ACTIVATING EXTRINSIC AND INTRINSIC TOUGHENING MECHANISMS IN POLYCRYSTALLINE CERAMICS AND THEIR COMPOSITES VIA MICROSTRUCTURAL ENGINEERING

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Ferroelastic toughening is one of a limited number of intrinsic toughening mechanisms available for ceramics, yet rarely is it effectively implemented due to a limited understanding of the activation mechanisms within a polycrystalline framework. In the earliest descriptions of ferroelastic toughening, terms such as the transformation strain, coercive stress and process zone parameters were included following other (extrinsic) crack tip shielding models. In the years that have followed, constitutive models have become more sophisticated, incorporating crystal orientation, rate behaviors, and several other factors. However, further development of these models has been limited by the paucity of experimental observations linking ferroelastic switching with critical, yet common, microstructural variations (i.e. grain size, nearest neighbor orientations, secondary/grain boundary phases, etc.). Here we present a multi-scale experimental approach to explore the role of stress concentration, stress transfer and localized constraint in ferroelastic domain nucleation, motion and subsequent toughening. In situ TEM nanopillar and ex situ micropillar compression on single crystal specimens extracted from a polycrystalline ceramic have been used to correlate crystallographic orientation with coercive stresses for domain nucleation and motion. The comparison between these two length scales also highlights the importance of boundary conditions on the nucleation of ferroelastic domains and sheds light on the grain size dependence of domain nucleation probability extracted from Vicker's indentation of polycrystalline ceramics of the same composition. This insight will ultimately be coupled with grain orientation, elastic anisotropy data and quantified stress distributions during deformation to establish the early foundations of a microstructural design framework for ferroelastically toughened ceramics.

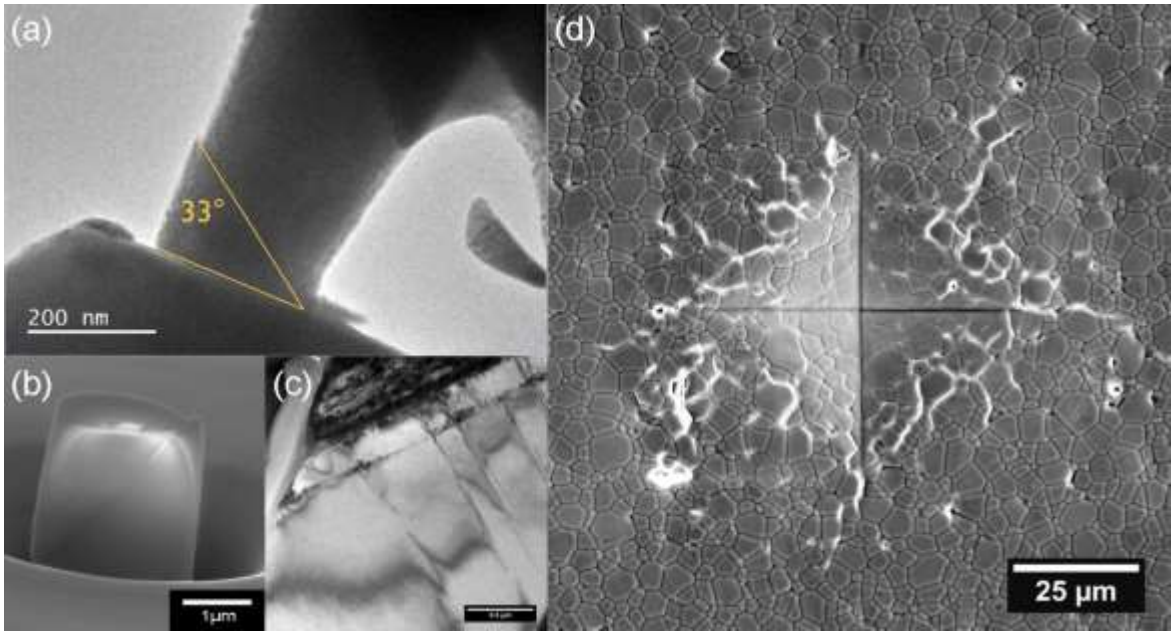

Figure 1 – An overview of the length scales probed in this study. (a) In situ single crystal nanopillar deformation as a function of crystal orientation. (b) Ex situ single crystal micropillar deformation at a lower surface to volume ratio. (c) TEM bright field imaging of the dislocation/twin structure following micropillar deformation. (d) Vickers indentation of a polycrystalline ceramic wherein twinning is observed in many but not all of the grains surrounding the indent.