Laser Switching of Thin Films of Vanadium Dioxide

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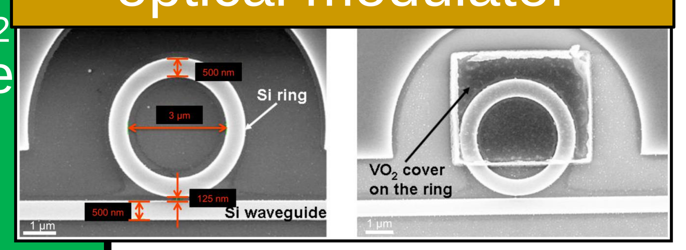
Introduction

Vanadium dioxide (VO_2) is widely studied for its semiconductor-to-metal phase transition. When heated above 68° C (340 K), VO_2 becomes much more conductive and much less transparent to light. Since VO_2's phase transition involves a significant change in its refractive index, it has the potential to be used in high speed photonic devices such as optical modulators (1).

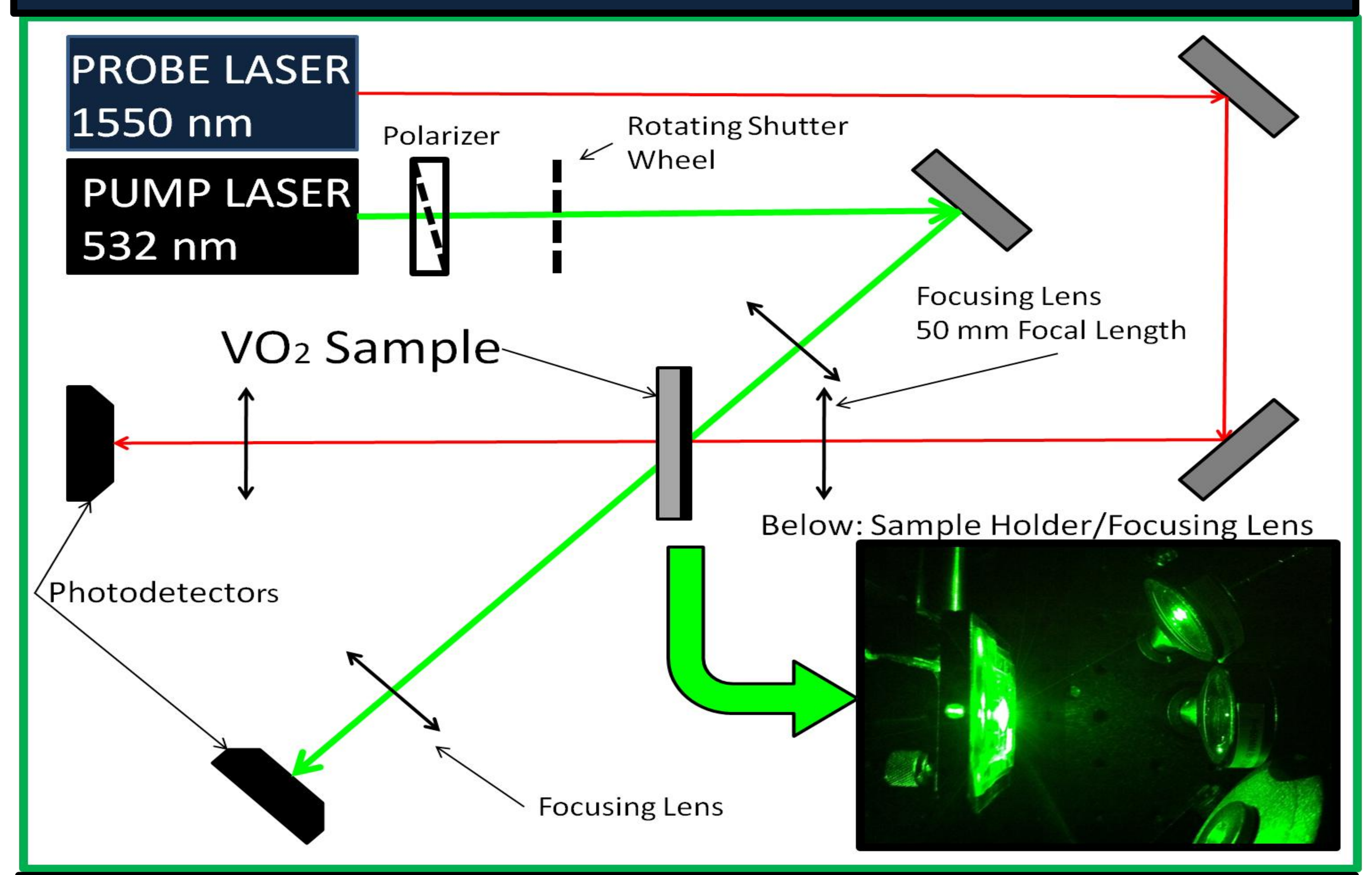
Research Goals

1) Switch thin films of VO_2 using a low-power laser
2) Simulate laser induced temperature rise
3) Long term: develop VO_2 based optical modulator

optical modulator



Experiment Layout

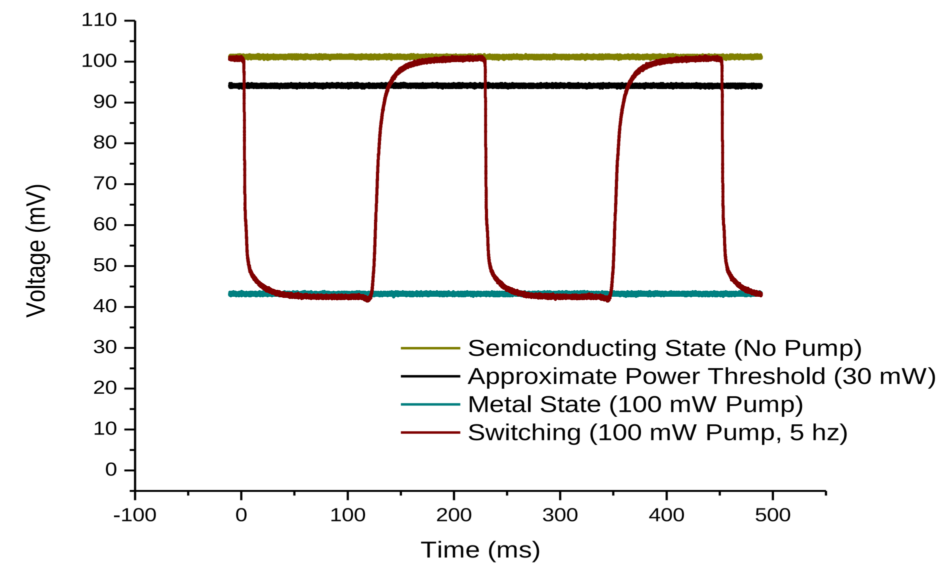


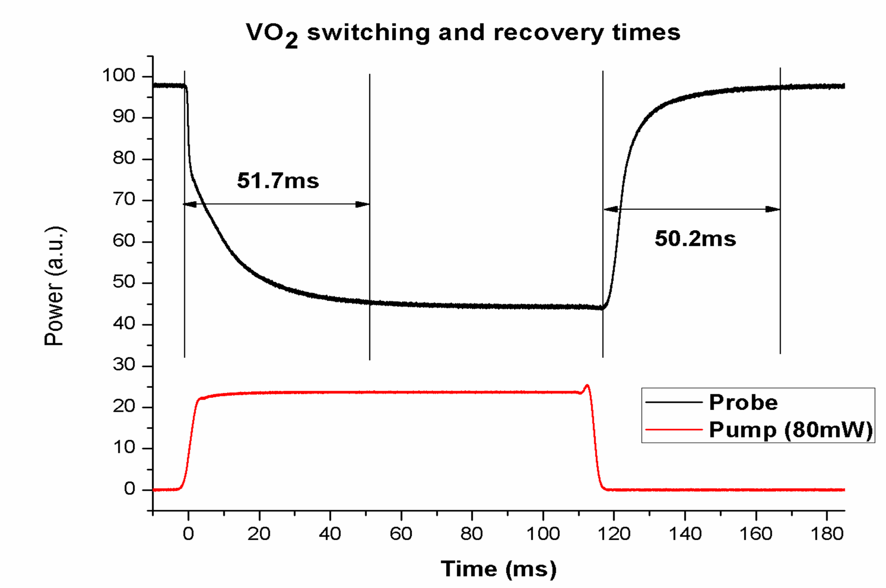
- 532 nm pump beam heats the VO_2
- 1550 nm probe beam measures transmission
- A sharp decrease in transmission occurs when the VO_2 switches.

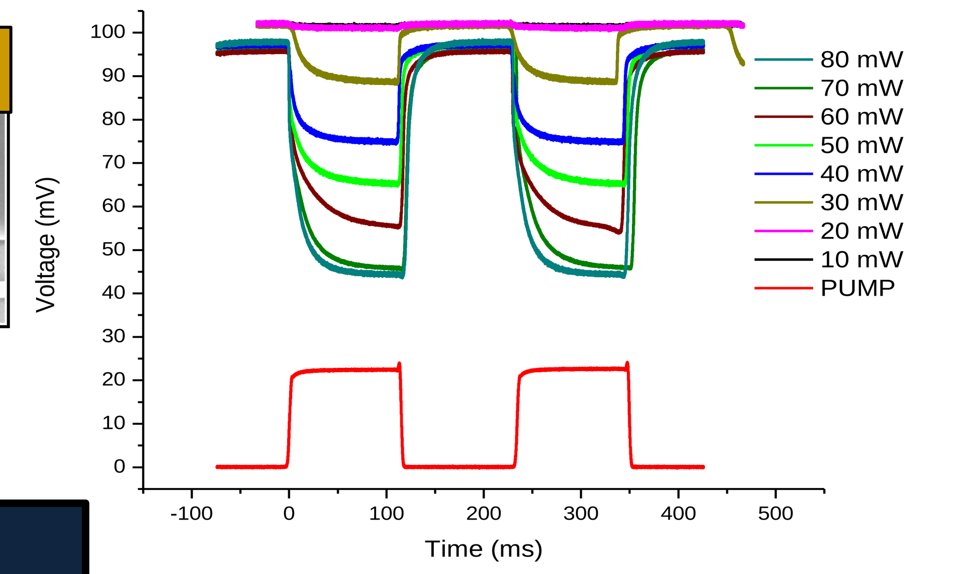
Experimental Measurements

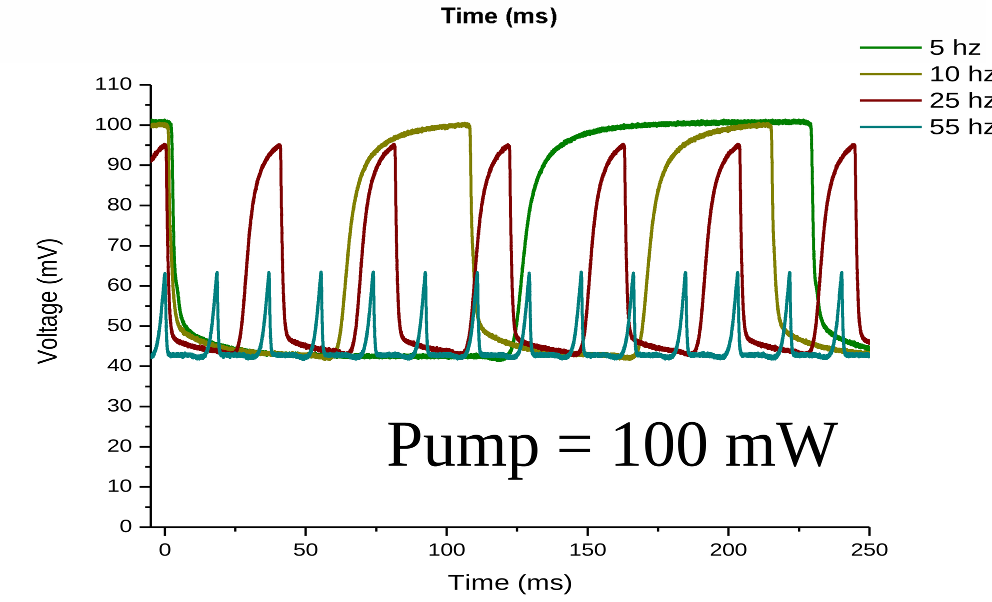
1) Minimum incident power needed to switch
2) Variation of transmission with incident power
3) Variation of signal with chopping frequency
4) Approximate time to reach max contrast
5) Approximate recovery time

Experimental Results









- Minimum power needed to switch a 150nm-film = **30 mW at 532 nm**
- Maximum contrast = 60% decrease in transmission
- Saturation power = 70 mW and above
- Estimated time to max contrast = **51.7 ms**, recovery time = **50.2 ms**

Simulating Temperature Rise

Temperature Change with Time

Heat Source: Power/Volume

$$C_p \rho \frac{\partial T}{\partial t} - \kappa \nabla^2 T = Q$$

Heat Flow Through Given Volume

Heat Source Definition (3)

$$Q = (1-R)\gamma I_0 e^{\left(-2(r/Rf)^2\right)} e^{-\gamma |z|} \quad (W/m^3)$$

Measured Beam Parameters for 532 nm Pump

R = reflection coefficient = 0.2

d_{ab} = absorption depth = 146 nm

γ = absorption coefficient = $1/d_{ab}$

Rf = focal spot radius ($1/e^2$) = 37.5 nm

Sample Parameters

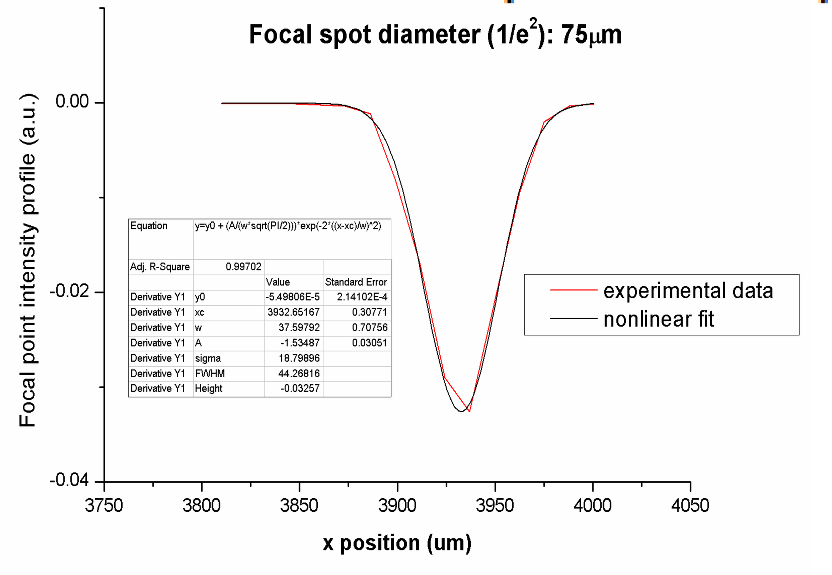
Th = VO_2 thickness = 150 nm

k = VO_2 thermal conductivity = 6.5 W/m K (2)

C_p = VO_2 specific heat capacity = 656 J/kg K (2)

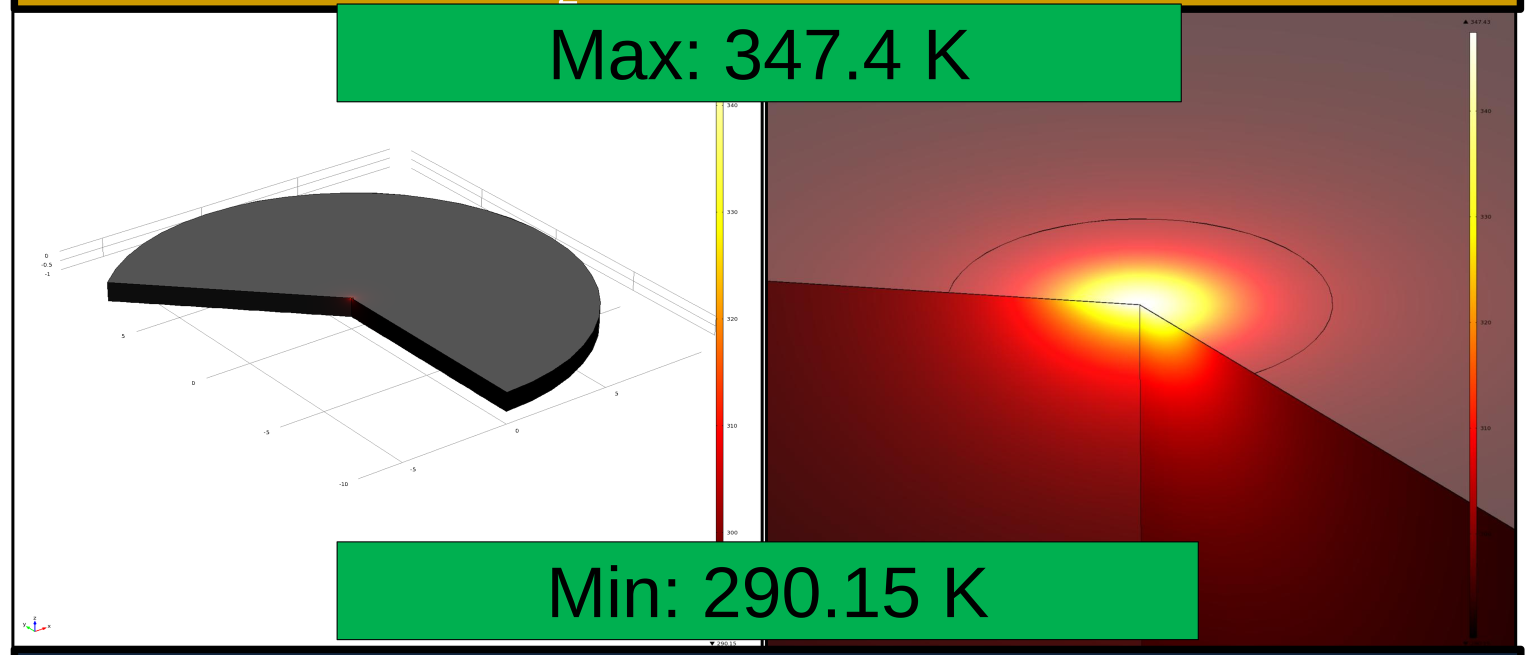
p = VO_2 density = 4650 kg/m³ (2)

Substrate Dimensions: 10 mm × 10 mm × 1 mm



Simulation Results

- For a pump power of 30 mW, Comsol simulations show a maximum temperature of 347.4 K for a 150 nm thick film after 1 second.
- The thin film's thickness and the wavelength dependent absorption coefficient (γ) are the major determinants of the maximum temperature.
- Since the glass substrate does not absorb any radiation, all of the heat is due to absorption within the thin film of VO_2.



Conclusions

1) We successfully switched VO_2 thin films with a 532 nm laser.
2) For a 150 nm-film, a minimum power of 30 mW, corresponding to a minimum intensity of 679 W/cm², was needed to switch.
3) . For a power of 30 mW, we calculated a maximum temperature rise of 347.4 K, which should be high enough for the phase transition.
4) The thickness of the VO_2 film and the wavelength dependent absorption coefficient determine the maximum temperature that can be attained for a given power.

The next phase for this research will be to study VO_2's optically induced phase transition, which will involve moving to high-power, pulsed lasers. The long term goal is to design and produce a laser controlled optical modulator using VO_2.

References/Acknowledgements

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(3) Grigoropoulos, Costas. "Lasers, Optics, and Thermal Considerations in Ablation Experiments." *Laser Ablation and Desorption*. Ed. John C. Miller and Richard F. Haglund. Jr Academic Press, 1998. Print.

Acknowledgements

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