In-situ Transmission Electron Microscopy Indentation to Characterize Deformation in Ceramics

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Background

This project focuses on determining the deformation mechanism in the ceramic material, mullite ($3Al_2O_3 \bullet 2SiO_2$ or $2Al_2O_3 \bullet SiO_2$).

Mullite has excellent high temperature properties and can be used for environmental barrier coatings, high temperature fibers for composites, and high temperature optically transparent windows.

By understanding the fundamental deformation mechanism of slip (dislocation movement) a complete characterization of the mechanical properties of mullite is achieved [1].

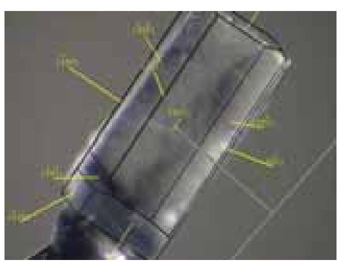
In-situ nano-indentation Transmission Electron Microscopy (TEM) is used to indentation the surface of single crystal mullite to create plastic deformation regions and create localized dislocations.

Single Crystal Mullite

This crystal, one of the last known crystals in existence, will be used for the sole purpose of determining the slip-system of mullite.

A rare single crystal of 2:1 mullite was grown by the late Dr. Wallrefen using the Czochalski method [2].

Crystallographic planes and directions were identified using a Bruker smart CCD diffractometer



Shear Stress

Slip planes (usually the planes with the weakest bonding between them) feel a maximum shear stress when the slip plane and slip direction are oriented 45 degrees to the applied compressive or tensile axis [3].

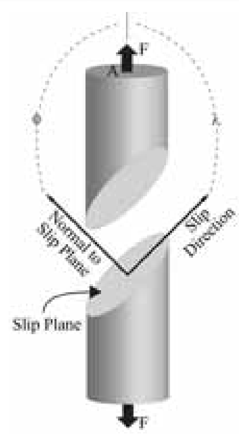
Resolved shear stress, τ, is determined by:

$$\tau = \sigma \cos\phi \cos\lambda$$

σ = applied stress

ϕ = angle between the normal to the slip plane and applied force

λ = angle between the slip plane direction and applied force

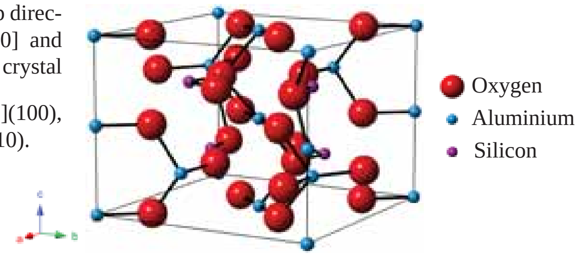


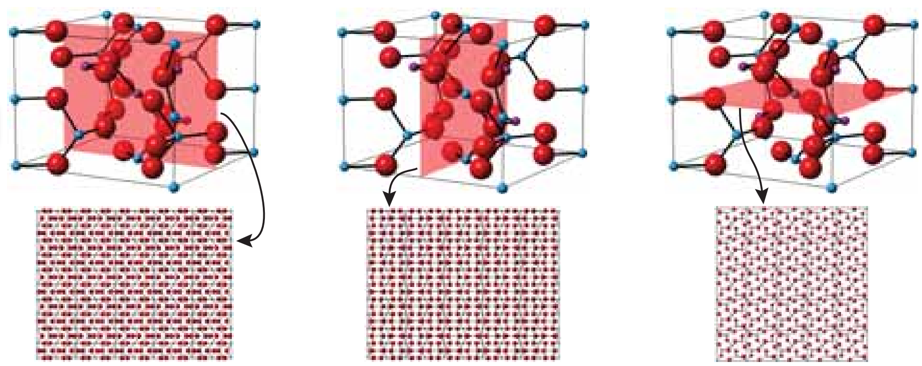
Crystallographic Planes of Interest

Previous research has shown the slip directions for mullite to be [100], [010] and [001] directions the orthorhombic crystal

The expected slip systems are [001](100), [010](100), [100](010) and [001](010).

We will also check [100](001) and [010](001) to verify that slip does not occur on (001).



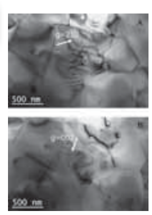


(100) Plane (010) Plane (001) Plane

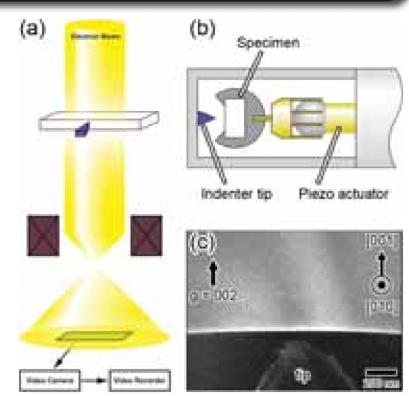
We postulate that the slip planes for mullite will be the atomically dense (100) and (010) planes, but not (001) as strongly bonded chains of polyhedra along the c-axis make (001) slip unlikely [4].

Dislocation Generation

Dislocations generated in mullite during deformation traversing the grain (*left images*) [1].



Samples will be placed inside the TEM where a piezo actuator controlled nano-indenter (*right image*) will deform the sample in order to produce dislocations [5].



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