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Increase of Structural Phase Transition Temperature with Cr Doping in Cr:VO_2 Thin Films

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Background and Motivation

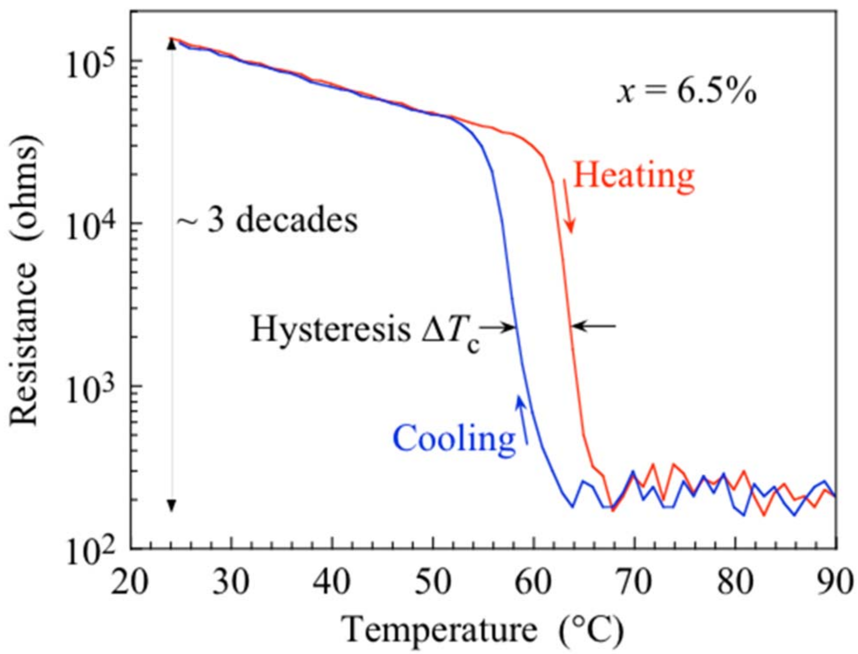
- Certain metal oxides exhibit a metal-to-insulator transition (MIT) between a metallic phase ($T > T_C$) and insulating/semiconducting phase ($T < T_C$).
- Desire to exploit resistance change across T_C for thermally based sensing and switching applications.
- Although phase change oxide materials exist with varying T_C values, most applications require precise target temperatures.
- Ideally, we could tailor the T_C associated with the phase change in a thin film material to match a specified switching temperature.
- Seek to identify a phase change oxide material whose composition can be modified to alter its T_C in a reproducible manner.

Sample Description

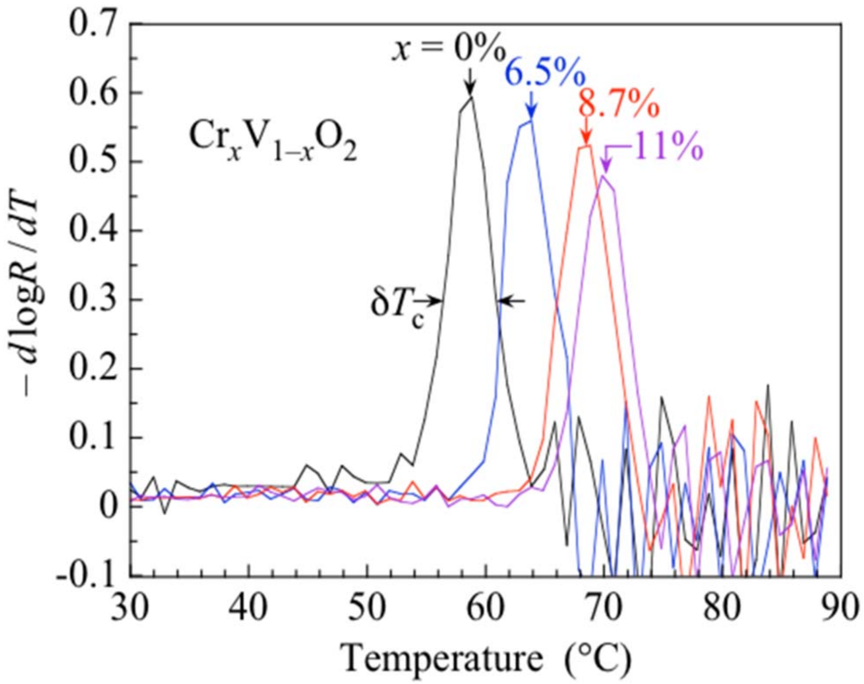
- $Cr_xV_{1-x}O_2$ thin films grown at ambient temperature on S_i/S_iO_2 substrates.
- Samples prepared with Cr fraction of $x = 0$, 0.065, 0.087, and 0.11.
- As grown samples post-annealed in a humid forming gas to develop the monoclinic VO_2 phase.
- X-ray diffraction verified presence of monoclinic VO_2 with a minority of insulating V_2O_5.

Electrical Characterization

Representative resistive phase transition for the $x = 0.065$ sample.



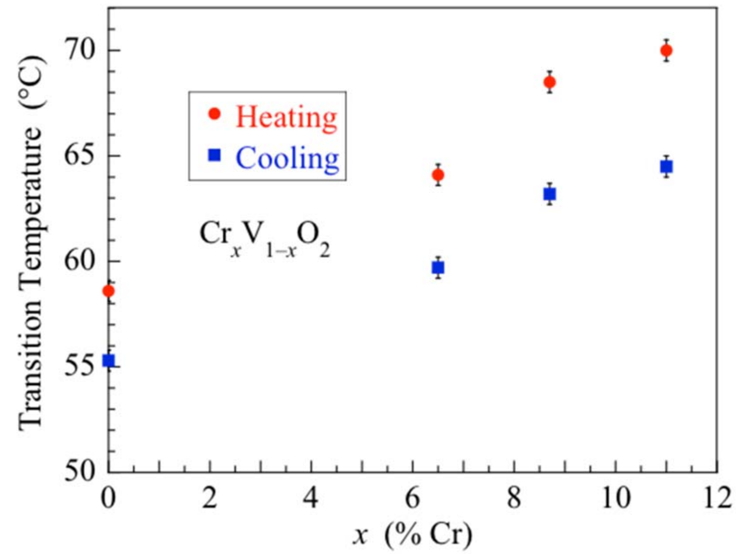
Define T_C as the temperature corresponding to maximum $-d(\log R)/dT$.



- DC resistance (R) of each sample measured in a four-point configuration.
- *R* vs. *T* data is similar for all samples.

Electrical Characterization

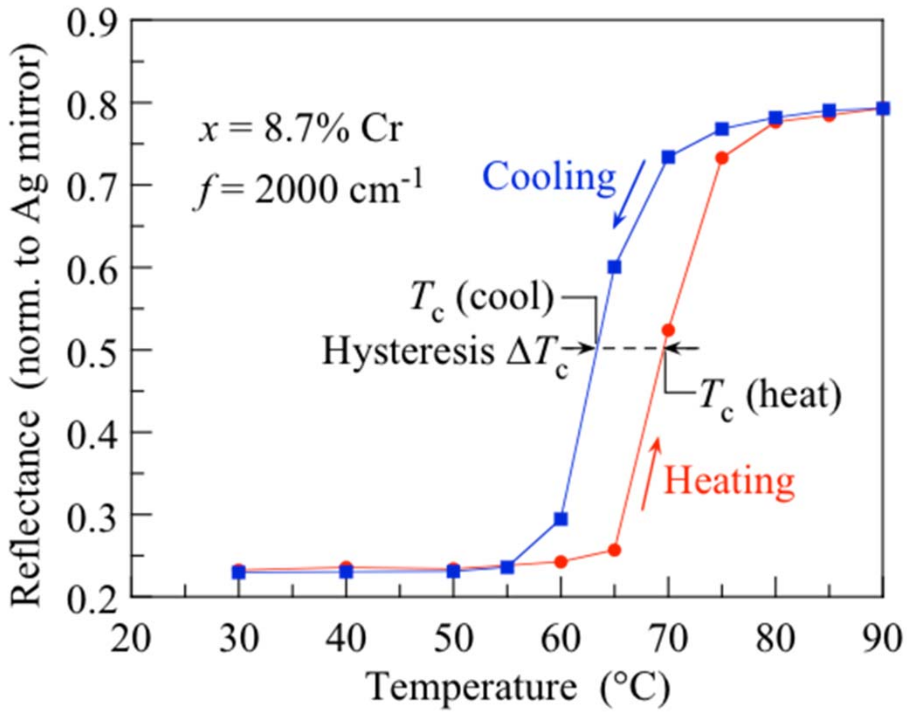
- T_c *(x)* systematically increases with increasing Cr concentration.
- Hysteresis (ΔT_c) for $x > 0$ samples consistently around 5 ^oC.
- T_c *(x)* appears to approach a saturation point for $x > 0.11$.
- Conductance contrast ratio $\Delta G/G$ and carrier density contrast $\Delta n/n$ decrease with increasing Cr.



x Cr (%)	T_c (heat)	T_c (cool)	dT_c (heat)	dT_c (cool)	ΔT	ΔG/G (dB)	Δn/n (dB)
0	58.6	55.3	4.4	4.1	3.3	31.7	28.5
6.5	64.1	59.7	5.1	4.8	5.2	27.8	26.1
8.7	68.5	63.2	5.2	5.0	5.3	24.1	23.6
11	70.0	64.5	4.6	4.9	5.5	21.6	23.7

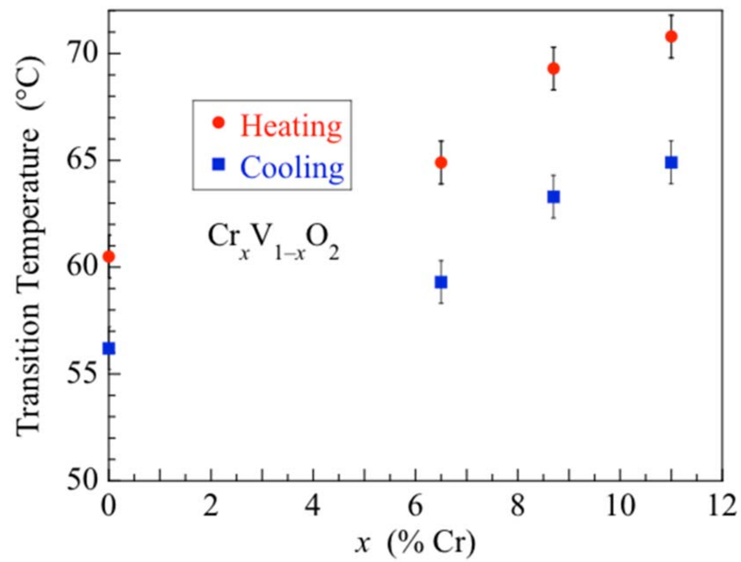
Optical Characterization

- FTIR measurements at 10^{o} off normal incidence.
- Spectra recorded over frequency range of $350 cm^{-1}$ to $2000 cm^{-1}$.
- Reflectance increases across MIT into metallic phase as expected.
- Data is similar for all samples.



Optical Characterization

- Trends similar to that of resistance transition at T_c.
- $T_c^{refl}(x)$ systematically increases with increasing Cr concentration.
- Hysteresis (ΔT_c^{refl}) for $x > 0$ samples consistently around 5 °C.
- $T_c^{refl}(x)$ appears to approach a saturation point for $x > 0.11$.
- Reflectance contrast Δr shows no systematic dependence on x.



x Cr (%)	T_c^{refl} (heat)	T_c^{refl} (cool)	δT_c^{refl} (heat)	δT_c^{refl} (cool)	ΔT^{refl}	Δr
0	60.5	56.2	5.7	5.3	4.3	0.60
6.5	64.9	59.3	7.0	6.6	5.6	0.62
8.7	69.3	63.3	8.4	8.7	6.0	0.56
11	70.8	64.9	9.6	10.4	5.9	0.58

Summary

- The effect of Cr doping into $Cr_xV_{1-x}O_2$ thin films on the MIT transition temperature has been investigated.
- Consistent with bulk and ceramic measurements in the 1970s, thin film T_c is shown to increase systematically with Cr percentage.
- T_c increase in thin films appears to saturate for $x > 0.11$, which differs from the trend demonstrated in bulk and ceramic samples.
- Parameters of interest for applications such as transition hysteresis and transition width are provided.
- Hall coefficients imply conductance change across the MIT is largely due to an increase of carrier density, rather than a large change in mobility.

Hall Effect

- Hall coefficients measured in four-point van der Pauw configuration for B ≤ 0.5T.
- Carrier density *n* inferred using single-band carrier interpretation ($R_H = 1/ne$).
- Relative carrier contrast *Δn/n is* similar to *ΔG/G*, suggesting conductance change across MIT due primarily to change in carrier density.
- By implication, carrier mobility must change only weakly across the MIT.