Tunable, All-Dielectric Metasurfaces using Insulator-to-Metal Transition Material VO_2

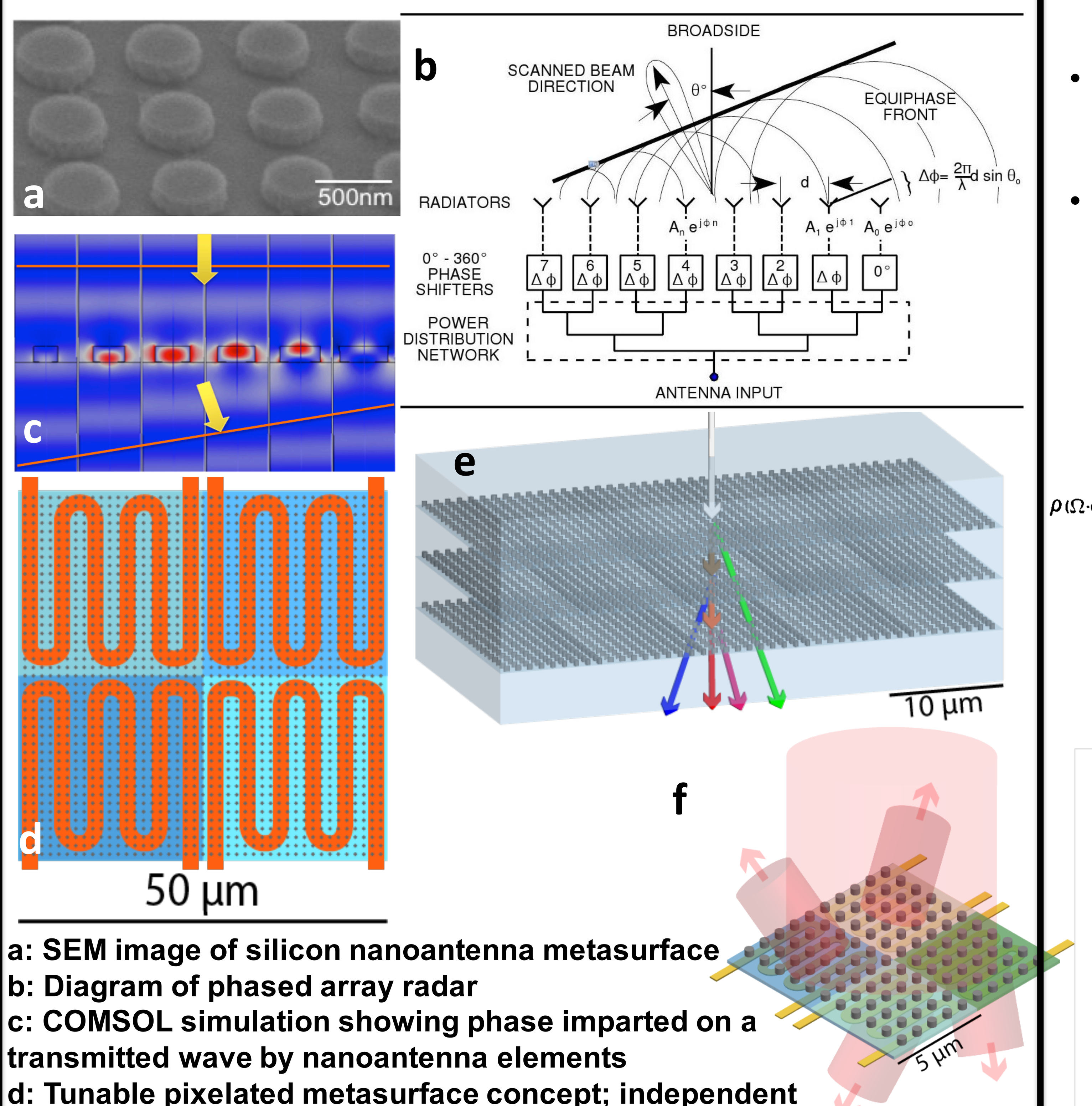
SMART — SUMMER MATERIALS RESEARCH @ TULANE

Nathan Kurtz[1,2], Adam Ollanik[2], Matthew Escarra[2]

[1]University of Southern Mississippi, [2]Tulane University

Abstract

- Metasurfaces have a wide range of possible applications
- Escarra lab has designed and modeled highly efficient all-dielectric metasurfaces
- Effect of these surfaces is fixed after fabrication
- By using metal-insulator-transition (MIT) material vanadium dioxide (VO_2) we hope to develop dynamically tunable metasurfaces



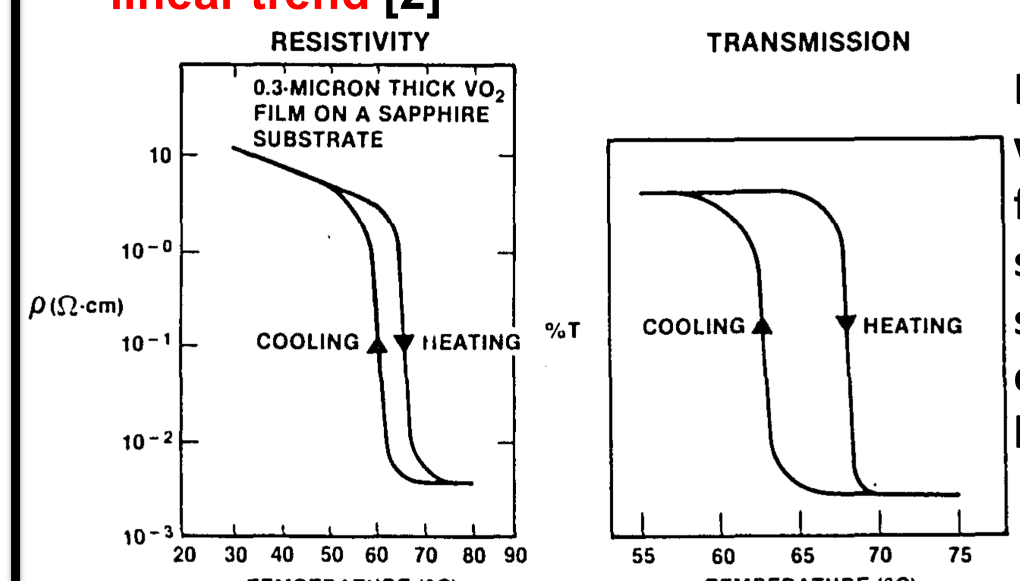
a: SEM image of silicon nanoantenna metasurface
b: Diagram of phased array radar
c: COMSOL simulation showing phase imparted on a transmitted wave by nanoantenna elements
d: Tunable pixelated metasurface concept; independent resistive heating strips placed on each pixel
e: Multiplexed spectrum splitting diagram; each layer manipulates finite spectral band with independent control over outgoing angle
f: Isometric view of pixelated metasurface concept showing each pixel deflecting/reflecting light by different angles

Background

- Arbitrary manipulation of light via introduction of abrupt phase discontinuities on a subwavelength scale [3,4]
- Highly efficient, dynamically tunable metasurfaces will allow the creation of tunable and reconfigurable optics
- The applications of this technology are endless; windows with tunable transmission of IR light, displays that can become mirrors with the flick of a switch, optical zoom for cameras in flat form factor, solar panels tracking the sun without moving, as well as many others

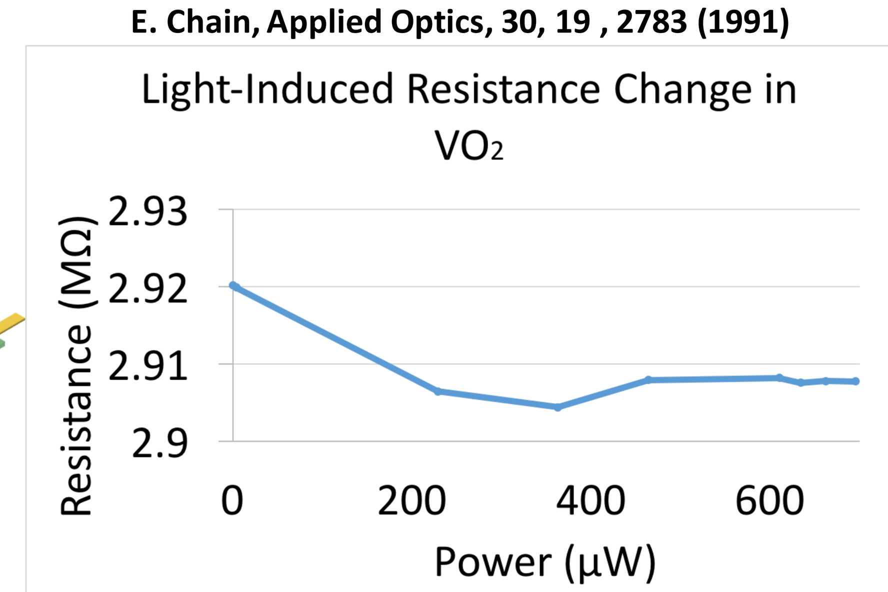
Why VO_2?

- Most conventional materials require extreme stimulus for required tunability
- VO_2 strongly tunable with minimal stimulus
- Reversible transition from insulating state to metal state when exposed to heat, electric field, or intense light
- When critical concentration of charge carriers is reached, lattice structure of VO_2 changes from monoclinic to tetragonal
- Dramatic increase in conductivity (On the order of $d\sigma=10^6$), accompanied by a large change in refractive index (on the order of dn=1)
- Intermediate states within this transition are stable, with changing material properties following a nearly linear trend [2]

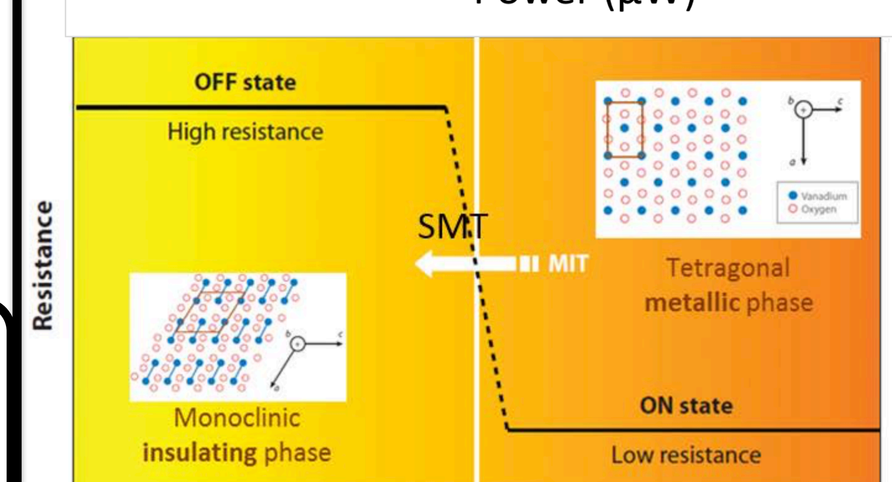


E. Chain, Applied Optics, 30, 19 , 2783 (1991)

Left: Resistivity vs. temperature for VO_2 on sapphire showing characteristic hysteresis loop



Left: Resistance vs. light power for 1100 nm light on year-old VO_2 sample from Prof. Wei's lab at Tulane

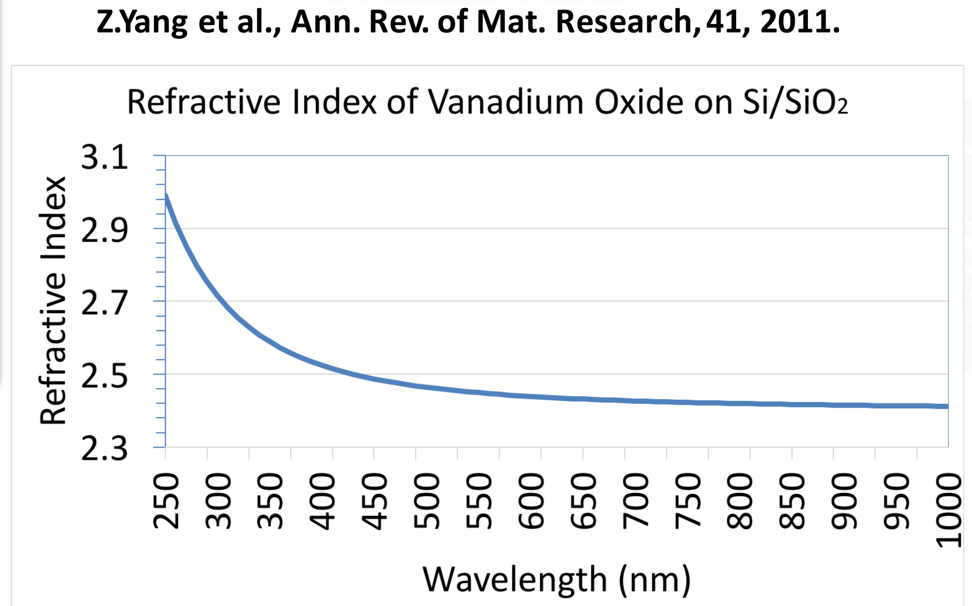


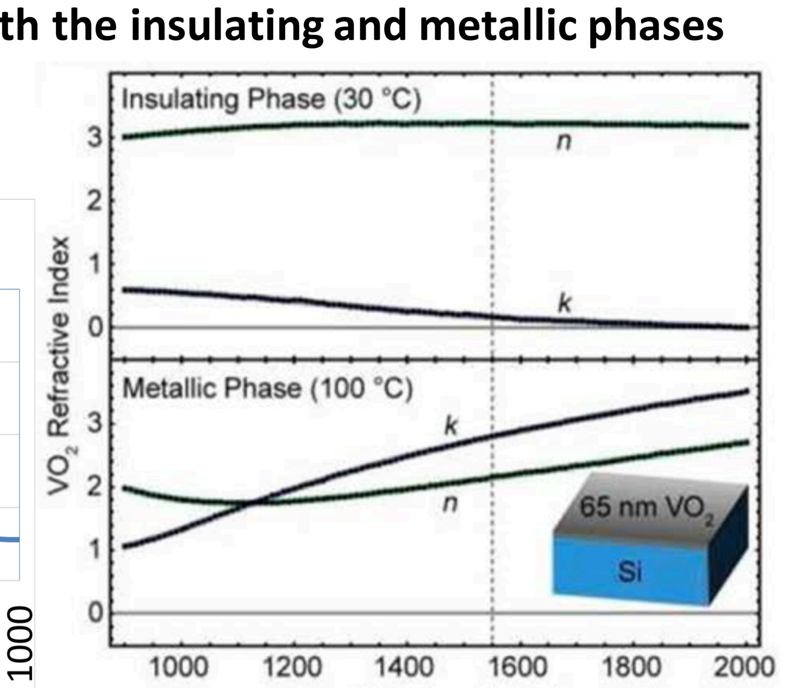
Z.Yang et al., Ann. Rev. of Mat. Research, 41, 2011.

Left: Resistance change and lattice reallignment illustration in VO_2 across the MIT

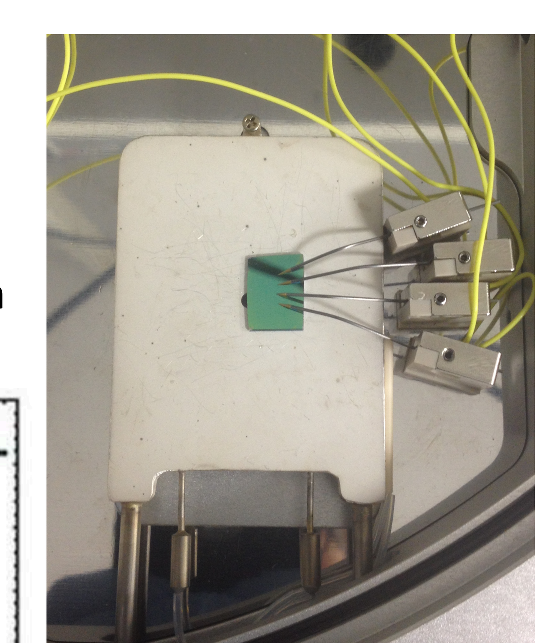
Bottom Left: Refractive index of our vanadium oxide film on Si/SiO_2 taken using ellipsometry

Bottom right: Refractive index for VO_2 in both the insulating and metallic phases





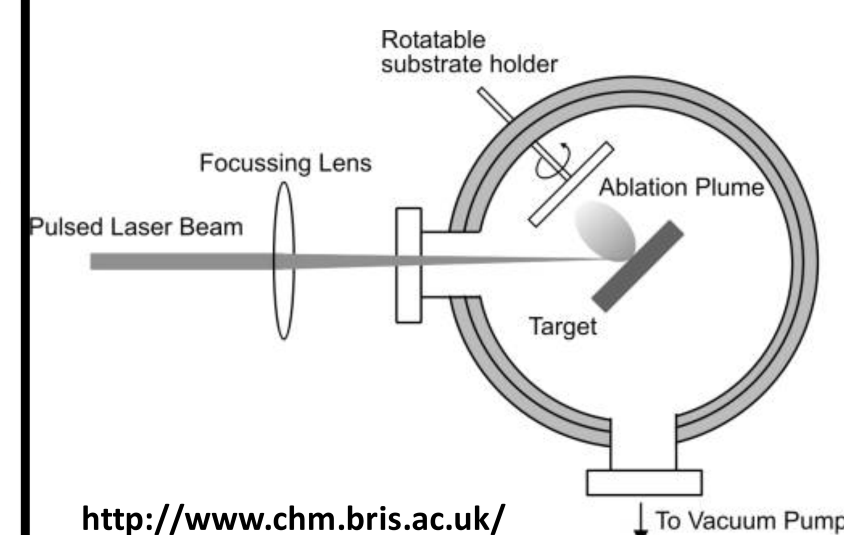
R.M.Briggs et al., Optics Express, 18(11), 2010.

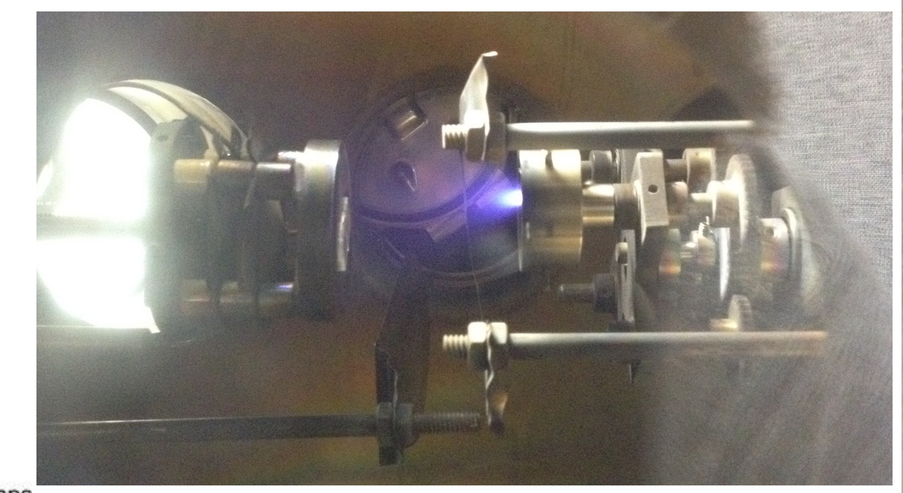


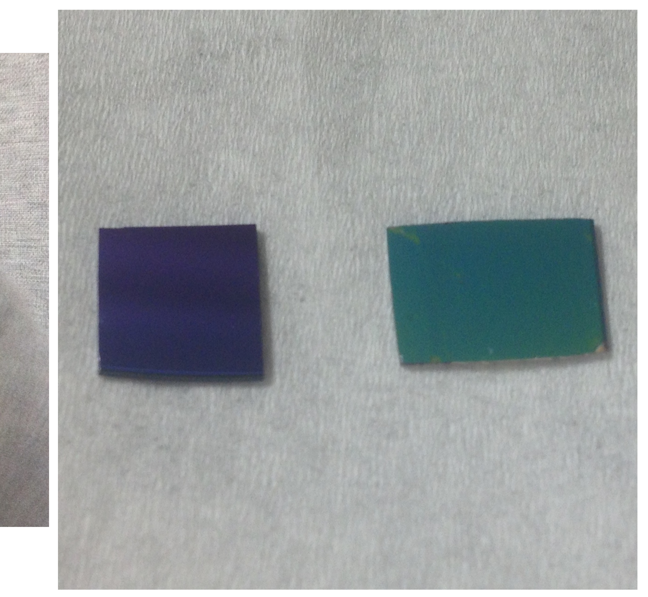
Above: Four-probe setup on Linkam stage for VO_2 on Si/SiO_2 to measure resistance as a function of temperature

Film Growth and Characterization

- Grown using pulsed laser deposition (PLD)
- Deposition parameters such as substrate temperature, vacuum pressure, oxygen flow rate, laser power, and pulse frequency must be optimized
- Film is characterized by measuring resistance as a function of temperature and incident light intensity
- Looking for MIT, expected to occur around 68 °C, or around 800 μW of incident power [1,2]

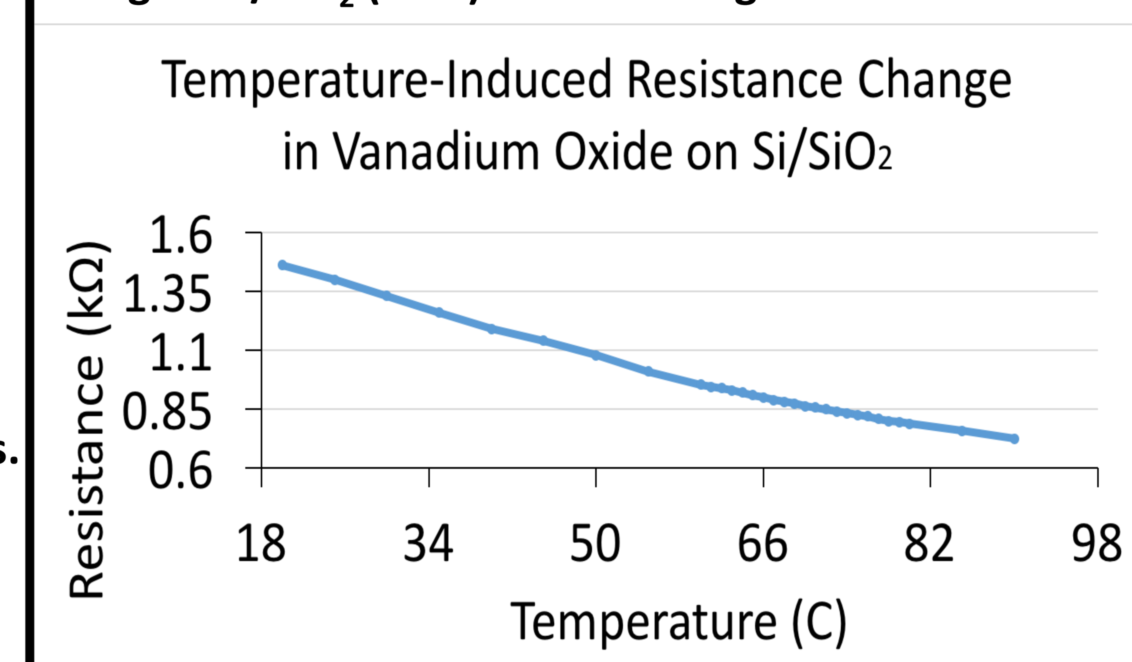


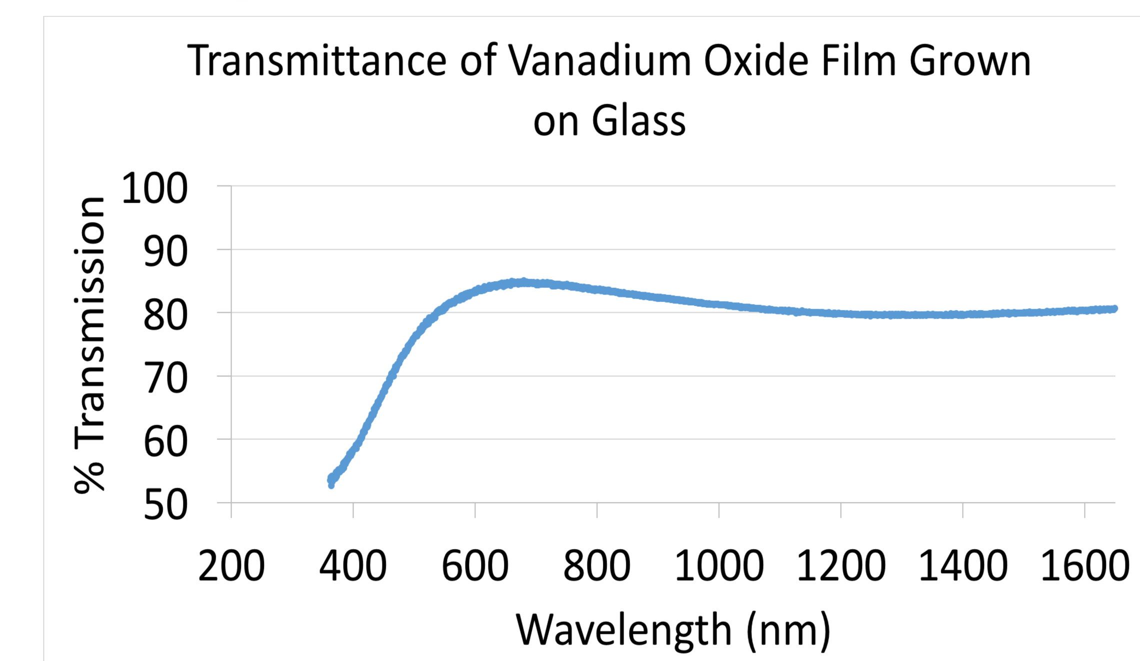




Left: Diagram of PLD chamber. Middle: PLD of vanadium oxide onto glass with visible plasma plume

Right: Si/SiO_2 (blue) next to PLD-grown vanadium oxide on Si/SiO_2 substrate (green)





Left: Resistance vs temperature for vanadium oxide grown on Si/SiO_2 substrate.

Right: Transmission measurement of vanadium oxide on glass

Conclusions

- Performed exhaustive search for tunable materials
- VO_2 was chosen as the antenna material for MIT, strongly tunable index
- PLD used to grow preliminary films
- Grown films do not show characteristic behavior
- Films show a linear change in resistance with temperature, characteristic of a typical semi-conductor
- Process refinement required to grow crystalline VO_2

Acknowledgements

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References

- [1] H. Wang, et al., 540 (2013)
- [2] K. O'Brien, et al., *40* (2012)
- [3] M. Decker et al., Adv. Optical Mater., 3.6 (2015)
- [4] N. Yu et al., Science 334, 333 (2011)

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