Lattice Rotation in Laser-fabricated Single Crystals in Glass: Its Origin and Implications for Lattice Engineering

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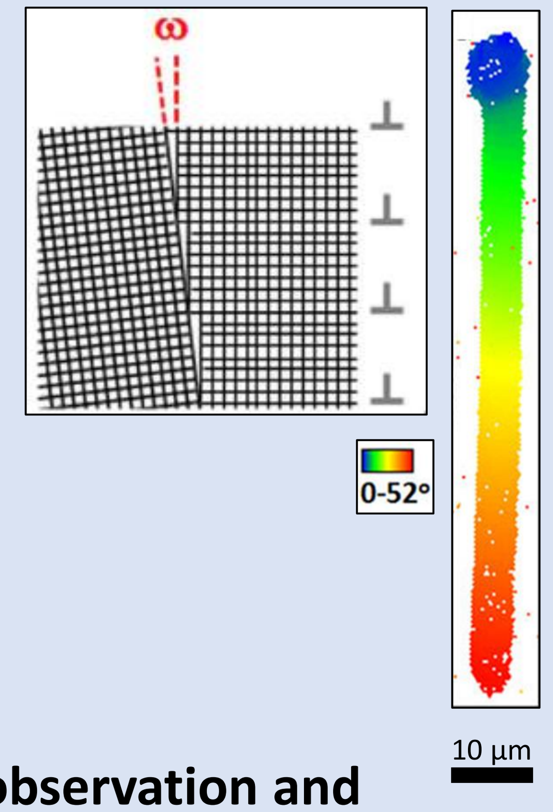
Abstract

Laser heating of a glass surface can be used to fabricate single crystal architecture that exhibit a characteristic lattice rotation. These rotating lattice single (RLS) crystals rotate about an axis parallel to the glass surface and perpendicular to the growth direction. This type of controlled crystal growth can be used to produce lattice engineered metamaterials with potential applications in photonic and optical devices. A dislocation-based mechanism was hypothesized for this rotation based on µXRD results. We validate this hypothesis by direction observation and characterization of these dislocations via transmission electron microscopy (TEM) in Sb_2S_3 crystal lines fabricated in Sb-S-I glass as a model system. We demonstrate that rotation rates measured by electron diffraction agree with those calculated by the observed dislocation densities and Burgers vectors. Using the dislocation-based mechanism, we go on to show how the rotation rate depends on the direction of crystal growth with a maximum in the direction of the largest dislocation. These results provide direct proof of the dislocation mechanism for lattice rotation in RLS crystals, and very likely other forms of growth actuated lattice bending, twisting and non-crystallographic branching seen in spherulites and other unique forms of crystal growth in nature.

Background

- Surface crystallization of glass can cause lattice rotation [1]
- Rotating lattice single (RLS) crystals can be created via laser irradiation and exhibit well-defined and controllable lattice rotation [2]
- A dislocation-based mechanism has been hypothesized for RLS crystals based on micro X-ray diffraction [3]



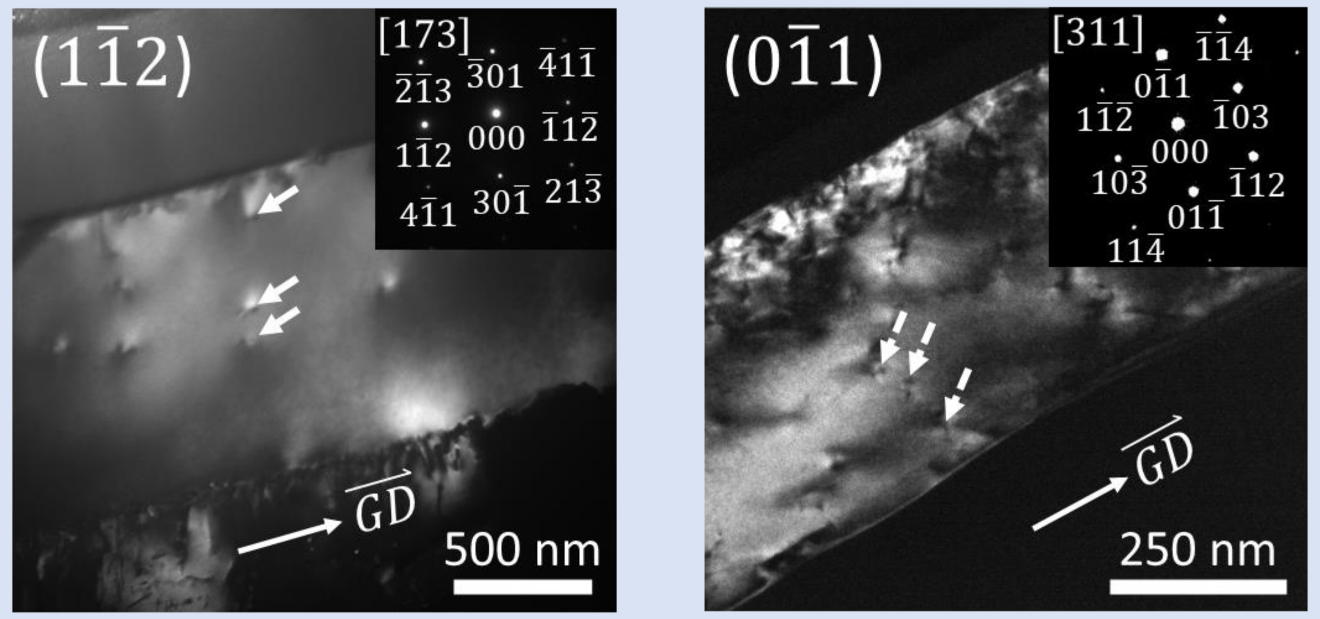
Objective:
Confirm dislocation-based mechanism via direct observation and explore the implications on the rotation rate magnitude

Experimental Procedure

- **Glass and crystal system**
  - Glasses:
    - 84 Sb_2S_3 - 16 SbI_3 and Sb_2S_3[4]
  - Orthorhombic Sb_2S_3 crystals
    - a = 11.314 Å, b = 3.837 Å, c = 11.234 Å
- **Laser parameters**
  - 639 nm CW diode laser
  - 100-150 µW/µm²
- **Rotation Rate Measurements**
  - Electron backscatter diffraction (EBSD)
  - Selected area electron diffraction
- **Dislocation Analysis**
  - Transmission electron microscopy
  - Geometric dislocation characterization
  - Rotation rate calculated from Nye's formula [5]
    - Θ is rotation rate
    - $b_{\overrightarrow{GD}}$ is the Burgers vector component along $\overrightarrow{GD}$
    - $\rho_{\vec{B}}$ is dislocation density

$$\Theta = b_{\overrightarrow{GD}}\, \rho_{\vec{B}}$$

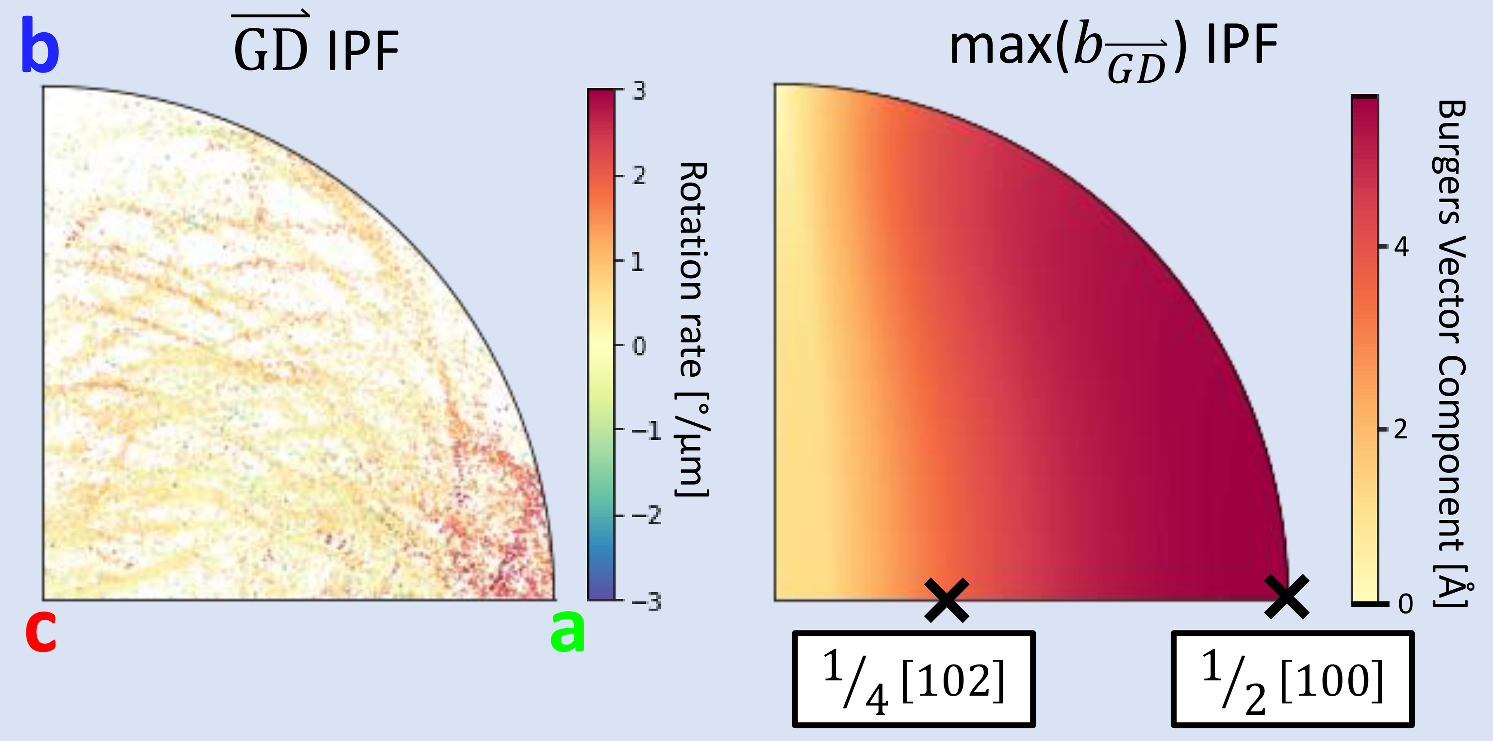
Results: Dislocation Analysis



Rotation rate Θ	Sample 1	Sample 2
Measured	0.11°/µm	0.69°/µm
Calculated	0.16°/µm	0.73°/µm

- Direct observation of dislocations in RLS crystals
- Agreement between measured and calculated rotation rates
- More details in ref. [6]

Results: Predicting Rotation Rate



- Local rotation rate measured over several orientations
- Highest rotation rates measured when crystal grows along a-axis
  - Same direction as largest dislocation
- Relative rotation rate does not fully correlate with the magnitude of the Burges vector component

Summary

- Confirmed dislocation-based lattice rotation by direct observation
- Measured lattice rotation can be completely accounted for by dislocations present
- The direction of the largest dislocation corresponds with the crystal growth direction with the greatest rotation rate

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