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Sandia National Laboratories

Understanding the Plastic Anisotropy of Ta Single Crystals under High Temperature and Dynamic Impact Testing

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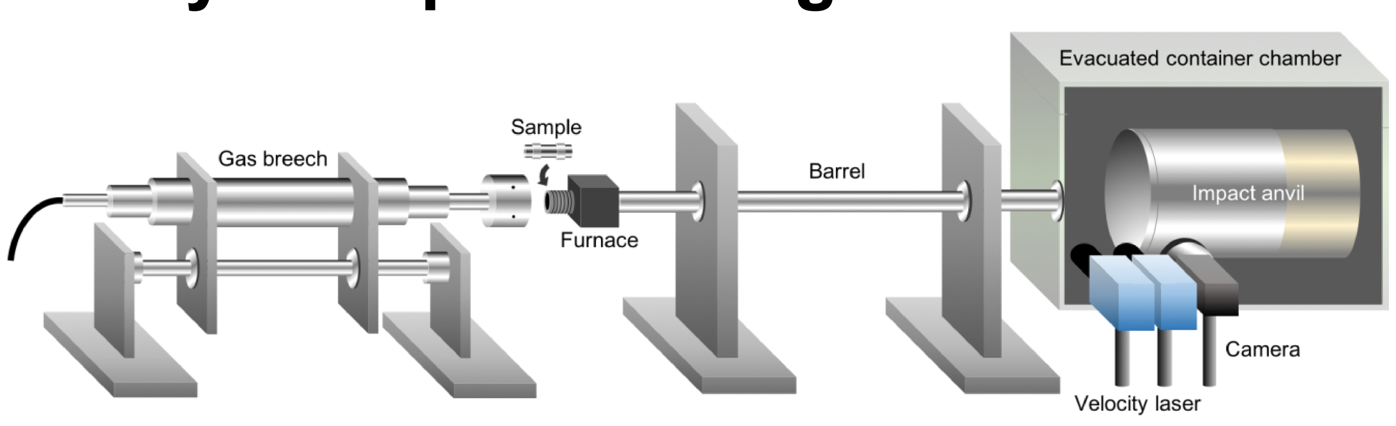
Motivation

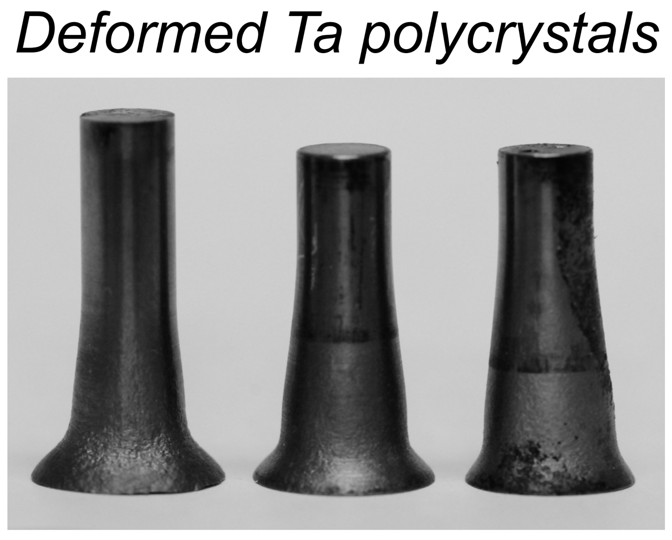
- Due to their high strength and high melting temperatures, refractory metals (such as tantalum) are appealing for high-reliability applications and extreme environments
- Refractory metals show complex deformation mechanisms under dynamic and high temperature regimes, which complicate their use
- Multi-scale, multi-physical, and microstructure-aware plasticity models are necessary to accurately predict material response

Taylor Impact Testing[1]

LANL impact facility



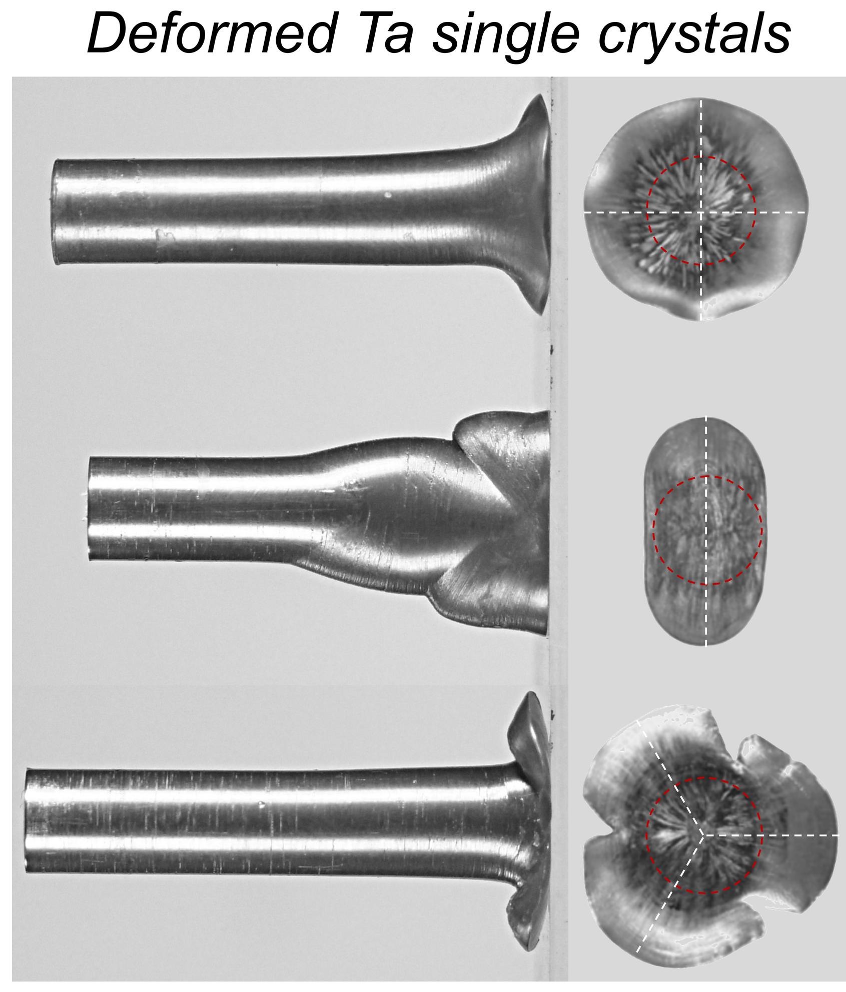
Deformed Ta polycrystals



25 °C   250 °C   300 °C

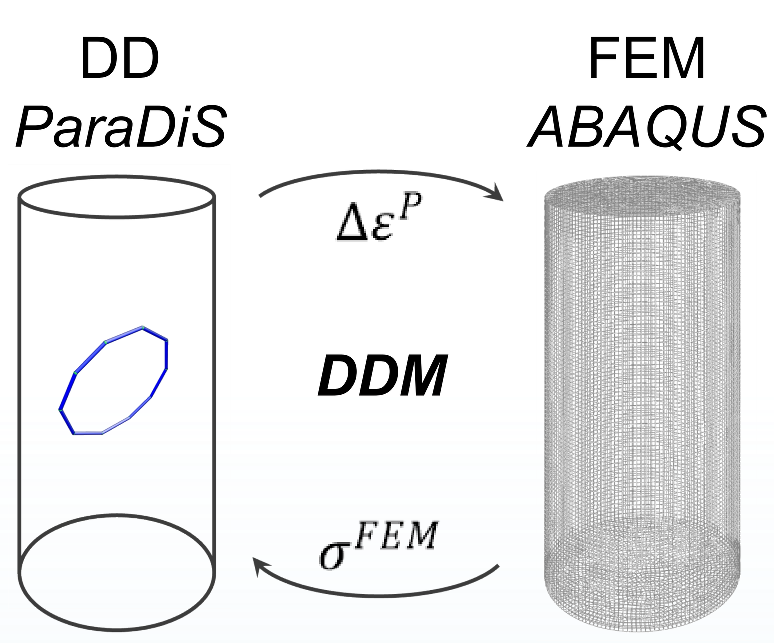
- Simple, robust & inexpensive technique
- Large strain-rate gradients
  $$\dot{\varepsilon} < 5 \cdot 10^4\ s^{-1}$$
- Large temperature gradients
  $$T < 1000\ K$$
- High temperature environments show a significant effect in deformed shape

Deformed Ta single crystals



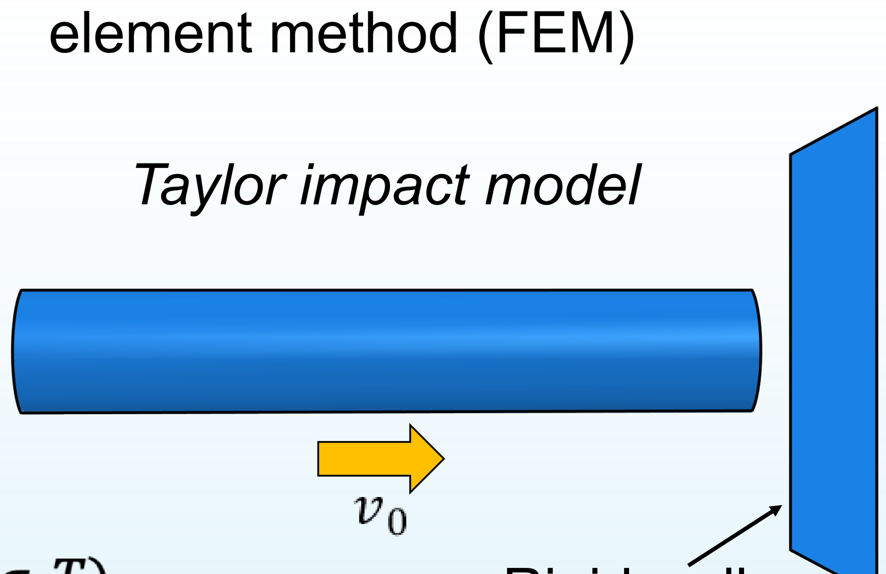
- Impact surfaces show strong axial symmetries:
  - [100] → four-fold
  - [110] → two-fold
  - [111] → three-fold
- Accurate temperature and strain-rate dependent strength models are necessary to predict microstructural evolution

Multi-scale Defect Dynamics Modeling[2]



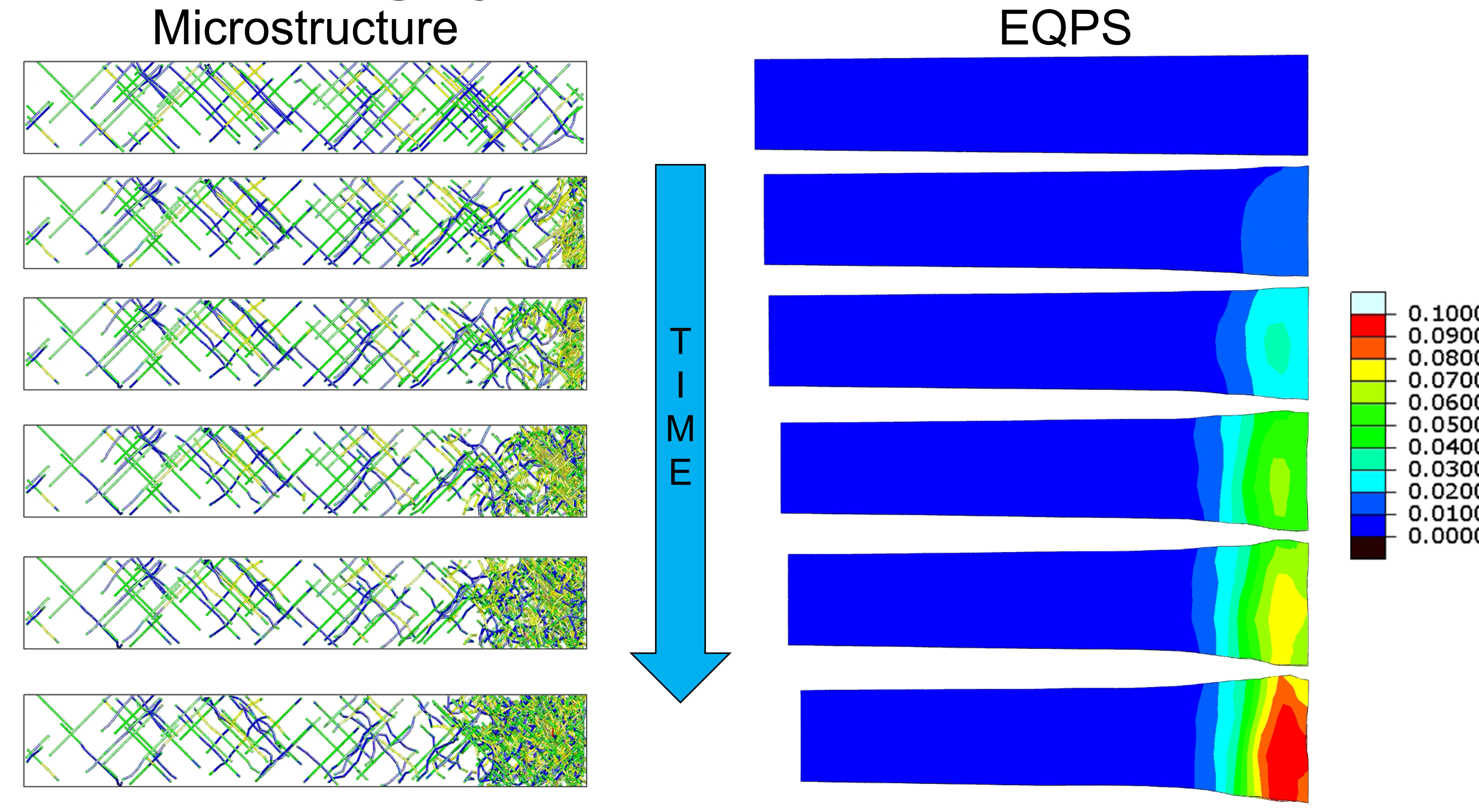
- Defect dynamics modeling (DDM) concurrently couples mesoscale dislocation dynamics (DD) and continuum finite element method (FEM)

Taylor impact model



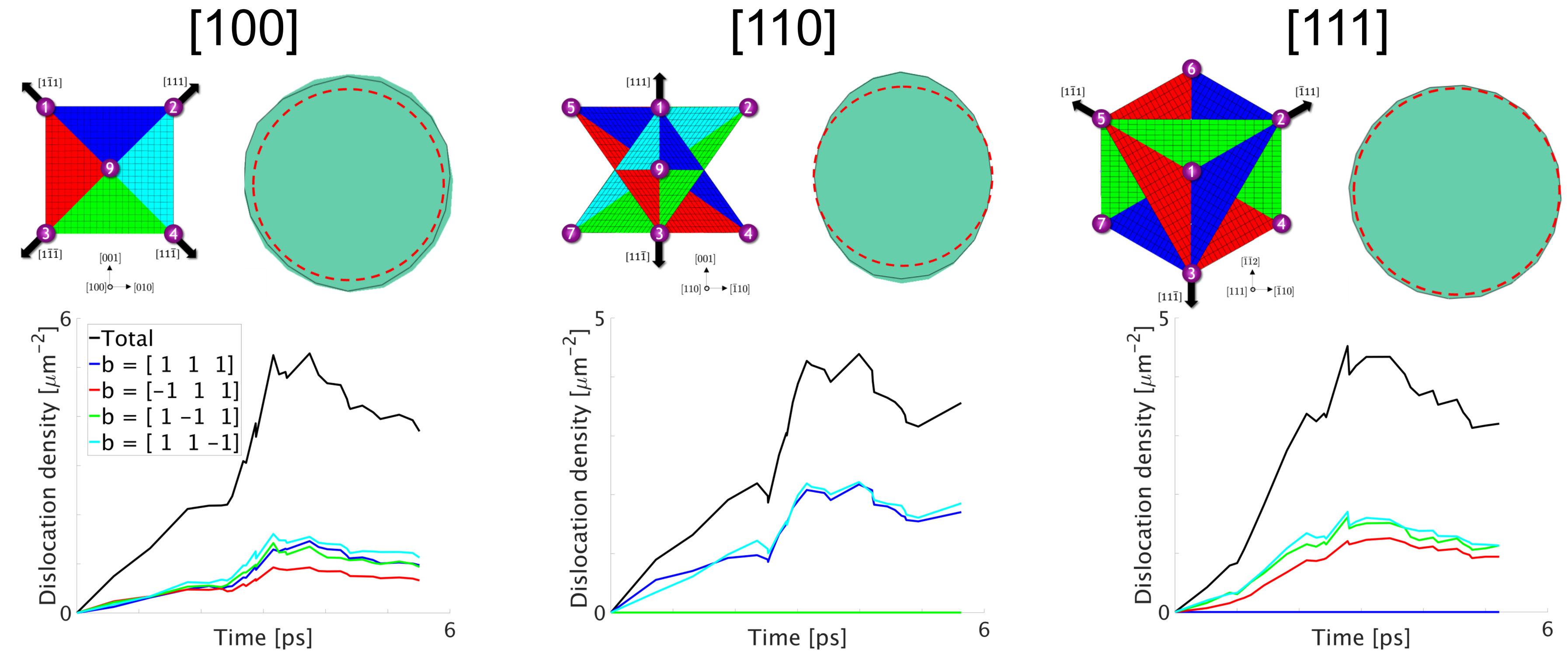
- Thermally-activated deformation mechanisms[3]:
  - Dislocation velocity - $v(\sigma, T)$
  - Dislocation nucleation – $G_C(\sigma, T)$

Highly Localized Deformation

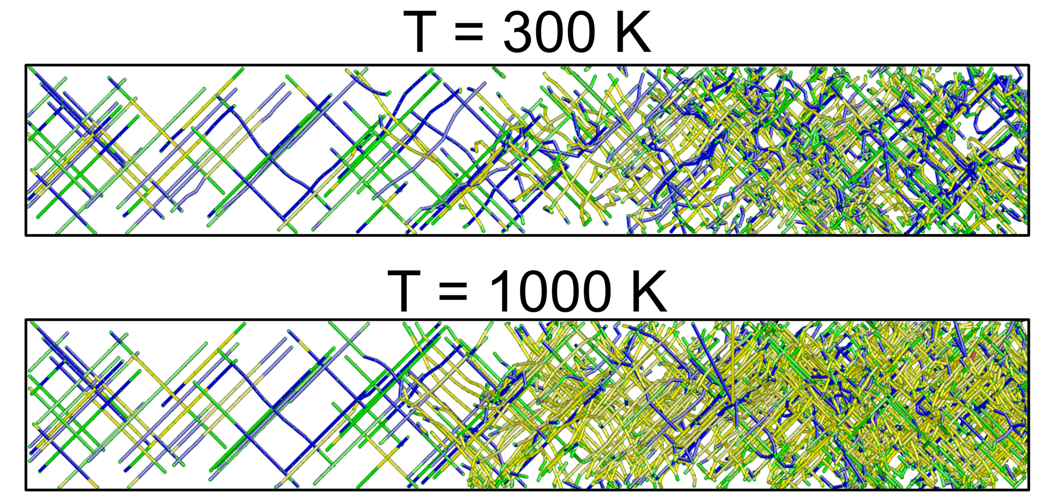


Anisotropy and Temperature Dependence

- Anisotropy of impact surfaces can be attributed to the number of activated slip directions upon initial impact



- DDM can predict impact foot shape and detailed slip activity



- Plastic deformation increases and extends further along the sample due to elevated temperature

Conclusions

- Microstructure has a strong effect on both macroscopic behavior and local fields in extreme environments
- In contrast to generalized FEM, our novel multi-scale model incorporates the effects of defects and microstructural features
- The developed model provides insight on complex plasticity mechanisms during impact testing, and aims to improve plasticity models within *ALEGRA* and *SIERRA Solid Mechanics*

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1) H. Lim, J.D. Carroll, C.C. Battaile, S.R. Chen, A.P. Moore & J.M.D. Lane, *Scientific Reports* (2018)
2) P.C. Nguyen, N.K. Aragon, T. Park, F. Pourboghrat & I. Ryu, *JMPS* (Under Review)
3) N.K. Aragon, S. Yin, H. Lim & I. Ryu, *Materialia* (2021)

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