# Transport Properties of Hydrogenated $VO_2$ Thin Films

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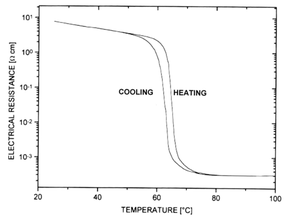
## Introduction

$VO_2$ is a transition-metal oxide, a class of materials comprised of transition metals and oxygen that often shows either insulating or conducting phases. $VO_2$ undergoes a sharp metal-insulator (MI) transition at around 350 K, with thermal hysteresis.

### Electrical Resistance vs. Temperature of $VO_2$

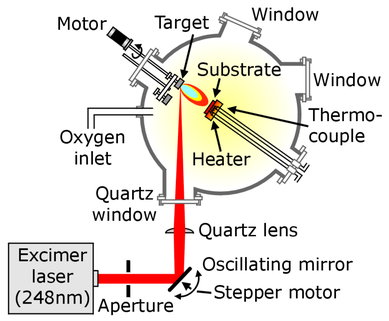



[J.Nag *et. al.* J. Phys. Condens. Matter. 20 266416(2008)]

There are many applications to the MI transition such an information technology, smart materials, and sensors. Since there are strong interplays between lattice, charge, orbital degrees of freedom in strongly correlated $VO_2$, the MI transition is easily tuned by carrier doping, such as hydrogen insertion (hydrogenation). It has been shown that hydrogenation in $VO_2$ nanobeams can control the MI transition [H. Zhou *et. al.* Journal of Applied Physics. 110 073514(2011)]. However, the work has not been done on $VO_2$ films. Here, we present the hydrogenation study on $VO_2$ films for the first time.

## Material and Methods

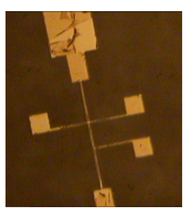
### Schematic Diagram of PLD System




[physics.colorstate.edu]

- $VO_2$ film grown on $Al_2O_3$ substrate using pulsed laser deposition method (PLD)
- $O_2$ pressure: 10mTorr
- Thickness of film=80nm
- Cool down rate= 20K/min, in 10mTorr of $O_2$.
- Substrate temperature: 600°C
- Target: $V_2O_5$ polycrystalline.

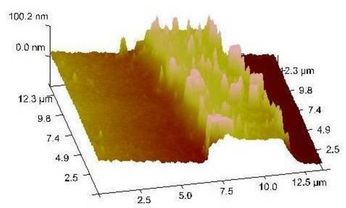
### Film Patterning



Microscopic Image of $VO_2$ Wire Structure

photoresist is applied to the films, then spin-coated to create an even layer of around 5 μm, then exposed to UV light in a mask aligner.

### AFM Image of $VO_2$ Wire Structure

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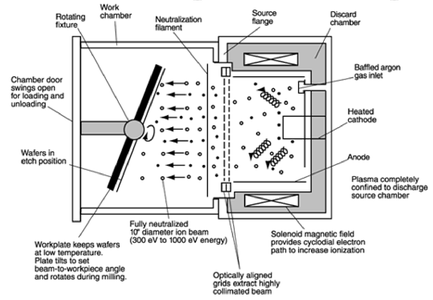
## Methods and Materials

### Schematic Diagram of Ion Milling



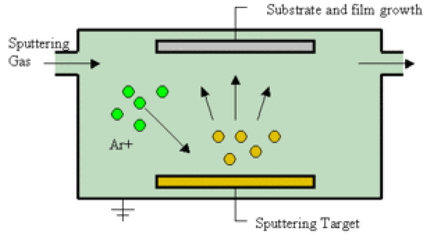

[Ionbeammilling.com]

Photoresist protects the active area while the rest of the film is etched away by an beam of argon ions.

### Electrode preparation

- A second mask aligning was used to place gold pads on top of $VO_2$ wire.

### Schematic Diagram of Gold Sputtering




[http://en.wikipedia.org/wiki/Sputter_deposition]

- Photoresist covers everywhere but the gold pads. Gold is applied to the entire film and later lifted-off everywhere but the gold pads.

### Hydrogenation

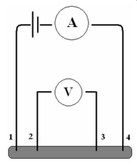
- Sample annealed in Mixed gas with 5% $H_2$+95%He, 1 atm, 1 day, in a tube furnace.
- Sample annealed at the various temperatures: 200°C, 300°C.

### Resistivity Measurement

- Resistivity of the film measured by four-probe method in a Physical Property Measurement System (PPMS)

- The IV curve was measured using the four-probe method by a 1-K insert.

### Schematic Diagram of Four-Probe Method

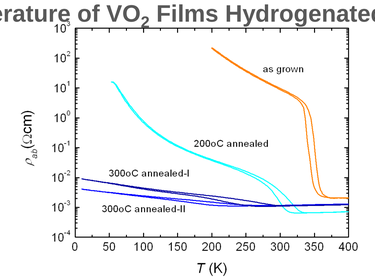



Uses separate pairs of current carrying and voltage measuring wires to make a more accurate reading than the traditional two-probe method

[http://en.wikipedia.org/wiki/Four-terminal_sensing]

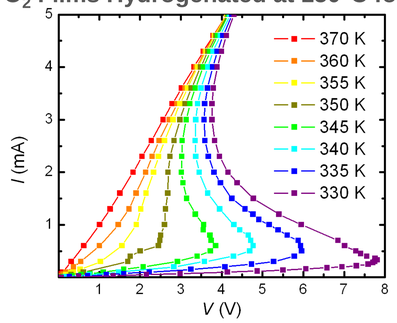
## Results

### Resistivity vs. Temperature of $VO_2$ Films Hydrogenated in a Tube Furnace




- Transition temperatures are decreased with increasing hydrogenation temperatures.
- MI transition is suppressed with increasing hydrogenation temperatures.

### *IV* Plot of $VO_2$ Films Hydrogenated at 150°C for 1 day at 1 atm




- Sharp change of *IV* slope indicates current-induced MI transition through heating effect.
- Critical current $I_C$ is as small as 0.3 mA.

## Conclusions

- We succeeded in growing $VO_2$ thin film on a $Al_2O_3$ substrate with (0001) orientation and fabricated a $VO_2$ wire with a width of 5 μm.
- Metal-insulator transition of $VO_2$ wires is suppressed with increasing hydrogenation temperatures.
- We observed current induced metal-insulator transition with critical current as small as 0.3 mA in *IV* curves.

## Acknowledgements

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