic regions (light blue, green, and red colors) give higher scattering near-field amplitude compared with the insulating phase (dark blue color). See (*13*) for details.

Qazilbash, et al, 2007

Conductivity During MIT

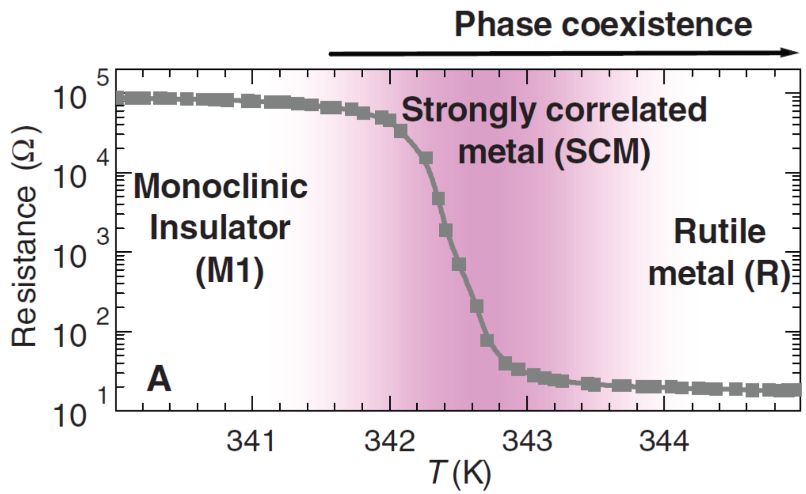
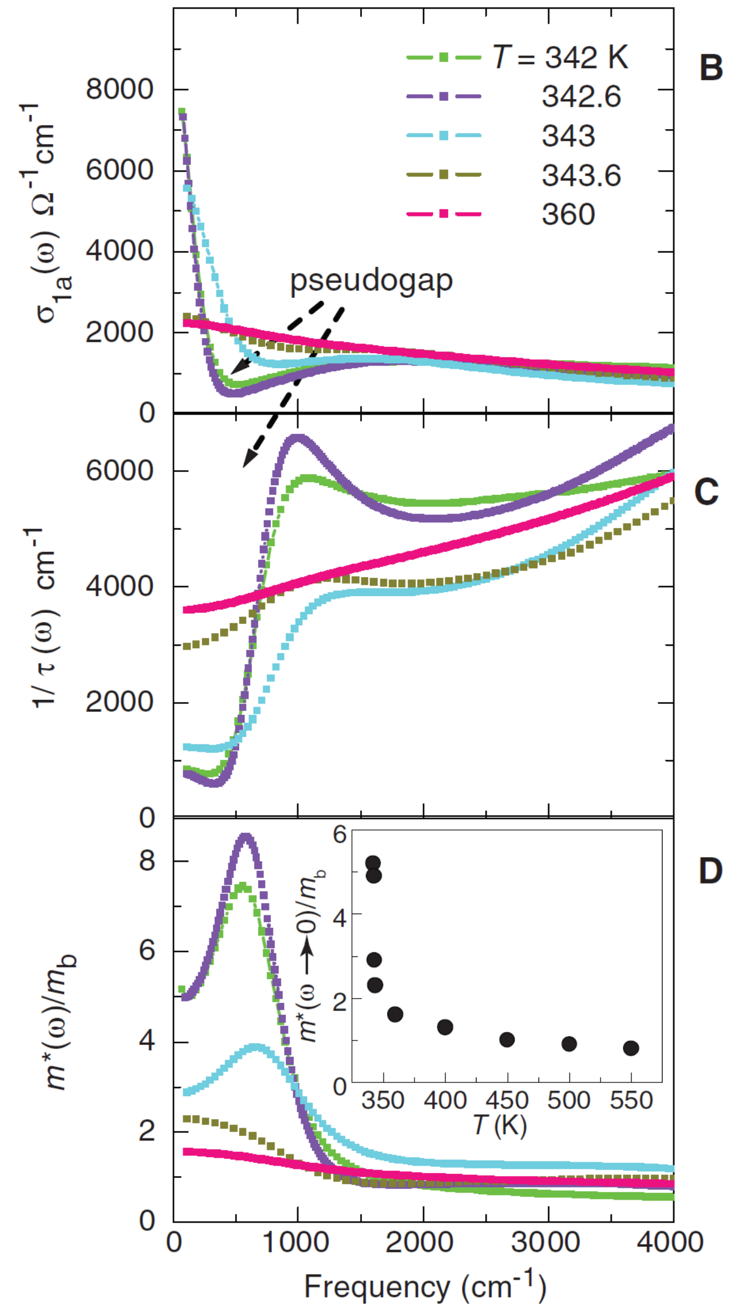


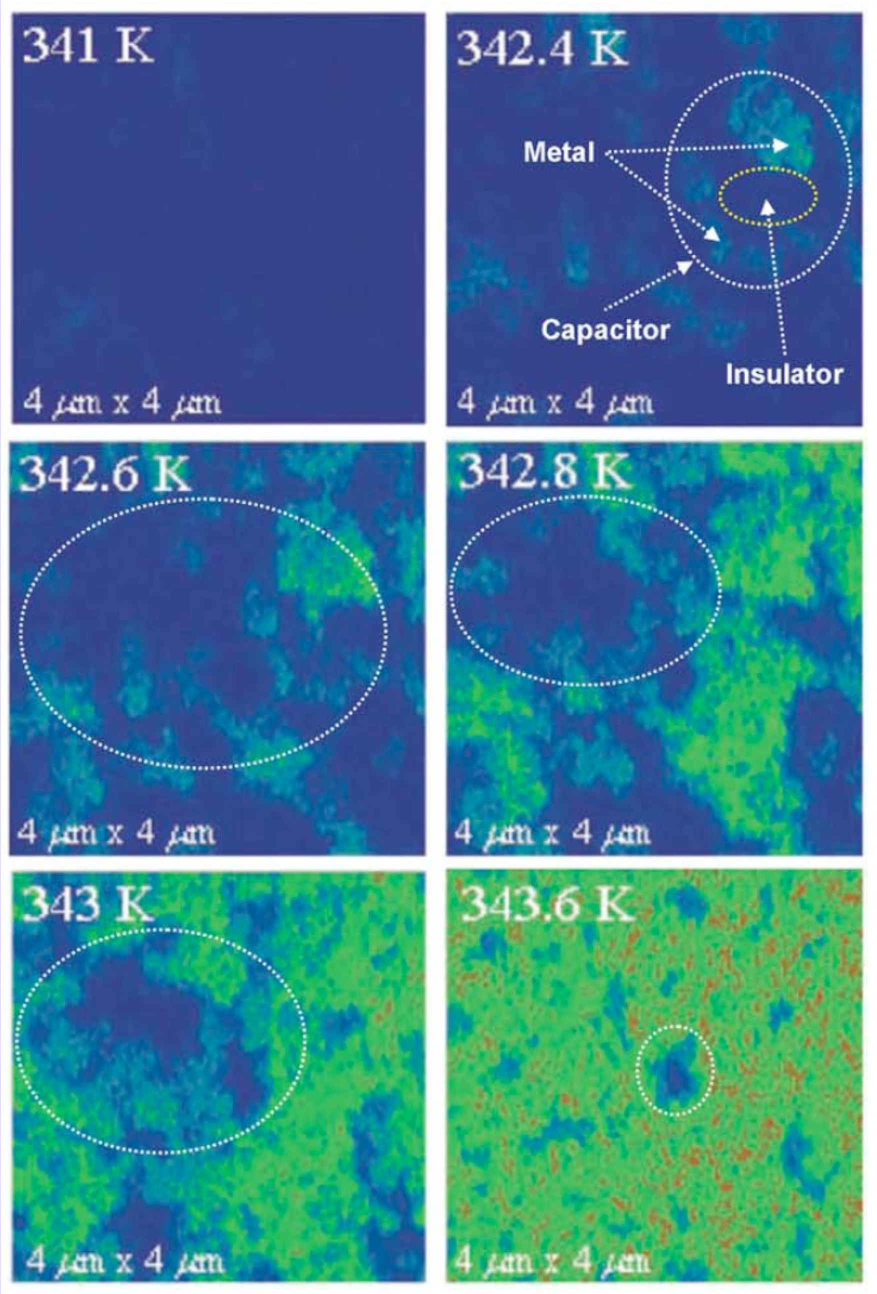
Fig. 3. (**A**) The phase diagram of VO_2 and the resistance-temperature curve showing the insulator-to-metal transition. The shaded area highlights the region of the phase diagram in which the strongly correlated metal (SCM) with divergent quasi-particle mass and an optical pseudogap exists. (**B** to **D**) The evolution of the optical conductivity $\sigma_{1a}(\omega)$, the scattering rate $1/\tau(\omega)$, and the optical effective mass normalized by the band value $m^*(\omega)/m_b$ of the metallic regions of VO_2 with increasing temperature. The inset in (D) shows the $\omega \rightarrow 0$ limit of the mass enhancement factor as a function of temperature. The data points between T = 400 K and 550 K are taken from (*22*).



Nature of the VO_2 MIT

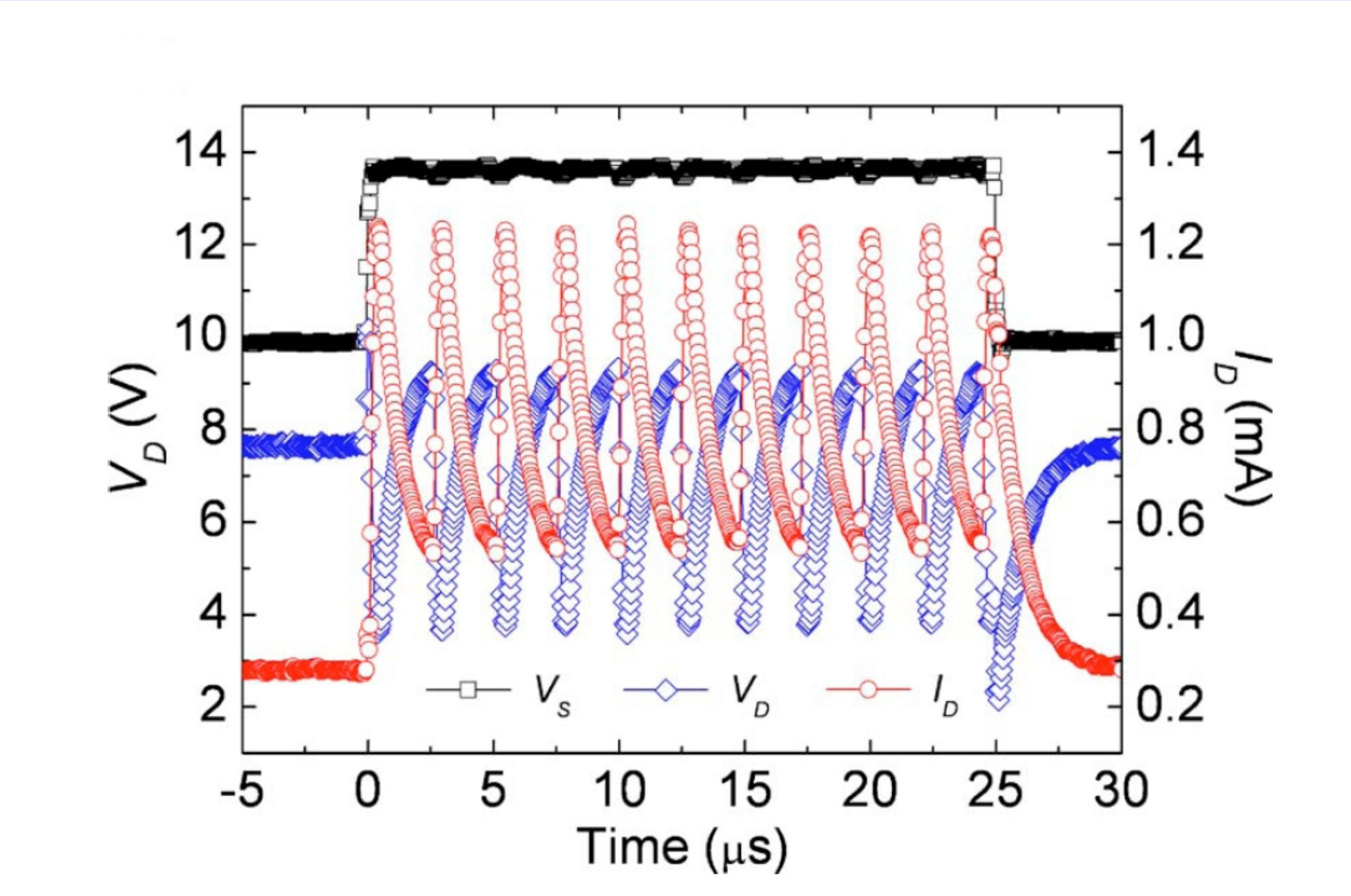
- We cannot treat the conducting regions (or "puddles") during the transition as isolated regions of the purely metallic phase
- The behavior of the puddles has all the attributes of a Mott transition.
- The structure of the puddles can be determined by X-Ray diffraction

Capacitance of VO_2 During MIT



Kim, et al, 2010

Electrical Oscillations Induced by MIT

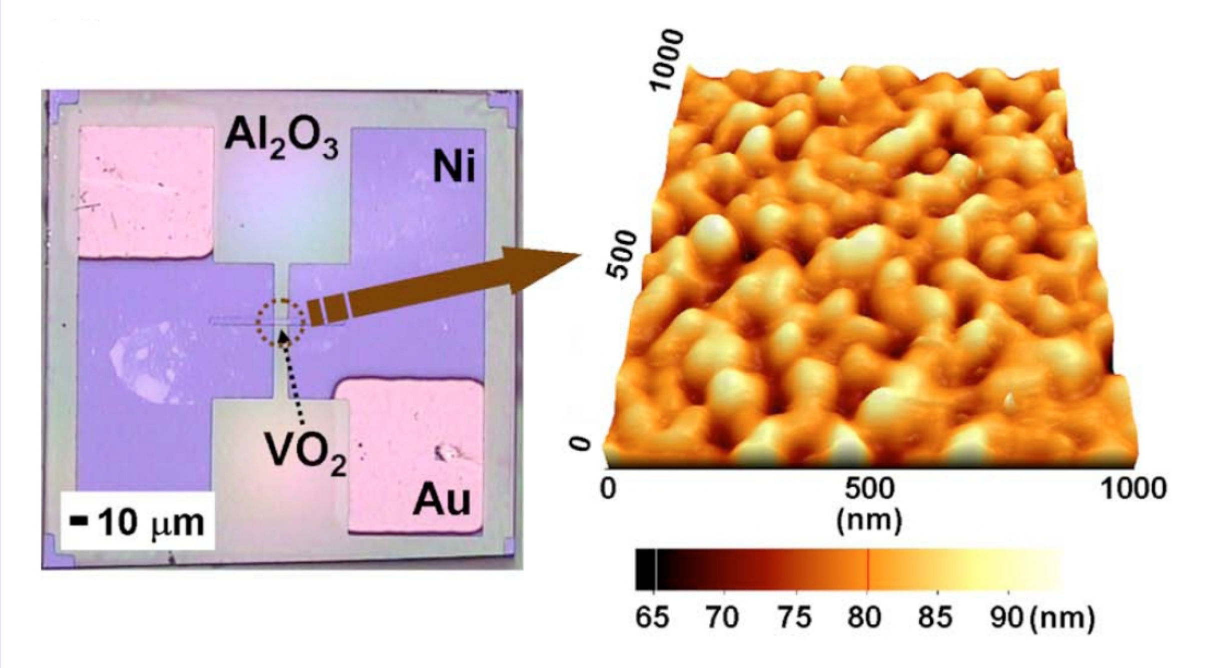


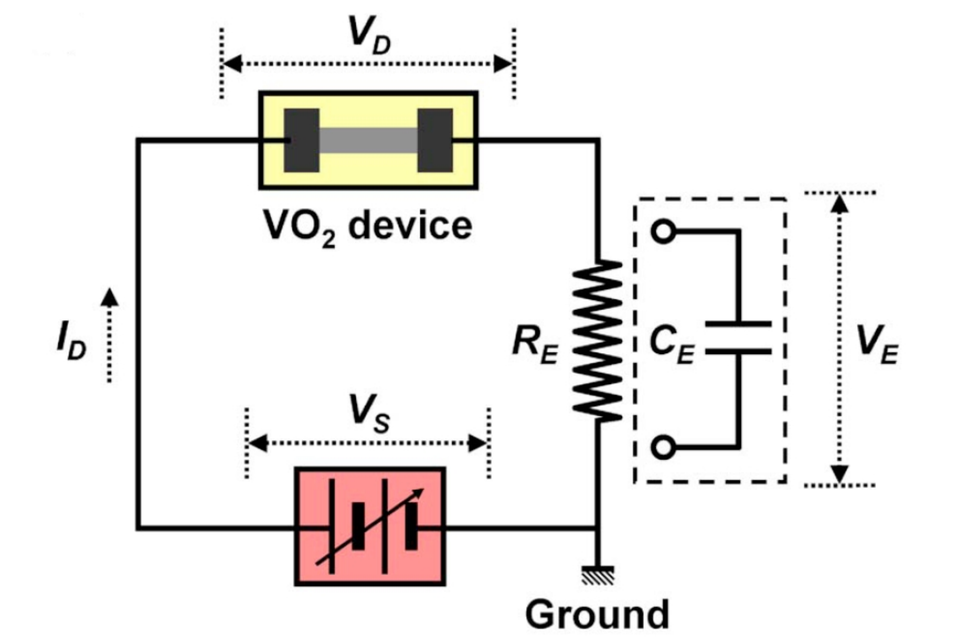
Blue: Voltage across device.
Red: Current through device.
Black: Source voltage

Measured at room temperature

Kim, et al, 2010

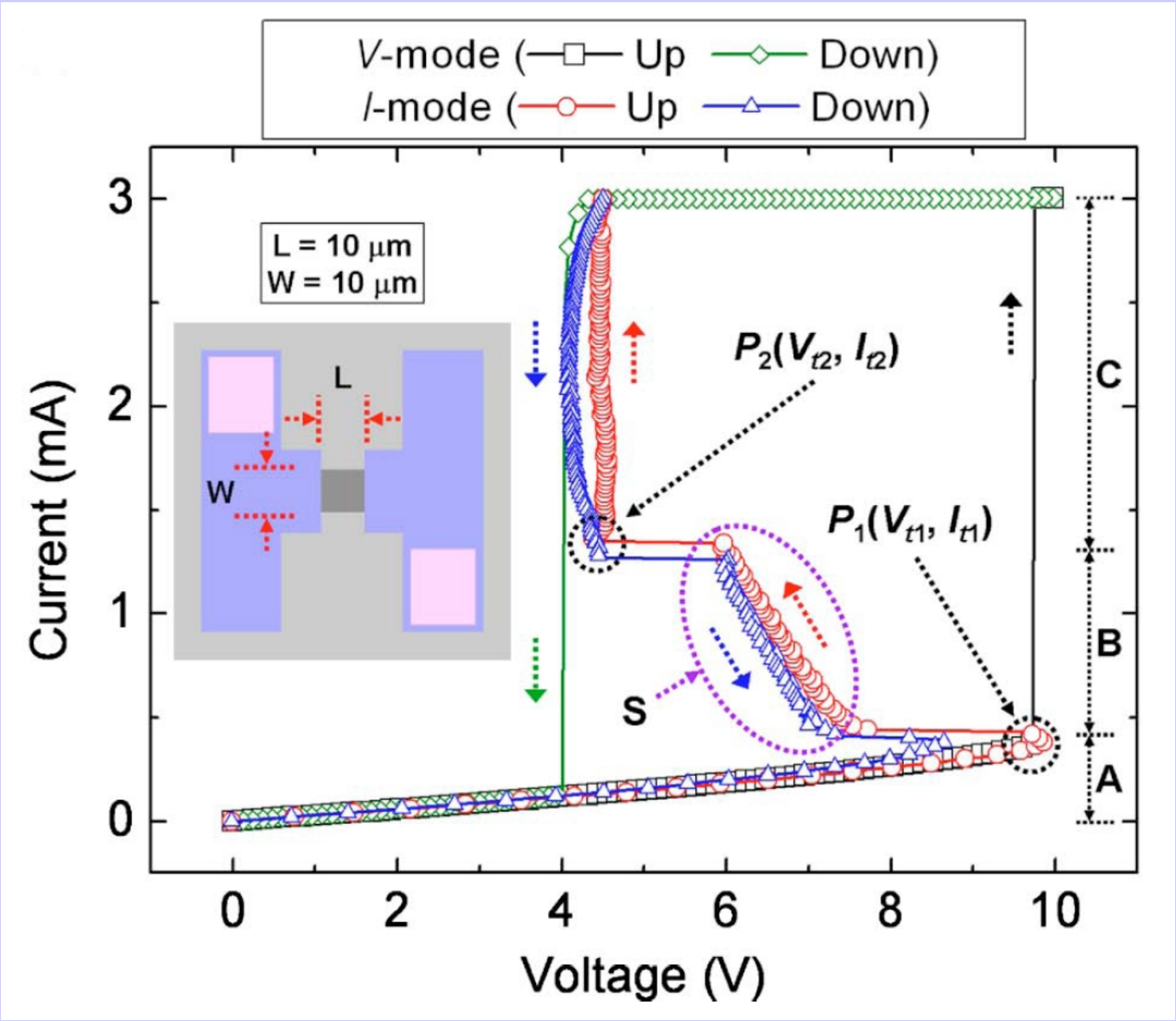
Experimental Setup





Kim, et al, 2010

V vs. I Hysteresis Characteristics



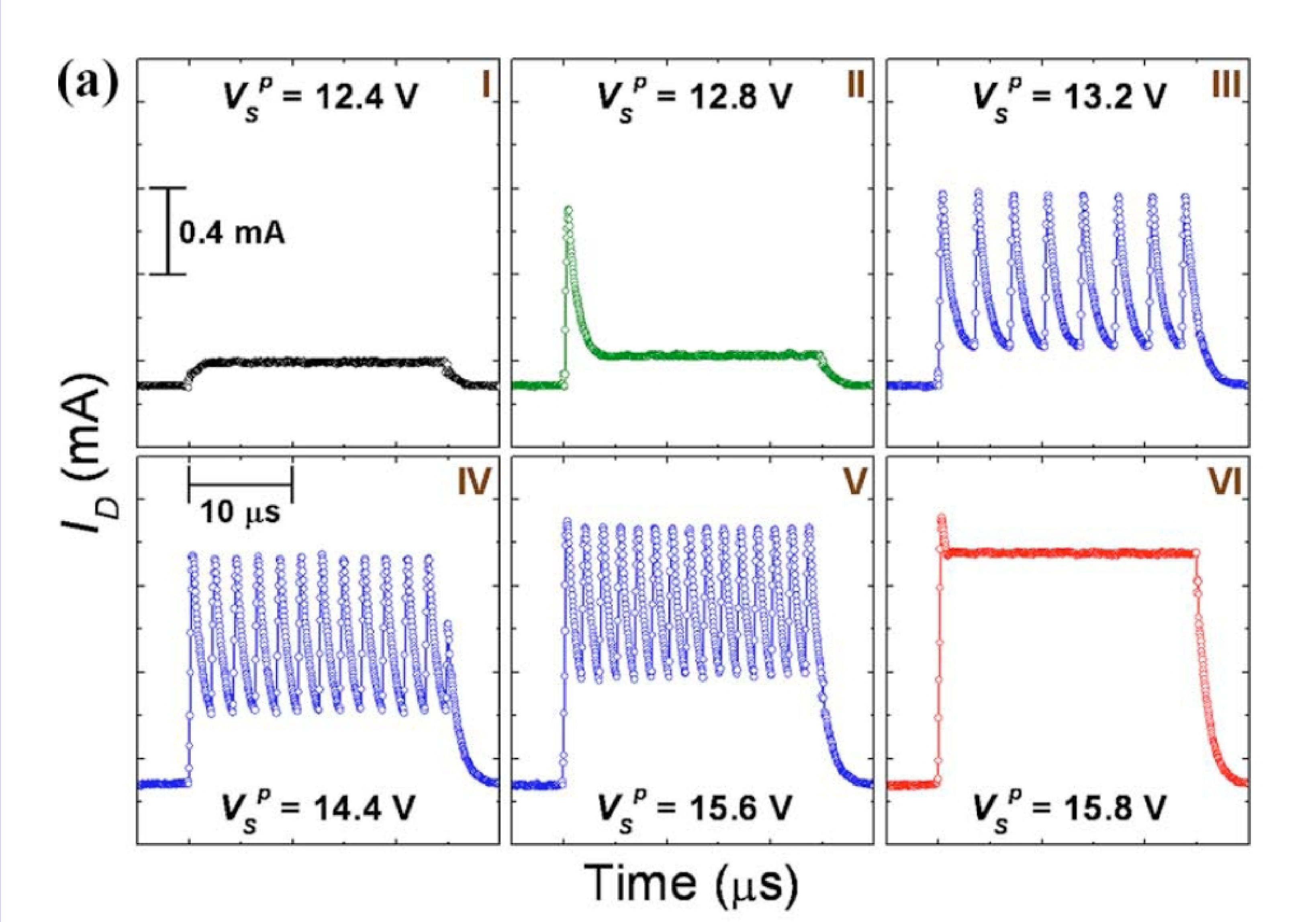
Measured by attaching "parameter analyzer" to gold electrodes

V-mode: applied V, measured I_D

I-mode: applied I, measured V_D

Kim, et al, 2010

Range of Oscillation Generation



Kim, et al, 2010

Oscillation Waveform

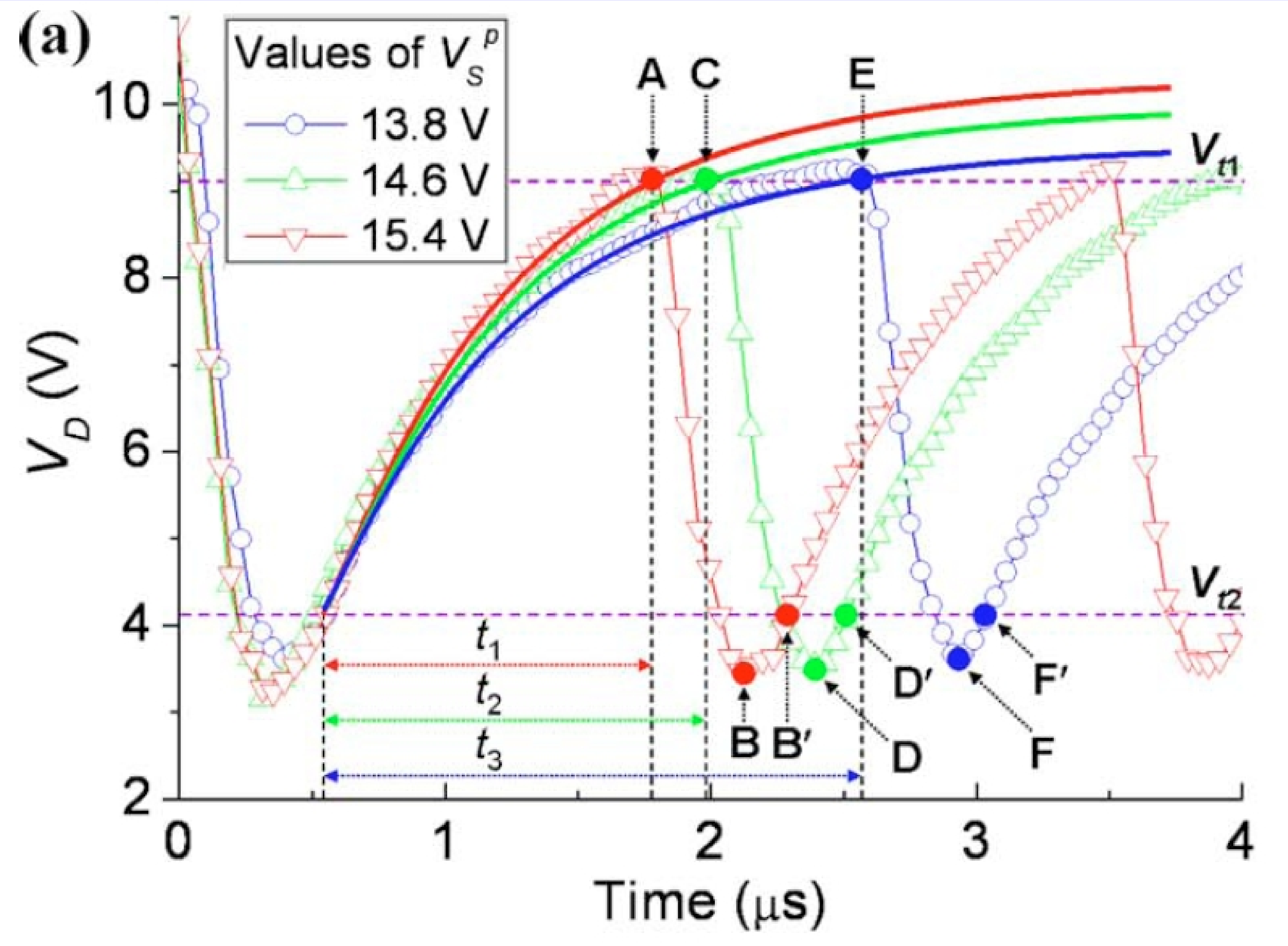
- The voltage/current rises/decays according to the usual RC-circuit behavior, with

$$\tau_0 = R_E C_D$$

$$V_D(t) \propto V_S^p[1 - \exp(-t/\tau_0)],$$

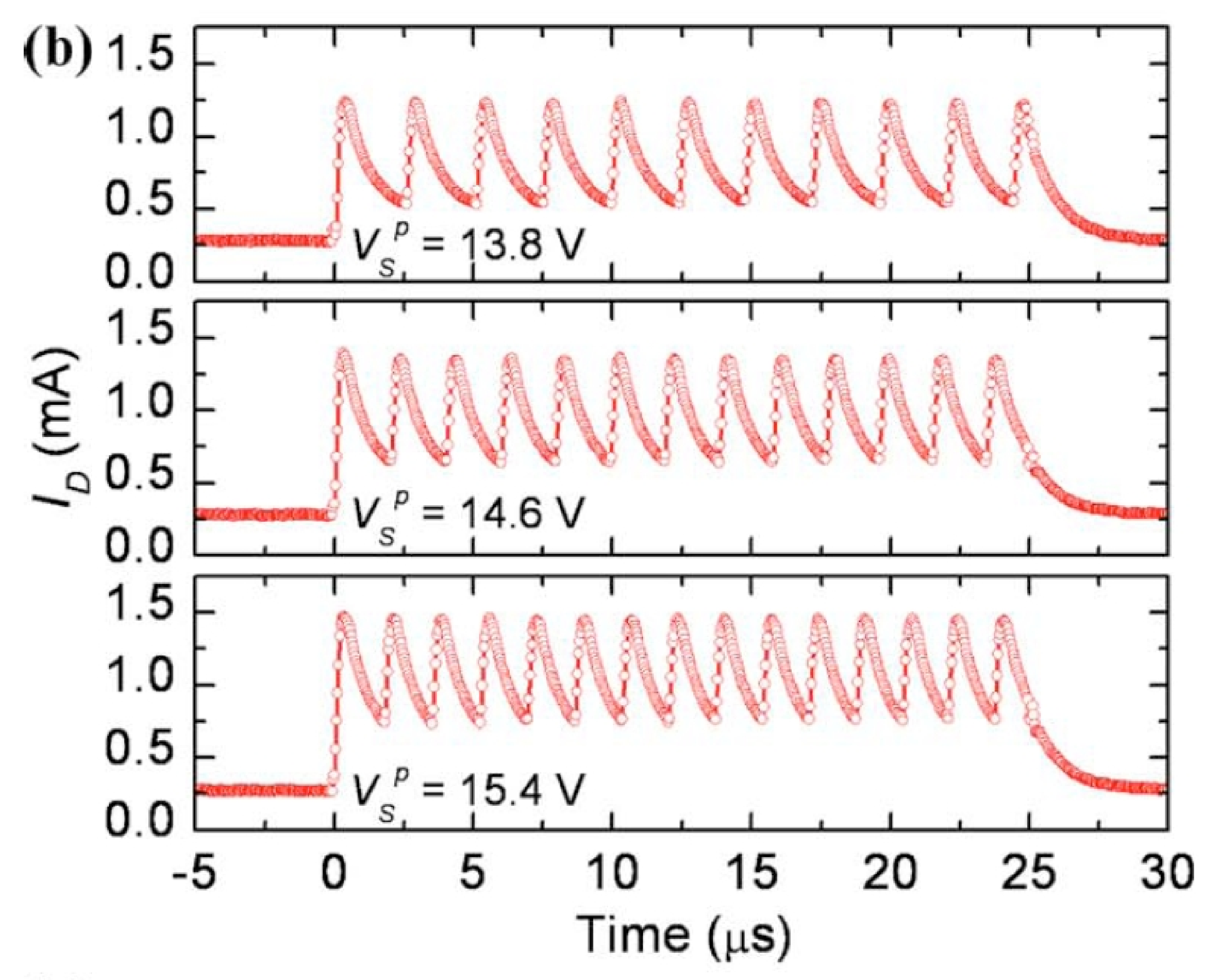
$$I_D(t) \propto V_S^p[1 + (R_D/R_E)\exp(-t/\tau_0)].$$

Oscillation Waveform

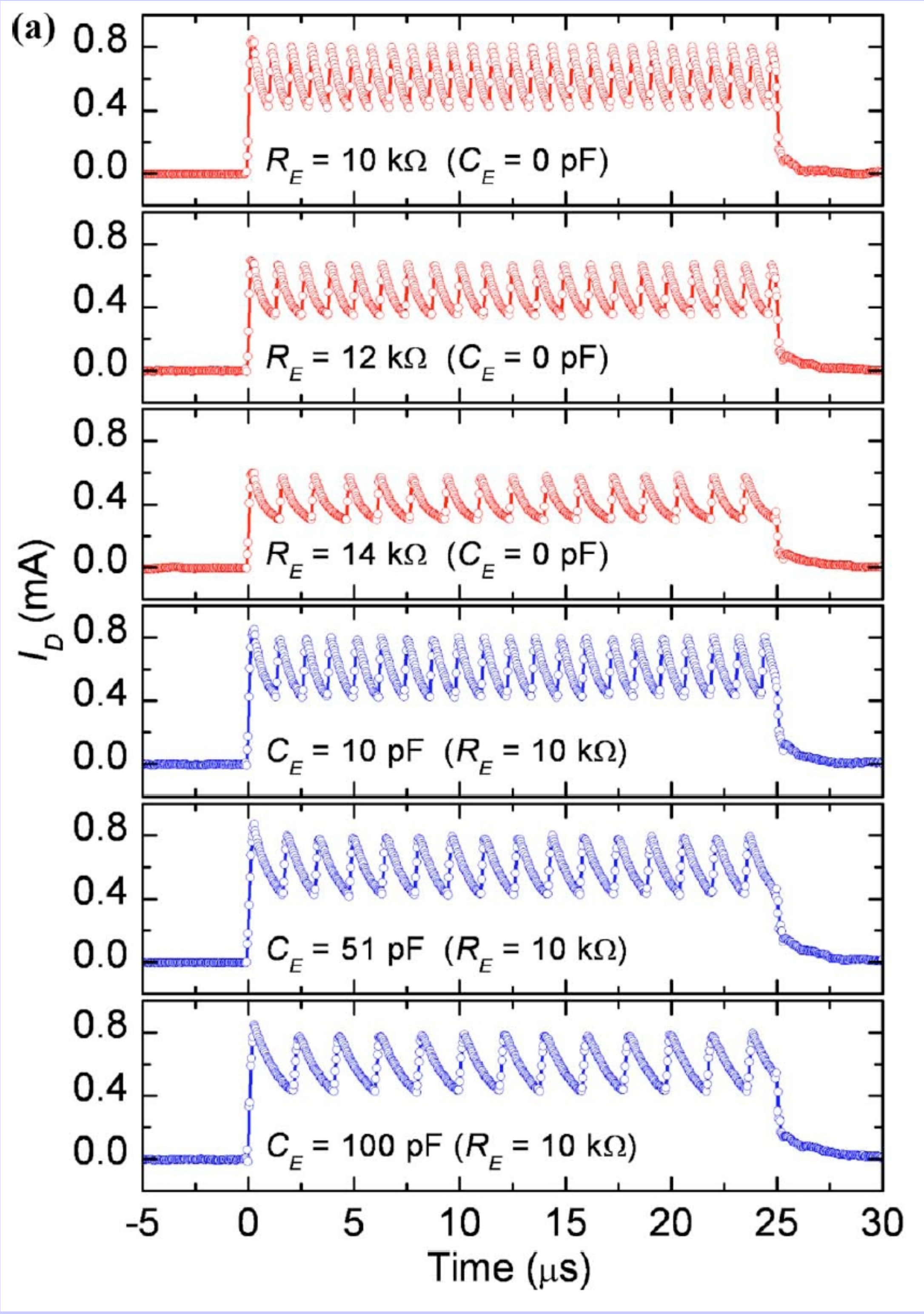


Kim, et al, 2010

Frequency Dependence



Kim, et al, 2010



Kim, et al, 2010

Nature of the Oscillation

- The high frequency behavior (can be >1MHz) rules out a structural-phase-change driven MIT.
- Multiple experiments further verify that drastic changes in resistance can happen without the SPC
- We can confidently say that VO_2 undergoes a hole-driven Mott MIT

References

- Hyun-Tak Kim,Bong-Jun Kim, et al, *Electrical oscillations induced by the metal-insulator transition in* VO_2,J. OF APPLIED PHYSICS **107**, 023702 2010

- M. M. Qazilbash, M. Brehm, et al, *Mott Transition in* VO_2 *Revealed by Infrared Spectroscopy and Nano-Imaging*, Science **318**, 1750 (2007);

-Imada, Fujimori, and Tokura, *Metal-insulator transitions*, Rev. Mod. Phys., Vol. 70, No. 4, October 1998