Optimizing Anatase-TiO_2 Deposition for Low-loss Waveguides

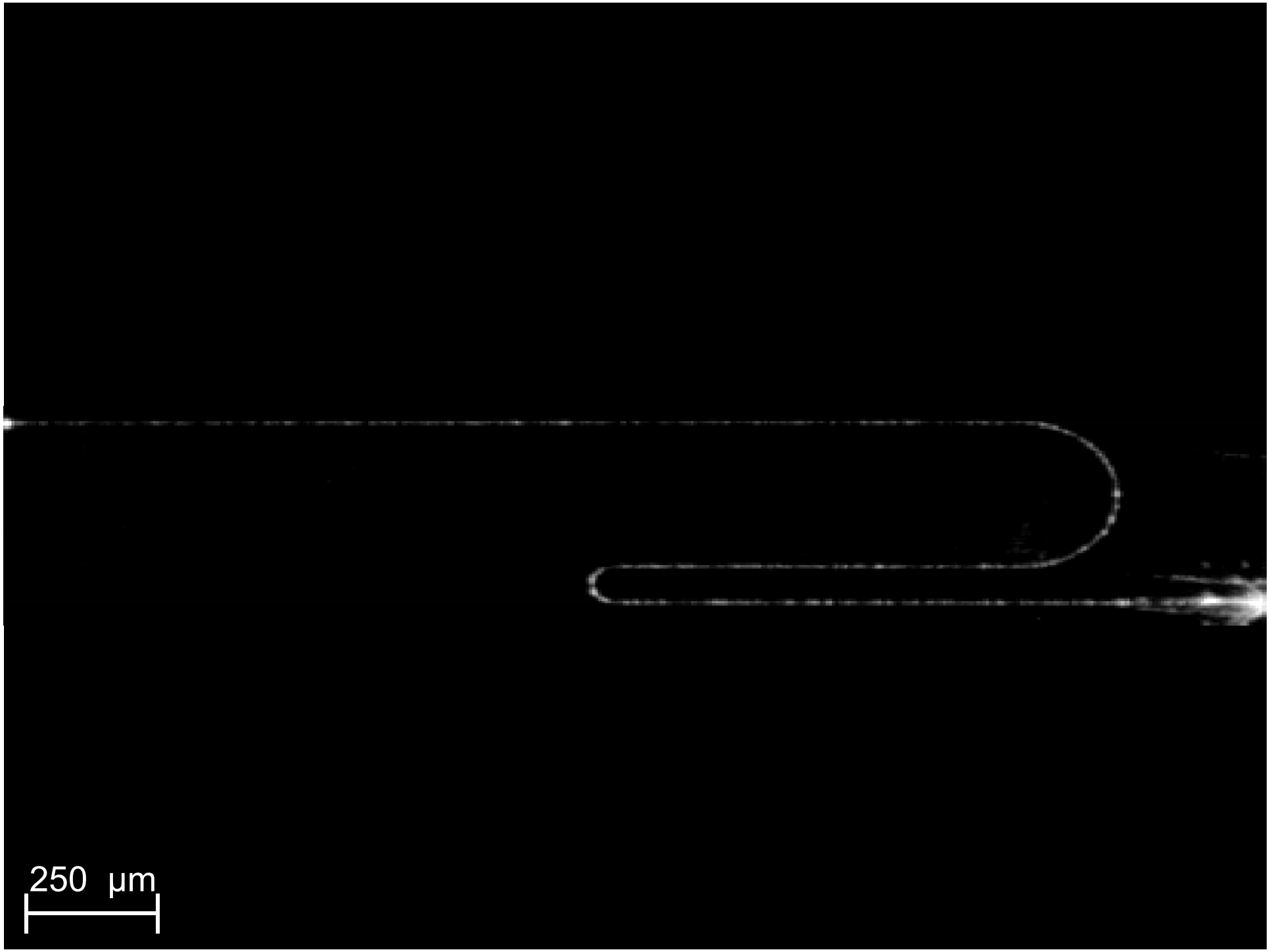
Lili Jiang

Christopher Evans, Orad Reshef, Eric Mazur

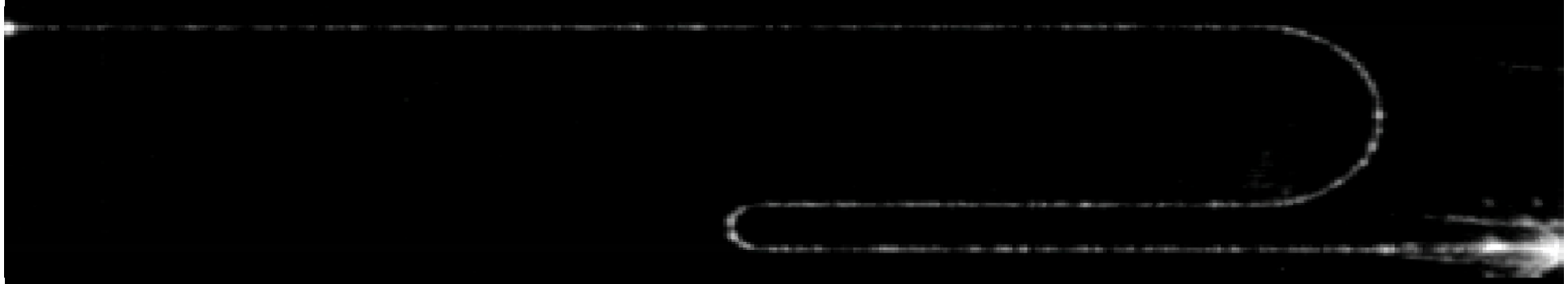
Harvard University

250 μm

Feb 5, 2013

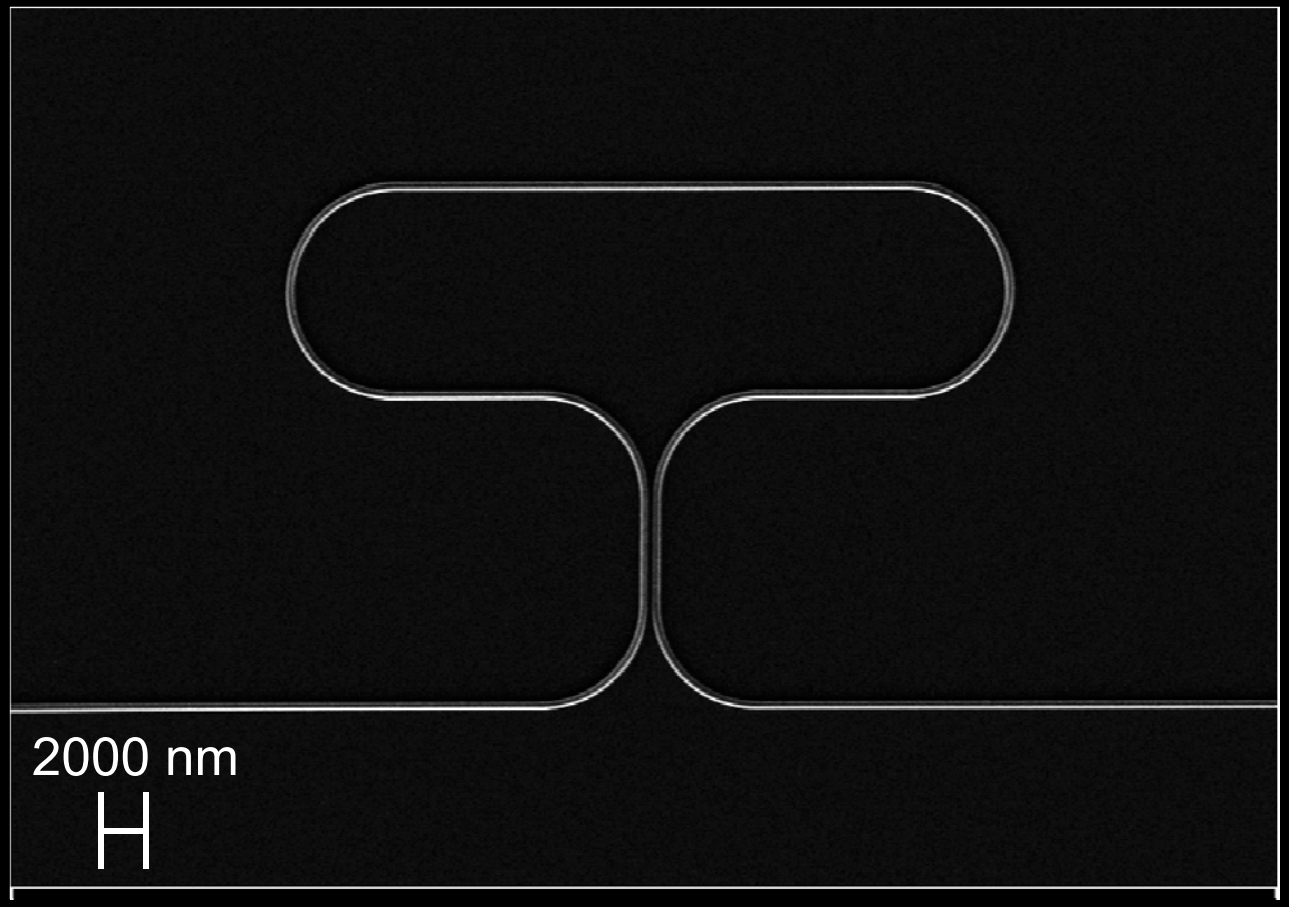

250 µm

TiO_2 Nonlinear Optics in Nanophotonic Devices



250 μm

Nanophotonic Devices



Optical XOR Gate

Input		output
A	B	
0	0	0
1	0	1
0	1	1
1	1	0

an XOR gate

TiO_2

- High transparency for $\lambda \geq 400$ nm
- High refractive index: $n_0 = 2.4$ at 800 nm
- High nonlinearity: 30 x SiO_2 at 1064 nm

Waveguide Fabrication

TiO_2
SiO_2

Material

TiO_2
Bulk

•Bradley, J. D. B et. al, "Submicrometer-wide amorphous and polycrystalline anatase TiO2 waveguides for microphotonic devices," Optics Express, 20, 23821-23831 (2012).

Waveguide Fabrication

TiO_2
SiO_2

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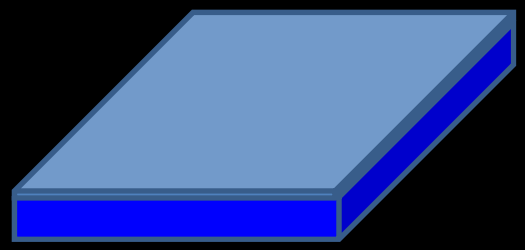
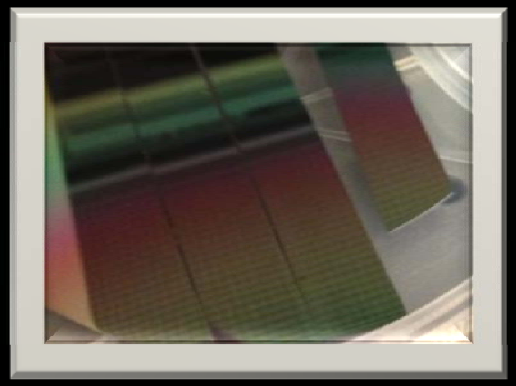
Deposition



TiO_2
Thin Film



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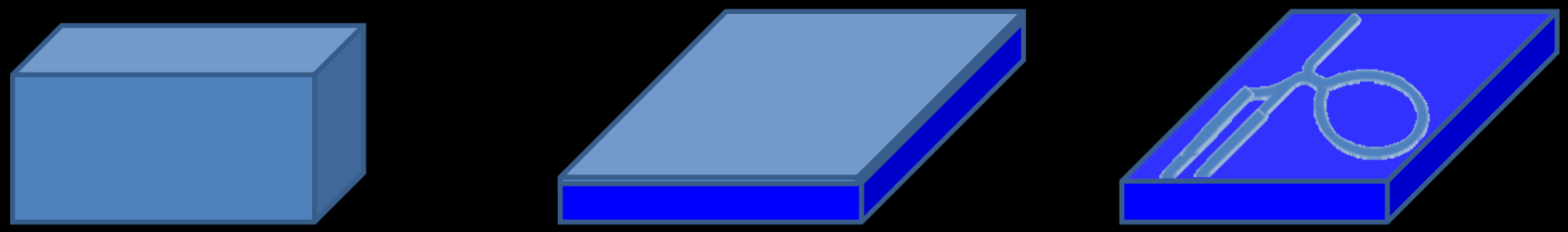
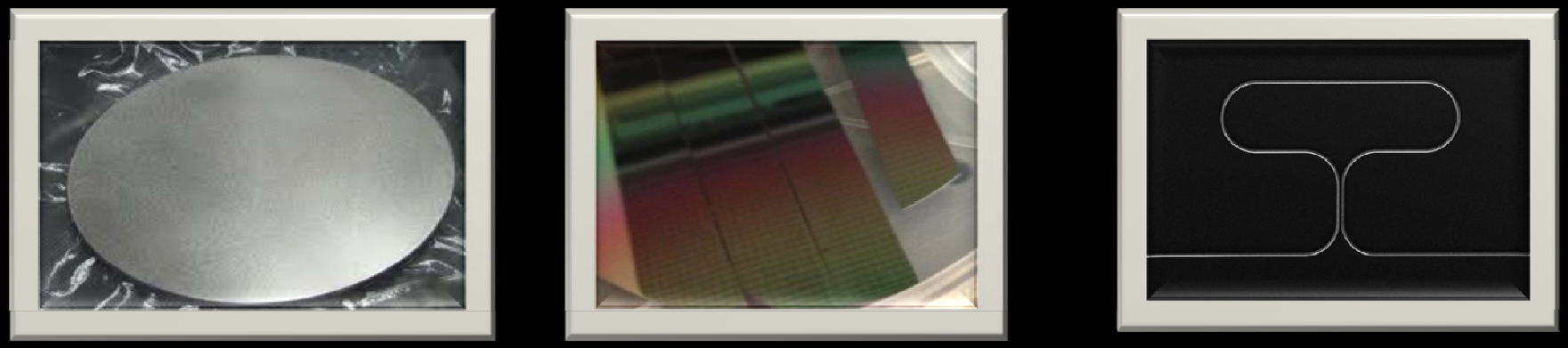
Waveguide Fabrication

TiO_2
SiO_2

Material	Deposition	Fabrication



TiO_2 Bulk	TiO_2 Thin Film	TiO_2 Waveguide



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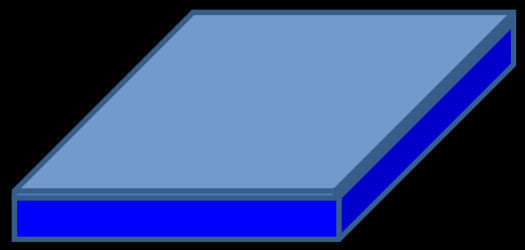
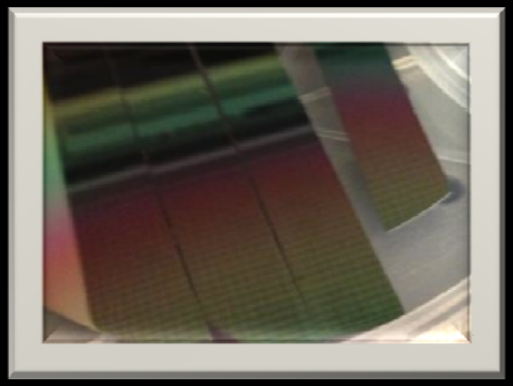
Waveguide Fabrication

TiO_2
SiO_2

Deposition



TiO_2
Thin Film



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Polymorphs of TiO_2

Polymorphs of TiO_2

Amorphous

Anatase

Brookite

Rutile

Polymorphs of TiO_2

Amorphous

Anatase

Brookite

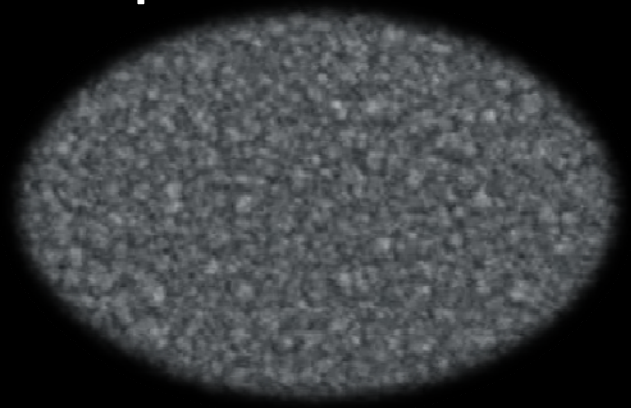
- Difficult to deposit

Rutile

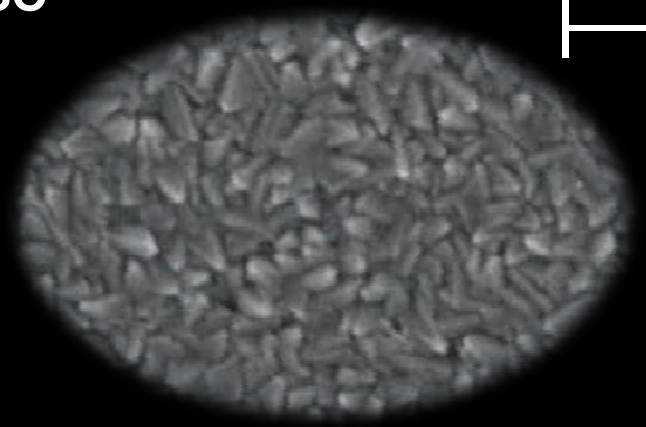
- Difficult to deposit

Polymorphs of TiO_2

Amorphous



Anatase



Brookite

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Rutile

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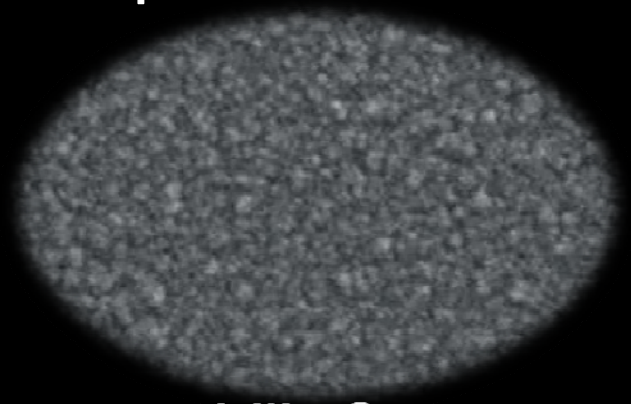
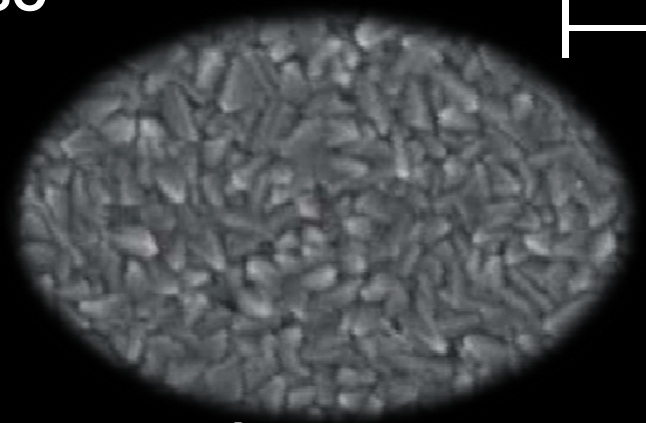
Polymorphs of TiO_2

Amorphous



- Stability?

Anatase



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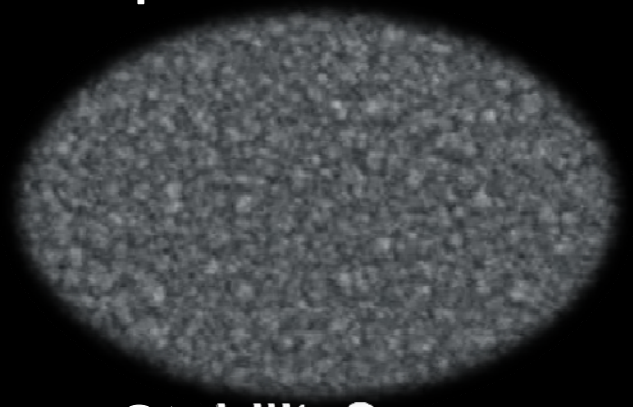
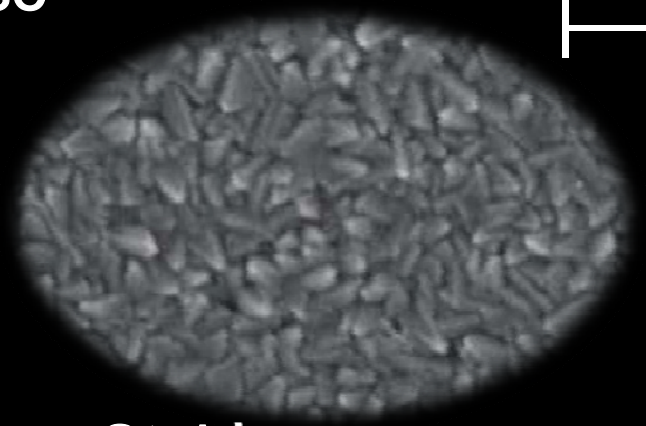
Amorphous



- Stability?
- High deposition rate

Anatase



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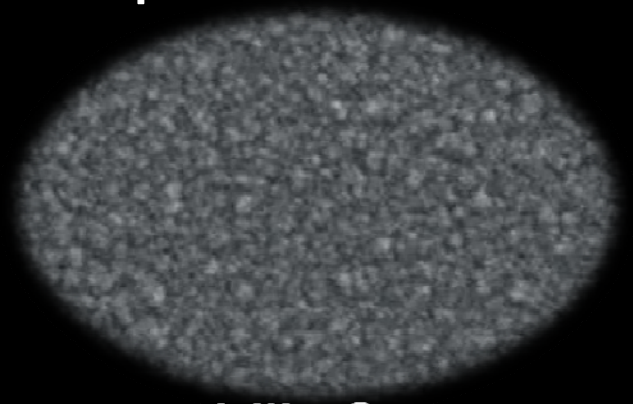
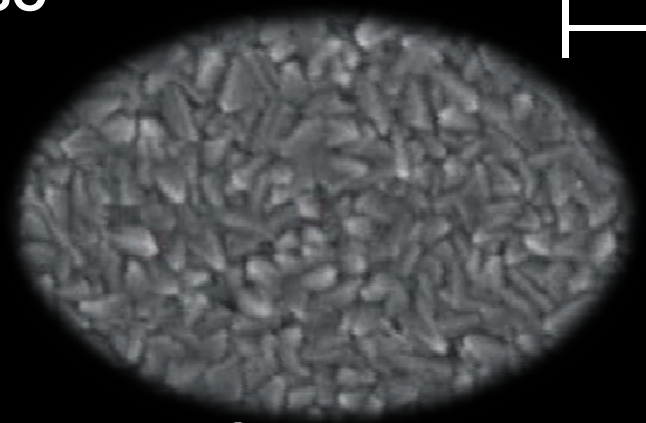


- Stability?
- High deposition rate
- Low Loss

Anatase



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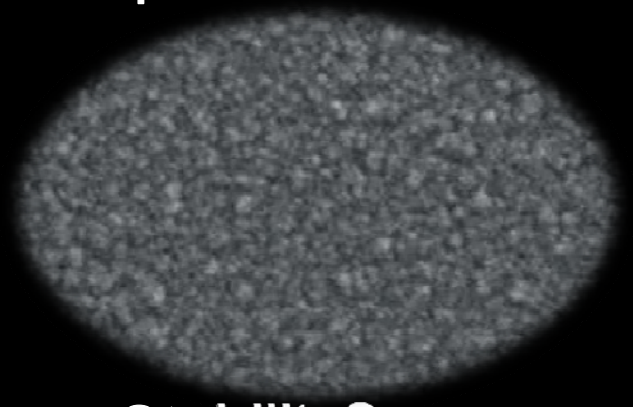

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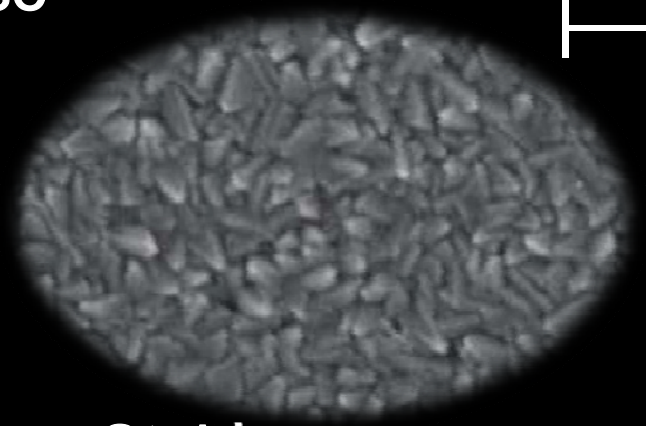
Anatase



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Polymorphs of TiO_2

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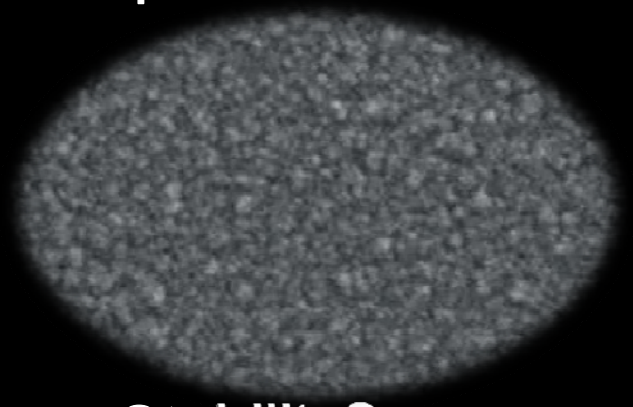

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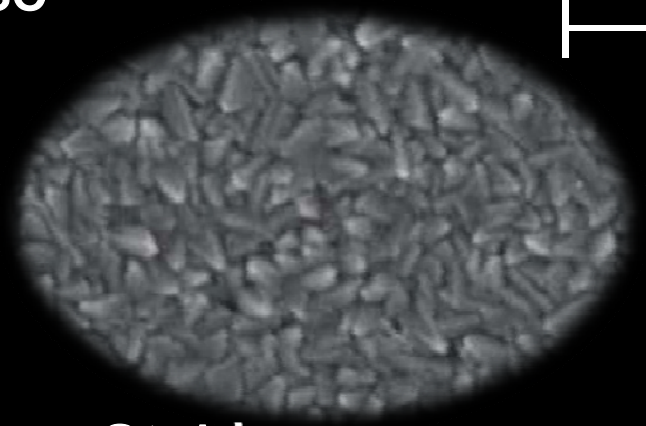


- Very Stable
- Low deposition rate
- High Loss

Brookite

- Difficult to deposit

Rutile

- Difficult to deposit

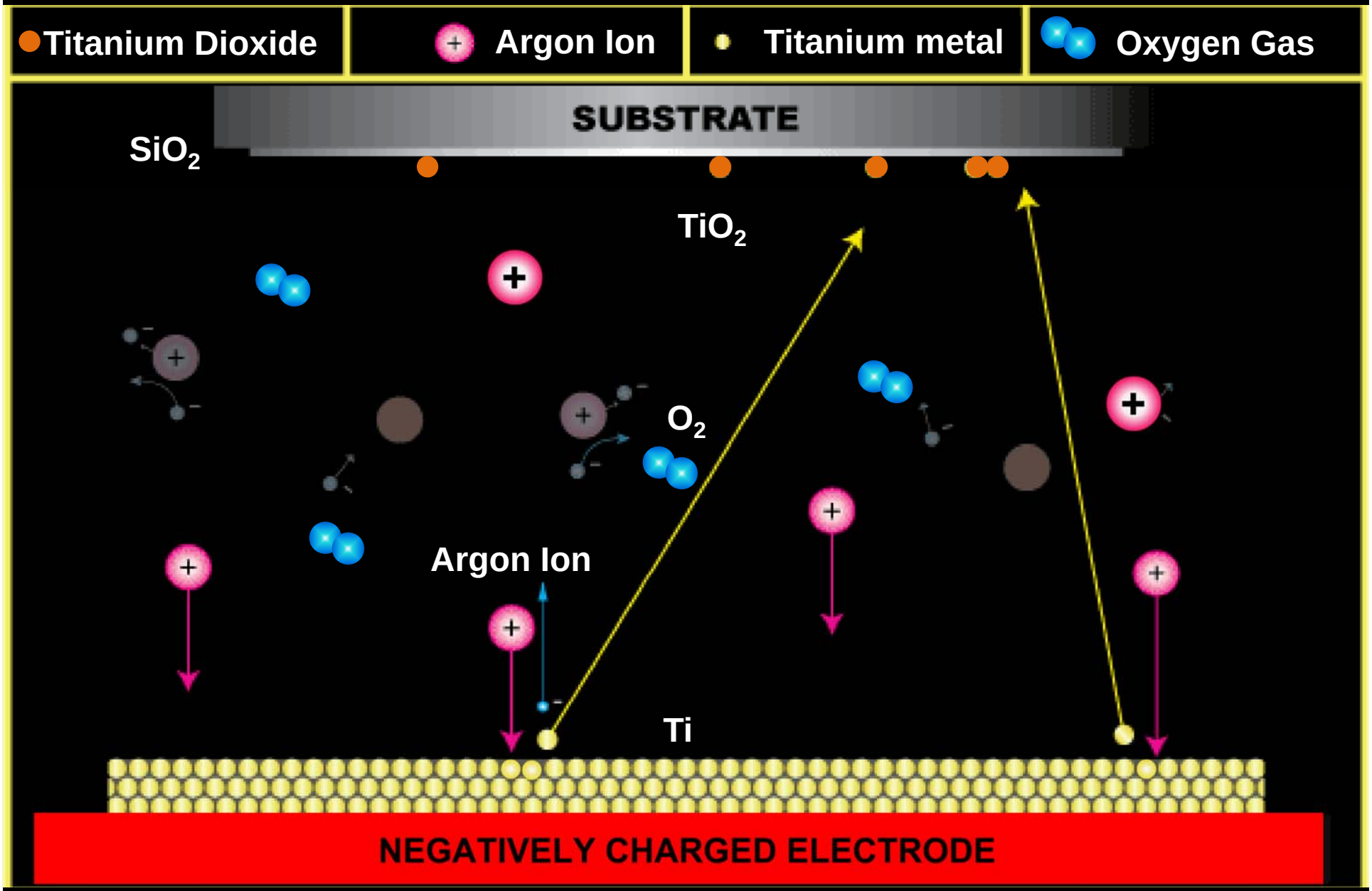
Objective

- To optimize Anatase-TiO_2 deposition for low-loss waveguides

Method and Material

Sputtering System

http://cns.fas.harvard.edu/facilities/tool_detail.php?MID=130



http://www.ajaint.com/whatis.htm

Method

- Reactive Sputtering: amorphous → Annealing: anatase

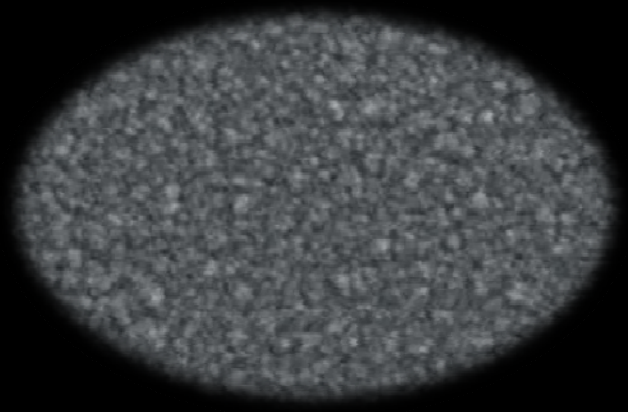
Method

- Reactive Sputtering: amorphous → Annealing: anatase

- Reactive Sputtering: anatase

Annealing

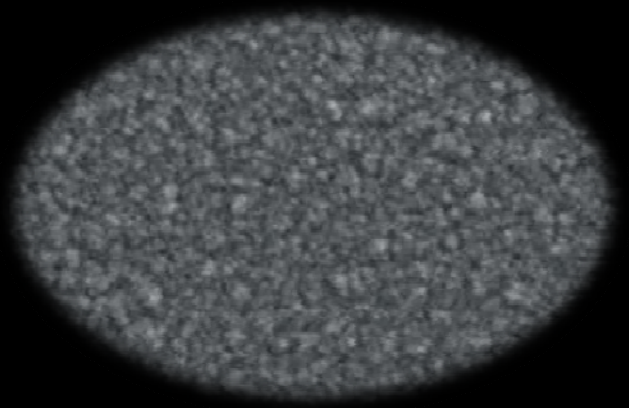
Amorphous



Annealing

Amorphous

Furnace



Heat

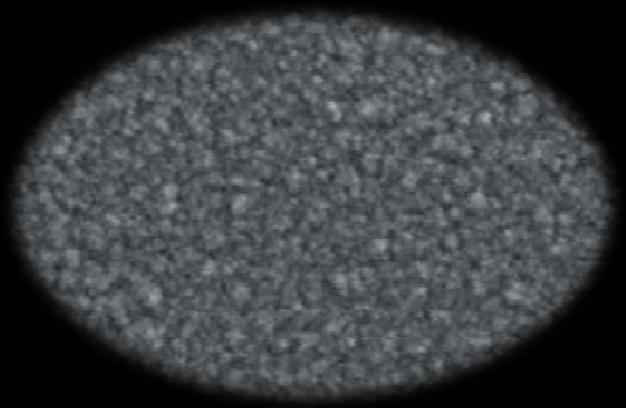
200 nm

Annealing

Amorphous

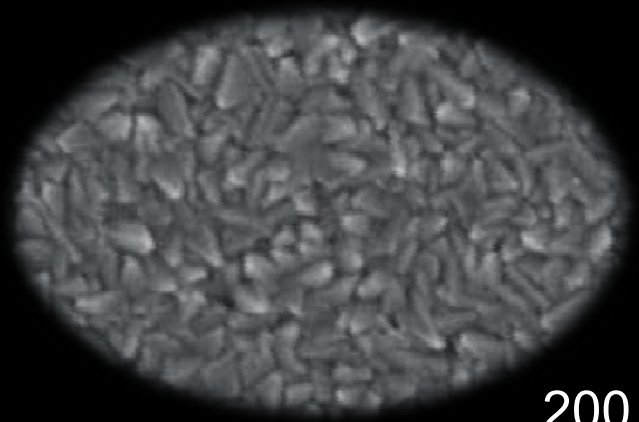
Furnace

Anatase



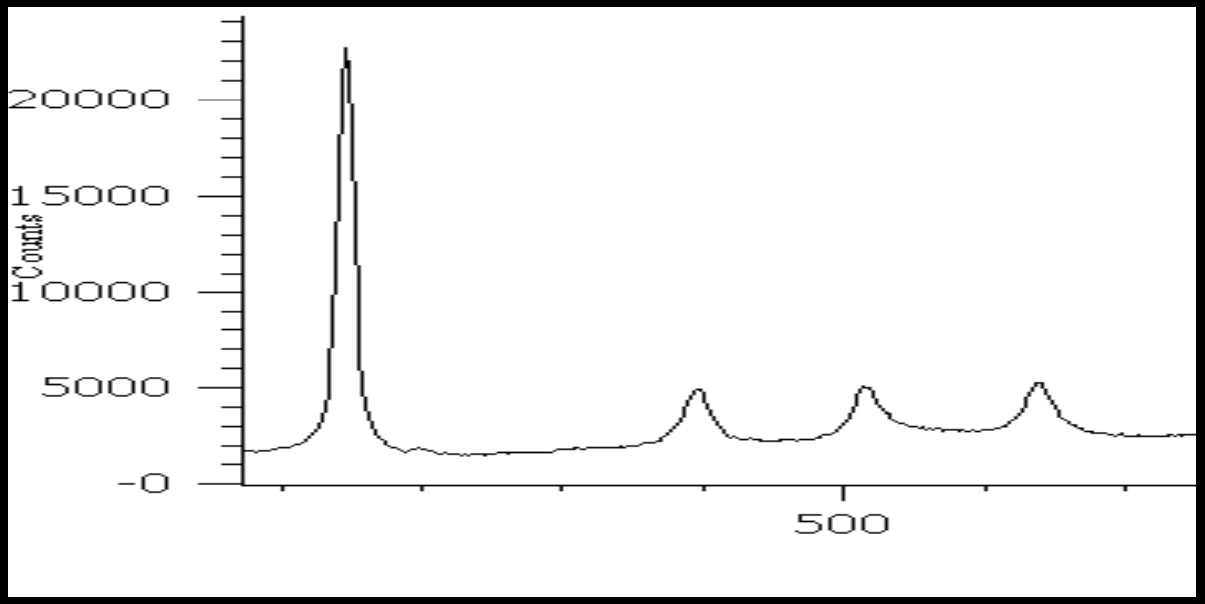
?

Heat

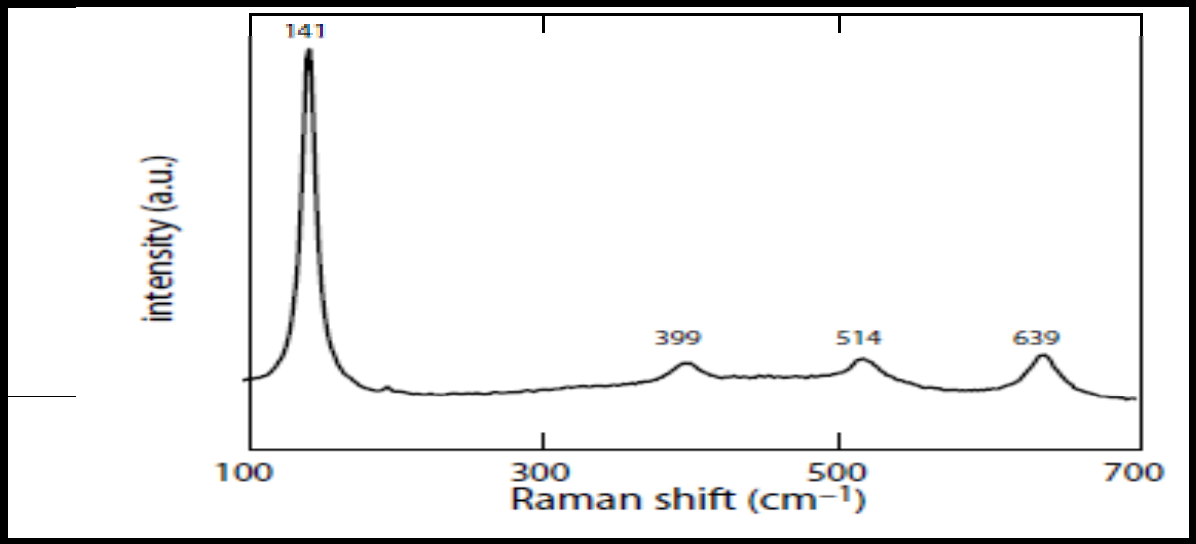


200 nm

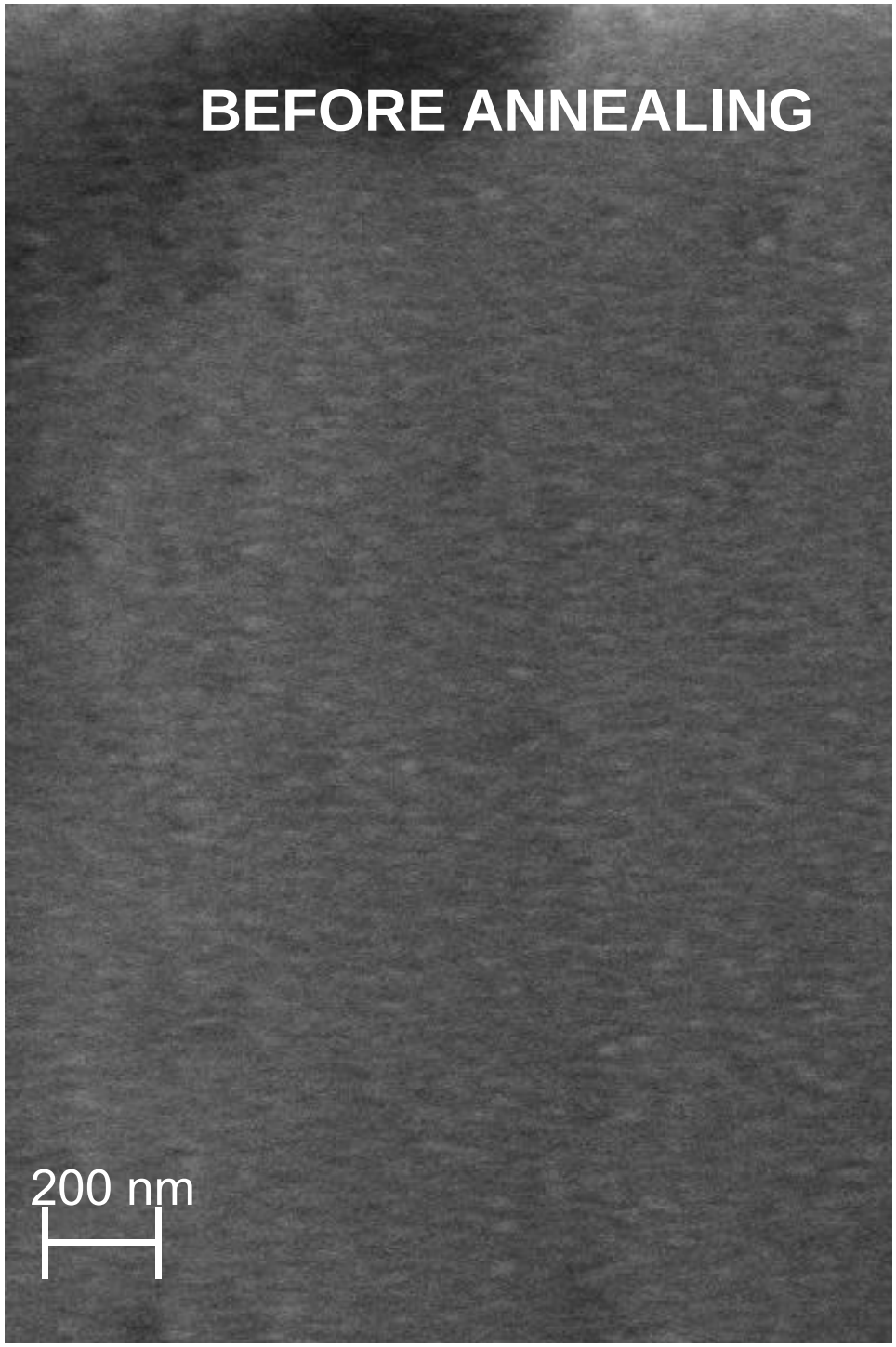
Annealing

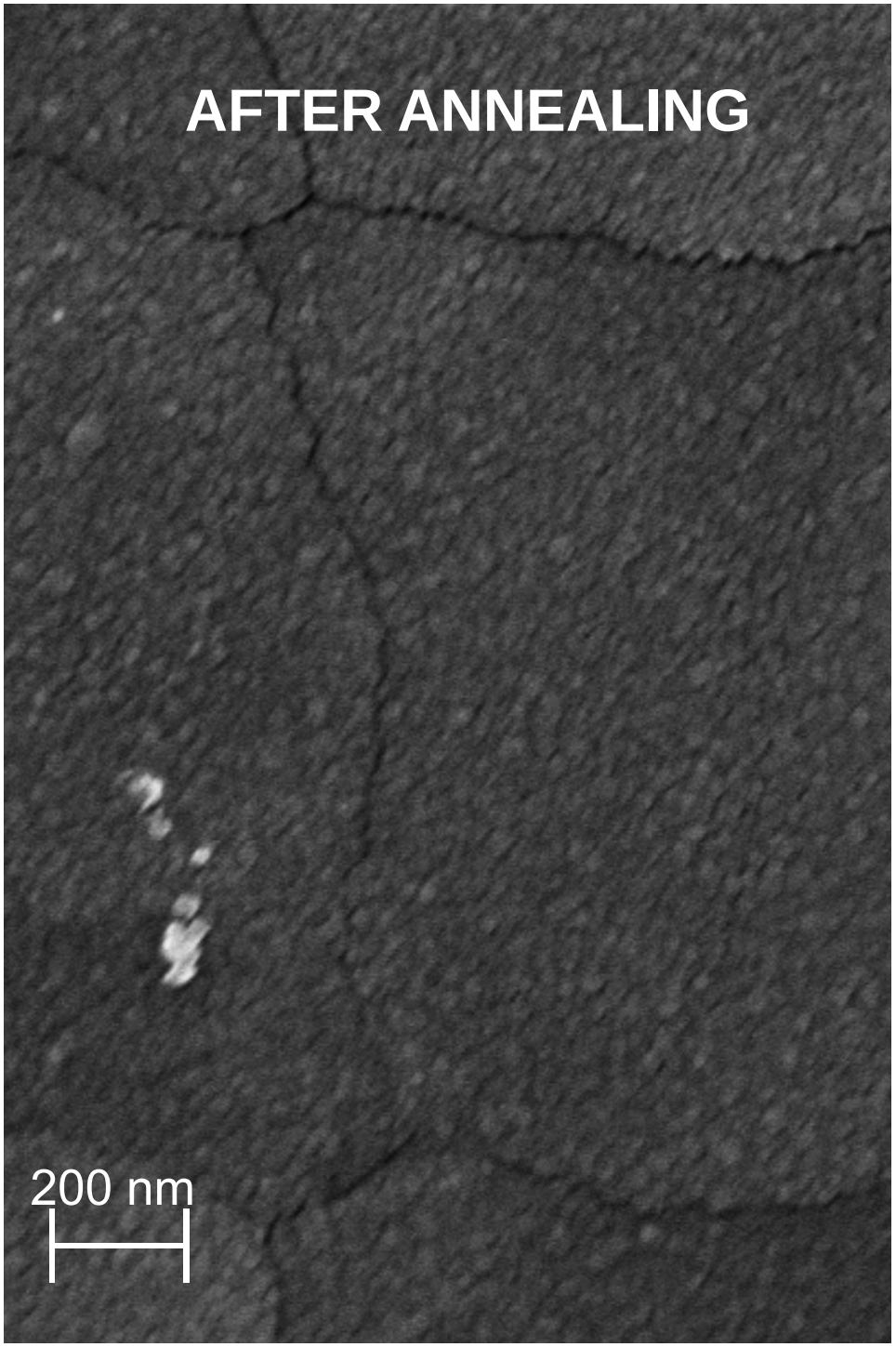


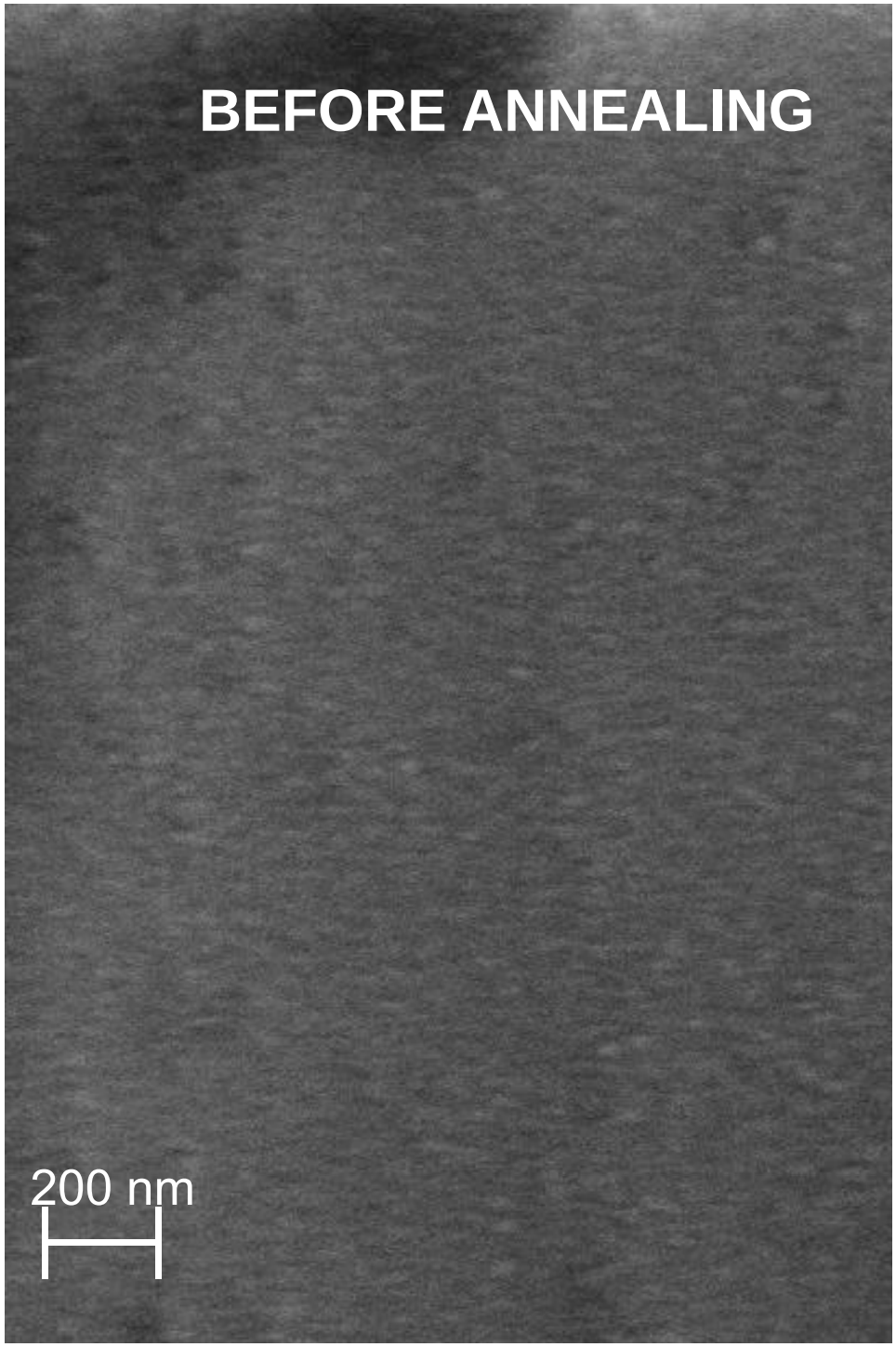
- Annealing at 500 ºC



- Standard Anatase Raman Spectrum


BEFORE ANNEALING
200 nm


AFTER ANNEALING
200 nm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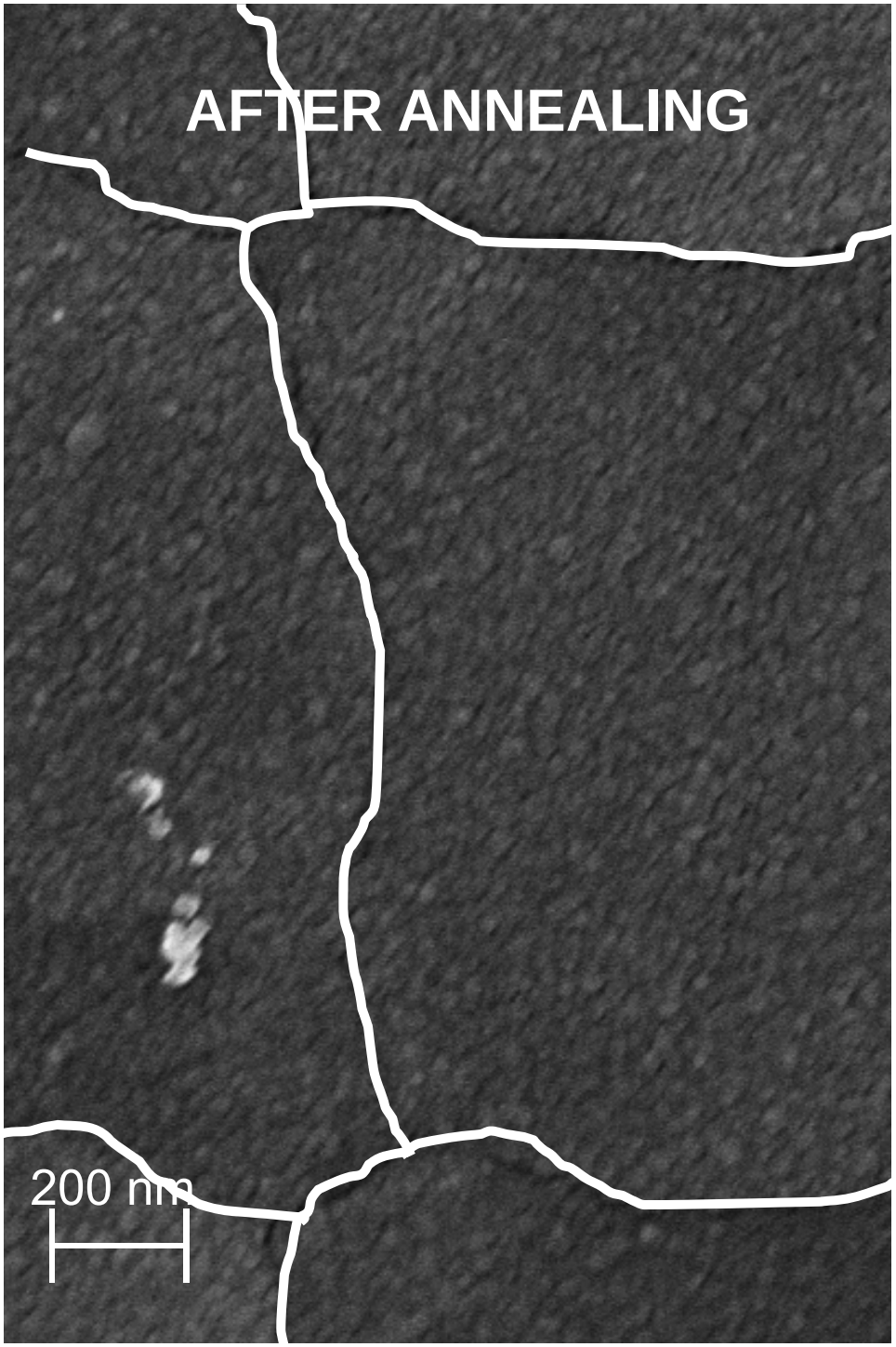
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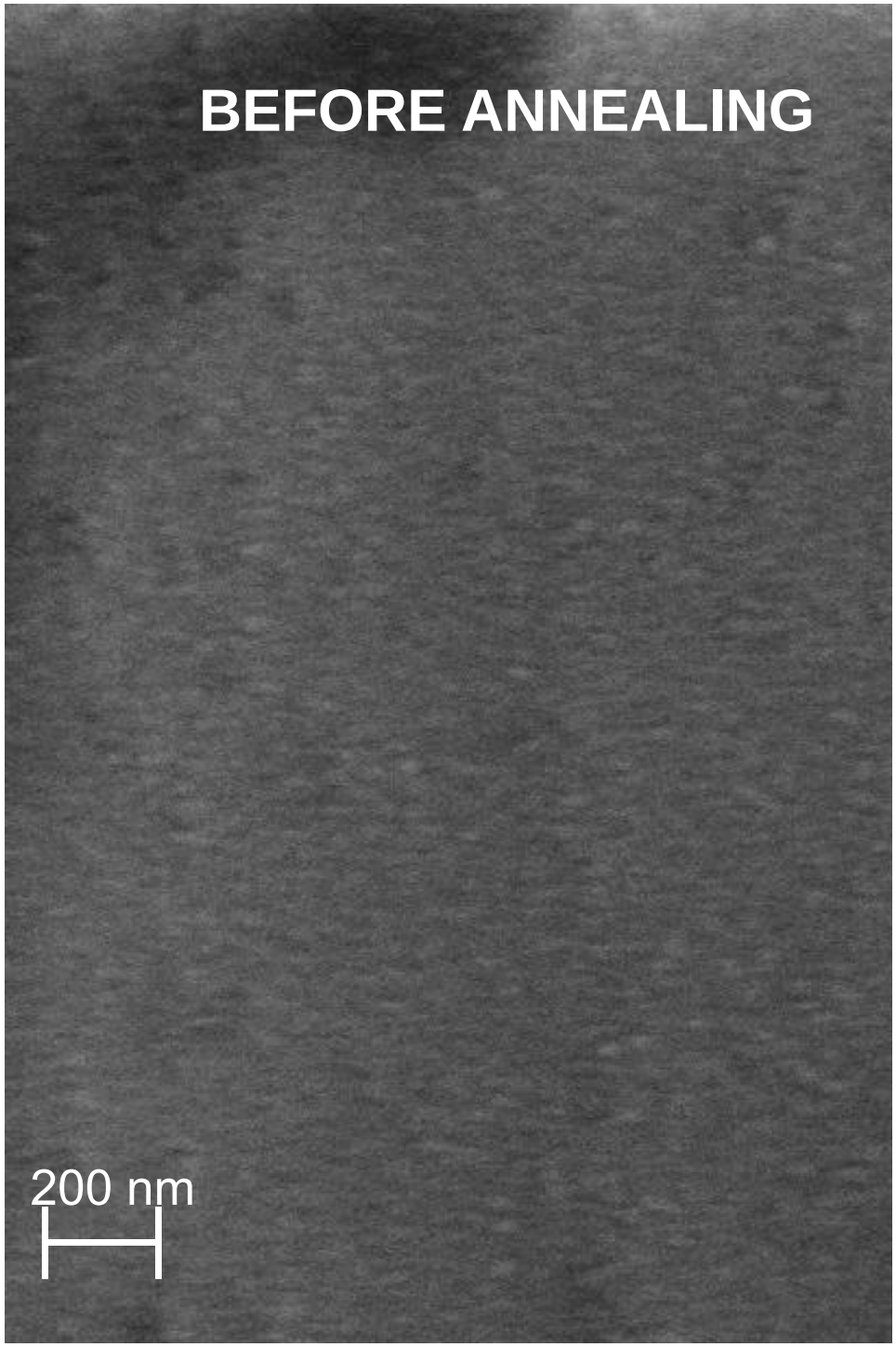
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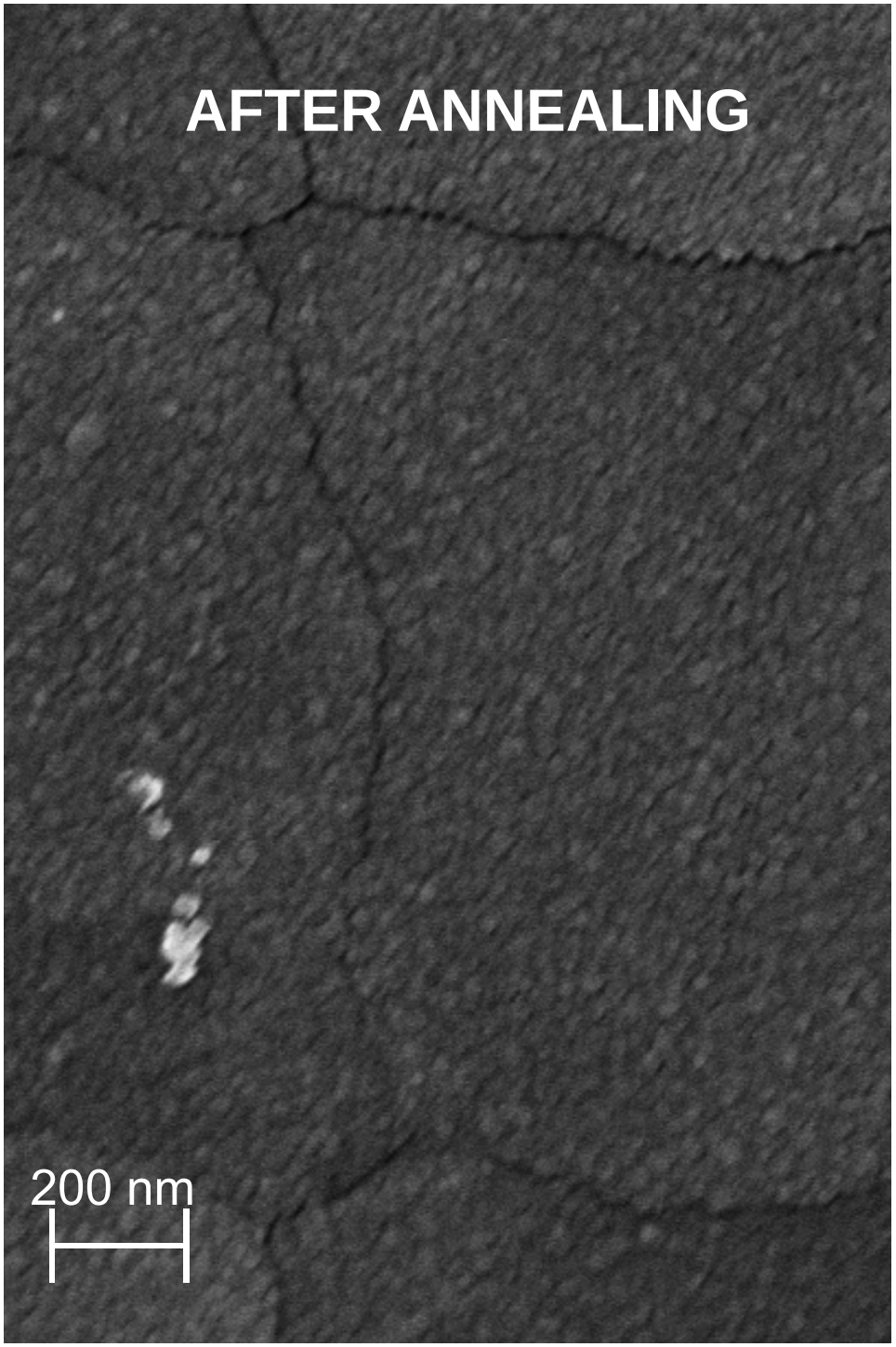
AFTER ANNEALING
200 nm

- Reactive Sputtering: amorphous → Annealing: anatase

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- Reactive Sputtering: anatase
  - Oxygen flow rate

- Reactive Sputtering: amorphous → Annealing: anatase

- Reactive Sputtering: anatase
  - Oxygen flow rate
  - Power

- Reactive Sputtering: amorphous → Annealing: anatase

- Reactive Sputtering: anatase
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  - Power
  - Temperature

- Reactive Sputtering: amorphous → Annealing: anatase

- Reactive Sputtering: anatase
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  - Power
  - Temperature
  - Chamber Pressure

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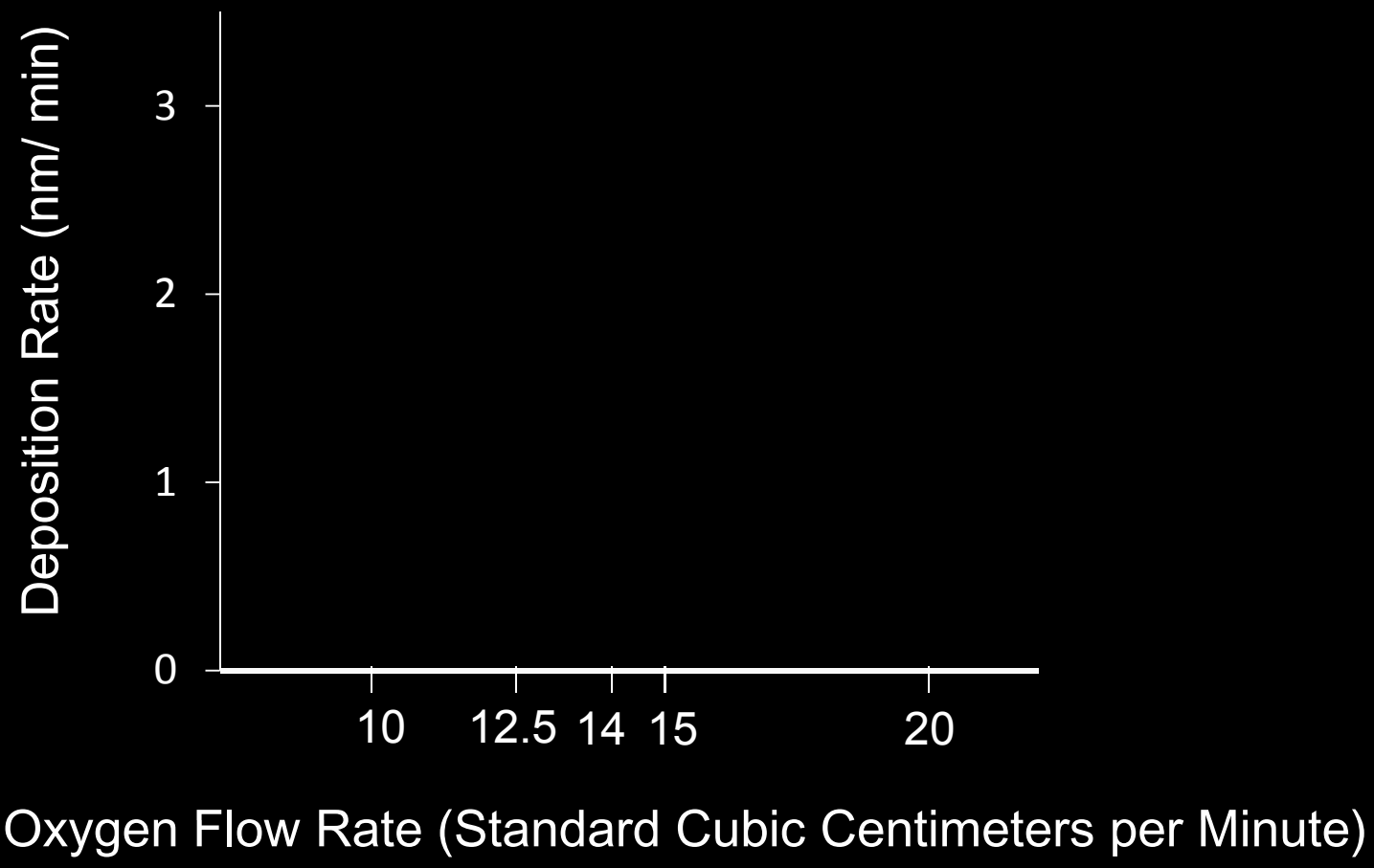
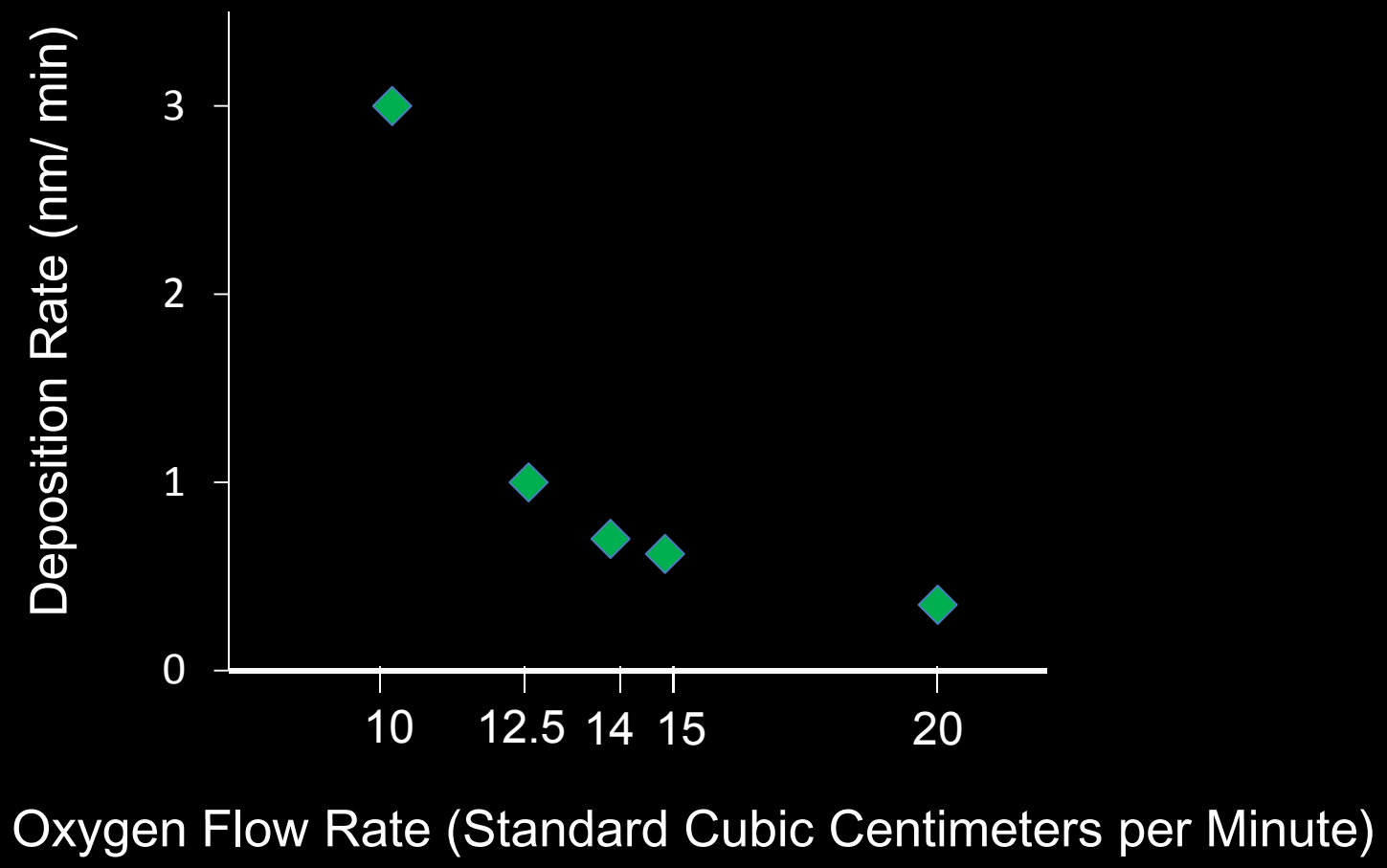
O_2 Flow Rate and Deposition Rate

O_2 Flow Rate and Deposition Rate

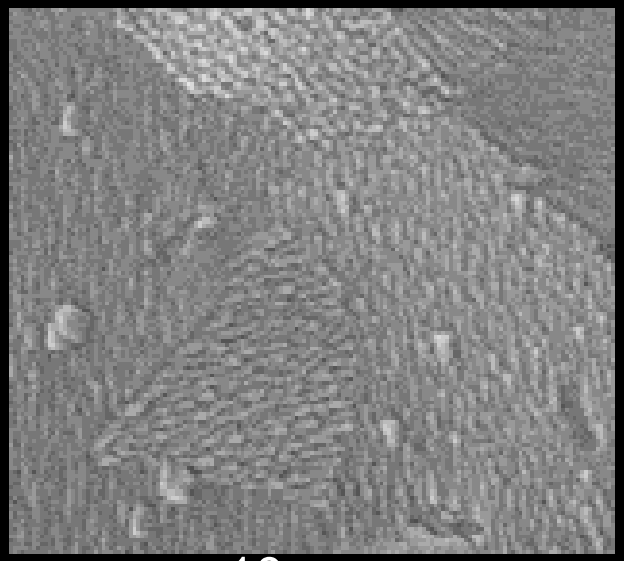


O_2 Flow Rate and Deposition Rate

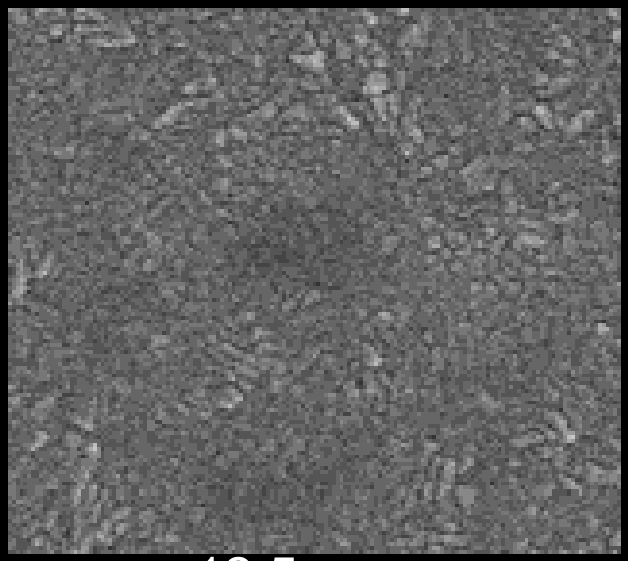


O_2 Flow Rate and Grain Size

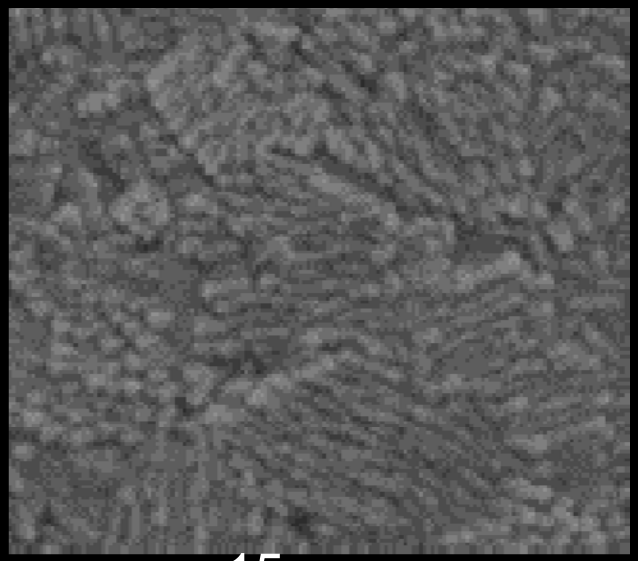
O_2 Flow Rate and Grain Size



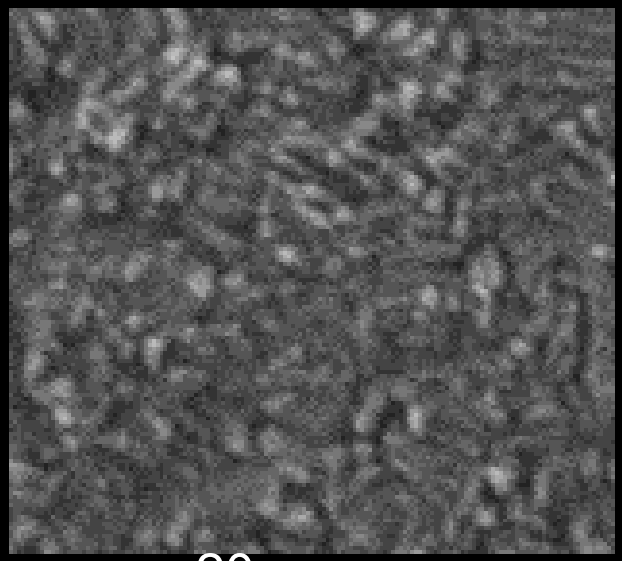
10 sccm



12.5 sccm



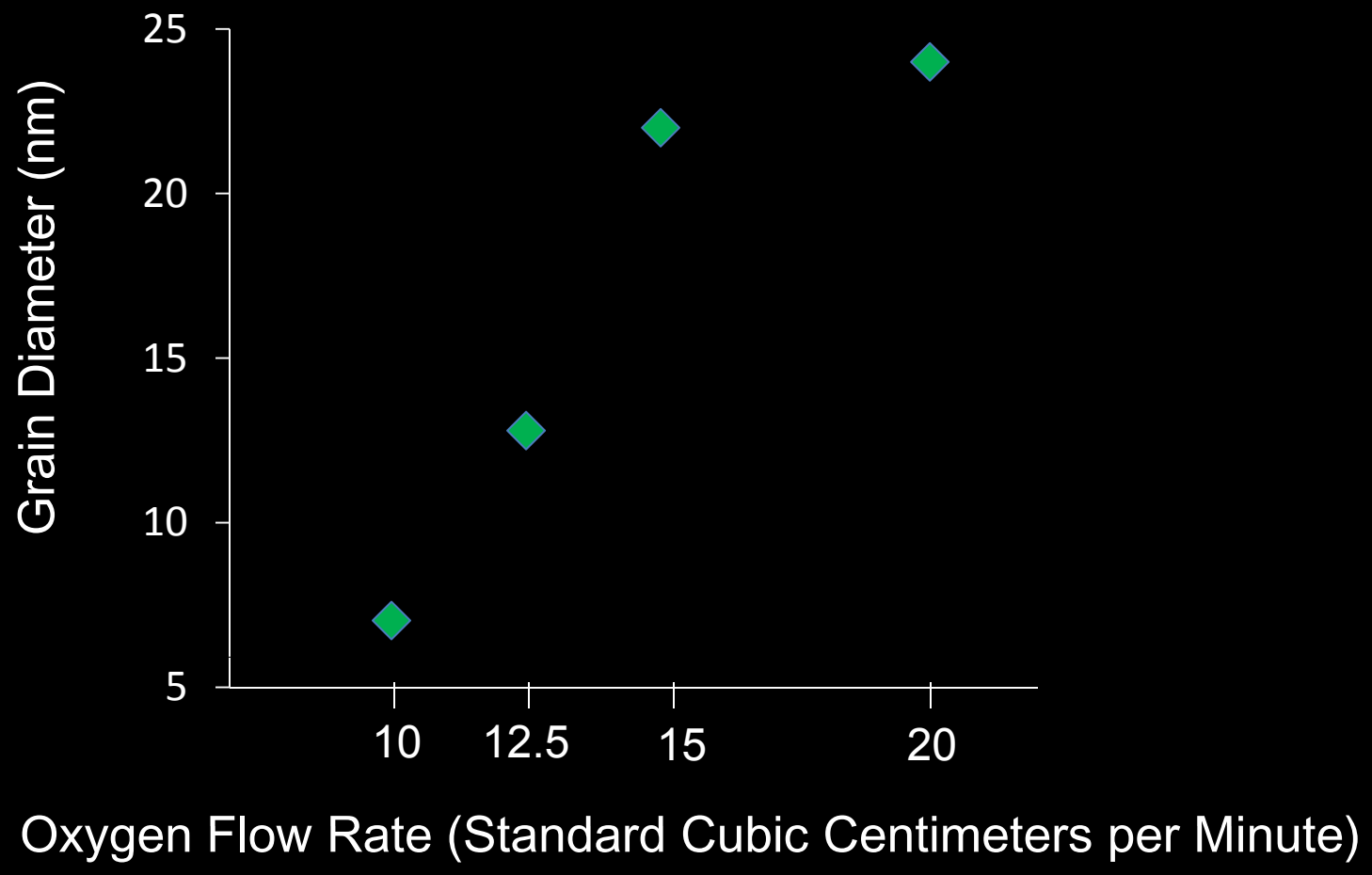
15 sccm



20 sccm

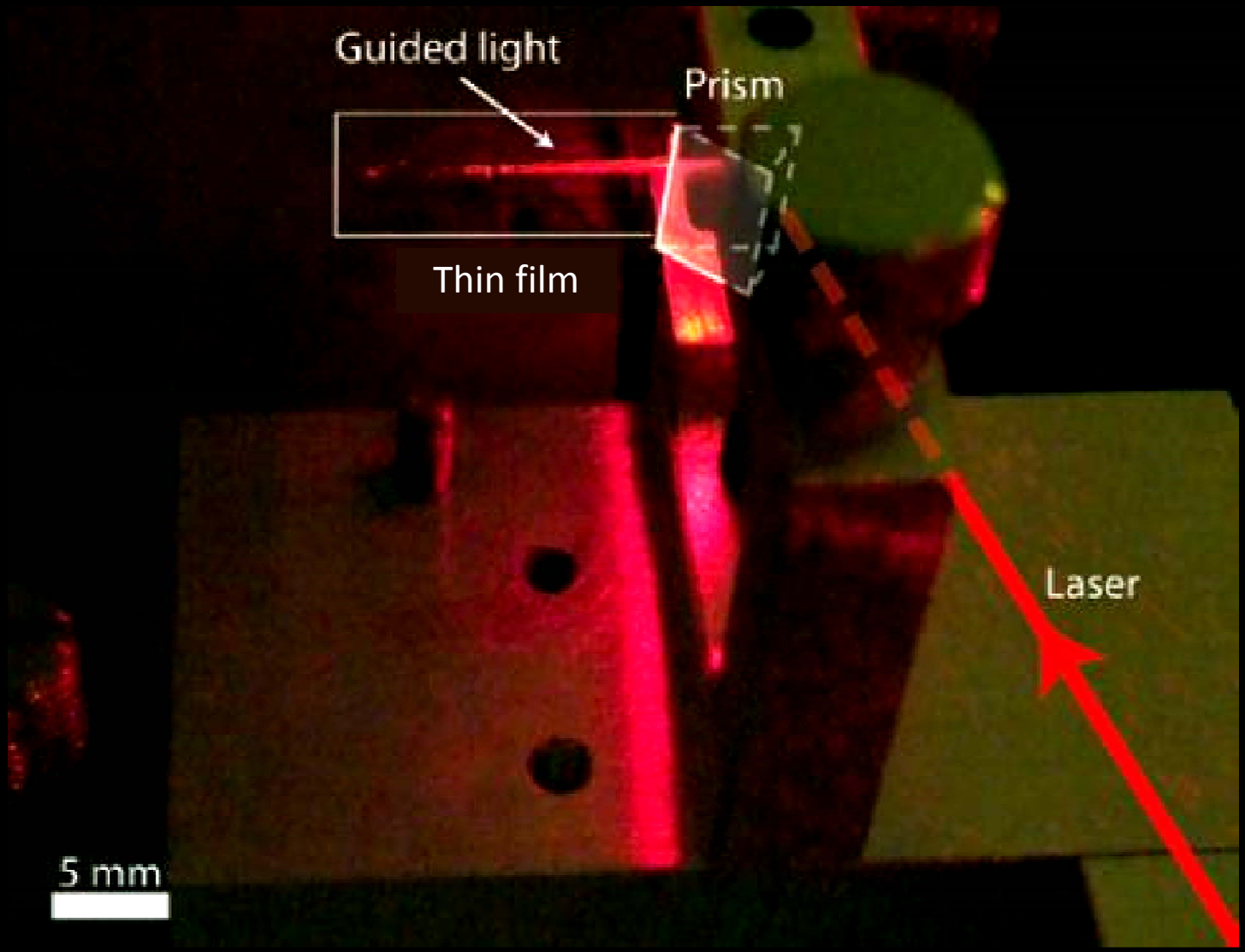
100 nm

O_2 Flow Rate and Grain Size



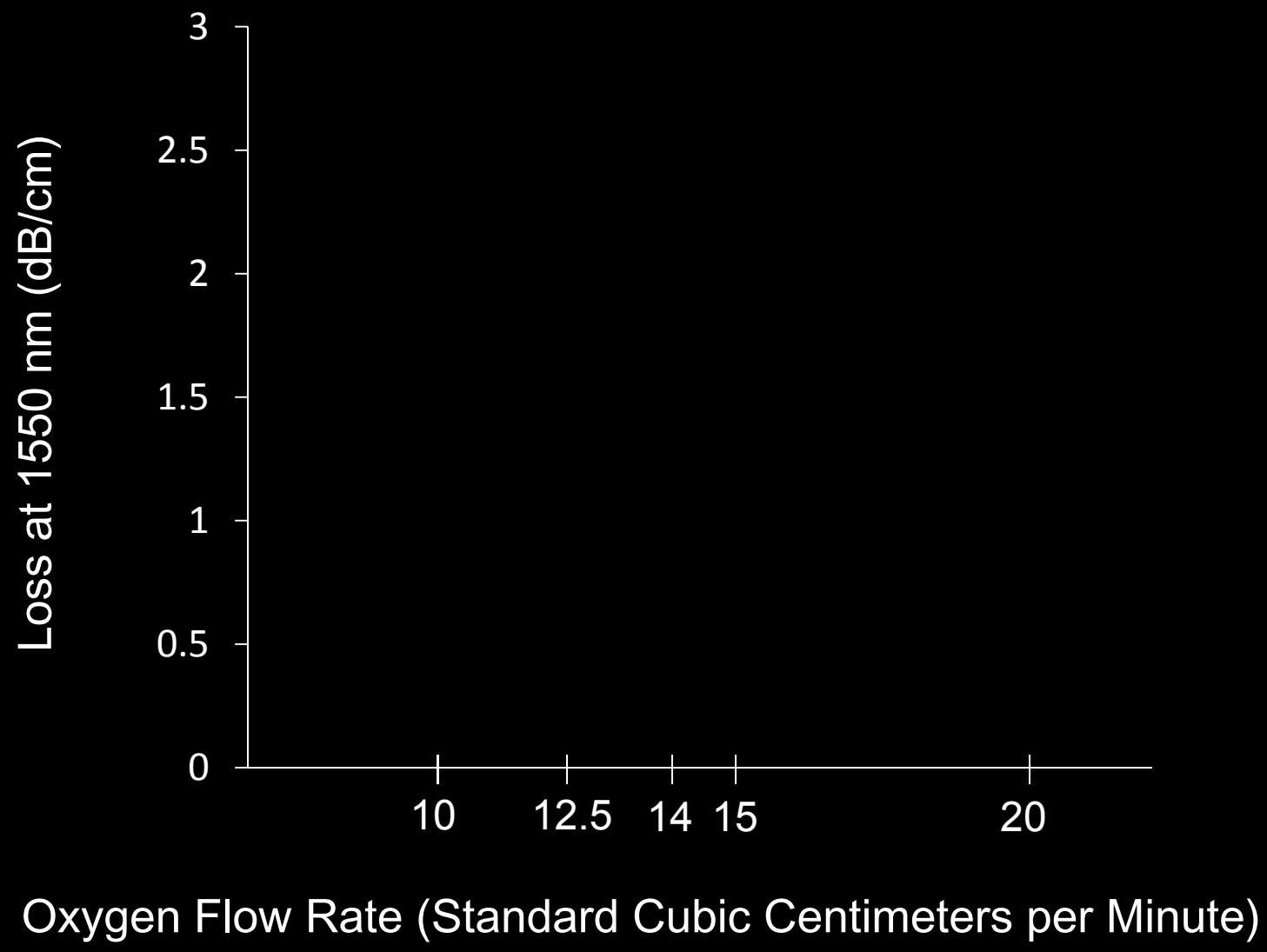
Lower losses?

Loss Measurement

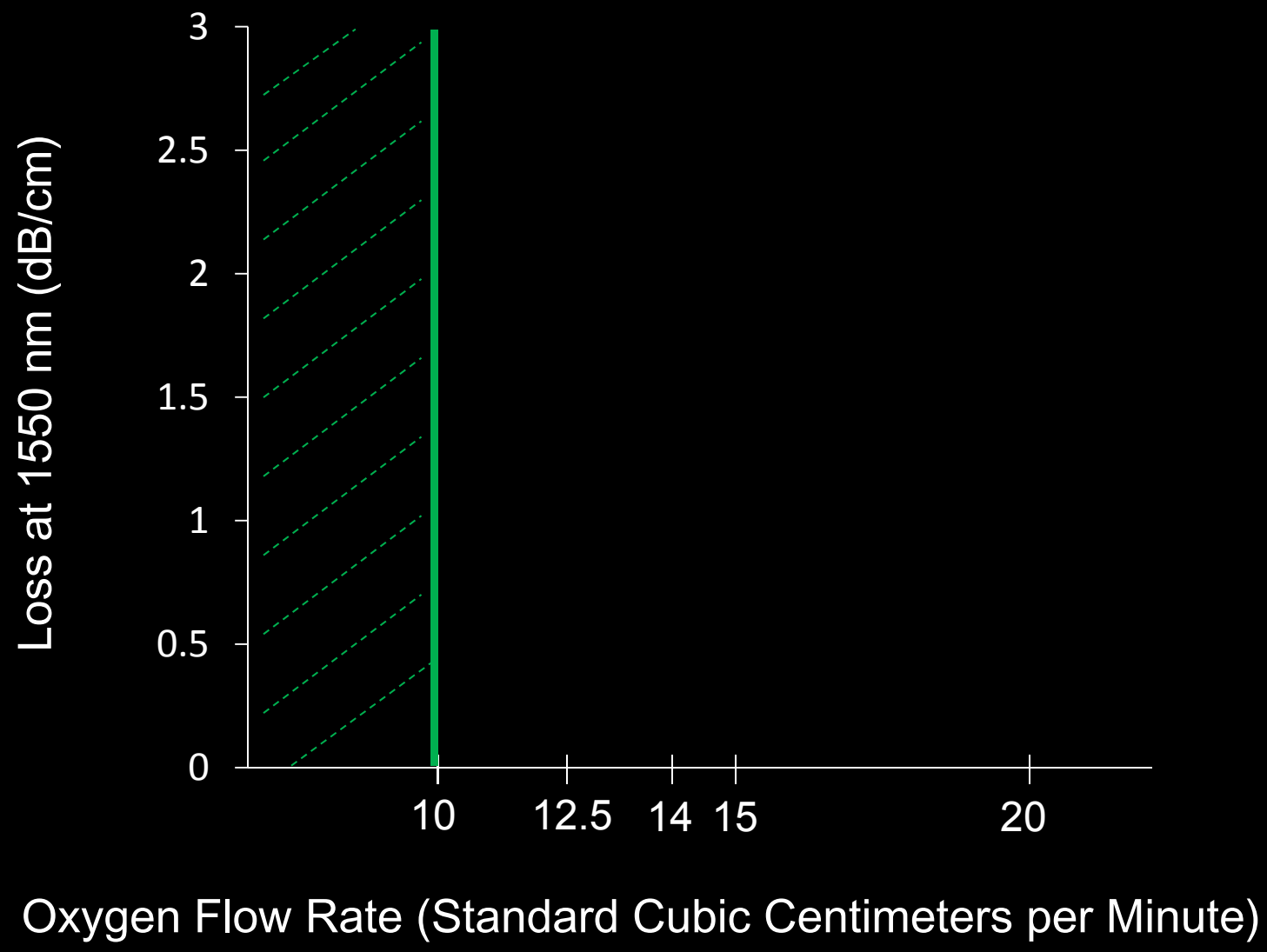


O_2 Flow Rate and Loss

O_2 Flow Rate and Loss



O_2 Flow Rate and Loss



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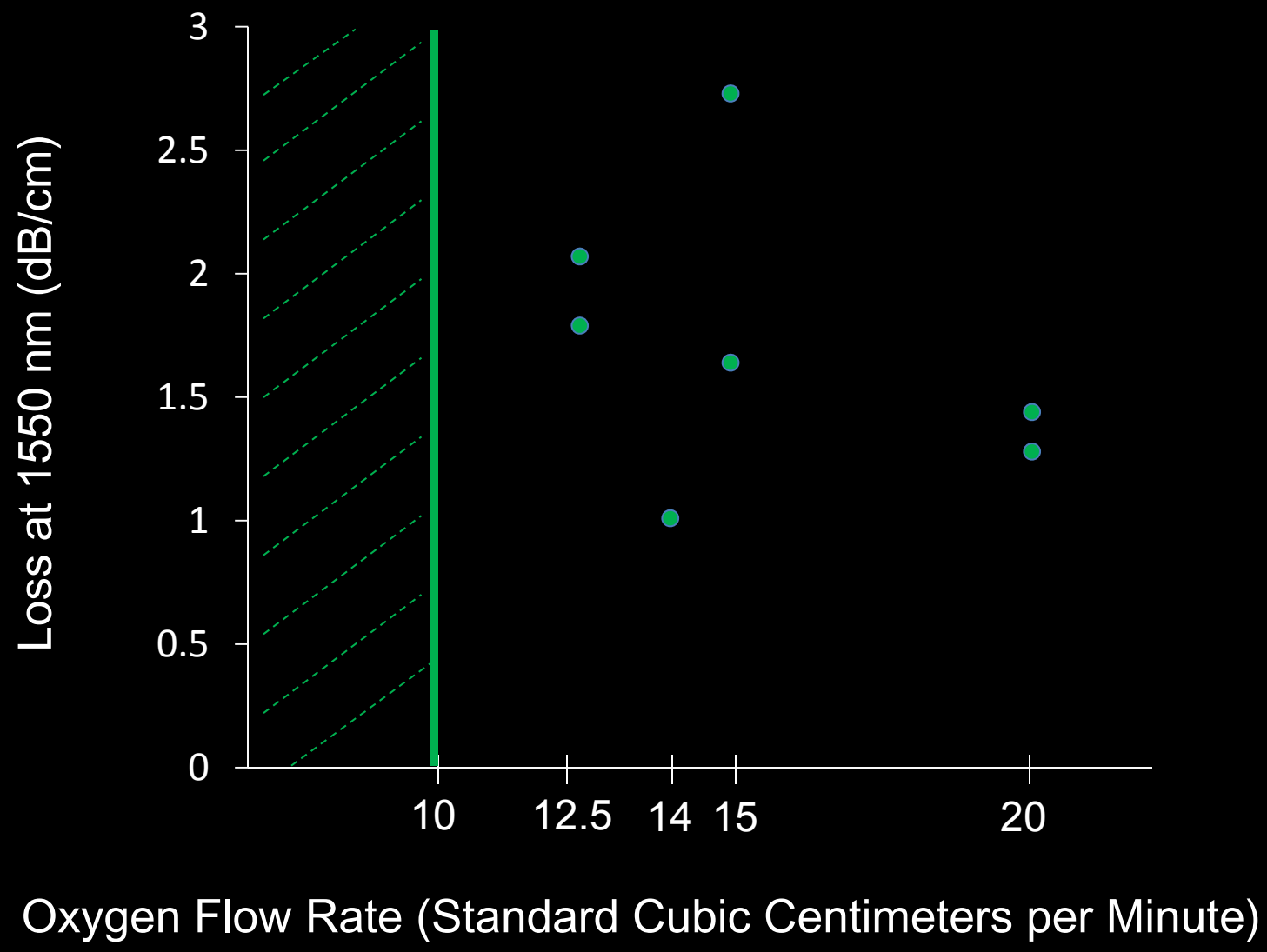

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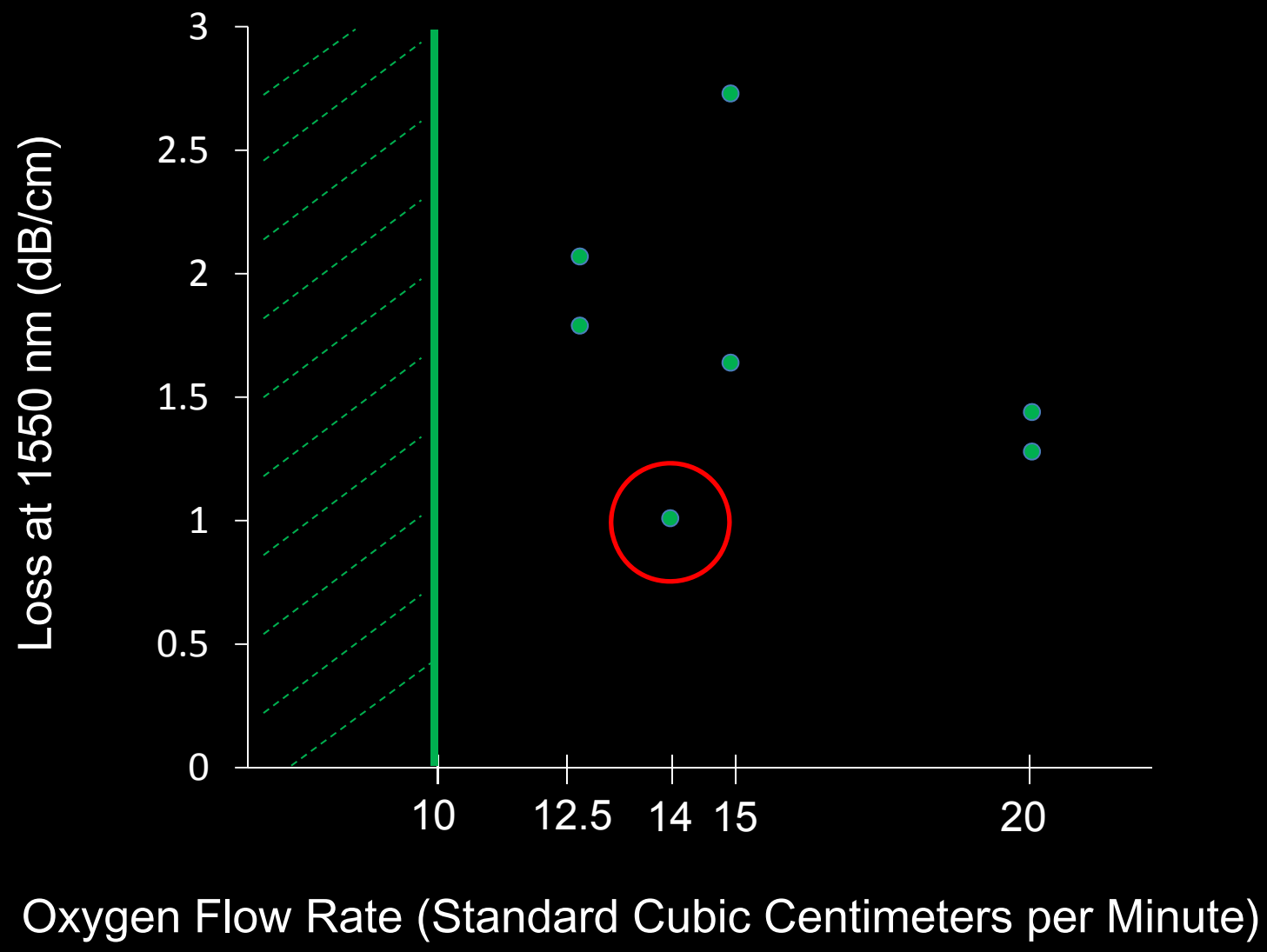

Deposition Recipe

Sputtering System

Power: 200 *W*

Ar: 40 *sccm*

O_2 : 14 *sccm*

Pressure: 2 *mT*

Temperature: 350 ^{o}C

Deposition Recipe

Sputtering System

Power: 200 *W*

Ar: 40 *sccm*

O_2 : 14 *sccm*

Pressure: 2 *mT*

Temperature: 350 ^{o}C

>>

Dep Rate: 0.7 *nm/min*

Loss (dB/cm): 1 *dB/cm*

Conclusions

- Nanoscaled cracks on the surface of annealed sample degrades its waveguiding ability
- Decreasing O_2 flow rate speeds up deposition and gives smaller grain size
- Present a better recipe with loss at 1 dB/cm at 1550 nm

Acknowledgements

Eric Mazur

Christopher Evans

Orad Reshef

Center for Nanoscale System

- Harvard Physics Department
- Mazur Group
- NSF

Thank you!