Effects of annealing on optical properties of TiO_2 planar waveguides

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Outline

Introduction: TiO_2 for nanophotonic applications

Optimization of optical parameters of TiO_2 thin films

Results: Reduction of Propagation Losses through Annealing

Introduction

Applications of TiO_2 thin films

- photocatalysis
- solar cells
- relfective coatings
- dielectric layers

- nanophotonics

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High nonlinearity: $n_2 \geq 30 \times n_{2,SiO2}$ at 1064 nm*

*Adair et. al., *Phys Rev B.* **39**, 1989.

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High refractive index: $n_0 \cong 2.4$ at 800 nm
High nonlinearity: $n_2 \geq 30 \times n_{2,SiO2}$ at 1064 nm

Potential applications:
photonic crystals, nonlinear optics,
active devices, passive devices

Optimization of TiO_2 Thin Films

In order to exploit these properties, we require TiO_2 thin films with:

high linear index (n_0)

low propagation losses

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amorphous films

high index (n_0 = 2.34)*

low loss (0.4 dB/cm)**

*λ = 826 nm

** Fundamental mode, TE polarization, λ = 826 nm

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Annealing of TiO_2 Thin Films

Annealing can cause transitions between different phases of TiO_2, which have different optical properties.

In the literature*

Phase	Anneal Temperature (^{o} C)	Refractive Index (n_0)
Amorphous	As deposited	2.1
Anatase	300	2.2
Rutile	700-900	2.3

*Martin et. al., *Thin Solid Films.* **300**, 1997.

Annealing of TiO_2 Thin Films

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In the literature

Little to no discussion of the effects of annealing on the waveguiding properties of TiO_2 thin films.

Annealing of TiO_2 Films

Goal: Determine if losses can be improved via annealing

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Films were deposited onto oxidized silicon wafers using Reactive Sputtering under ambient conditions.

Film Properties	
Thickness	310 nm
Refractive index (n_o)*	2.34
Phase	Amorphous
Propagation losses**	> 15 dB/cm

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Annealing of TiO_2 Films

Several anneals were conducted between 100 and 800° C.

Each anneal was conducted:

for 180 minutes

in an oxygen environment (250 sccm)

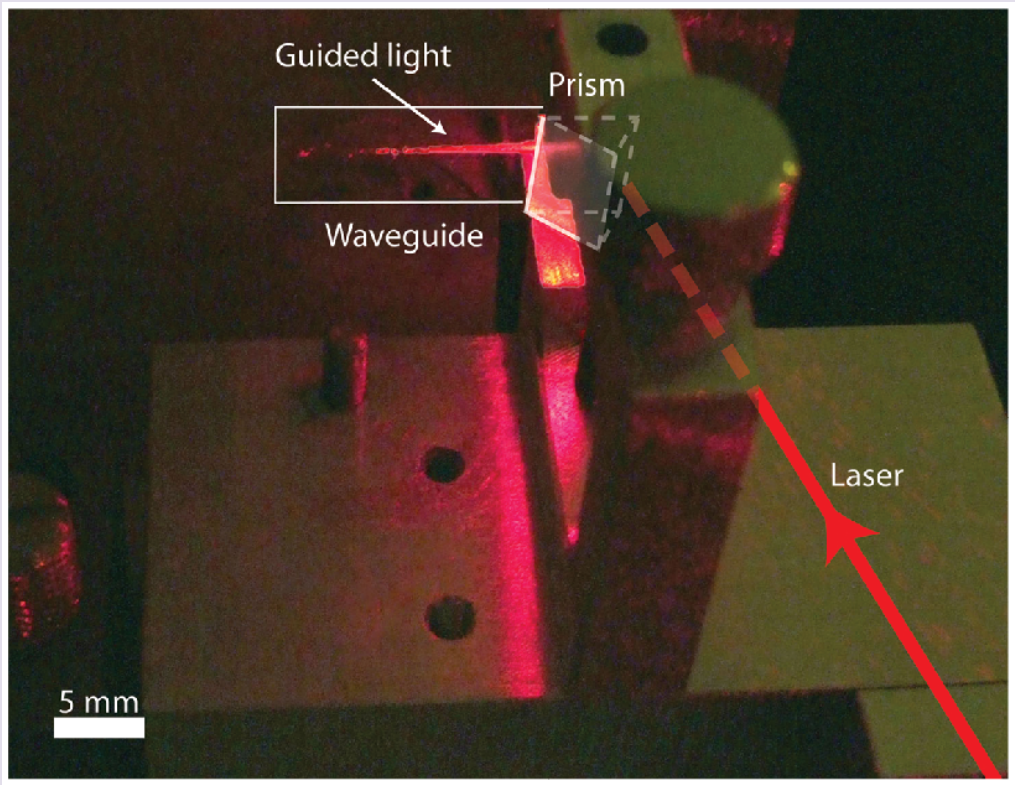
Results

Film Characterization Methods

- Refractive Index: prism coupling
- Crystalline phase: Raman spectroscopy
- Propagation losses: prism coupling

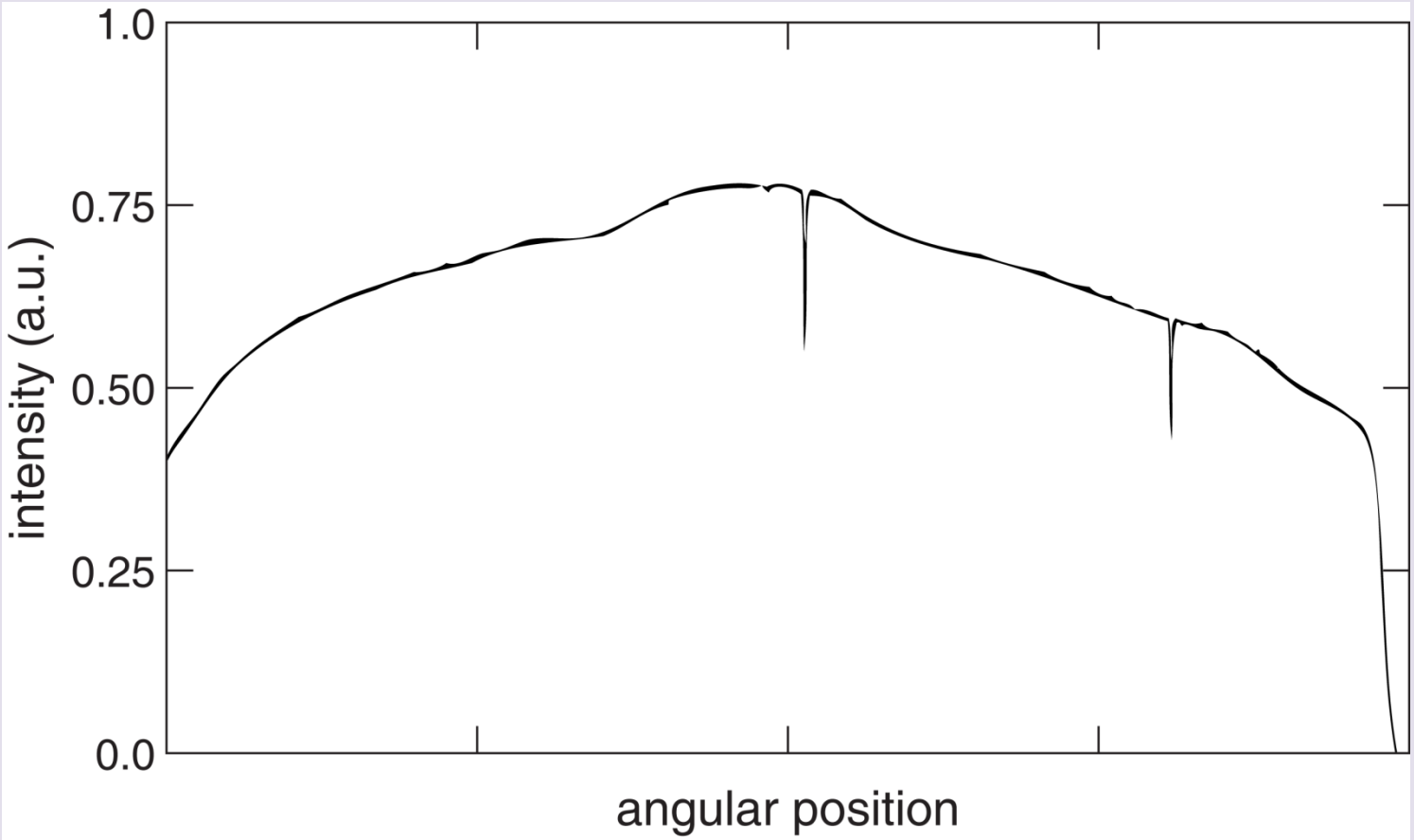
Results

Prism Coupling



Results

Prism Coupling



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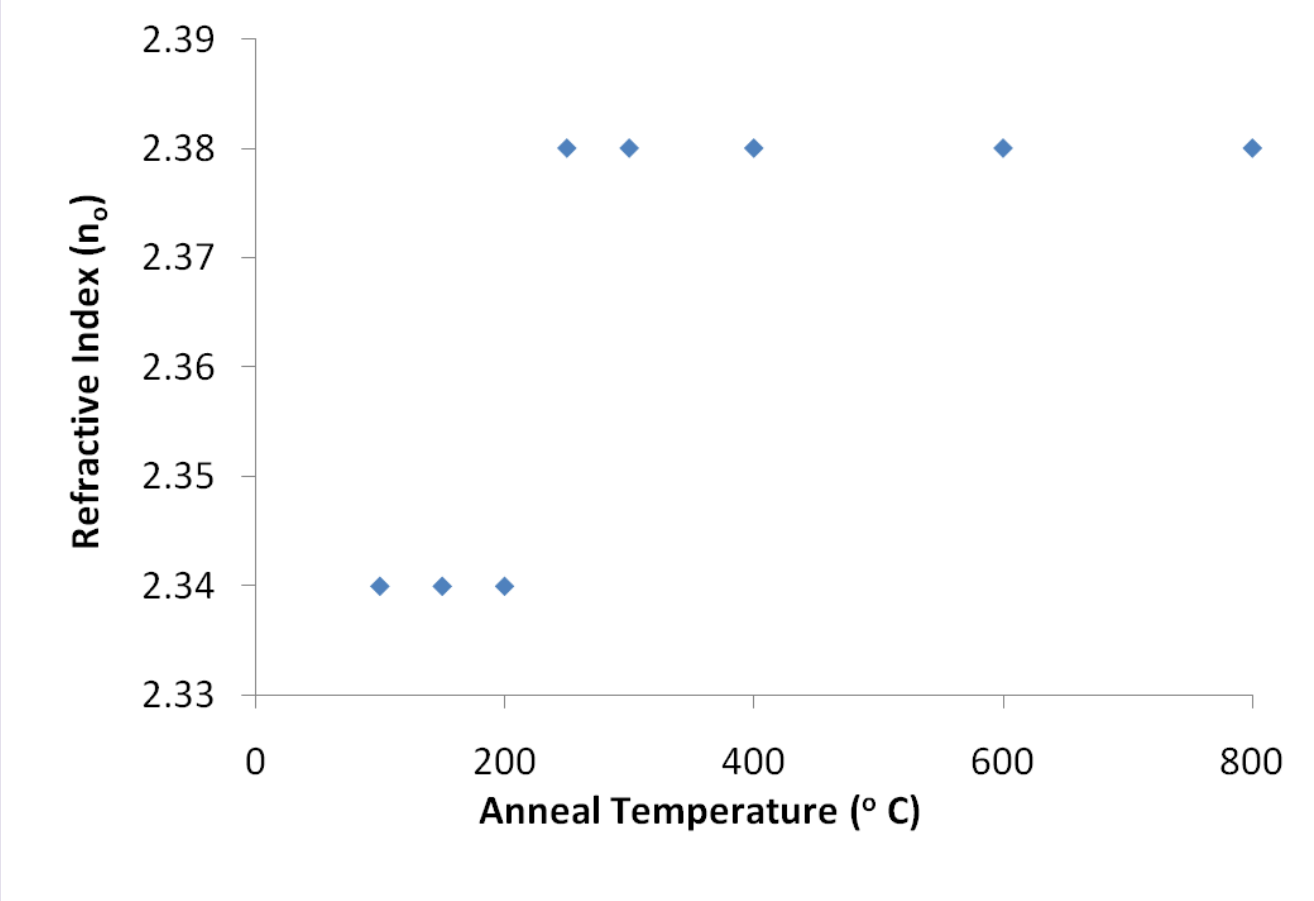
Refractive index*



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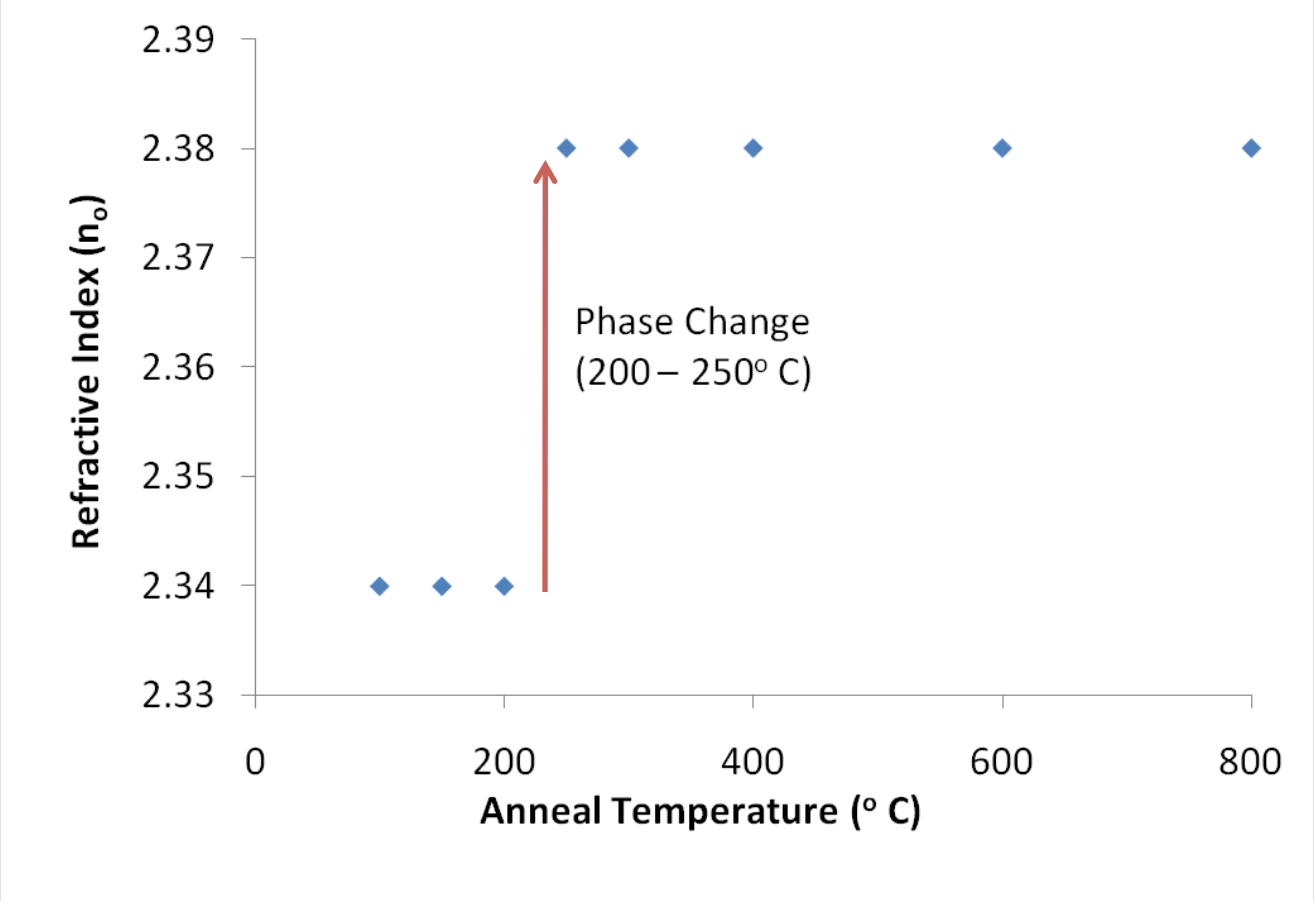

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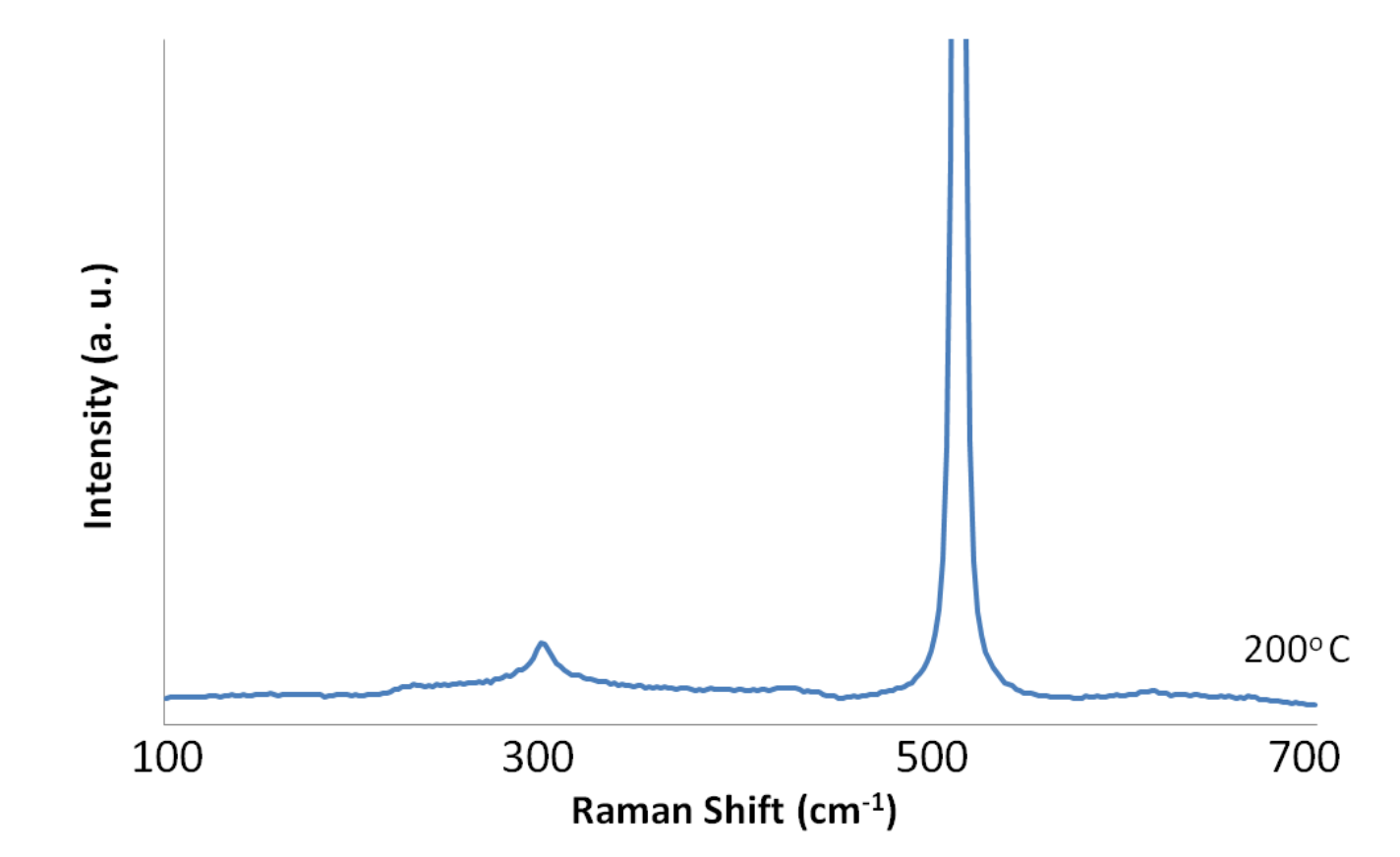
Crystalline Phase



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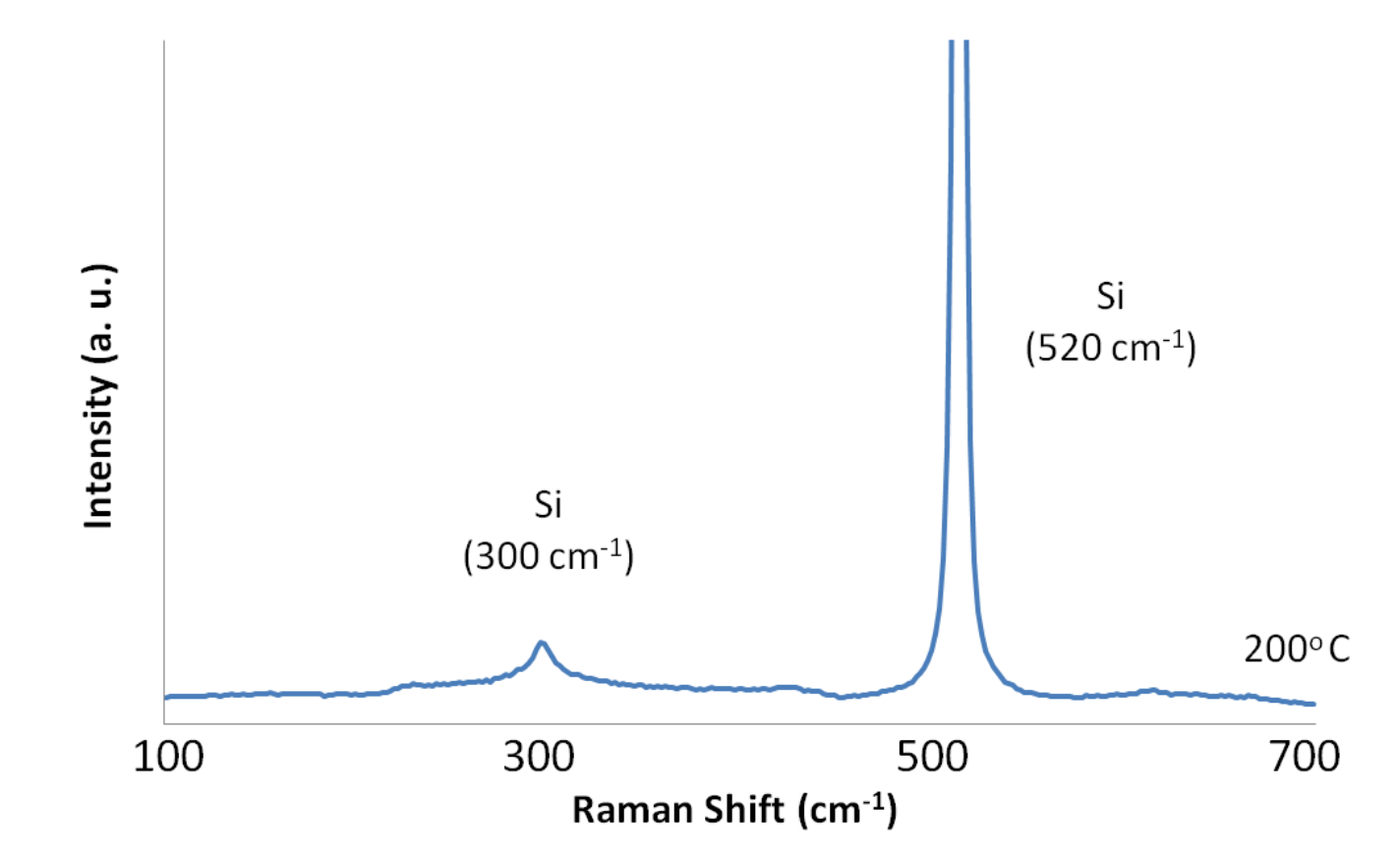

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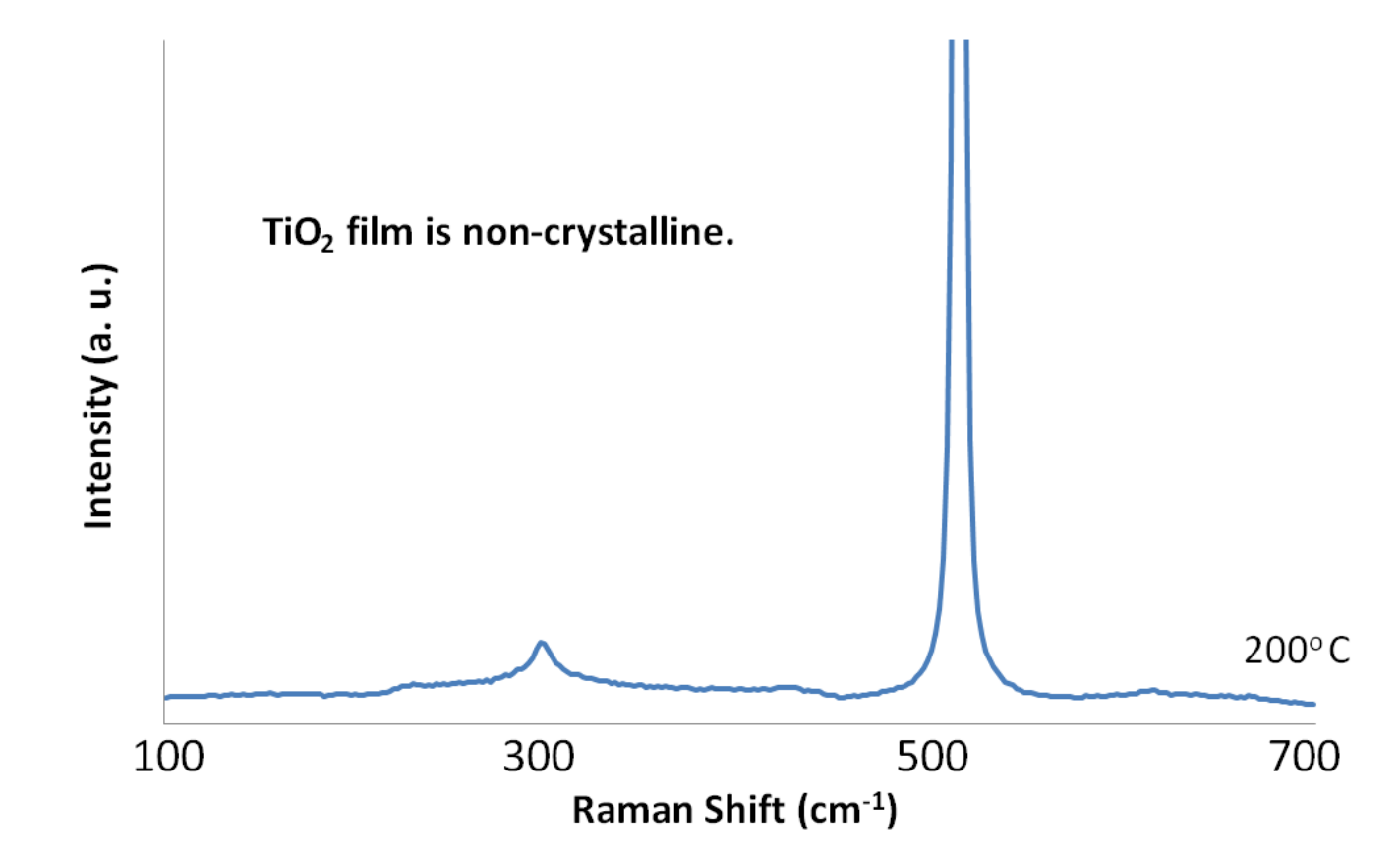

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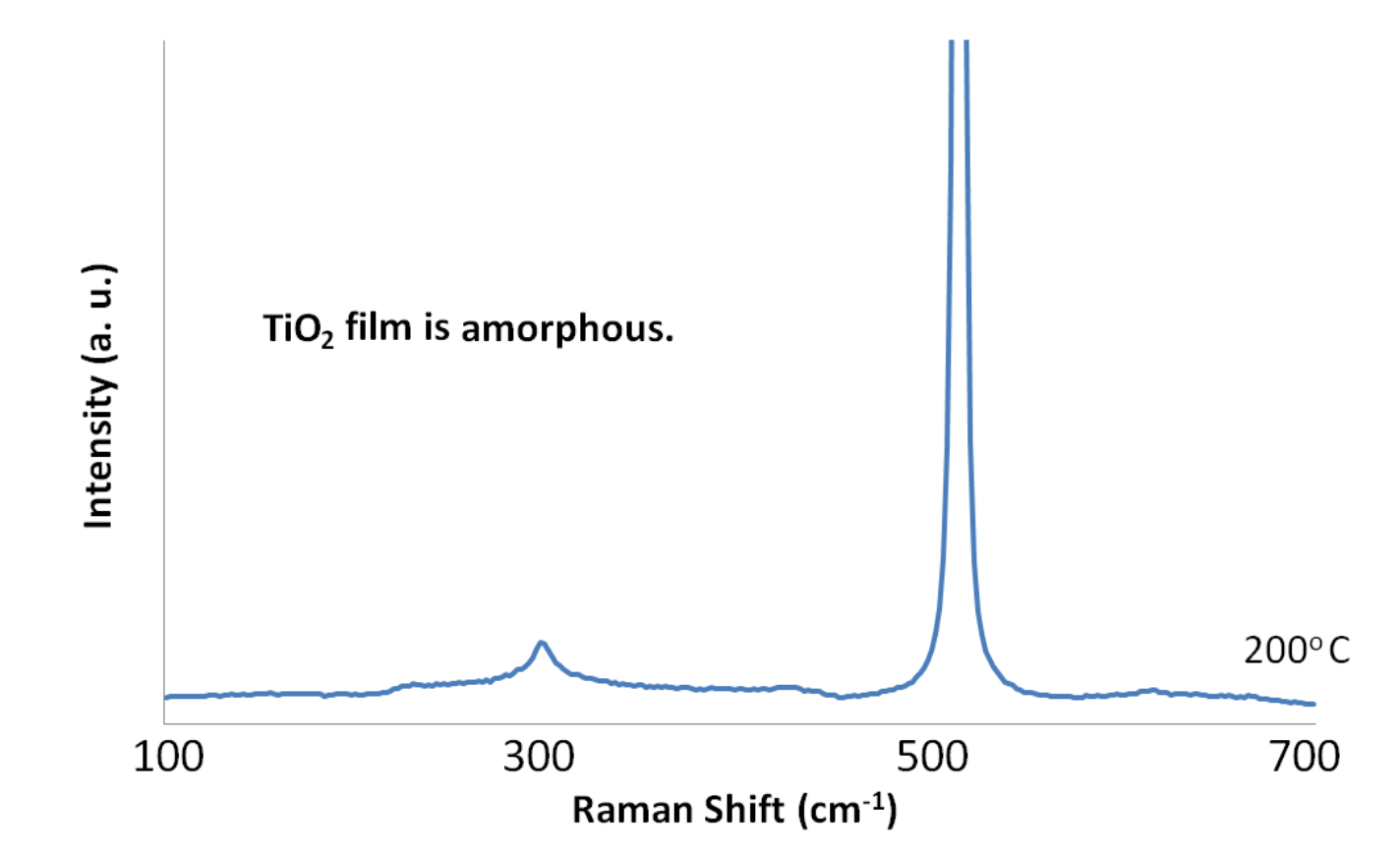

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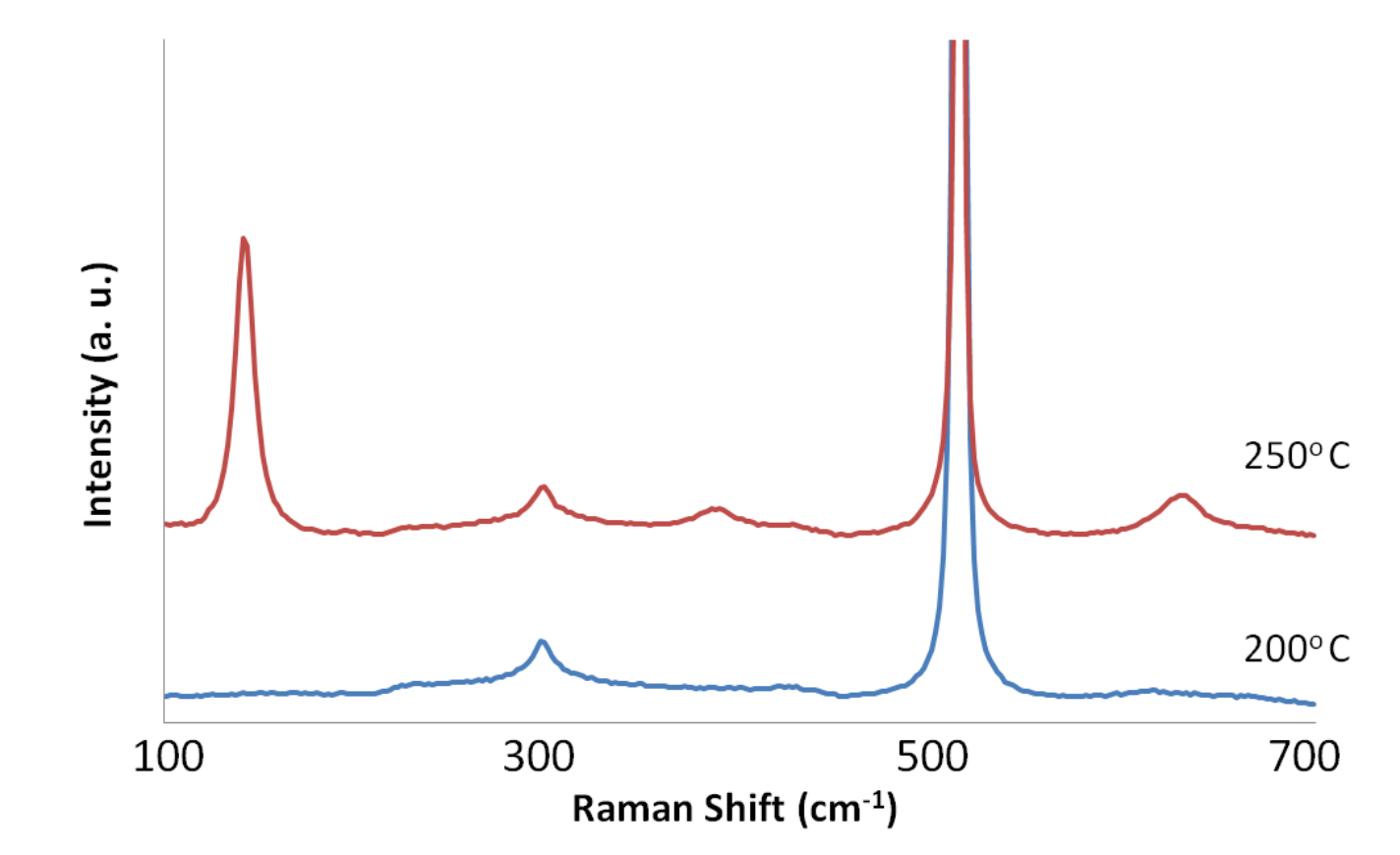

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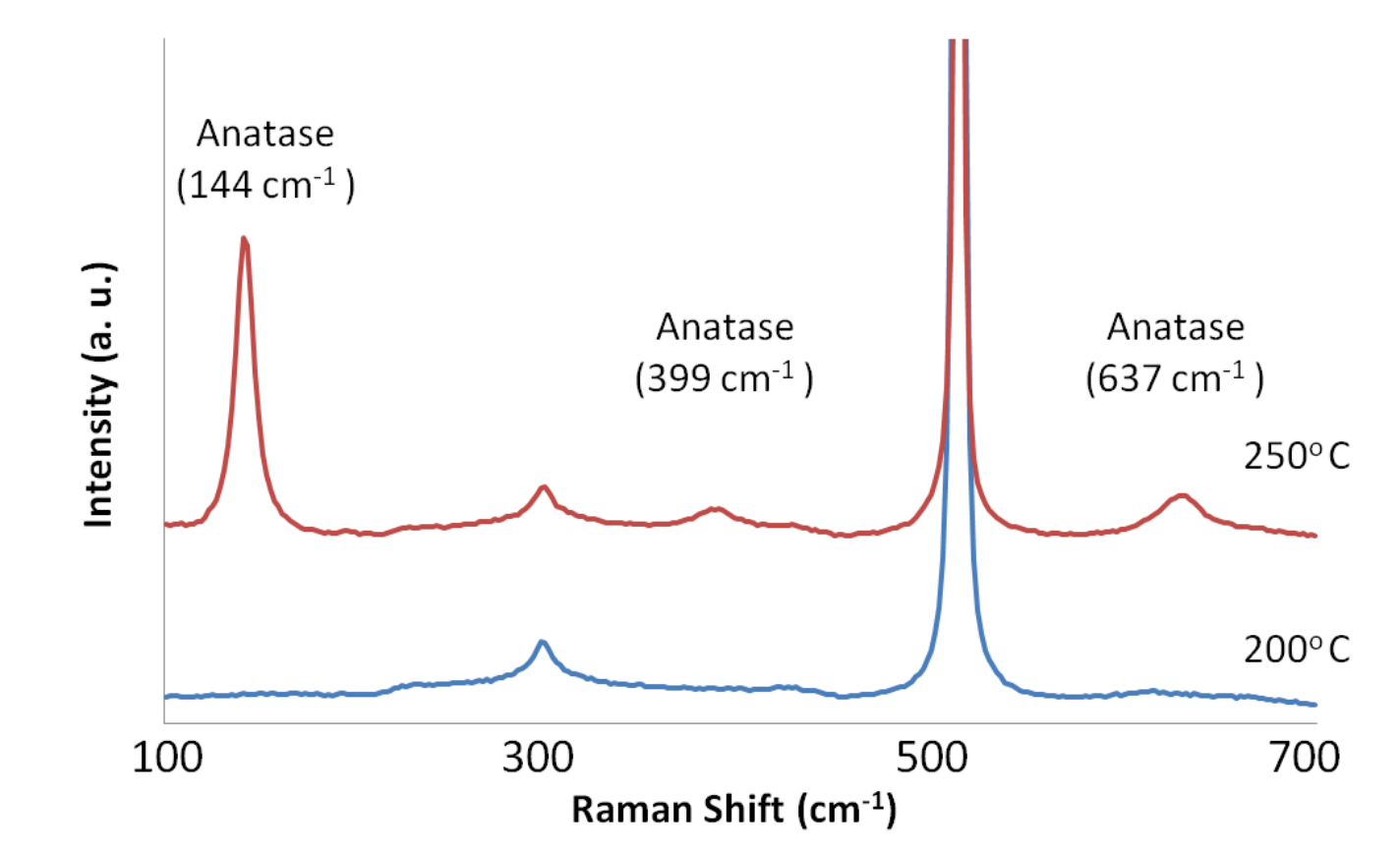

Ohsaka et. al., *J. Raman Spectrosc.* **7**, 1978.

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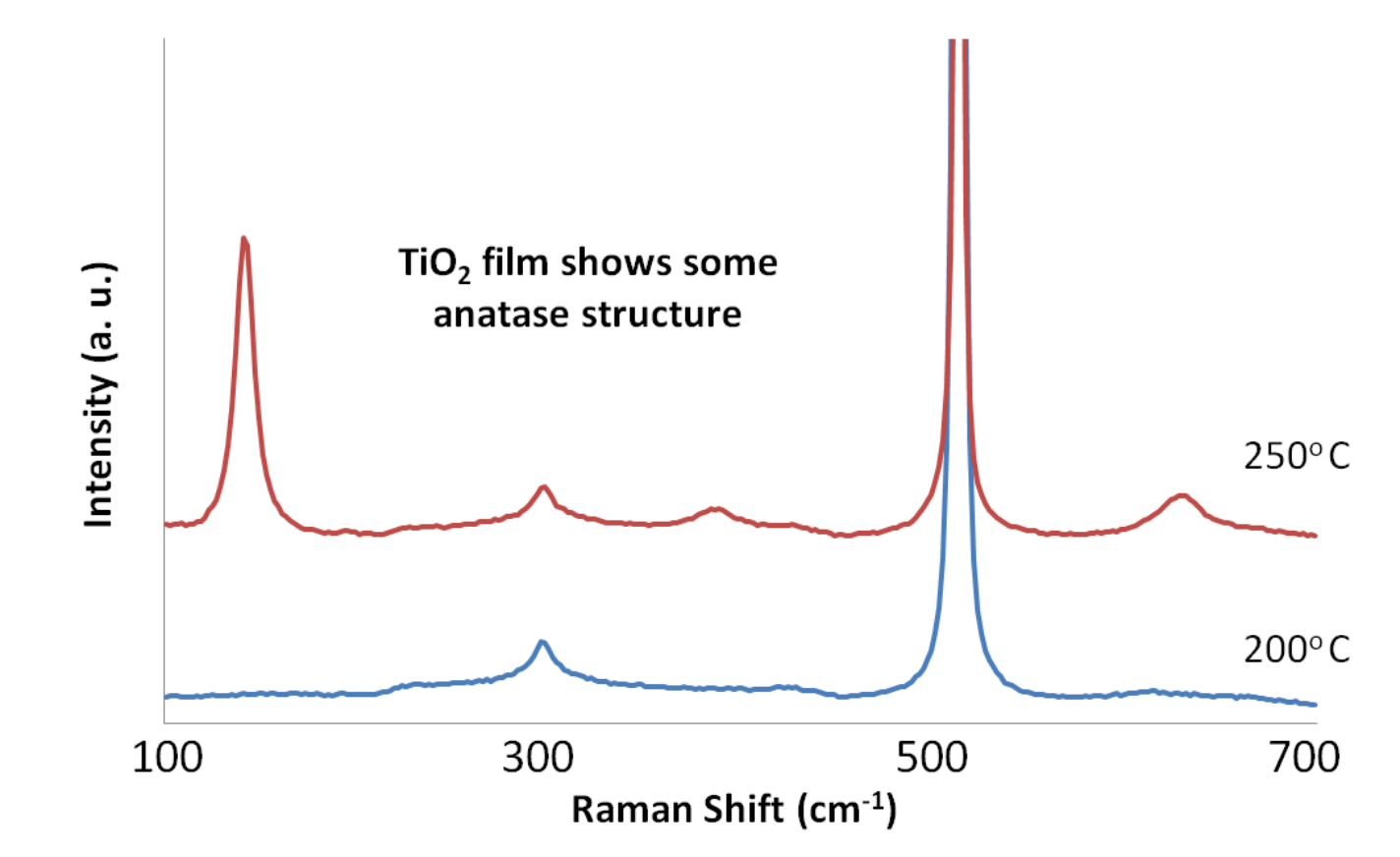

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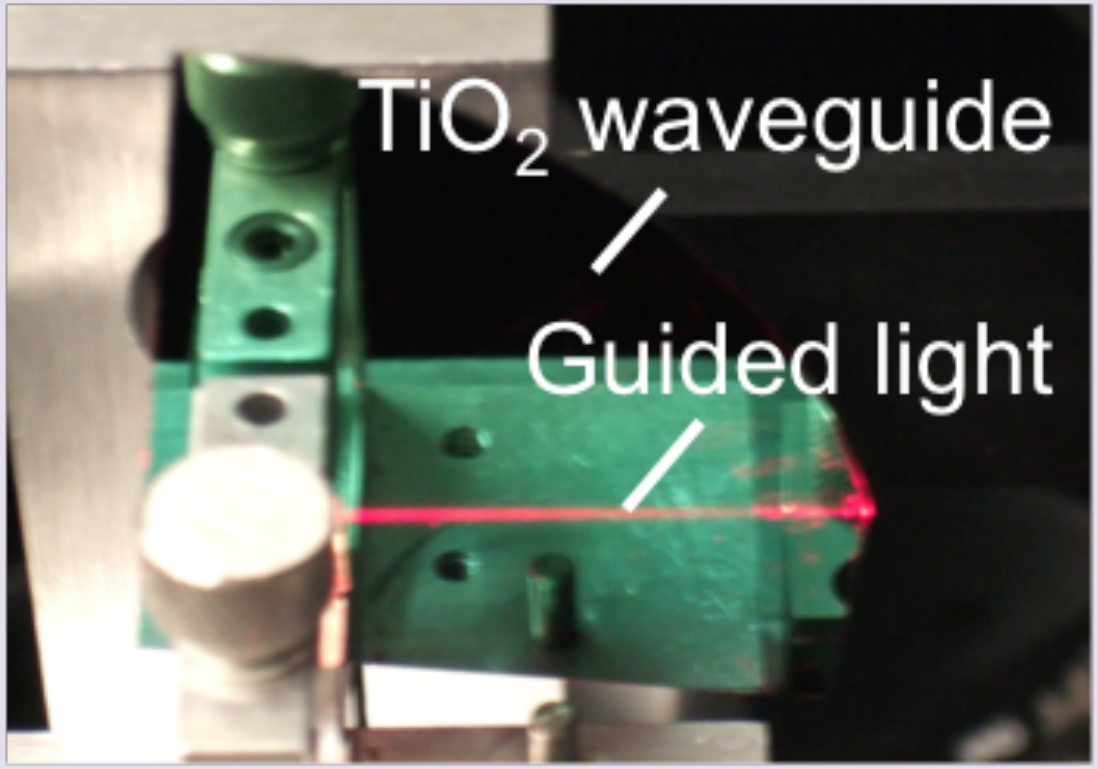
Propagation Loss



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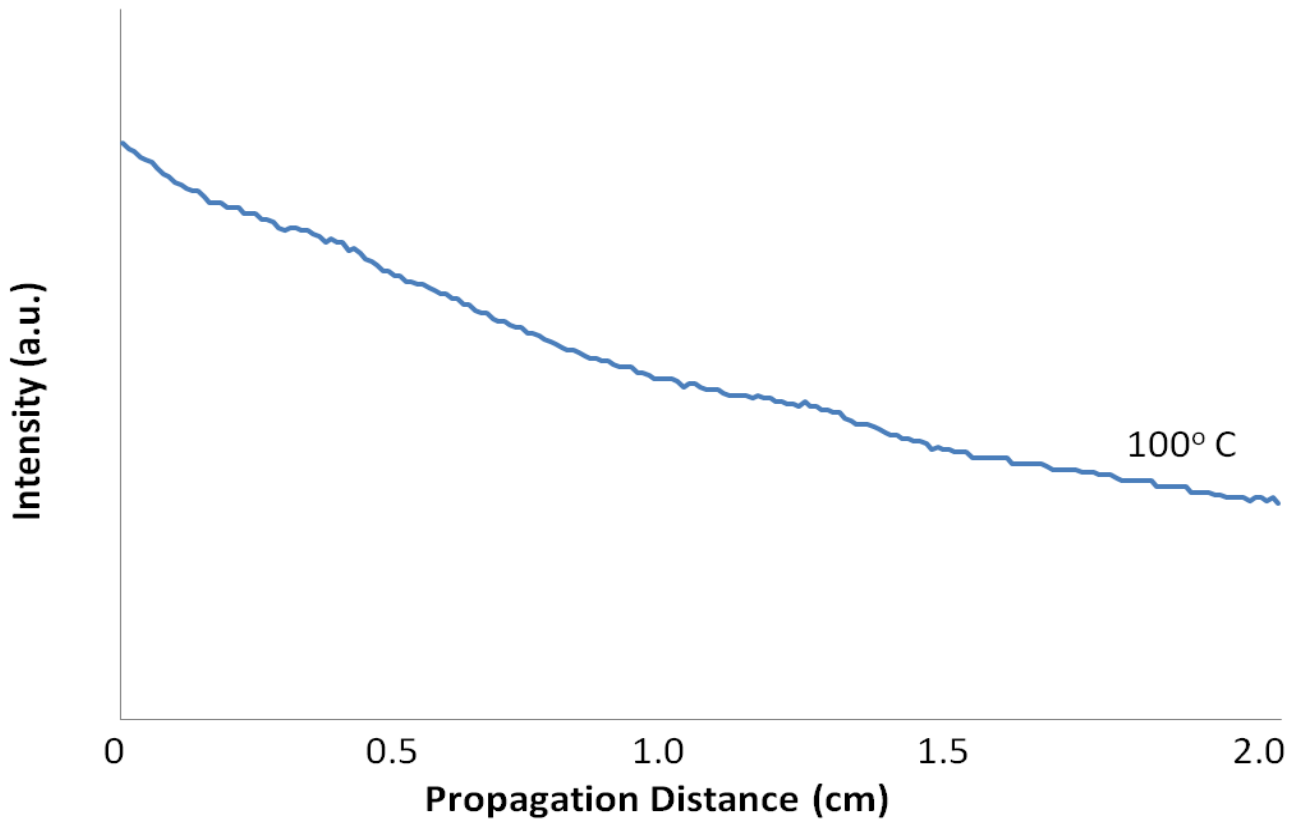

Fundamental mode, TE polarization, λ = 826 nm

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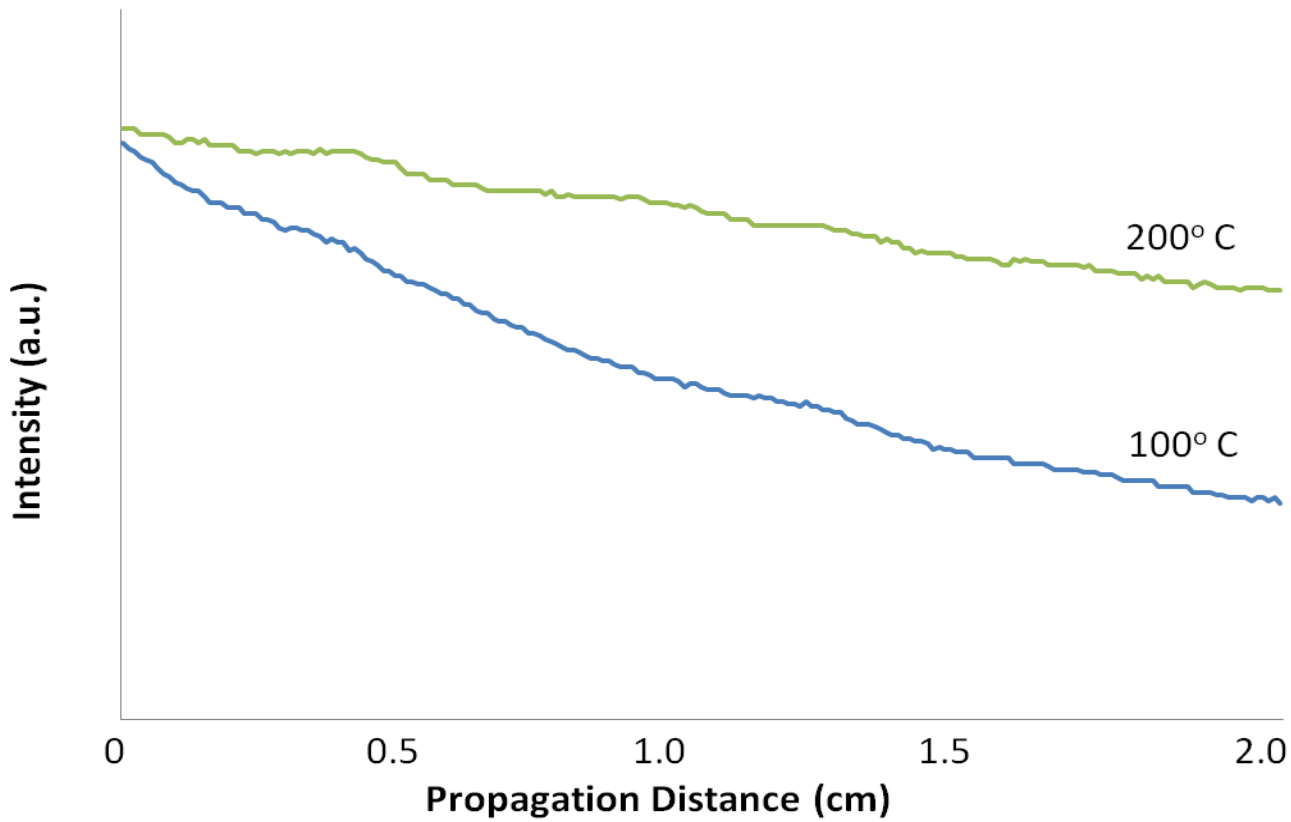

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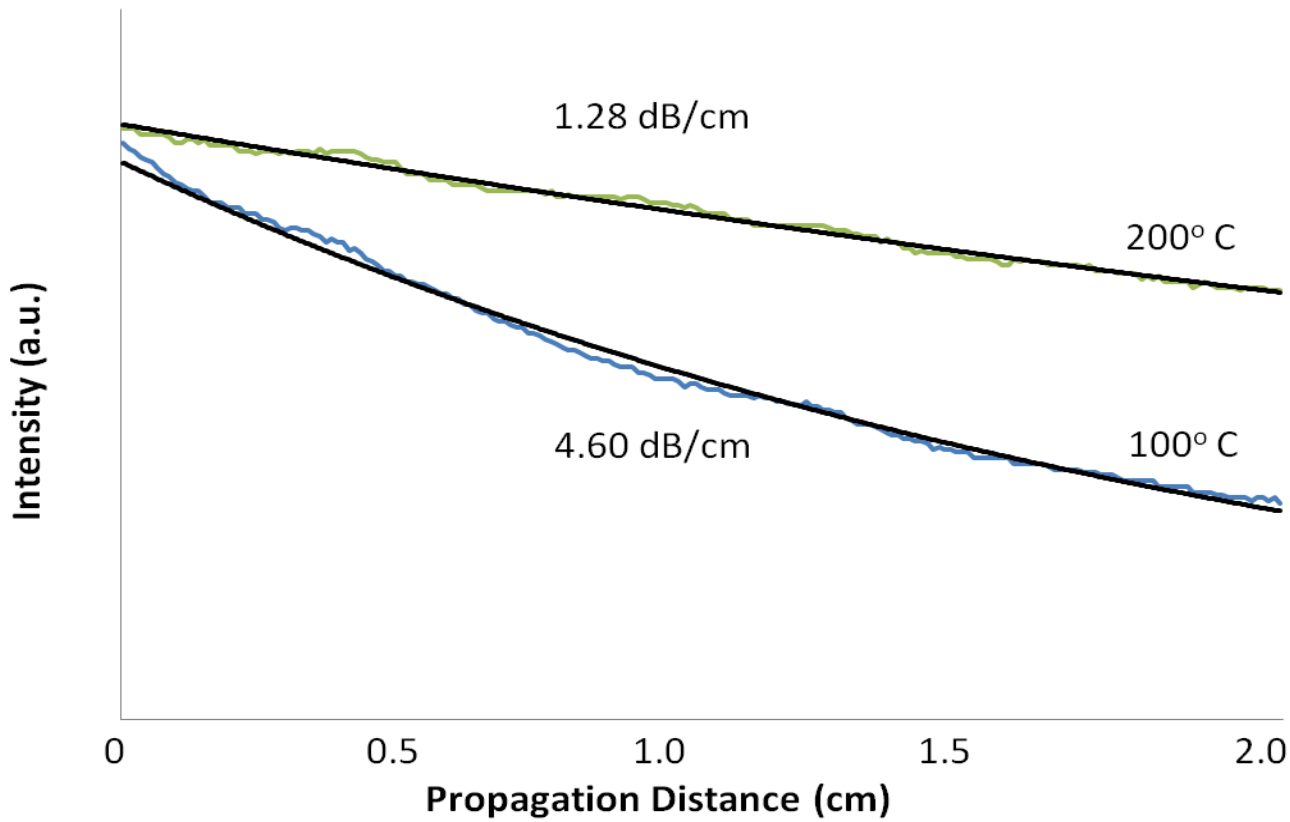

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Results

Anneal Temperature [^{o} C]	Propagation loss* [dB/cm] ± 0.05 dB/cm
As deposited	> 15
100	4.60
150	1.62
200	1.28
250	> 15
300	> 15
400	> 15
600	> 15
800	> 15

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Loss measurements stable over time at room temperature

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Anneal Temperature [^{o} C]	Propagation loss* [dB/cm] ± 0.05 dB/cm	Phase
As deposited	> 15	Amorphous
100	4.60	Amorphous
150	1.62	Amorphous
200	1.28	Amorphous
250	> 15	Anatase
300	> 15	Anatase
400	> 15	Anatase
600	> 15	Anatase
800	> 15	Anatase

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Results

Anneal Temperature [° C]	Propagation loss* [dB/cm] ± 0.05 dB/cm	Phase	Index (n_o) ± 0.01
As deposited	> 15	Amorphous	2.34
100	4.60	Amorphous	2.34
150	1.62	Amorphous	2.34
200	1.28	Amorphous	2.34
250	> 15	Anatase	2.38
300	> 15	Anatase	2.38
400	> 15	Anatase	2.38
600	> 15	Anatase	2.38
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Implications

- low loss TiO_2 thin films fabricated through low temperature process
  - compatible with hybrid technologies for integrated optics

Potential Drawback

- phase transition above 200° C
  - potential devices limited to lower temperatures

Conclusion

Annealing at low temperatures (< 200° C) results in:

- amorphous films
- no change in index (2.34)
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Annealing at higher temperatures results in:

- anatase films
- higher index (2.38)
- higher propagation losses (> 15 dB/cm)

Conclusion

We have reduced planar propagation losses in TiO_2 thin films by annealing

TiO_2 thin films show promise for nonlinear nanophotonics

Acknowledgements

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