Electron Microscopic Investigation of Post-Annealed Superconducting $GdBa_2Cu_3O_{7-\delta}$ Thin Films on MgO

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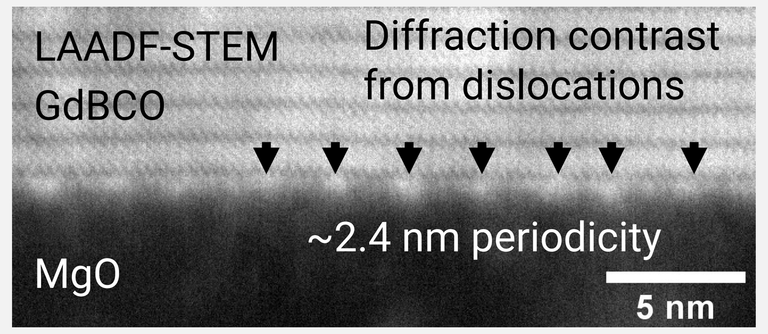
GdBCO-MgO interface

- (Mean) lattice mismatch of ~8.1% (tensile) results in periodic array of misfit dislocations[3] with a theoretical periodicity d_m

$$d_m = \frac{d_{020,MgO} \cdot d_{020,GdBCO}}{|d_{020,MgO} - d_{020,GdBCO}|} = 2.37\ \text{nm}$$

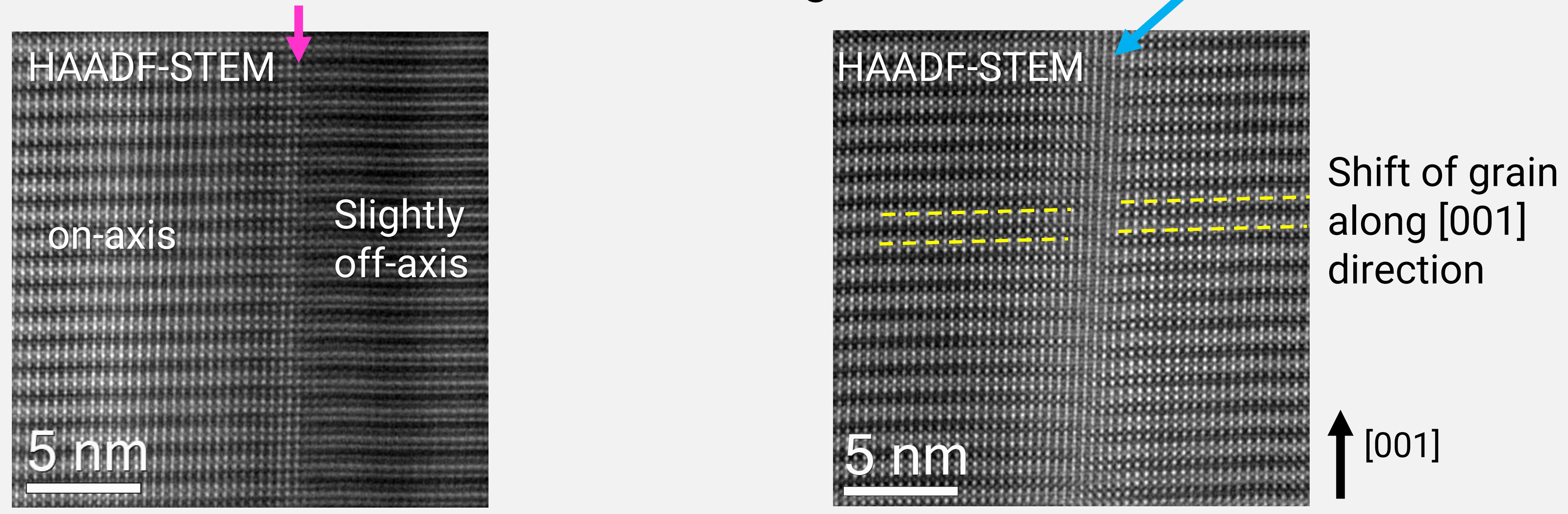
$$d_{020,MgO} = 0.2105\ \text{nm} \qquad d_{020,GdBCO} \approx 0.1933\ \text{nm}$$

GdBCO growth starts at CuO plane[3]



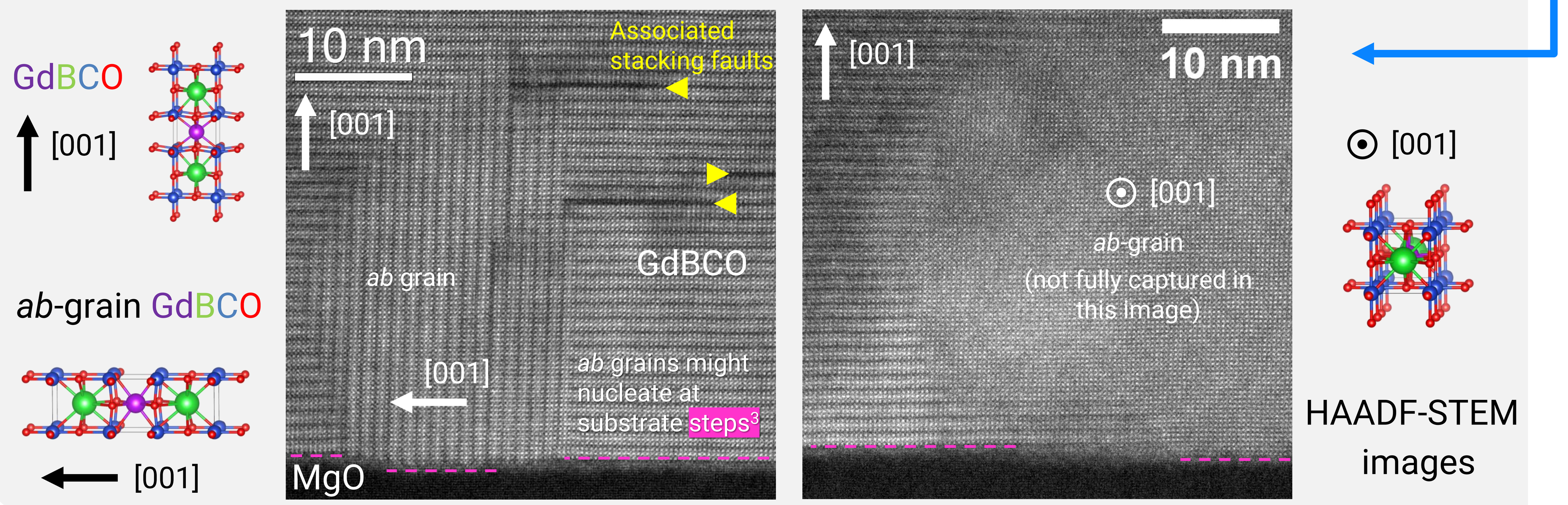
Vertical defects

- Vertical defects in cross-section images are twin-, antiphase-, low-angle [001]-tilt-boundaries[4], and threading dislocations



a/b-oriented grains („ab grains")

- Large ab grains[3,5] observed at substrate interface

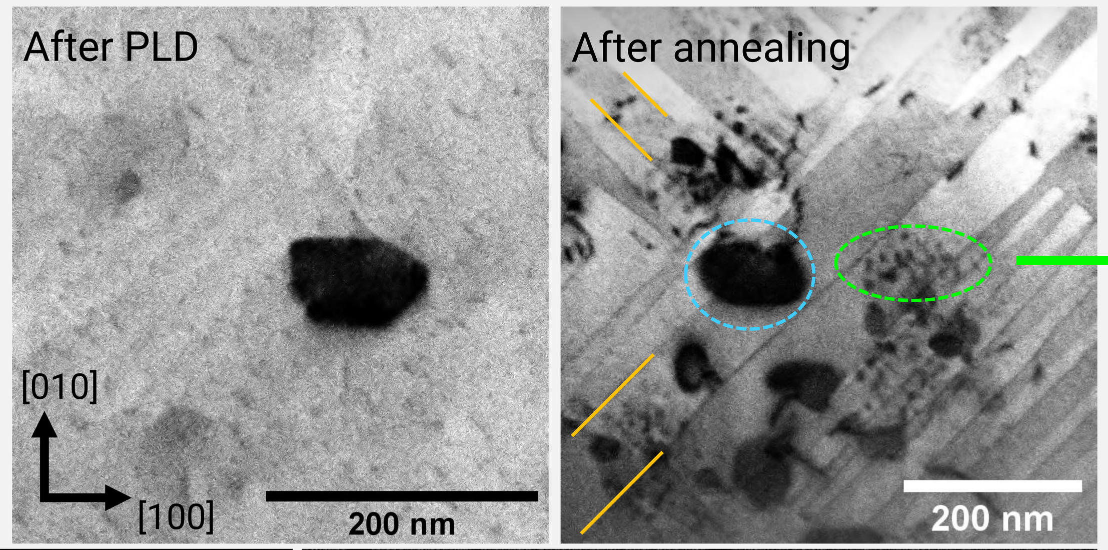


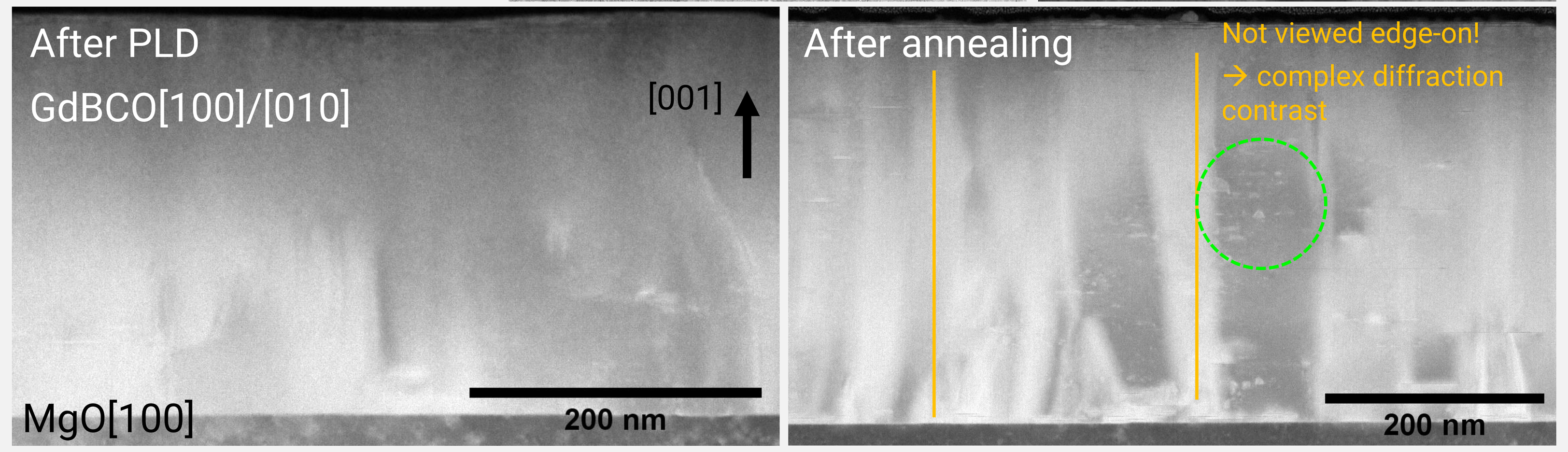
Introduction

- Epitaxially grown superconducting **$GdBa_2Cu_3O_{7-\delta}$ (GdBCO)** thin films are of interest for fundamental research and applications[1]
- nm-sized structural defects desirable for magnetic-flux pinning[2]
  - Increased critical current density
  - Structural changes in film during *ex-situ* O-annealing, which is used to form the superconducting orthorhombic phase ($\delta \approx 0$)
- (Scanning) transmission electron microscopy (STEM) for detailed structural and chemical analysis of nanoscale defects and interfaces

Influence of annealing

- [110]-twin-formation during tetragonal-to-orthorhombic phase transition[2]
- High density of precipitates (small and large) visible after O-annealing





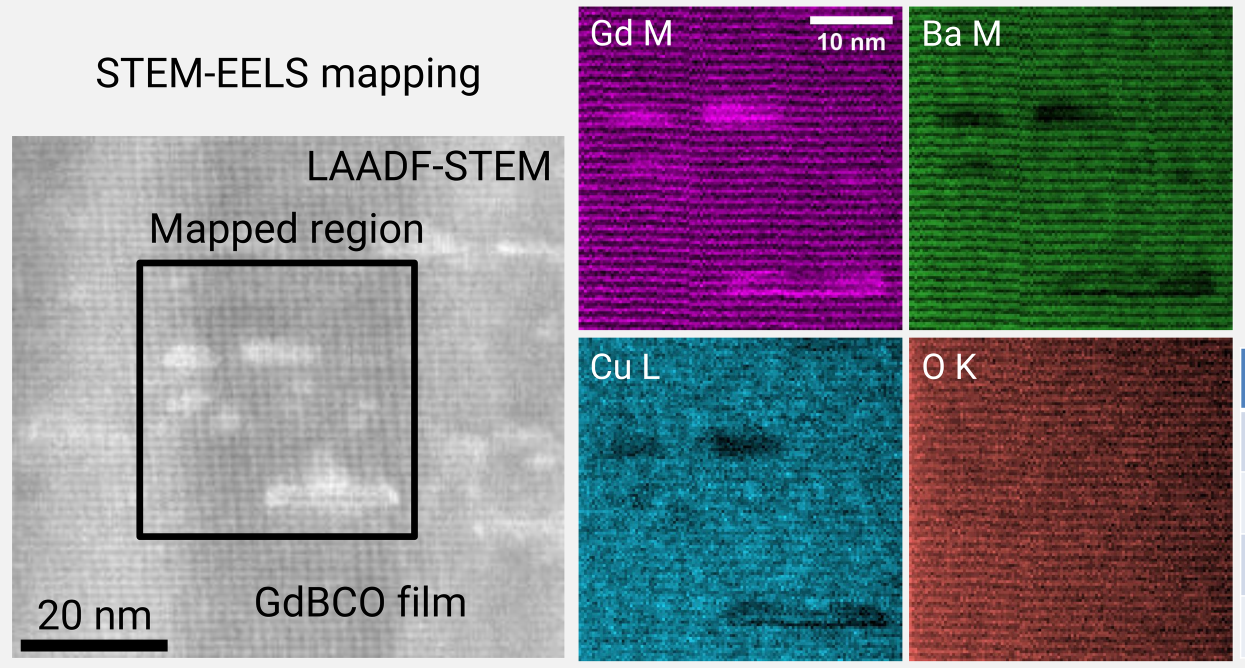
Summary

Understanding of defects and structure-property relations in GdBCO requires **extensive EM-analyses**

Ex-situ annealing introduces additional defects such as twin-boundaries and precipitates

Coherent precipitates

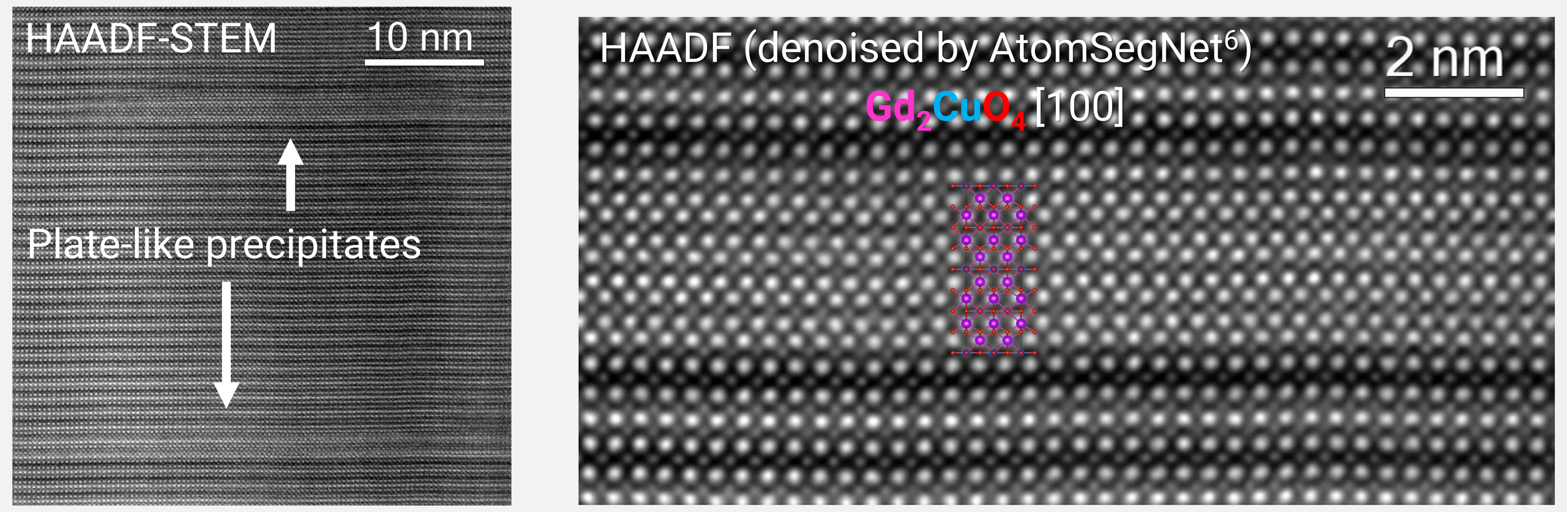
- Small, coherent, plate-like precipitates (probably Gd_2CuO_4)



Extracted EELS core-loss edge net-intensities after filtering with principal component analysis.

Changes in EELS signal (↑, ↓, ≈) near precipitates qualitatively fits Gd_2CuO_4

	$GdBCO_7$	Gd_2CuO_4
Gd / at%	7.7	28.6 (↑)
Ba / at%	15.4	0 (↓)
Cu / at%	23.0	14.3 (↓)
O / at%	53.9	57.1 (≈)



Structure fits well with Gd_2CuO_4

Materials and methods

- GdBCO ($\delta \approx 1$) grown by pulsed laser deposition (PLD) on MgO(001) and subsequent *ex-situ* annealing (450°C, 1 bar O_2, 30 min)
- TEM cross-section and plan-view sample preparation by focused-ion-beam *in-situ* lift-out (FEI Strata 400S & Thermo Scientific Helios G4 FX)
- High/Low-angle annular dark-field (H/LAADF) STEM and electron energy-loss spectroscopy (EELS): FEI Titan³ 80-300, GIF Tridiem 865 ER

[1] Obradors and Puig, *Supercond. Sci. Technol.* **27** (2014) 044003
[2] Hervieu et al., *Phys. Rev. B* **36** (1987) 3920–3922
[3] Træholt et al., *Physica C: Superconductivity* **230** (1994) 297–305
[4] Oktyabrsky et al., *Journal of Materials Research* **14** (1999) 2764–2772
[5] Popov et al., *J. Phys.: Conf. Ser.* **1559** (2020) 012038
[6] Lin et al., *Scientific Reports* **11** (2021) 5386

For STEM-in-SEM analyses of superconducting thin films see the Poster „Analysis of superconducting thin films in a modern FIB/SEM dual-beam instrument"

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