

**Engineering Conferences International  
ECI Digital Archives**

---

Electric Field Assisted Sintering and Related  
Phenomena Far From Equilibrium

Proceedings

---

Winter 3-6-2016

# Influence of an electric field on grain growth and sintering in strontium titanate

Wolfgang Rheinheimer  
*Karlsruhe Institute of Technology*, [wolfgang.rheinheimer@kit.edu](mailto:wolfgang.rheinheimer@kit.edu)

Fabian Lemke  
*Karlsruhe Institute of Technology*

Michael Hoffman  
*Karlsruhe Institute of Technology*

Follow this and additional works at: [http://dc.engconfintl.org/efa\\_sintering](http://dc.engconfintl.org/efa_sintering)



Part of the [Engineering Commons](#)

---

## Recommended Citation

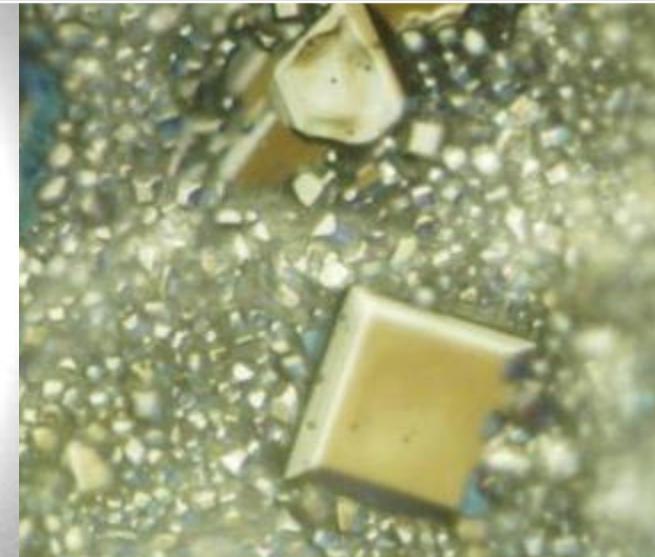
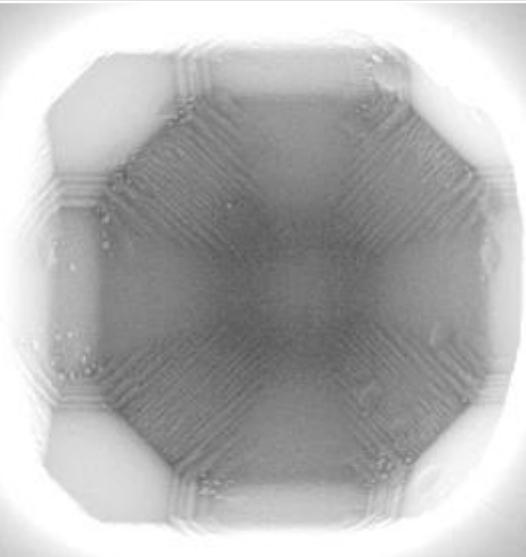
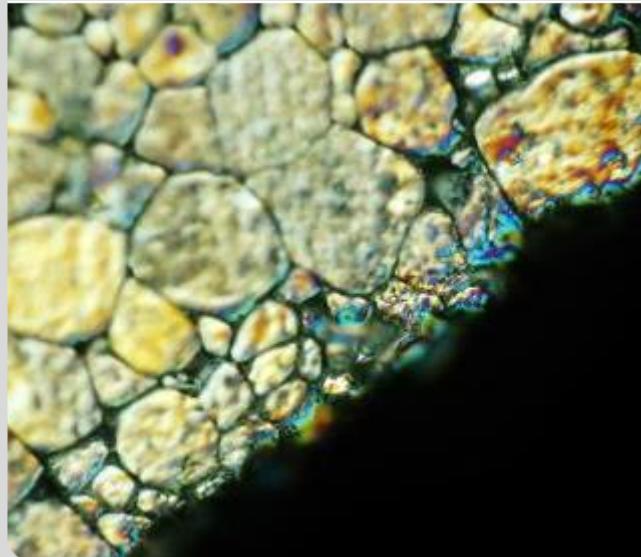
Wolfgang Rheinheimer, Fabian Lemke, and Michael Hoffman, "Influence of an electric field on grain growth and sintering in strontium titanate" in "Electric Field Assisted Sintering and Related Phenomena Far From Equilibrium", Rishi Raj (University of Colorado at Boulder, USA) Thomas Tsakalakos (Rutgers University, USA) Eds, ECI Symposium Series, (2016). [http://dc.engconfintl.org/efa\\_sintering/12](http://dc.engconfintl.org/efa_sintering/12)

This Abstract and Presentation is brought to you for free and open access by the Proceedings at ECI Digital Archives. It has been accepted for inclusion in Electric Field Assisted Sintering and Related Phenomena Far From Equilibrium by an authorized administrator of ECI Digital Archives. For more information, please contact [franco@bepress.com](mailto:franco@bepress.com).

# Impact of electric fields on grain growth in SrTiO<sub>3</sub>

Fabian Lemke, Wolfgang Rheinheimer and Michael J. Hoffmann

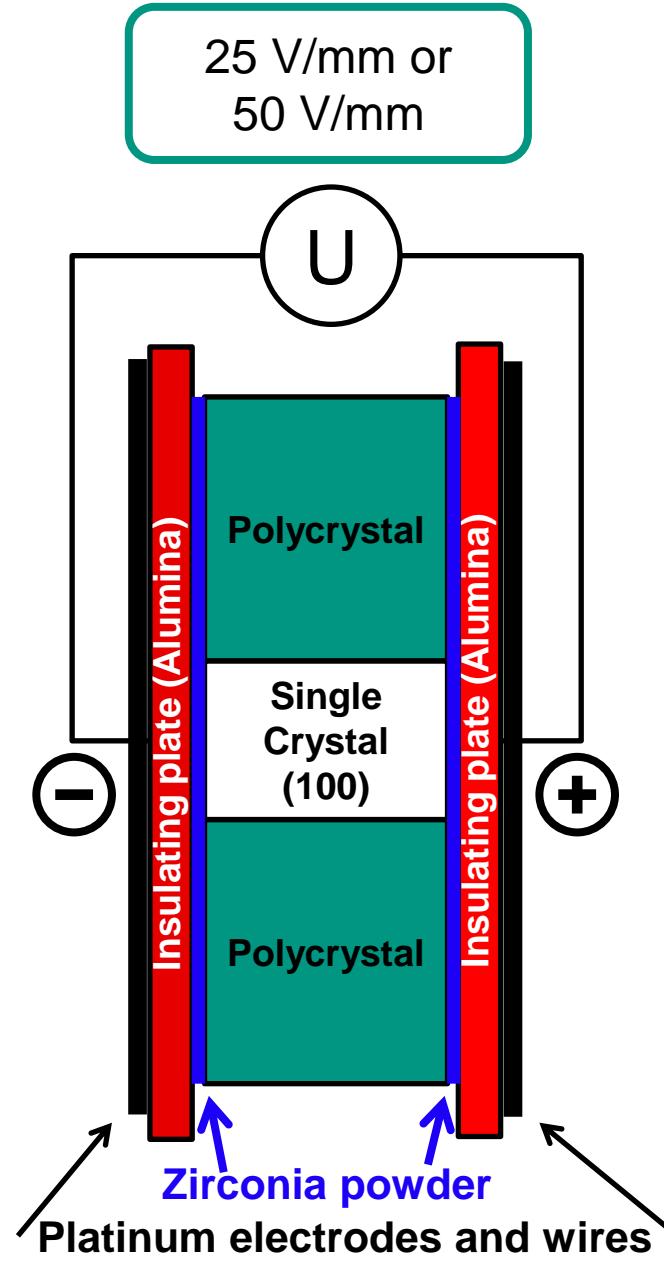
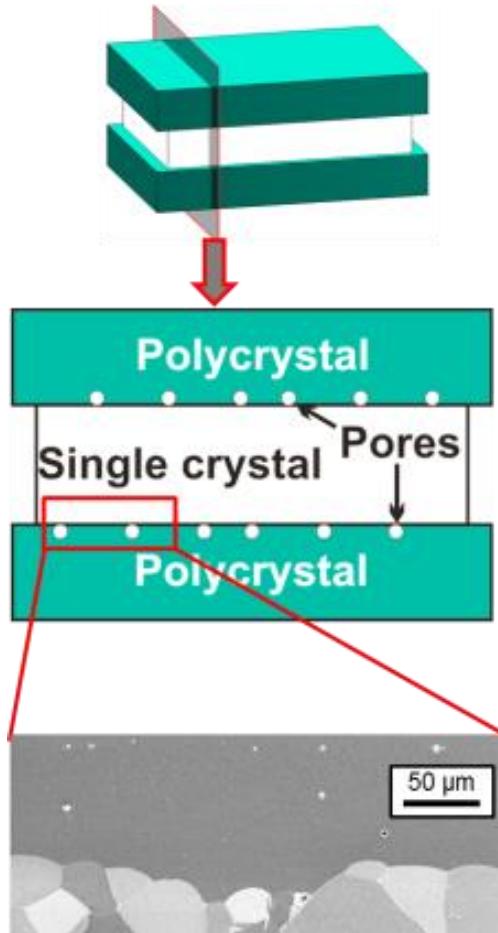
Institute for Applied Materials - Ceramic Materials and Technologies



# Outline

- Experimental setup
- Growth length of single crystal
- Grain growth in the polycrystal
- Impact of defect chemistry

# Experimental setup



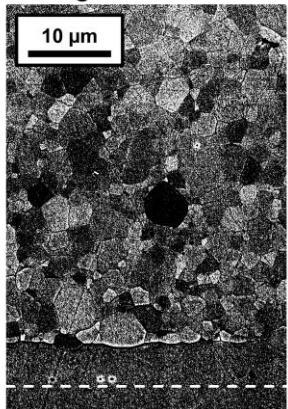
25 V/mm or  
50 V/mm

No current due  
to insulating  
alumina plates

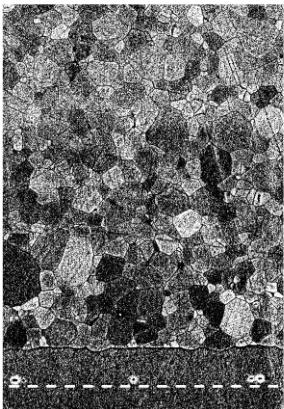
No chemical  
reaction due to  
coarse zirconia  
powder

# Microstructure for 50 V/mm

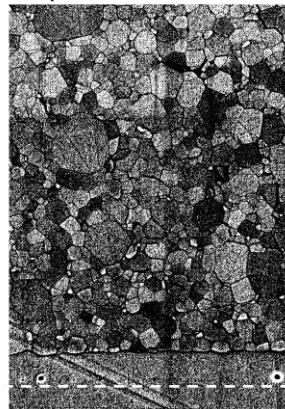
at negative electrode



middle

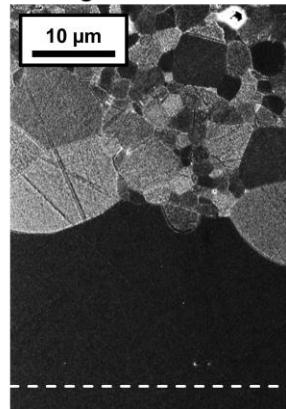


at positive electrode

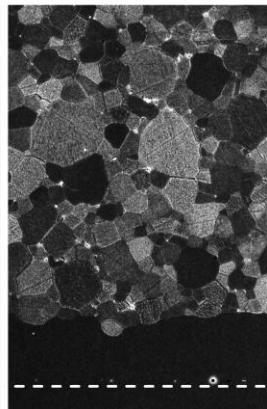


1350°C / 10h

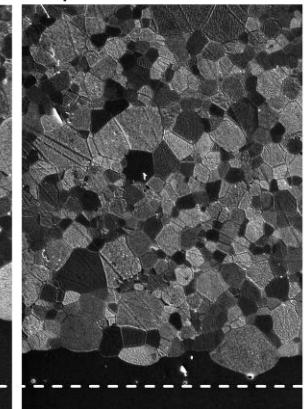
at negative electrode



middle

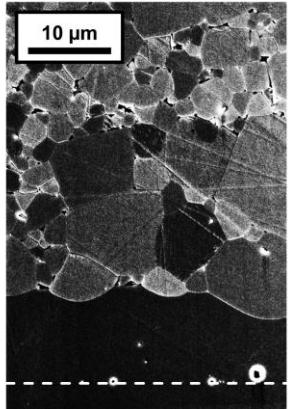


at positive electrode

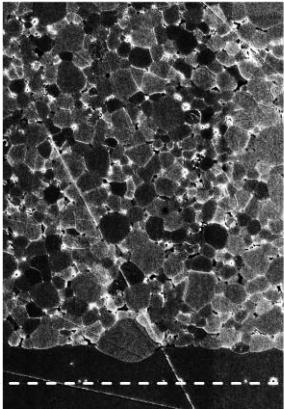


1460°C / 2h

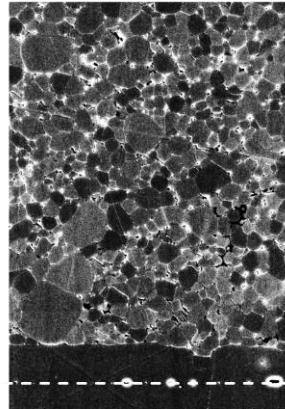
at negative electrode



middle



at positive electrode

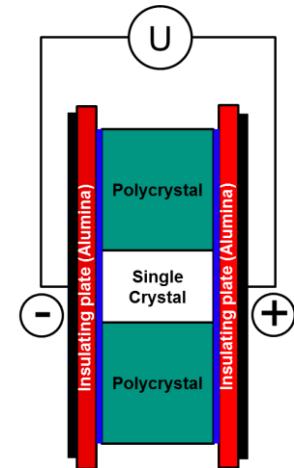
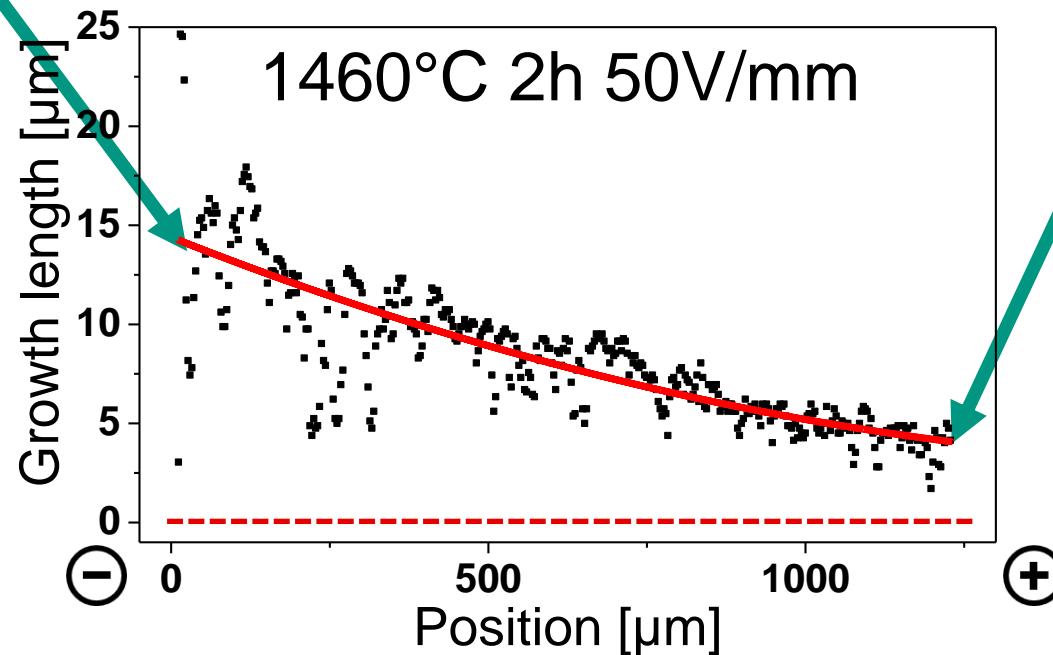
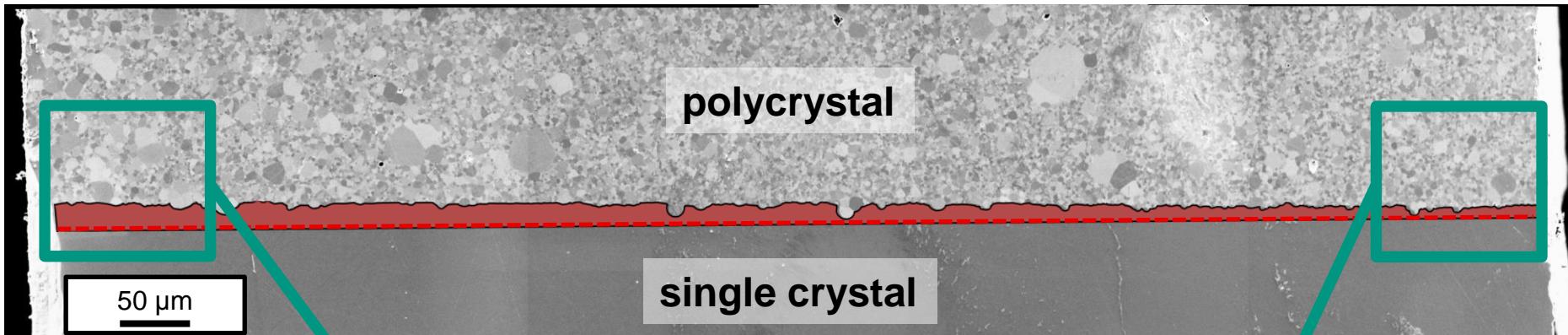


1550°C / 0.5h

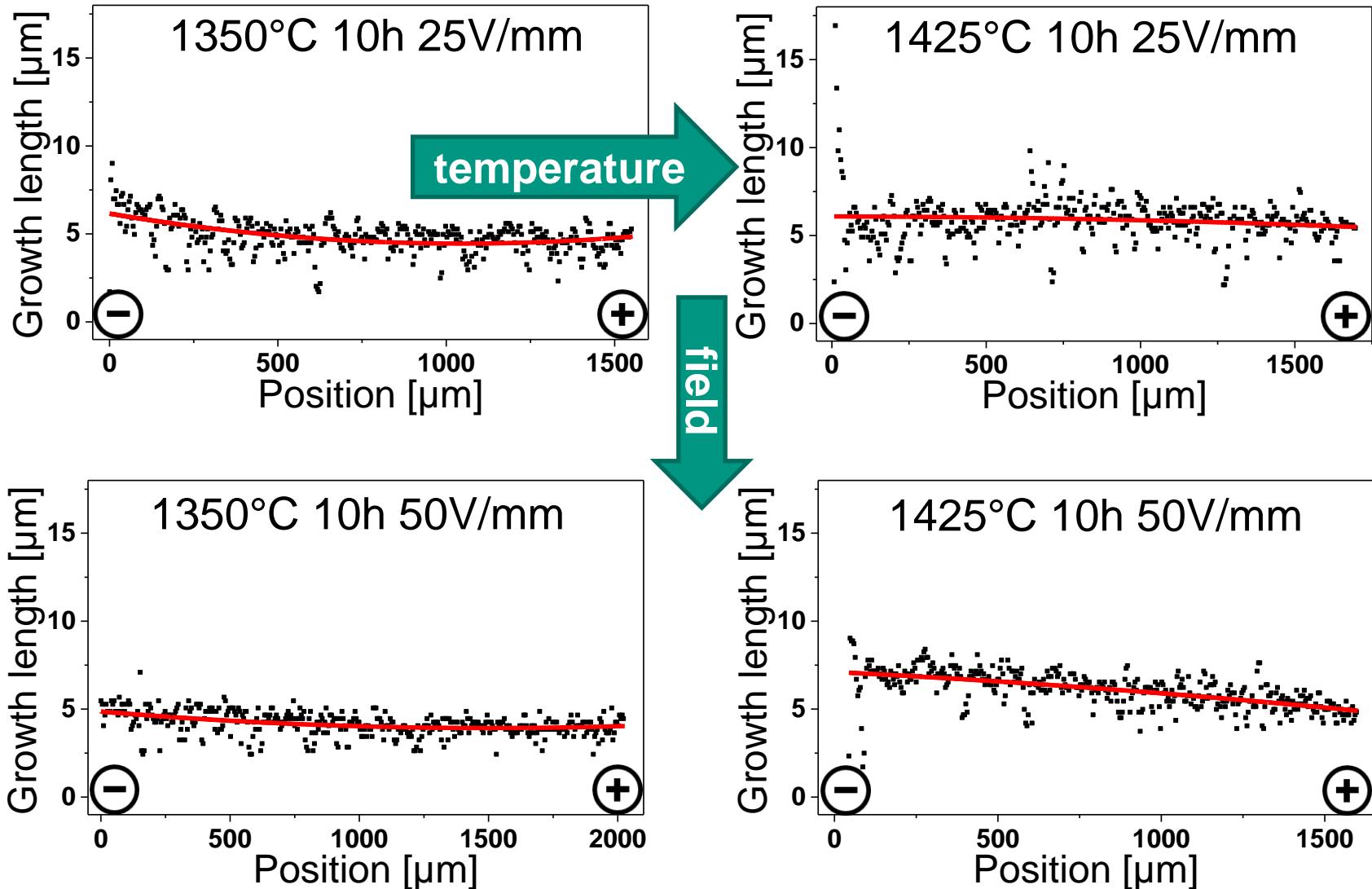
- Information about growth of single and polycrystal
- Impact of an electric field at higher temperatures
- Strong effect at negative electrode

- Experimental setup
- Growth length of single crystal
- Grain growth in the polycrystal
- Impact of defect chemistry

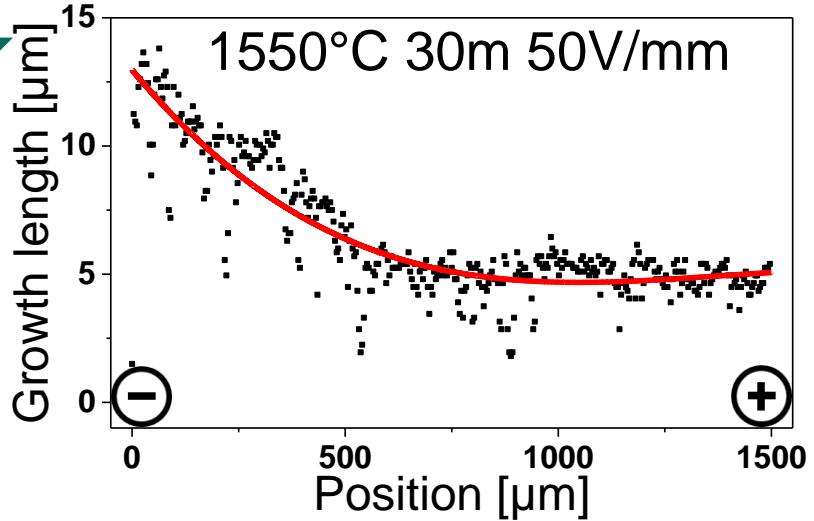
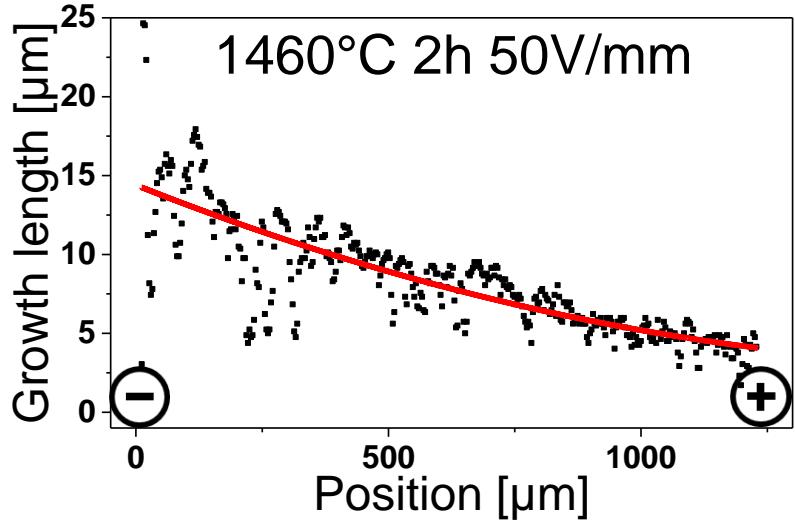
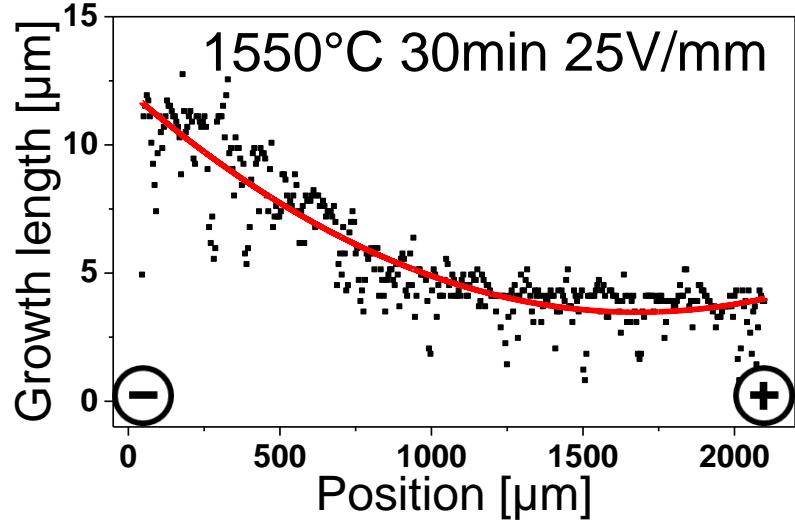
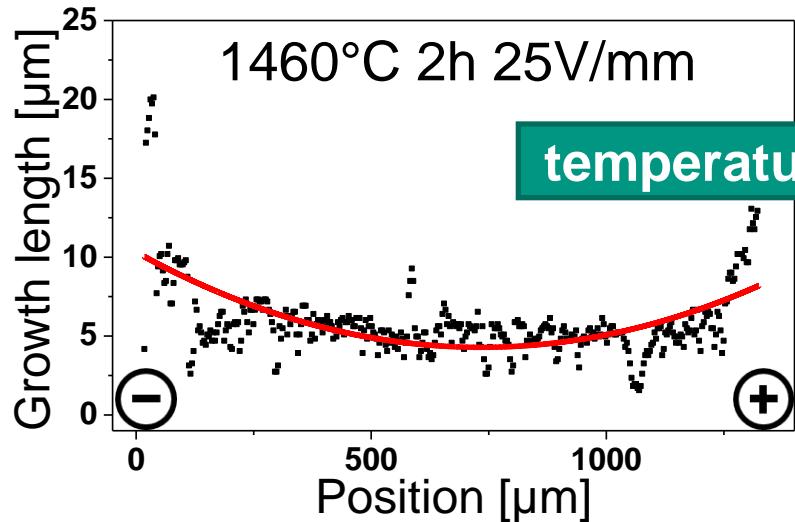
# Evaluation of the growth length



# Growth length of single crystals



# Growth length of single crystals



Strong effect of the electric field above 1425°C

- Faster growth at the negative electrode & for higher electric field

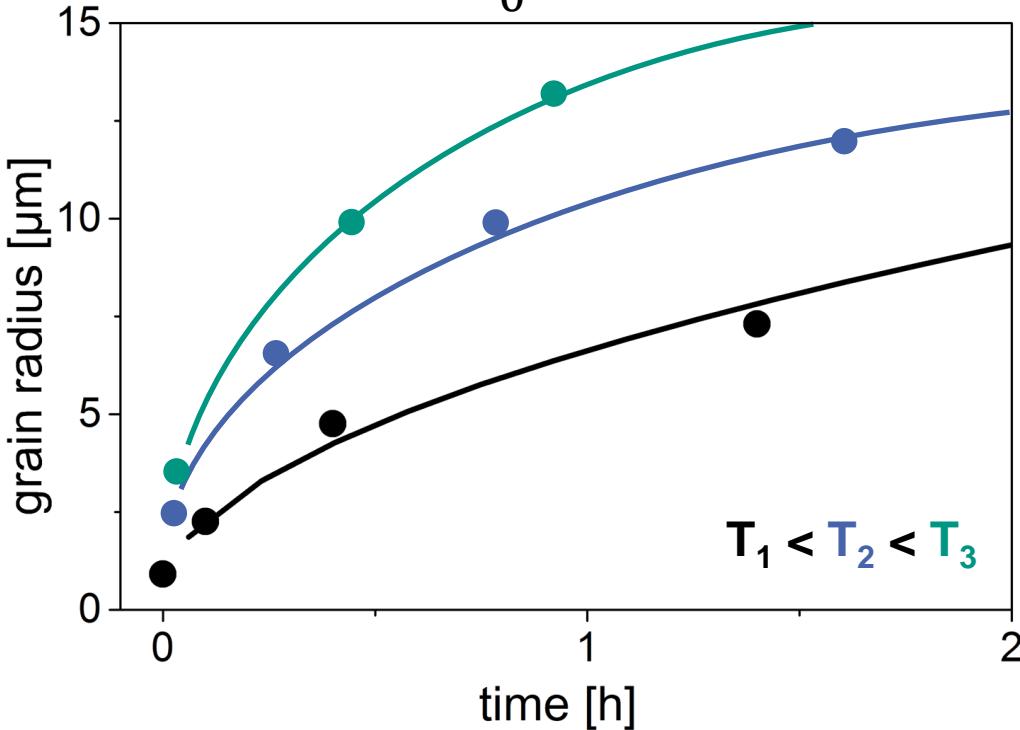
- Experimental setup
- Growth length of single crystal
- Grain growth in the polycrystal
- Impact of defect chemistry

# Grain growth in Strontium Titanate

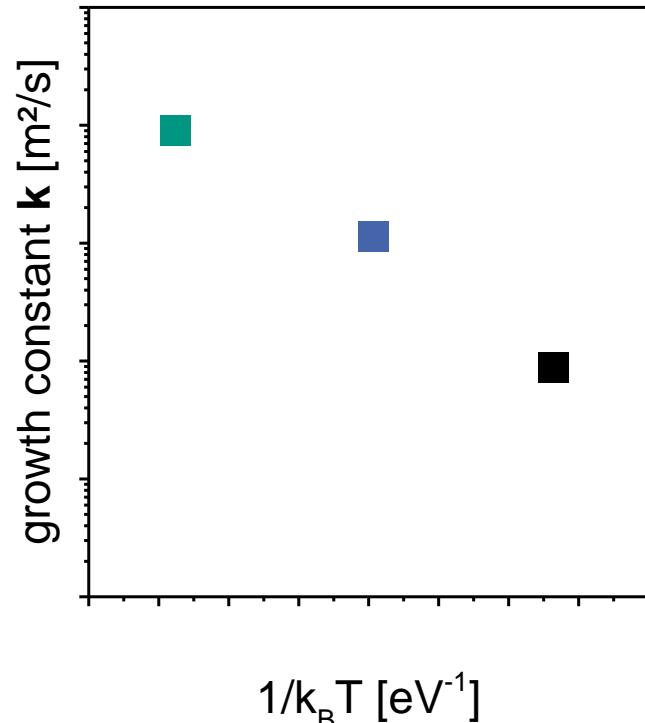
## Recrystallization and Grain Growth

Burke, Turnbull, *Prog. Met. Phys.* 3, p.220 (1952)

$$D^2 - D_0^2 = k \cdot t$$



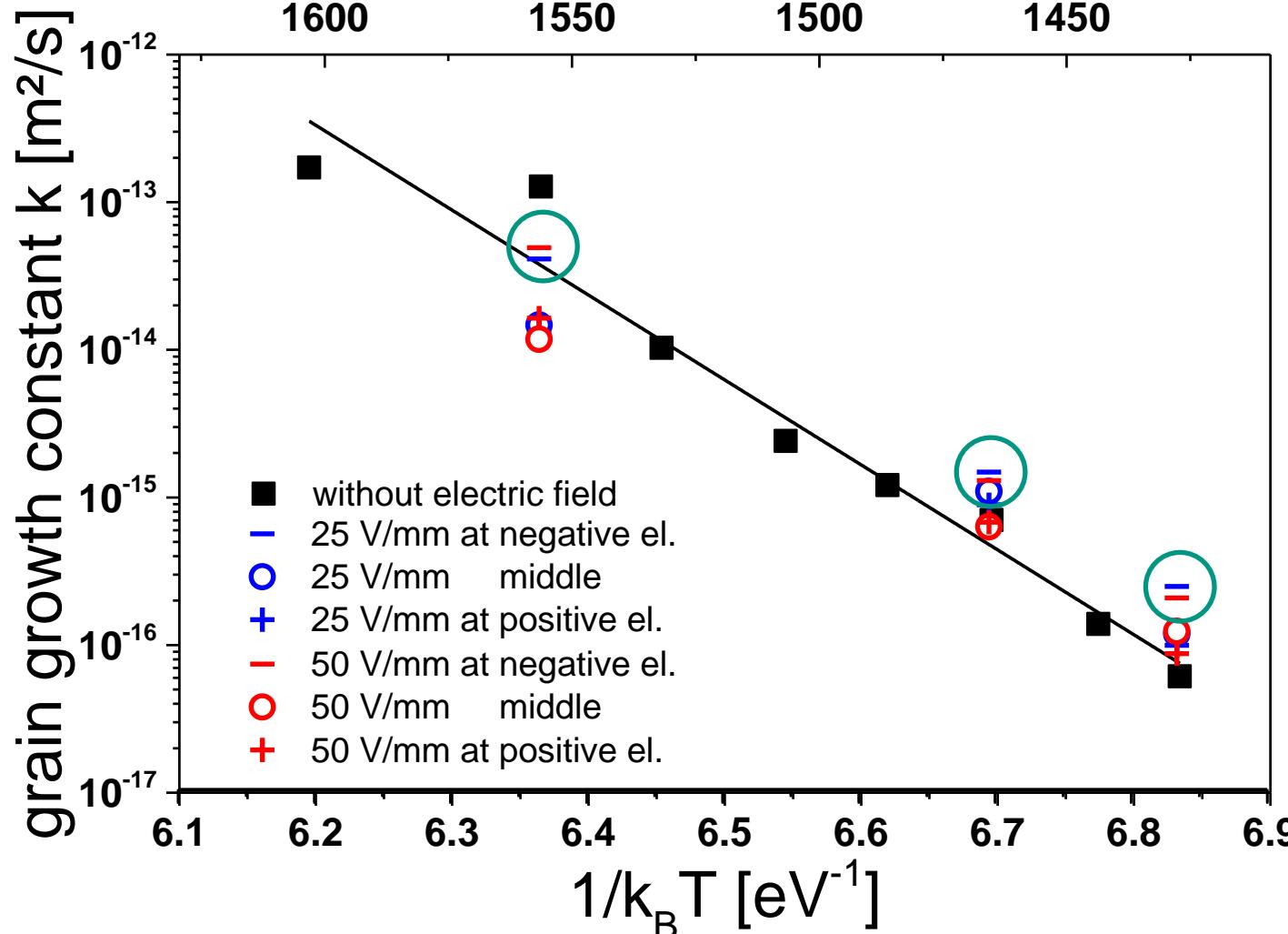
$$k = k_0 \cdot e^{\left(-\frac{E_{GG}}{k_B T}\right)}$$



Grain growth constant  $k$  as 'effective mobility'

# Grain growth constant $k$

## temperature [°C]

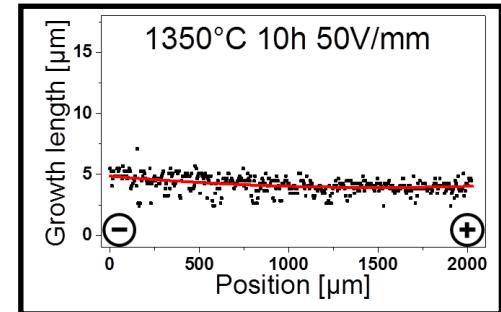


Grain growth overall is similar to results without field !

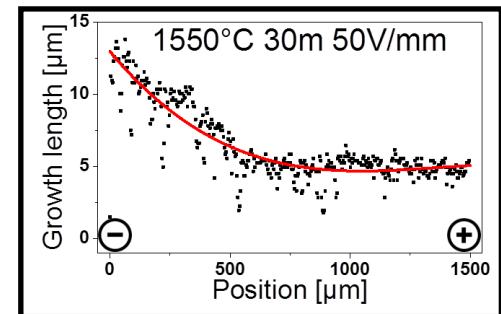
Strong effect at negative electrode for single and polycrystal !

# Grain growth in electric field

- Up to 1425°C weak impact of an electrical field



- Above 1425°C fast growth at negative electrode
- Effect is stronger for higher electric field
- Effect is similar for single and polycrystal

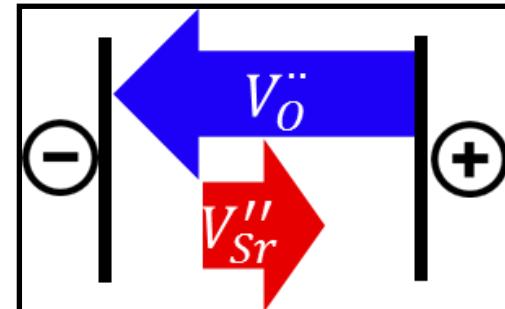


## What happens in the material?

- Defect redistribution
- Oxygen vacancies  $D(V_O^{\cdot\cdot}, 1400^\circ C) \approx 10^{-6} \text{ cm}^2/\text{s}$
- Strontium vacancies  $D(V_{Sr}^{\prime\prime}, 1400^\circ C) \approx 10^{-14} \text{ cm}^2/\text{s}$

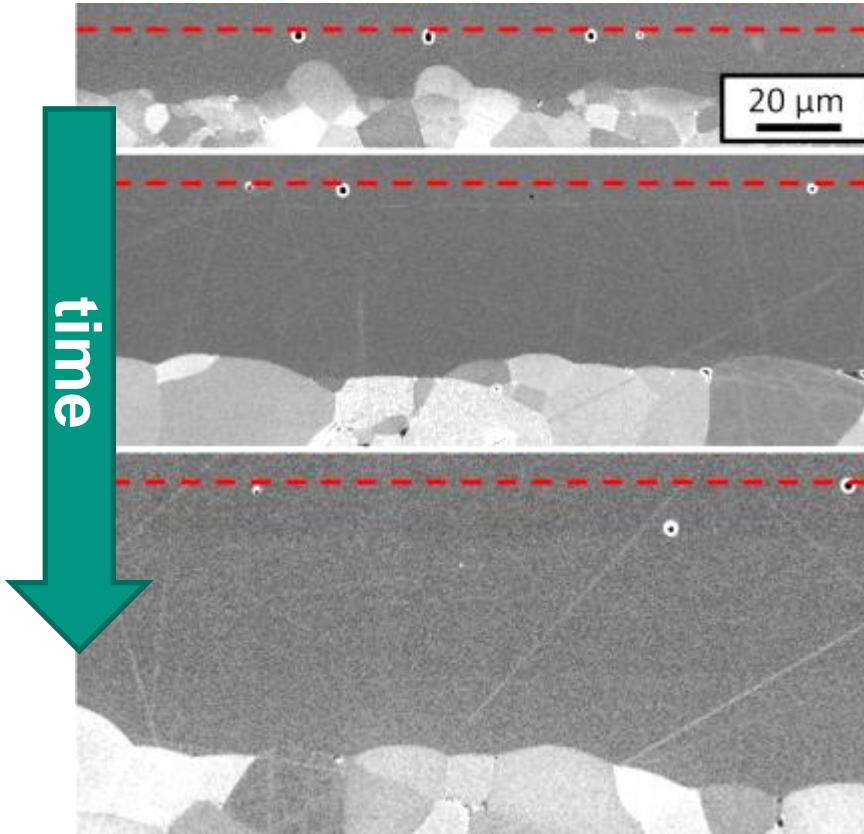
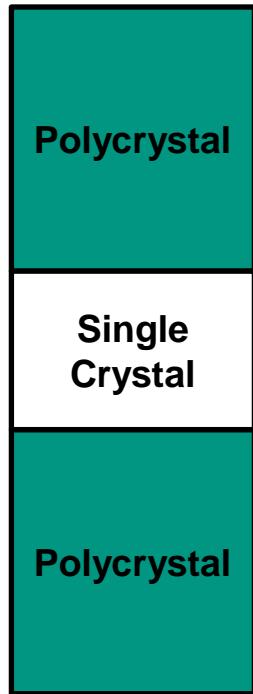
Moos, Härdtl, *J. Am. Ceram. Soc.* 80 (1997)

Meyer, Waser, Helmbold, Borchardt, *Phys. Rev. Lett.* 90 (2003)



- Experimental setup
- Growth length of single crystal
- Grain growth in the polycrystal
- Impact of defect chemistry

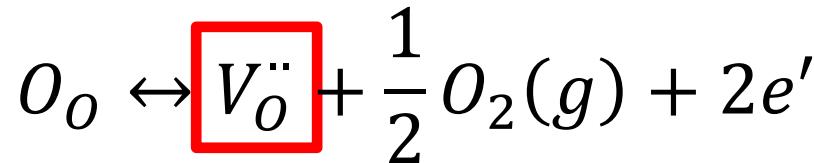
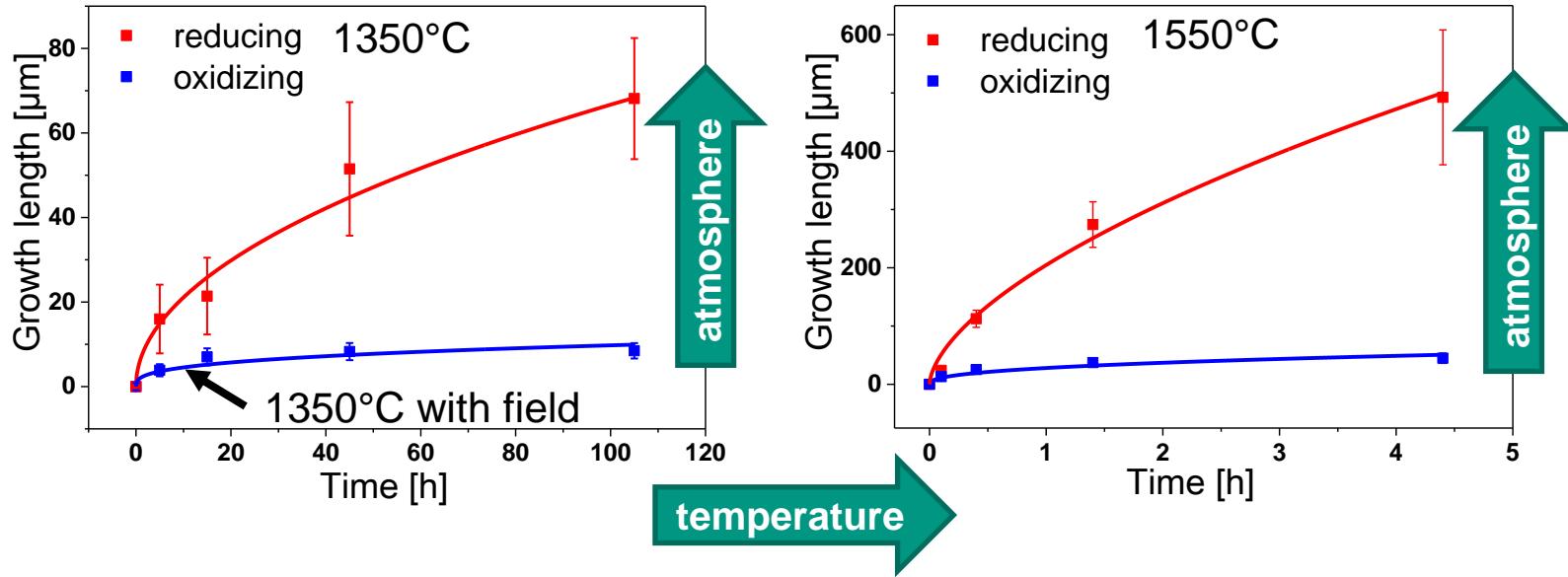
# Oxygen vacancies and grain growth



Parameter

- dwell time
- temperature
- atmosphere

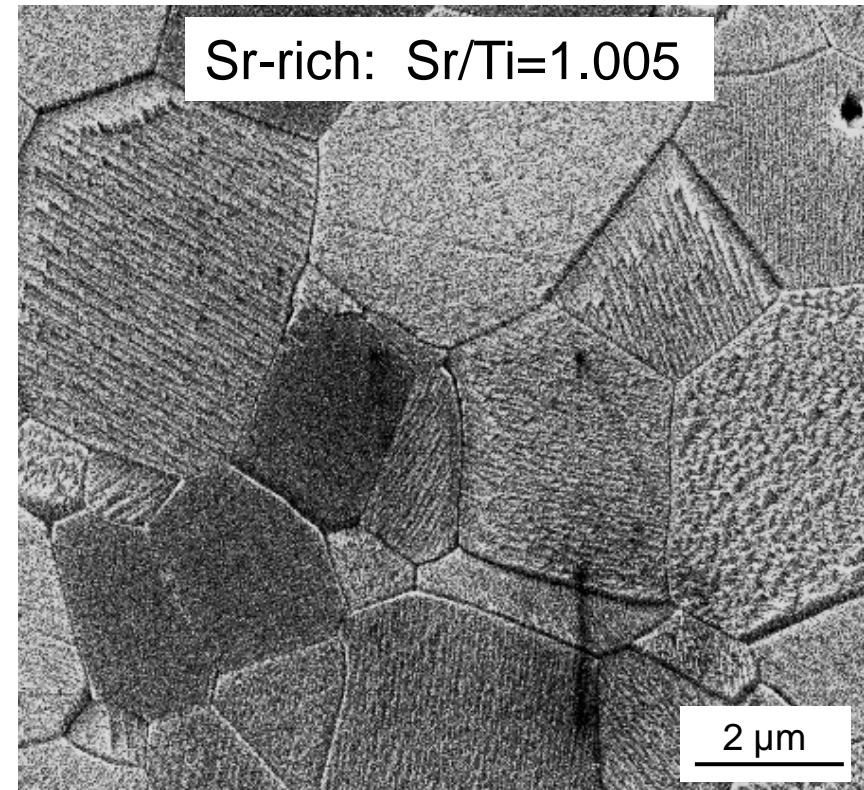
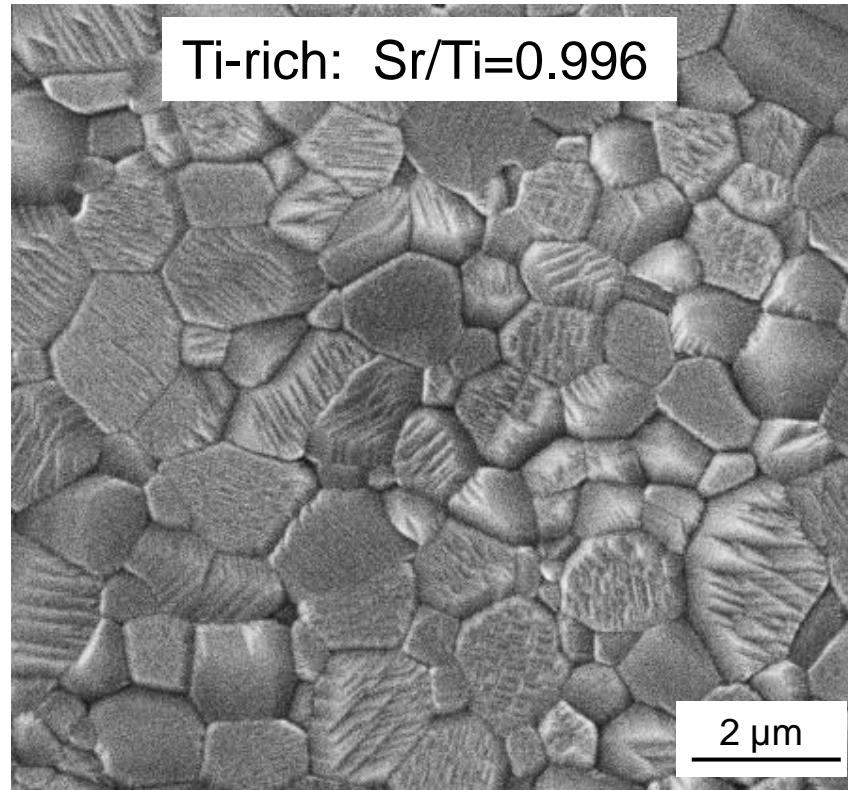
# Oxygen vacancies and grain growth



Reducing atmosphere creates more oxygen vacancies.  
 → Increase in growth rate of single crystal with ***high*** [ $V_O^{\cdot\cdot}$ ]

# Strontium vacancies and grain growth

1425°C 1h in oxygen



Sr-rich compositions reveal a stronger grain growth than Ti-rich ones.

→ Increase in growth rate of polycrystal with ***low*** [ $V''_{Sr}$ ]

# Effect of electric fields on grain growth

Grain growth is faster, if

- *high*  $[V_O^{\ddot{}}]$
- *low*  $[V''_{Sr}]$

1) Effect of Sintering Atmosphere on Grain Boundary Segregation and Grain Growth in Niobium-Doped SrTiO<sub>3</sub>

Chung, Kang, Vinayak  
*J. Am. Ceram. Soc.* 85, p.2805 (2002)

2) Effects of donor concentration and oxygen partial pressure on interface morphology and grain growth behavior in SrTiO<sub>3</sub>

Chung, Yoon, Kang  
*Acta Mater.* 50, p.3361 (2002)

3) A reversible wetting transition in strontium titanate and its influence on grain growth and the grain boundary mobility

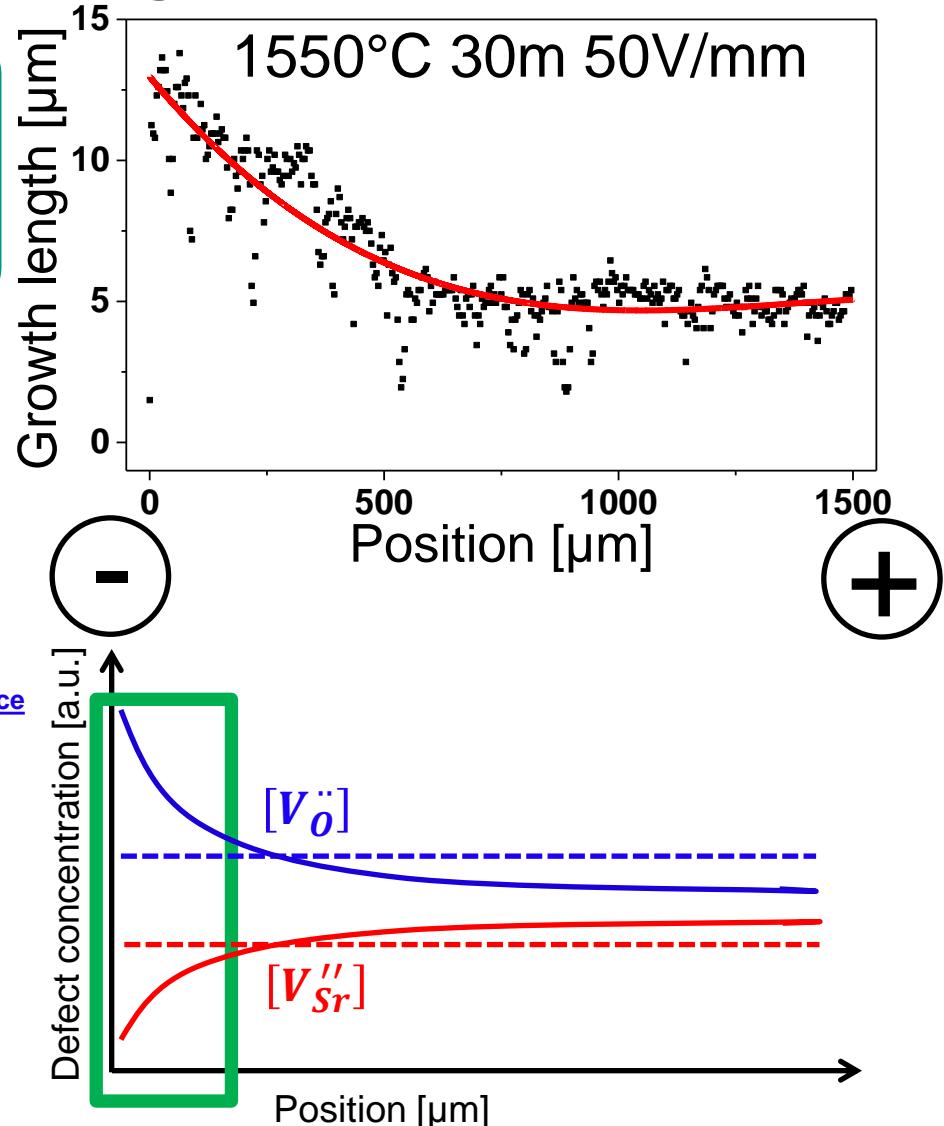
Rheinheimer, Bäurer, Hoffmann  
*Acta Mater.* 101, p.80 (2015)

4) Influence of Sr/Ti Stoichiometry on the Densification Behavior of Strontium Titanate

Bäurer, Kungl, Hoffmann  
*J. Am. Ceram. Soc.* 92, p.601 (2009)

5) Abnormal grain growth in undoped strontium and barium titanate

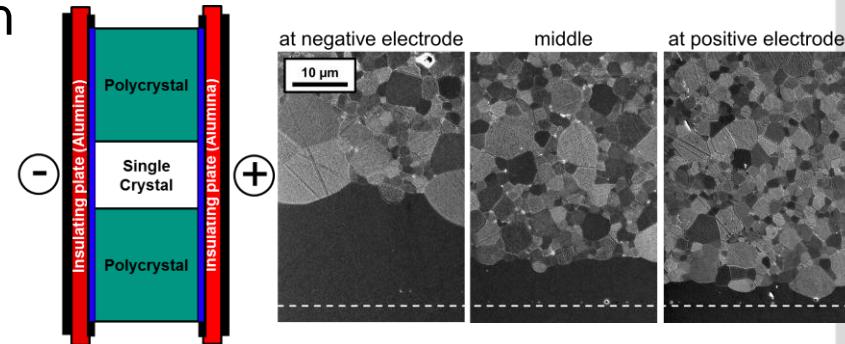
Bäurer, Shih, Bishop, Harmer, Cockayne, Hoffmann  
*Acta Mater.* 58, p.290 (2010)



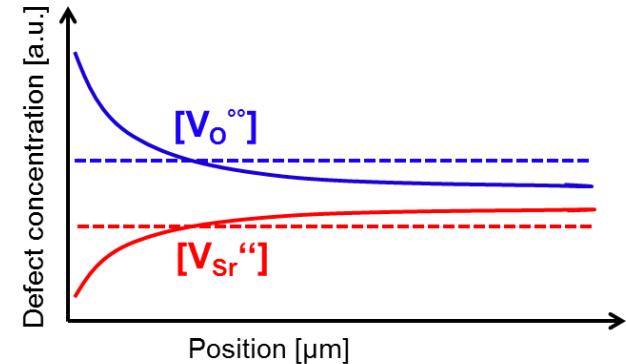
# Summary and conclusions

- Strong impact of the electric field on grain growth in  $\text{SrTiO}_3$  above 1425°C

- Appears in both single and polycrystal
- Faster growth at negative electrode
- Effect is stronger in higher electric field



- Fast growth at negative electrode is caused by
  - Redistribution of defects in the electric field
  - High oxygen vacancy concentration
  - Low strontium vacancy concentration



**Defects are important for grain growth in perovskites !  
 Grain growth with and without field can be treated similarly !**

# Thanks for your attention!

