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# Vanadium dioxide thin films prepared on silicon by low temperature MBE growth and *ex-situ* annealing

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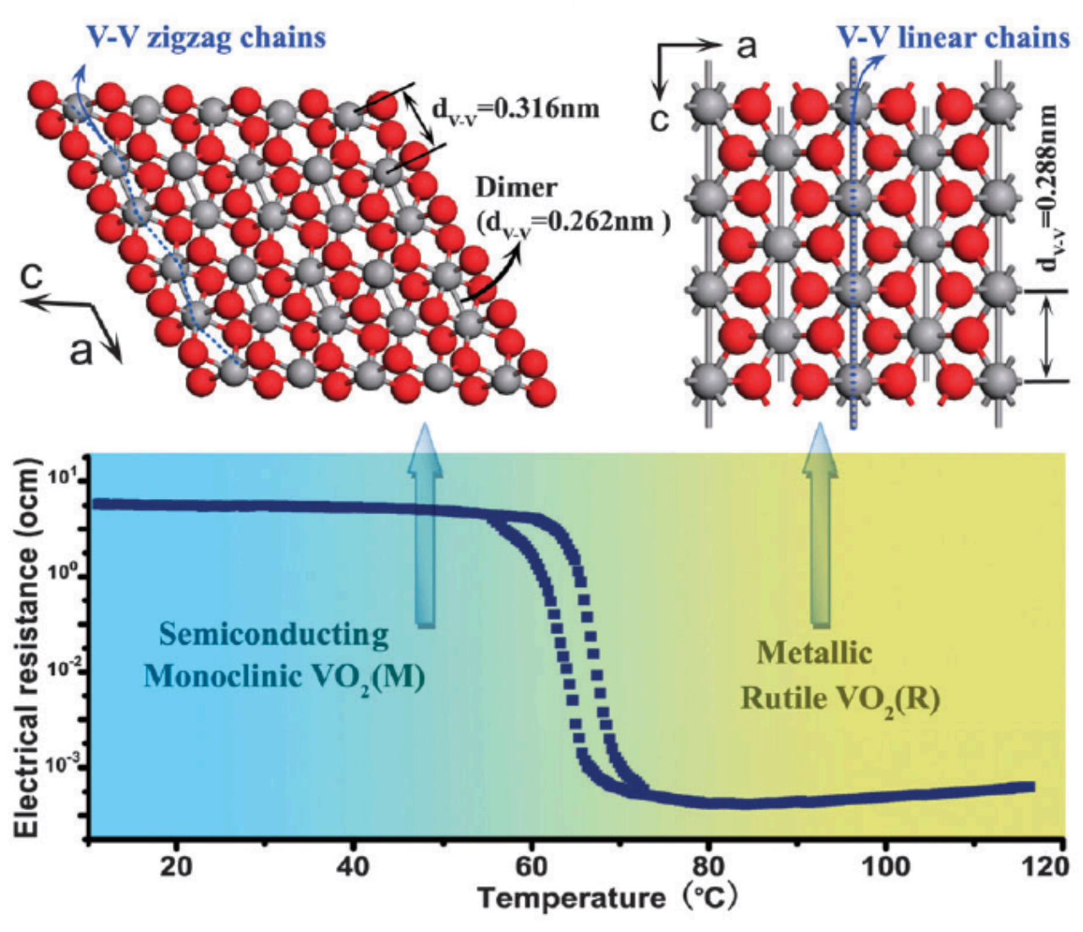
## Vanadium dioxide

$VO_2$ exhibits a metal to insulator transition (MIT) at 67 °C [1].



**ΔR = $10^4$ resistance change across the MIT !**

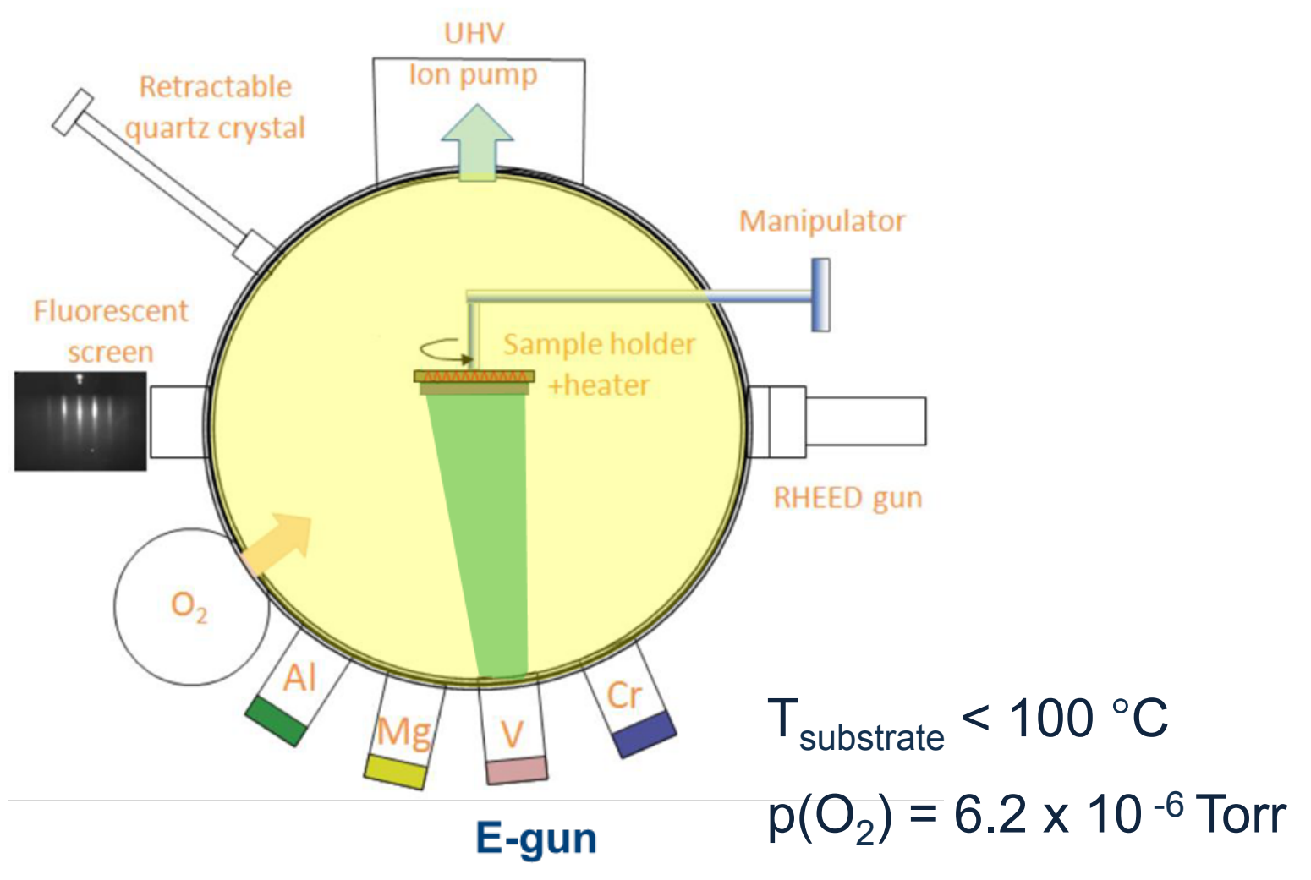
**MIT above RT, interesting for applications**

**Challenges:**

- Good quality films grown on Si for device integration
- Transition temperature closer to RT

## $VO_2$ thin film preparation

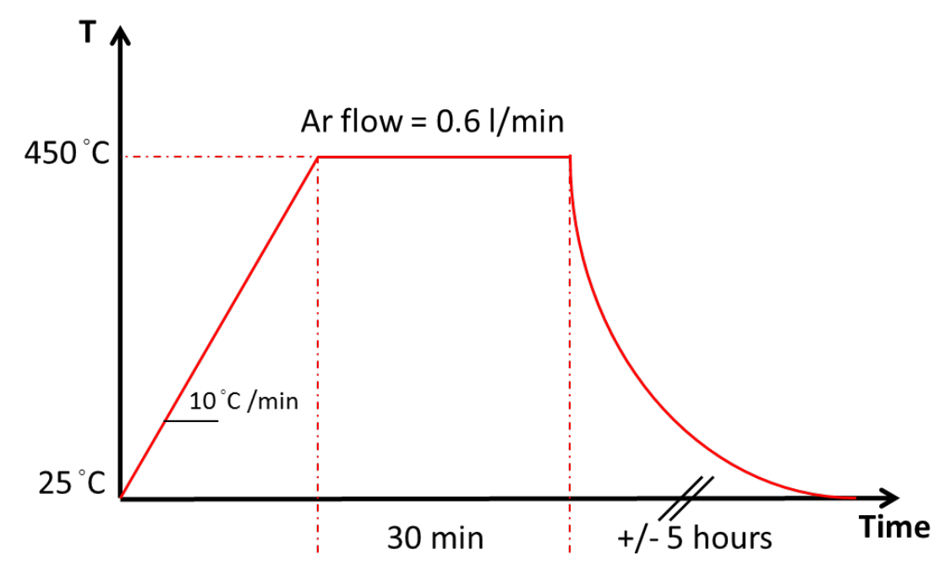
### I. Oxygen-assisted MBE growth



$T_{substrate}$ < 100 °C
$p(O_2) = 6.2 \times 10^{-6}$ Torr

Deposition of amorphous $VO_x$ on Si(100) with native $SiO_2$

### II. *Ex-situ* annealing



**Ar: 450°C – 30' in Argon**

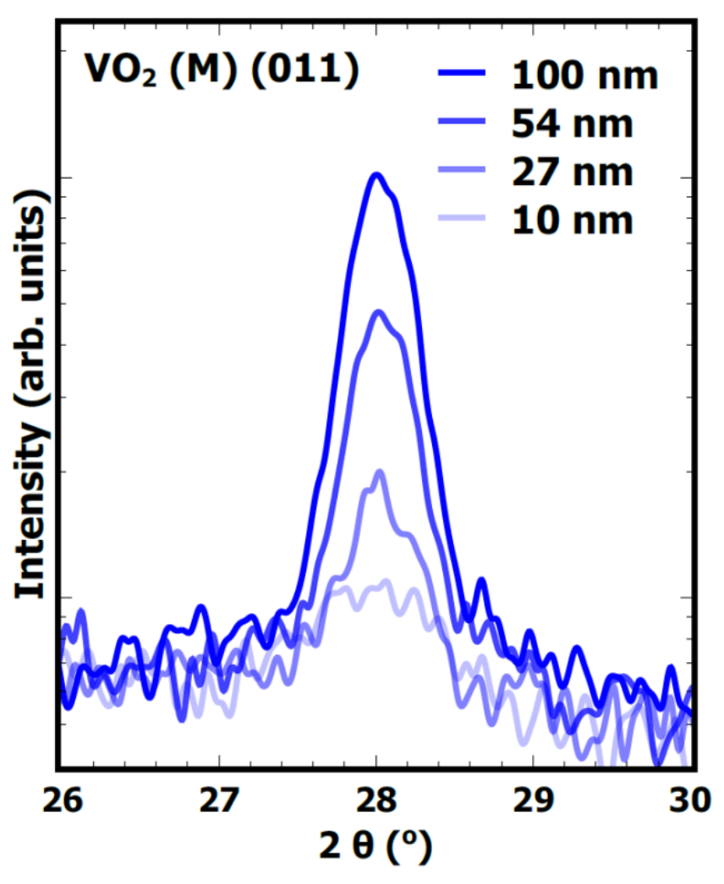
**FG1: 450°C – 30' in (Ar, $H_2$)**

**FG2: 450°C – 30' in (Ar, +$H_2$)**

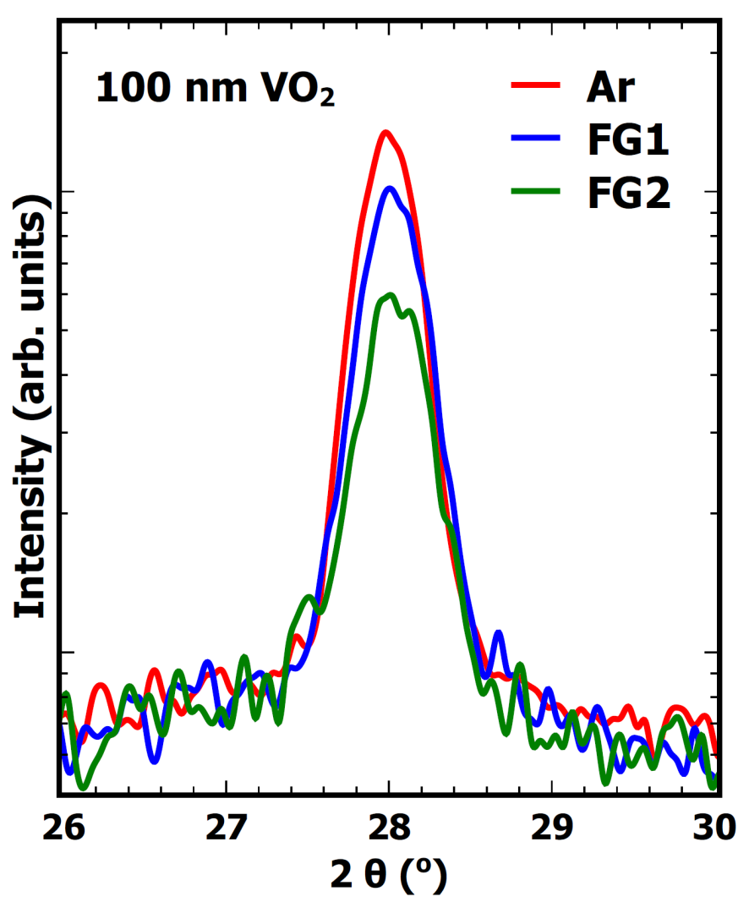
$VO_2$ films from 10 to 100 nm are prepared [2, 3]

## Results

### XRD

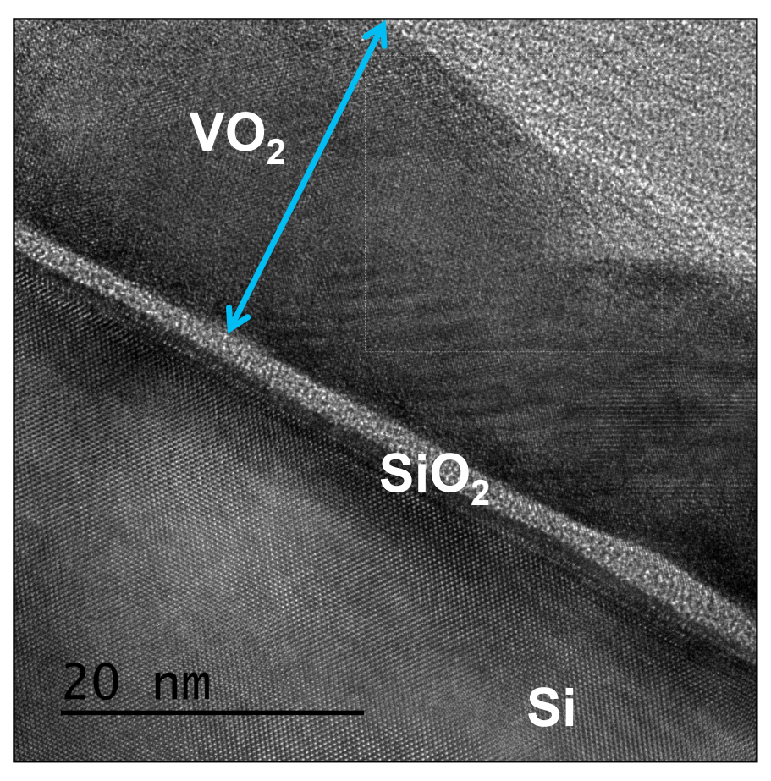


**$VO_2$ (011) preferred orientation**



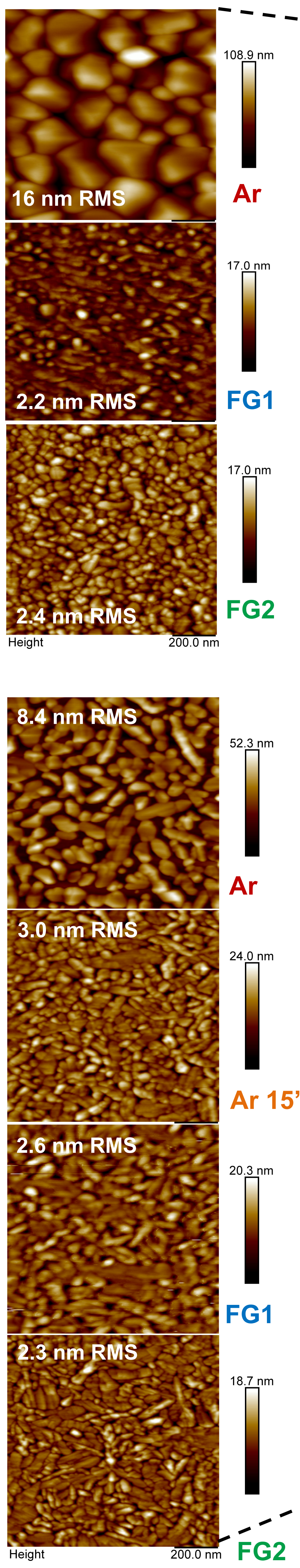
**(011) peak for different annealings**

### TEM

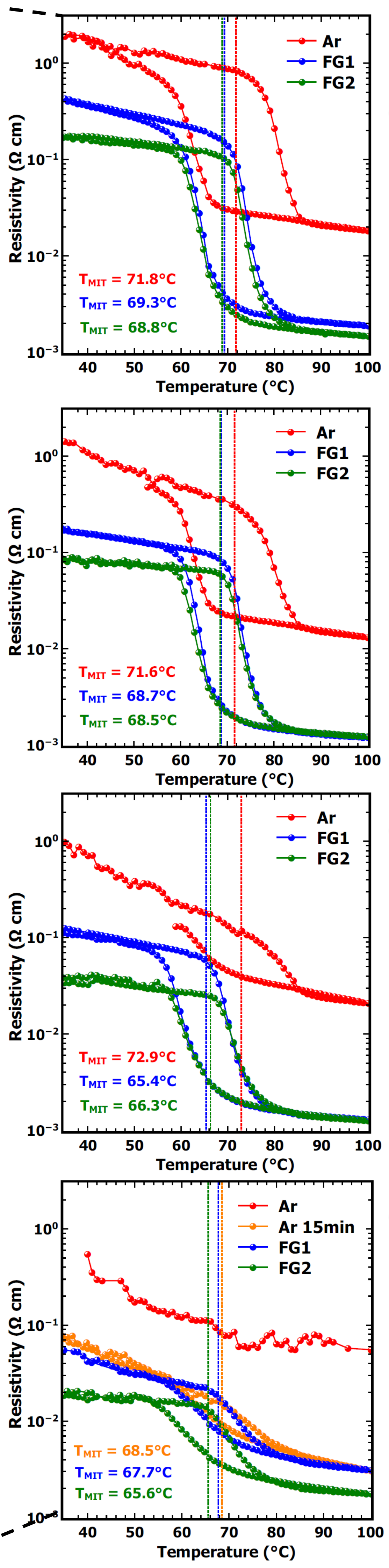


**Cross-section TEM image of 27 nm $VO_2$ (FG1)**

### AFM

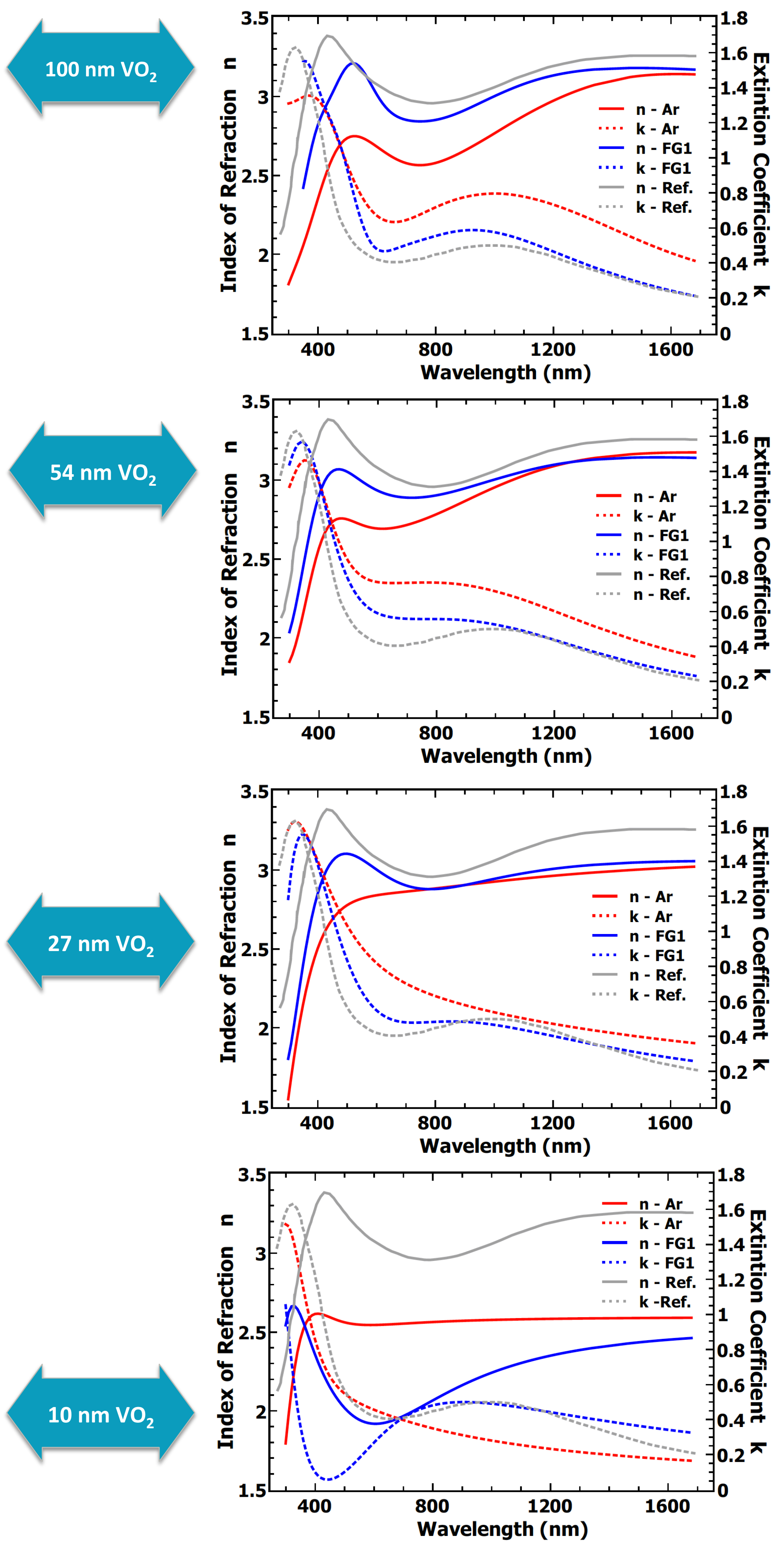


### MIT



**MIT in 10 nm films!**

### Spectroscopic Ellipsometry @RT



| | *n* (λ = 1550 nm) | | *k* (λ = 1550 nm) | |
|---|---|---|---|---|
| Temperature | 80 nm $VO_2$ | Ref. [4] | 80 nm $VO_2$ | Ref. [4] |
| 30 °C | 3.1 | 3.3 | 0.25 | 0.26 |
| 100 °C | 1.6 | 1.8 | 2.9 | 3.3 |

**Large change in optical constants across the transition!**

## Conclusion

- $VO_2$ films are prepared using different *ex-situ* annealing's at moderate temperatures, allowing its integration in Si devices.
- MIT and optical constants confirm a $H_2$ atmosphere helps regulating the stoichiometry of the films.

| Argon | FG1: (Ar, $H_2$) | FG2: (Ar, + $H_2$) |
|---|---|---|
| ✓ ΔR < $10^2$ across MIT | ✓ ΔR > $10^2$ across MIT | ✓ ΔR < $10^2$ across MIT |
| × No MIT in 10 nm films | ✓ MIT in 10 nm films | ✓ MIT in 10 nm films |
| × ↑ roughness | ✓ ↓ roughness | ✓ ↓ roughness |
| × $T_{MIT}$ > bulk | ✓ $T_{MIT}$ < bulk | ✓ $T_{MIT}$ ~ bulk |
| Mixed phases | | |

## References

[1] Wu *et al.* Chemical Society Reviews (2013), 42(12), 5157-5183.
[2] Van Bilzen *et al.* Thin Solid Films (2015), 591, 143-148.
[3] Homm *et al.* (in preparation).
[4] J. B. Kana Kana *et al.* Optics Communications (2011), 284, 807.

## Acknowledgments

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Sitoga PHRESCO

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