Transport Anisotropy of Epitaxial VO_2 films grown on (100) TiO_2

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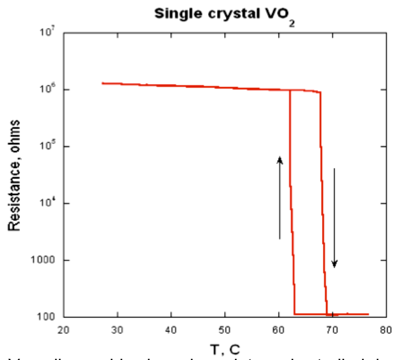
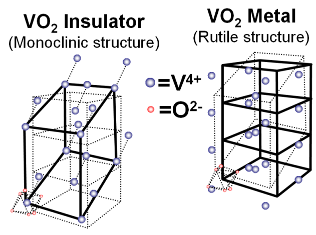
Introduction

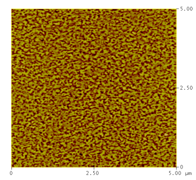




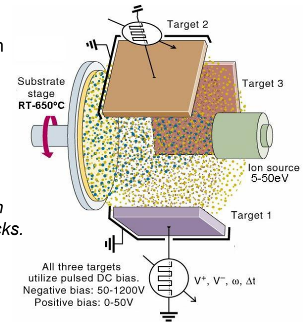
Vanadium oxides have been intensely studied during the past five decades because of the metal insulator transition (MIT) that several of the oxides exhibit. In particular, vanadium dioxide (VO_2) exhibits a metal semiconductor transition (MST) at 340 K. Below the transition temperature (T_{MST}), it is a semiconductor with a monoclinic structure. Above T_{MST}, it has a rutile structure and exhibits metallic properties. This transition is accompanied by the abrupt change in the electrical conductivity, optical transmittance and reflectance in infrared region, which can be used in advanced electronic devices such as sensors, switches, and memory. In this study, we have deposited an epitaxial VO_2 thin film on a (100) TiO_2 single crystal substrate and characterized the transport properties along <010> and <001> of rutile VO_2.

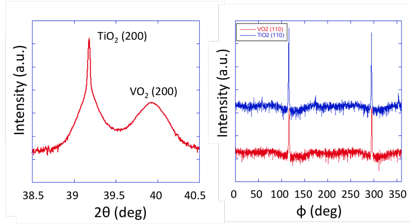
High quality VO_2 (single crystal like) film

We used a novel deposition process called "Reactive Bias Target Ion Beam Deposition". We have developed optimized processing to deposit VO_2 films of excellent quality.



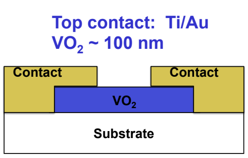
AFM image shows no pin holes or cracks.

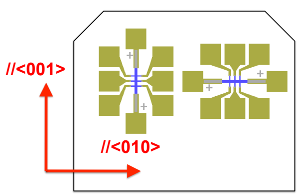




XRD scans confirm 100 nm VO_2/TiO_2
•Single phase VO_2
•Epitaxial to TiO_2 substrate

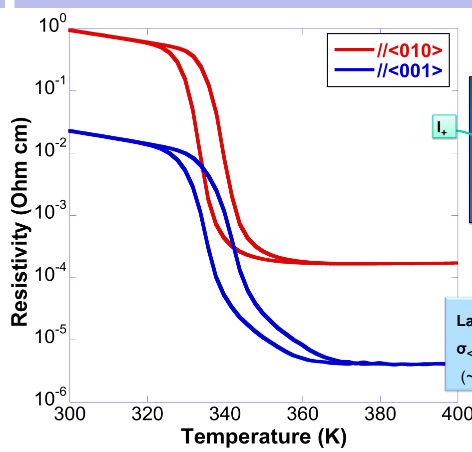
Device structure

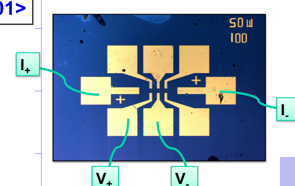




Two 5μm × 150μm Hall bars were fabricated along <001> and <010> directions.

Electrical transport measurement





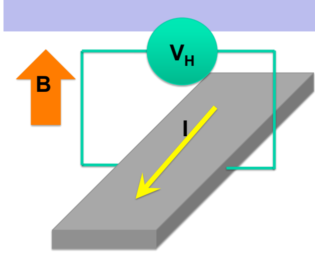
Largest anisotropy observed!
$\sigma_{<001>}/\sigma_{<010>}$ ~41.5 at 300K
(~ 2 for bulk single crystal VO_2)

VO_2 and TiO_2 lattice parameters
(*Calculated from XRD* scans)

	TiO_2	VO_2	bulk VO_2	strain %
a	4.5936	4.5121	4.5546	-0.93
b	4.5936	4.5109	4.5546	-0.96
c	2.9582	2.9076	2.8528	1.92

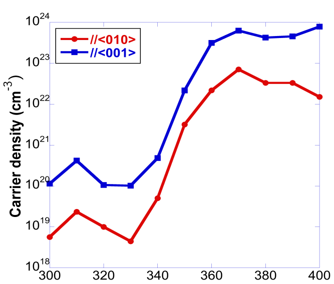
The epitaxial strain arising from the lattice mismatch between rutile VO_2 and TiO_2 (substrate clamping effect)

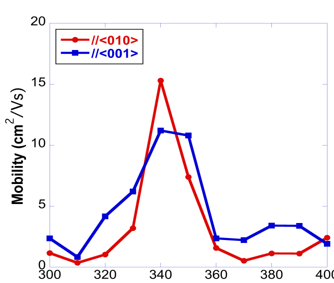
Hall effect measurement



$$V_H = \frac{-IB}{dne},$$ *n = carrier density, d = film thickness, e = electron charge*

$$\mu = \frac{\sigma}{ne},$$ *μ = Hall mobility, σ = conductivity*





• Measure Hall voltage as applying current of 1μA, with sweeping magnetic filed from -7 to 7 Tesla, at temperatures in range of 300-400K
• Calculate carrier density and mobility using Hall equations

Both carrier density and mobility are anisotropic.

Conclusion

	// <010>	// <001>
T_{MST} (K)	336.8	339.3
ΔT (K)	6.1	7.1
Resistivity at 300K (Ω cm)	9.58 × 10^{-1}	2.31× 10^{-2}
Resistivity at 400K (Ω cm)	1.72× 10^{-4}	4.15× 10^{-6}
Carrier density below MST (cm^{-3})	1.09× 10^{19}	1.85× 10^{20}
Carrier density above MST (cm^{-3})	3.49× 10^{22}	5.23× 10^{23}
Mobility below MST (cm^2/Vs)	1.43	3.38
Mobility above MST (cm^2/Vs)	1.35	2.65

• Hall bar along <001> is more conductive than along <010>
• Conductivity anisotropy ratio is 41.5 much larger than bulk VO_2
• Carrier density shows larger anisotropy than mobility, hence contributes more influence in the conductivity anisotropy

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