

Influence of residual stress on dislocation behaviour in 4H-SiC during high-temperature annealing

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Introduction

- Residual stress and dislocation densities are important characteristics of 4H-SiC substrates which can influence the device processing^{1,2}
- Both are influenced by thermal stresses during crystal growth and post-growth annealing
- High-temperature annealing can activate dislocation glide if the resolved shear stress (RSS) exceeds the temperature-dependent critical resolved shear stress (CRSS)³
- Wafer-scale annealing experiments were performed to investigate the interaction between initial residual stress, radial temperature gradients and dislocation evolution

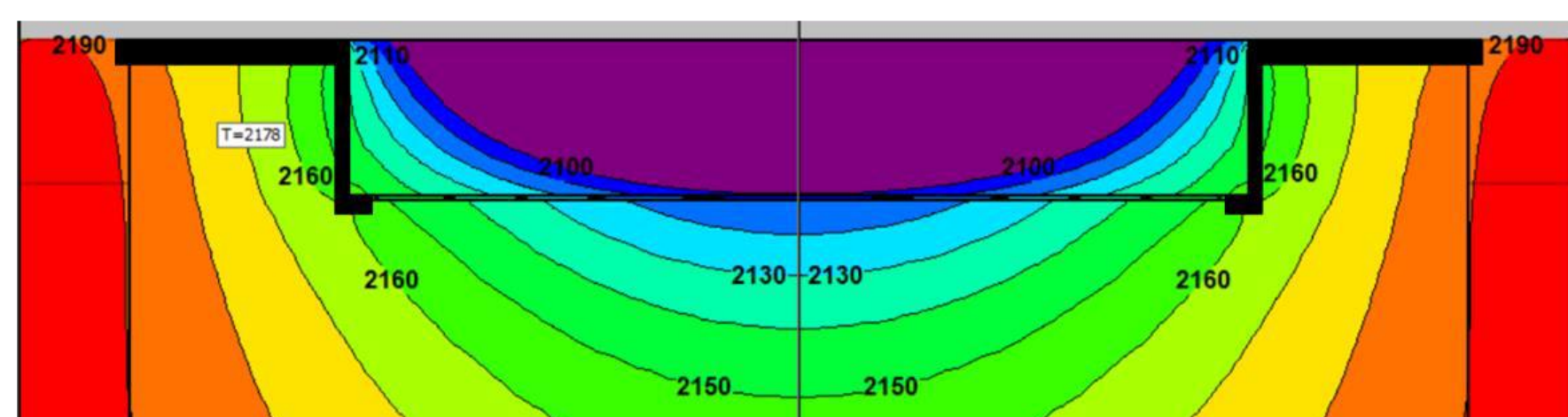
Methods

Characterisation

- The basal plane dislocation (BPD) distribution was measured by x-ray topography using a Rigaku XRTmicron
- Wafer-scale residual stress maps were obtained by photoelastic measurements using an ilis StrainScope Stepper at $\lambda = 590$ nm and the in-plane stress difference, $|\sigma_1 - \sigma_2|$, was determined using a photoelastic coefficient of $C = 2.8 \text{ TPa}^{-1}$ (taken from ⁴)
- According to the principal stress directions, the measured value for $|\sigma_1 - \sigma_2|$ is approximately equivalent to $|\sigma_\theta - \sigma_r|$
- Measurements done before and after thermal annealing

Thermal treatment

- 1 mm thick wafers were annealed at temperatures up to 2200 °C, under nominally uniform heating or with an imposed radial temperature difference of 35–70 K
- The experimental temperature field was simulated and used to calculate the elastic radial and tangential stresses
- Wafers were grinded to remove surface alteration and etched to remove grinding-induced damage

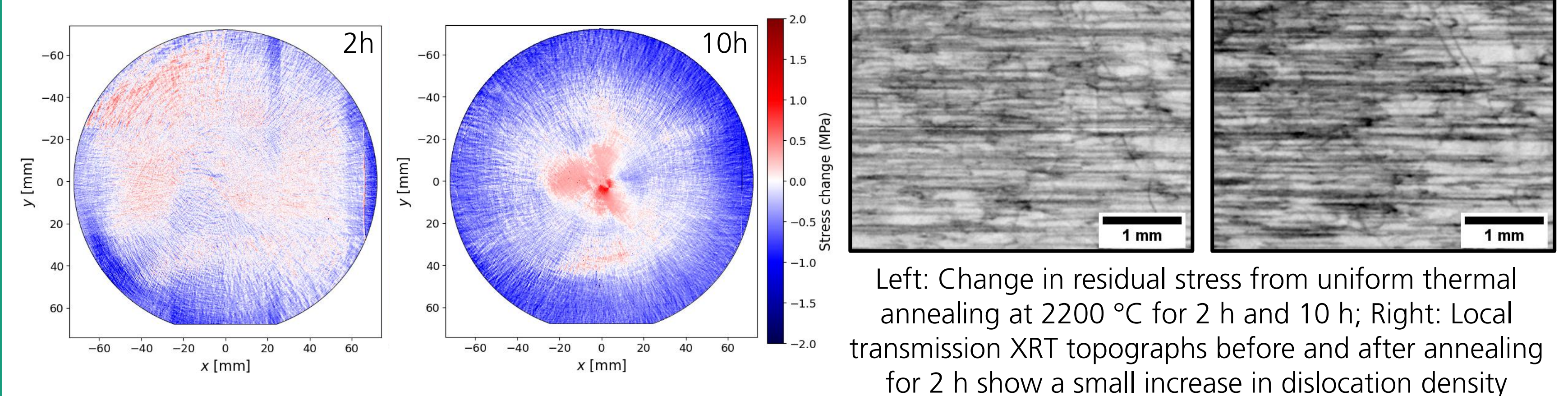


Simulated temperature distribution in the furnace for a nominally radial temperature difference of 50 K

Results

Homogeneous temperature

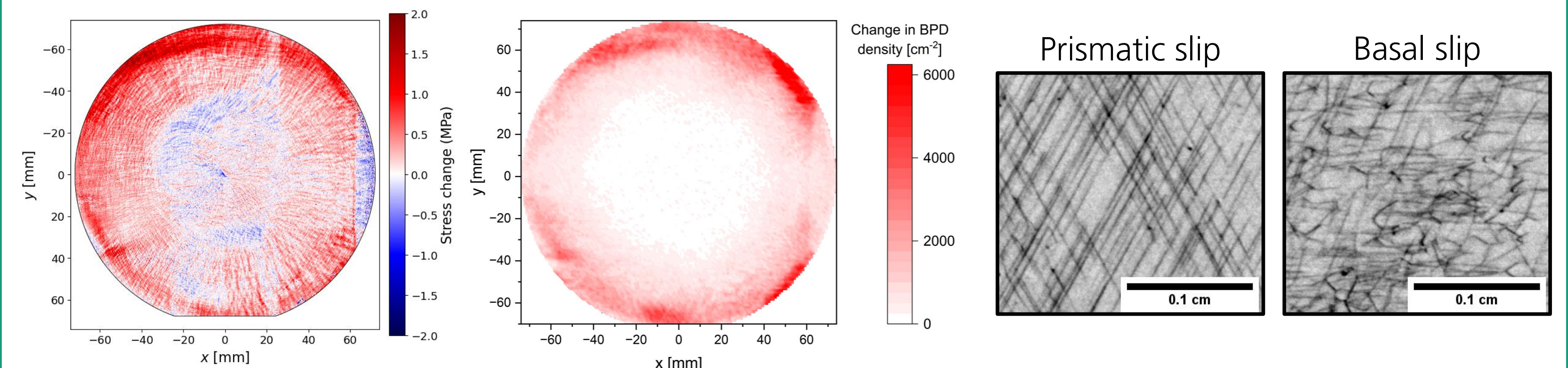
- Local BPD generation observed at 2200 °C
- Accompanied by a local decrease in residual stress at the wafer edge



Left: Change in residual stress from uniform thermal annealing at 2200 °C for 2 h and 10 h; Right: Local transmission XRT topographs before and after annealing for 2 h show a small increase in dislocation density

Thermal gradient

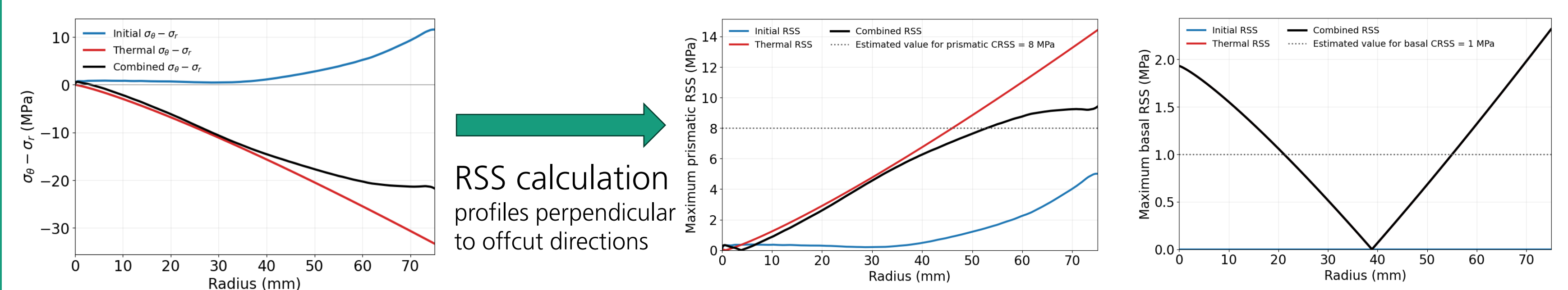
- Stress produced by $\Delta T = 50$ K causes BPD multiplication at the edge of the wafer
- Dislocation directions and distribution indicate activation of both prismatic and basal slip
- Residual stress increases concurrently with this BPD generation



Left: Change in residual stress and in dislocation density from thermal annealing at 2100 °C with a radial temperature difference of 50 K; Right: Local reflection topographs showing typical dislocation directions for prismatic but also basal slip

Expected stress distribution with thermal gradient

- Initial stress state: $\sigma_\theta - \sigma_r > 0$ MPa at the edge
- Thermal stress (from radial temperature gradient): $\sigma_\theta - \sigma_r < 0$ MPa at the edge

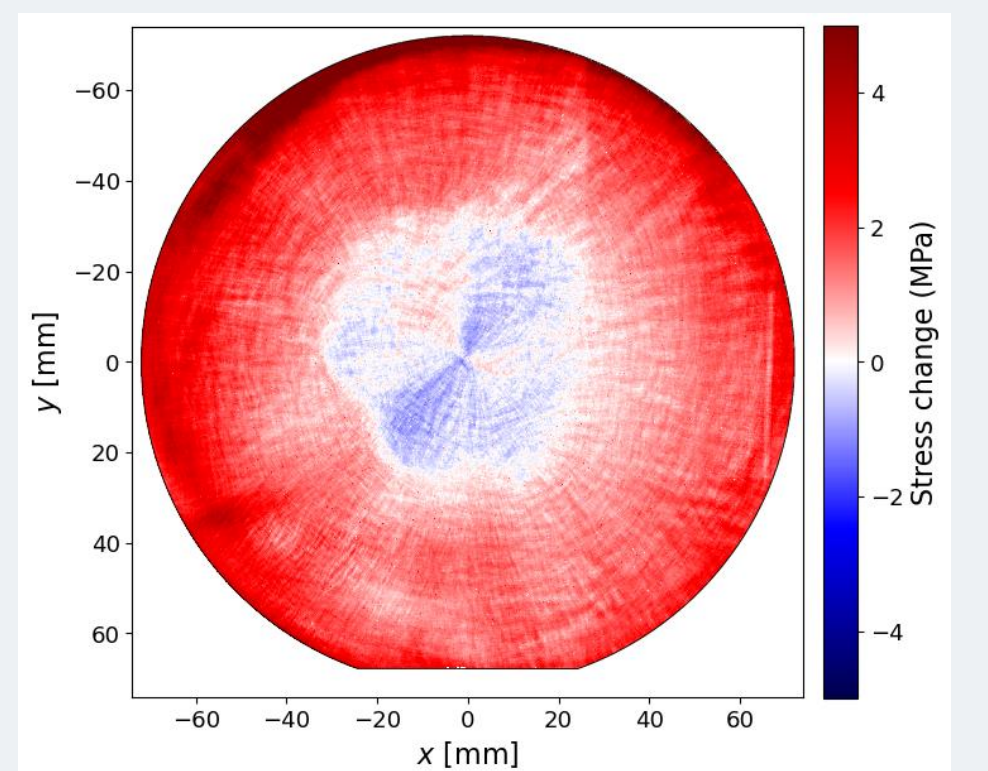


- Total stress distribution dictates RSS and consequently BPD generation
- Observation at $\Delta T = 50$ K in good agreement with a CRSS = 8 MPa for prismatic slip³

Apparently contradictory results from further experiments

~2 MPa higher initial stress at the wafer edge

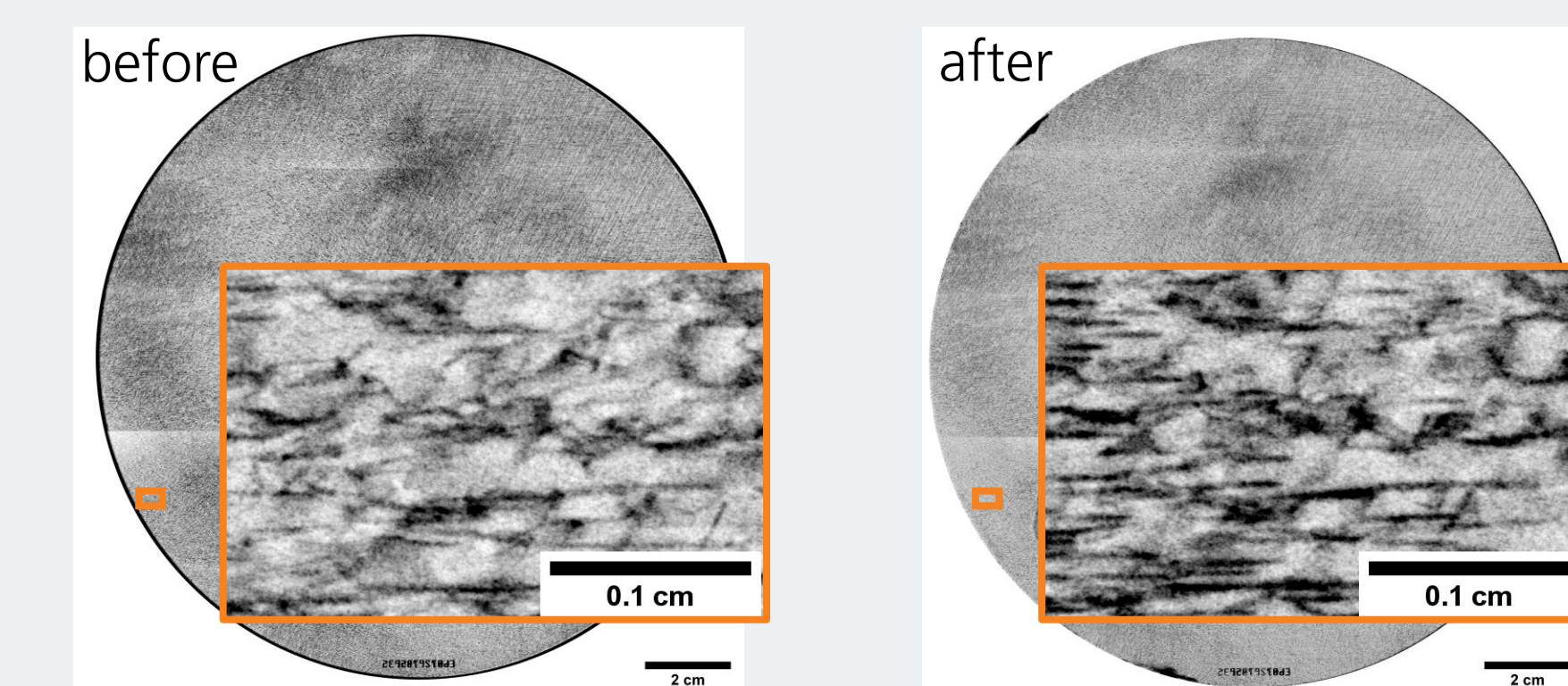
→ Larger stress increase observed



Change in Stress for $\Delta T = 50$ K

~7 MPa lower initial stress at the wafer edge

→ Only minimal edge BPD generation, even at $\Delta T = 55$ K



Transmission topographs before and after annealing with $\Delta T = 55$ K

Conclusion:

Slip was activated more readily in wafers with higher initial stress, despite the lower expected RSS. The origin remains unclear. Possible explanations include:

- Deviations from the simulated radial temperature field due to stress-dependent wafer deformation
- An additional axial temperature gradient, although this should mainly promote basal slip
- Additional stress generated during cooling due to growth-induced bonding of the wafer to the holder during annealing

Summary

High-temperature annealing locally generates BPDs and alters the residual stress distribution

A radial temperature gradient promotes BPD multiplication and activates both prismatic and basal slip

Wafers with higher initial tangential edge stress show more BPD generation despite lower expected RSS - the underlying mechanism remains unclear

References

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