Thermal Conduction in Semiconducting Oxide Alloys for Thermoelectrics

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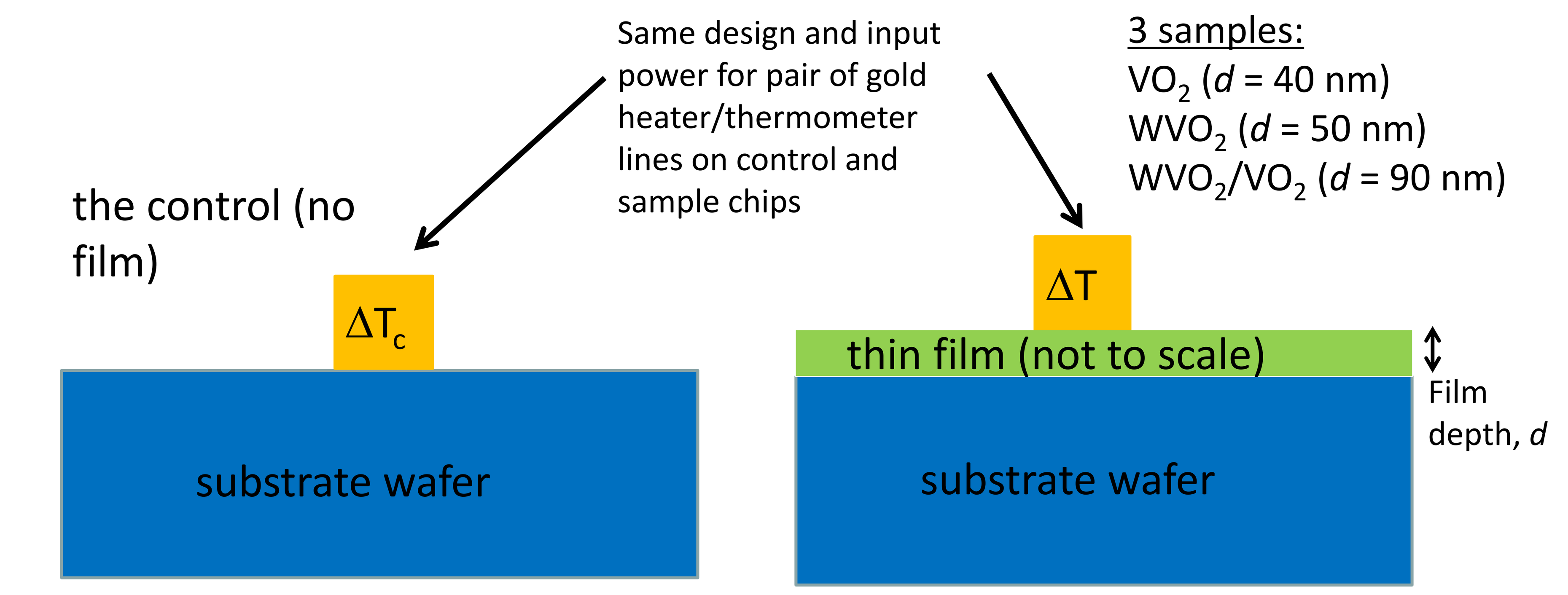
Exotic phase transition materials, such as vanadium oxide thin films, may enhance the heat flow for nanodevices. Thermal conduction measurements were made for VO_2 and WVO_2 (18% tungsten) thin films grown on silicon wafers. The differential 3ω method was used to measure cross plane thermal conductivity in the temperature range -20 to 100 ºC. Thermal conductivity ranged 0.9-1.9 W/m K. Phase transitions occurring for all films around 300-320 K had small (~20%) changes in thermal conductivity.

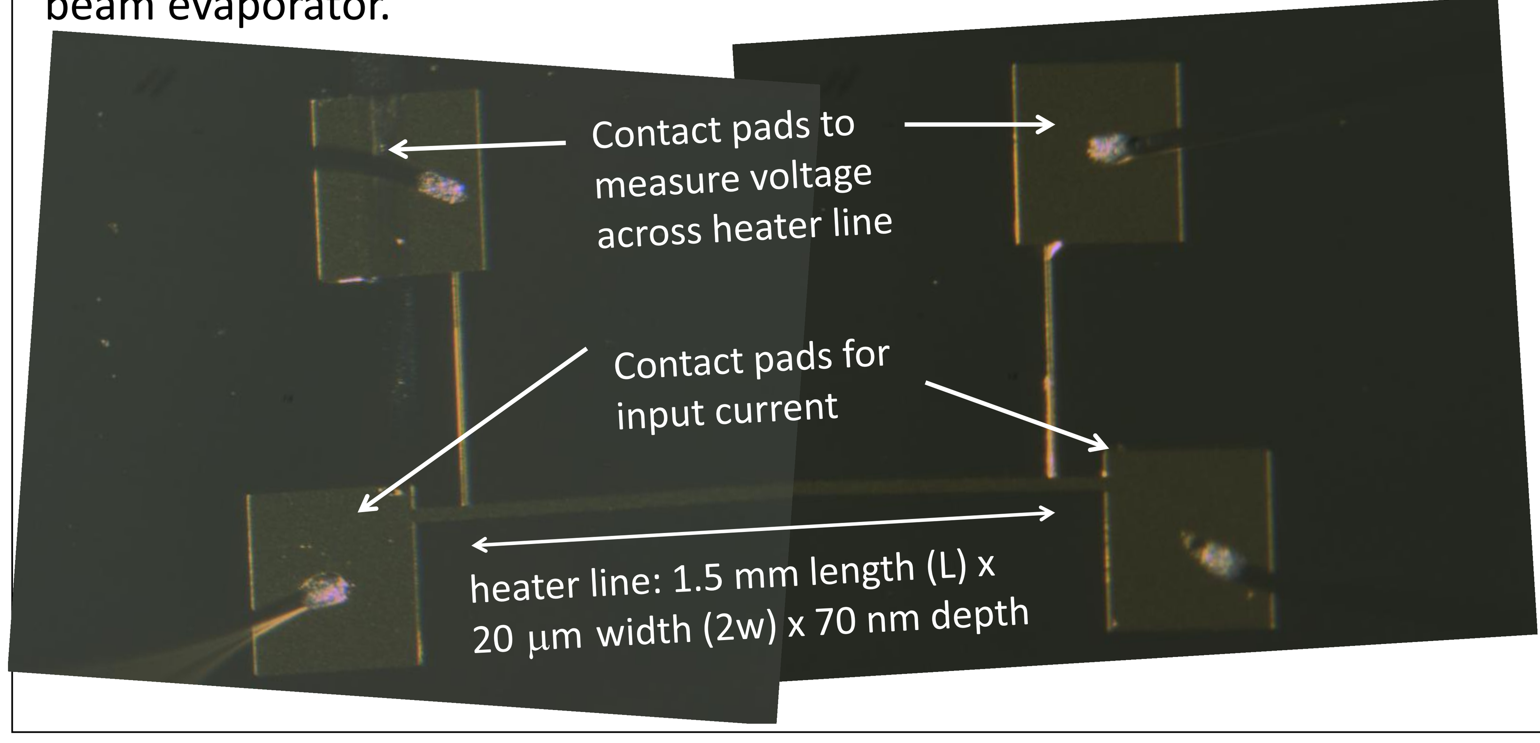
Differential 3ω (three-omega) experiment

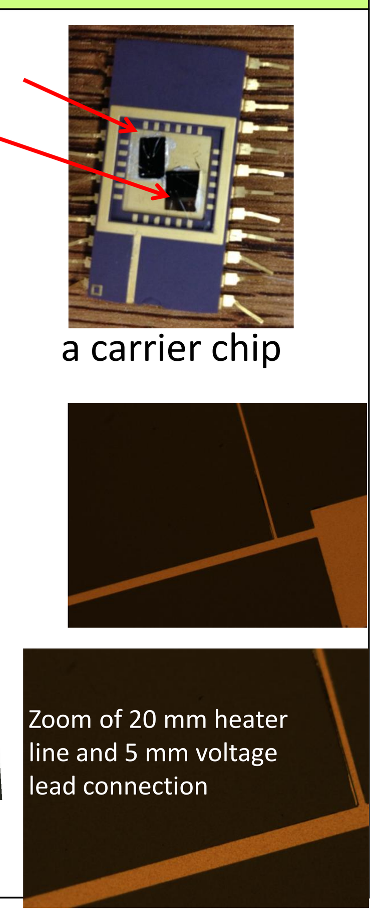


$$\Delta T_{film} = \Delta T - \Delta T_c$$

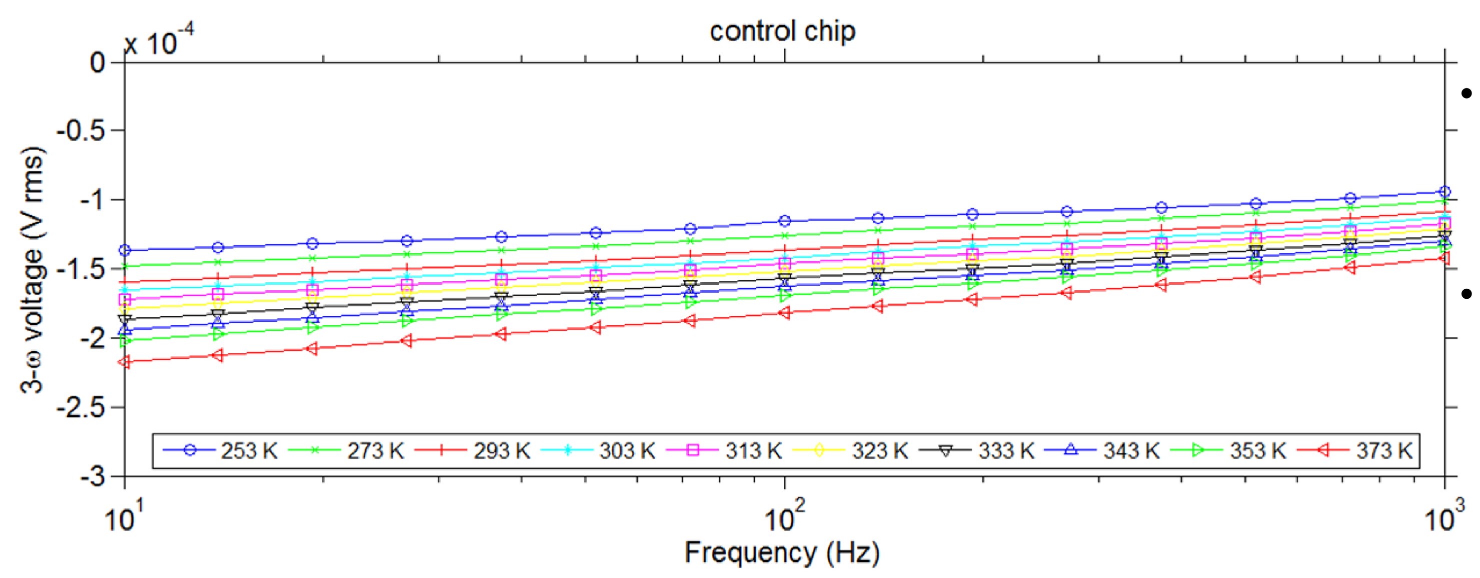
Heater/thermometer design

Below: a pure gold heater/ thermometer was fabricated on each chip using an e-beam evaporator.

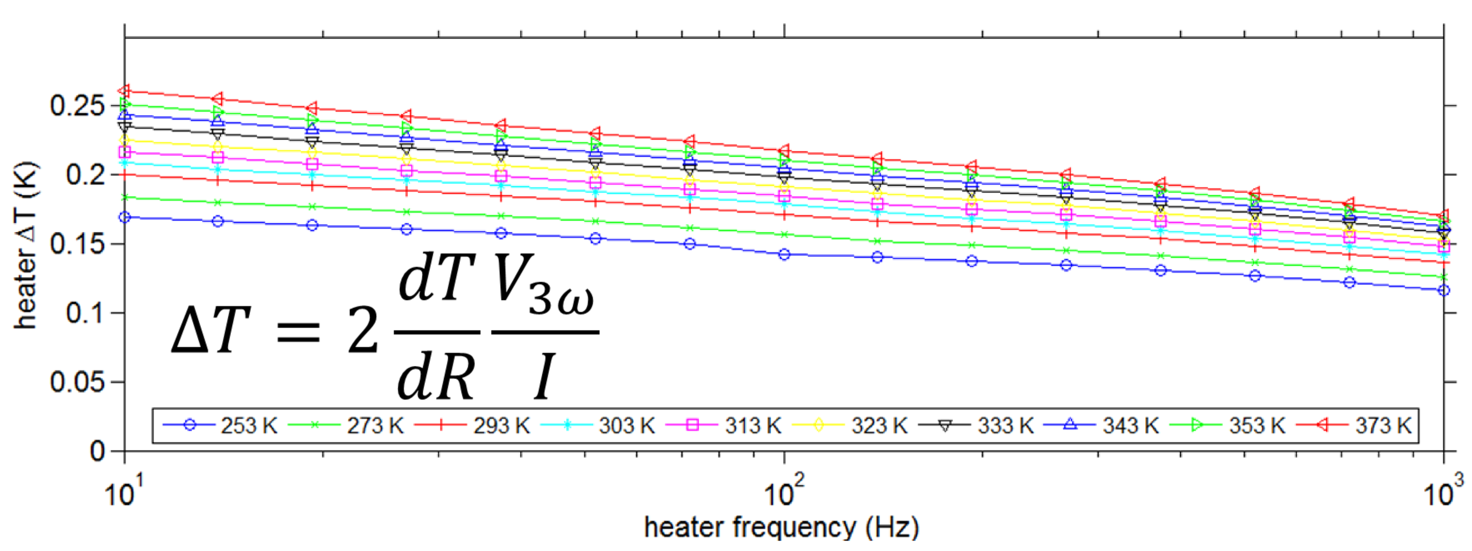




Measurements – control wafer shown



- Third harmonic, or "3ω" signal, was measured with phase locking oscilloscope
- Linear 3ω voltage vs log ω validated assumptions

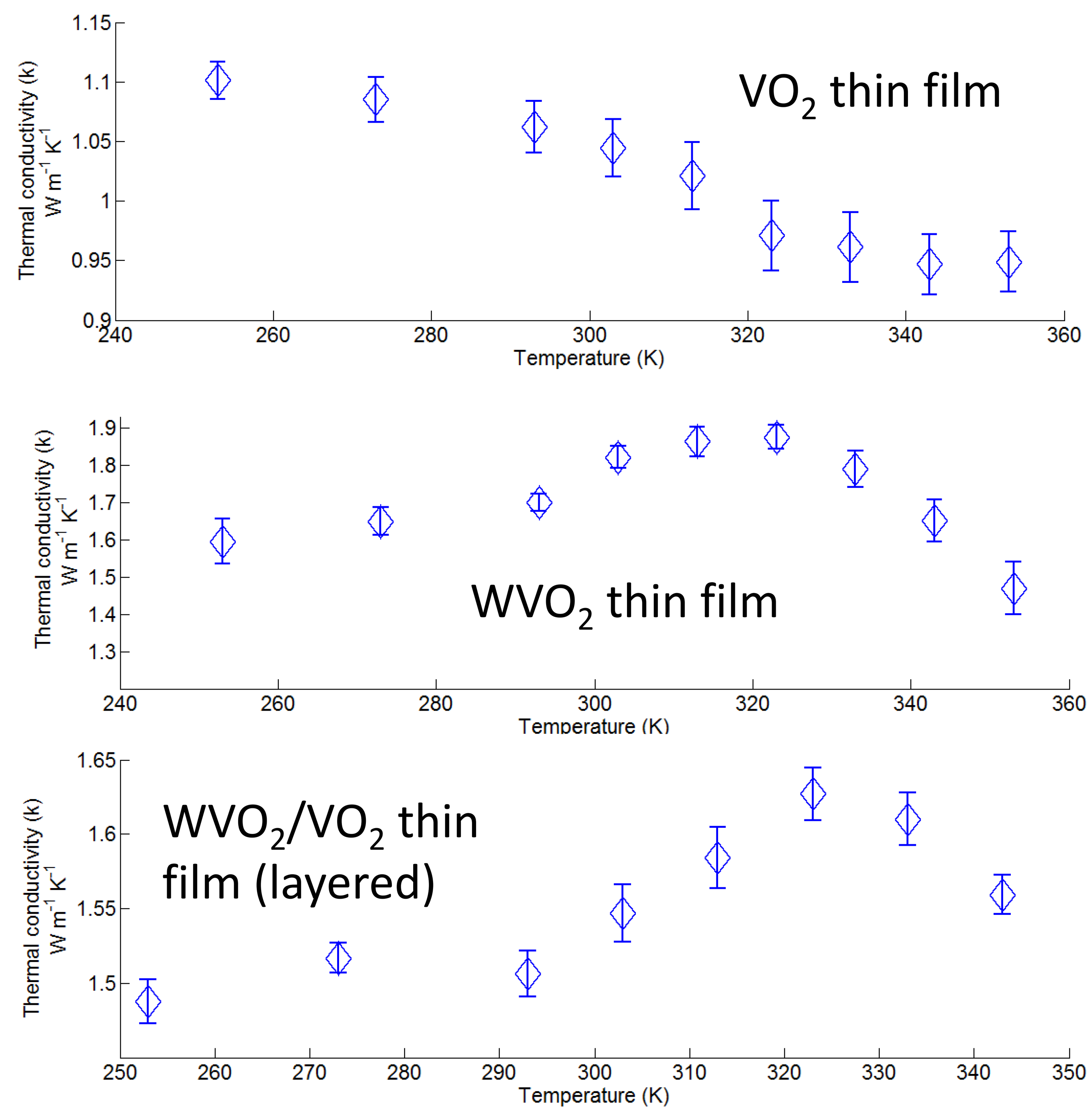


$$\Delta T = 2\frac{dT}{dR}\frac{V_{3\omega}}{I}$$

- ΔT_c and ΔT for each sample were calculated
- dT/dR is measured temperature coefficient of resistance TCR
- I= 25 mA input current

Thermal conductivity (W/m K) for the thin films

$$k = \frac{Qd}{2wL\Delta T_c},\ \mathrm{Q = heater\ power\ (const.)}$$



Conclusions:

- **Around 300-320 K, all thin film thermal conductivities changed**
- **Presumably due to a known phase transition**
- **VO_2 thin film k decreased from about 1.1 to 0.9 W/m K**
- **WVO_2 and layered WVO_2/VO_2 thin film k increased about 20% from around 1.5 and 1.6 W/m K, respectively**
- **Tungsten addition increased thin film conductivity relative to VO_2**
- **The small changes in thermal conductivity were likely due to the extreme thinness of the samples (40-90 nm)**
- **Future work may explore somewhat thicker nanofilms**

Acknowledgements: Devices fabricated in the UC Berkeley Marvell Nanofabrication Laboratory.

References

[1] Cahill, Thermal conductivity measurement from 30 to 750 K: the 3ω method, Rev. Sci. Instrum. 61 (2), 802-8, 1990.

[2] Dames, Chapter 2 Measuring the thermal conductivity of thin films: 3 omega and related electrothermal methods, Annual Review of Heat Transfer XVII, 2014.

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