Interface Structure and Kinetics in Doped Alumina

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Grain boundaries in polycrystalline microstructures are often decorated with dopants that are added intentionally, or impurities that are acquired during processing and service. The nature of the foreign substances profoundly influences various materials properties including diffusional transport, interfacial fracture, oxidation, corrosion and creep resistance. In many metallic and ceramic systems interfaces with various types of segregation, from sub-monolayer to thick microscopic films, have been observed. Recently, these interface phases have been considered as thermodynamically distinct three dimensional phases, called Grain Boundary Complexions. In the current work, alumina has been chosen as a model system to study the various boundary complexion types and its relationship with boundary mobility.

Grain growth kinetics measurements in hot pressed dense yttrium-doped and yttrium-silicon co-doped polycrystalline alumina showed boundary mobility varying over 6 orders of magnitude between 1200 °C and 2000 °C. Additionally, many different regimes of boundary mobility were observed. Microstructures corresponding to these distinct boundary mobility regimes were identified and quenched from the annealing temperatures to preserve the grain boundary structure. The presentation aims to focus on the relationship between the boundary mobility and the structural features of the interface complexions from complementary studies of electron microscopy and synchrotron XAFS.
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Creep in rare-earth doped alumina, Harmer Group, Lehigh

Creep in transition metal doped alumina, Ronald Gordon, Uni of Utah
Accelerated Grain Growth in Alumina

- PCA Tubes for HPD lamp jackets
- HT resistance, transparency are requirements
- Fully transparent jackets will enhance energy efficiency.

- Abnormal grain to consume the whole lent to become a single crystal tube
- Tested wit Lehigh and Osram joint work

Curtis Scott et al. JACerS 2004
TGO layers in Turbine Blades

- Thermally grown layer of alumina develops between bond coat and top coat
- Presence required for oxdn resistance
- But growth is deleterious
- Y, La etc are known to reduce TGO layer growth
- Grain growth kinetics not studied

Image: Nitin Padture, Science 2003
Materials Fabrication

Hot Press

Annealing Furnace

Image courtesy: Shen Dillon, UIUC
Grain Growth in La doped Alumina

(a) Microstructure of La doped Alumina

(b) Histogram showing grain size distribution

Number of Grains vs. Grain Size [µm]
Grain Growth Kinetics

\[ G_t^2 - G_0^2 = Kt \]

\[ G_t^3 - G_0^3 = Kt \]

\[ K = K_0 \frac{-Q_{gb}}{RT} \]
Grain Growth Kinetics

- Grain velocity (that is the evolution of grain size)

\[
\frac{dG}{dt} = v_b = F_b M_b
\]

- Driving Force: Curvature

\[
F_b = \frac{2\gamma_{gb}}{G}
\]

- Drag plus intrinsic force (F)

\[
v_b = \frac{F}{M_b^{-1} + \alpha C_\infty}
\]

- Representing the Cahn form for velocity differently (Gibbsian excess):

\[
v_b = \frac{F}{M_b^{-1} + \alpha' \Gamma_d}
\]
Grain Growth in La doped Alumina

Stationary Grain Boundary

Moving Grain Boundary

Solute distribution

Solute cloud
Grain Growth Kinetics

- Since the intrinsic mobility term is very low, velocity can be approximated to be only a function of Gibbsian excess.
  \[ v_b = \frac{F}{\alpha' \Gamma_d} \]

- Gibbsian excess varies with grain size
  \[ \Gamma_d = \frac{XG}{3\Omega} \]

- Velocity varies as inverse-square of grain size
  \[ \frac{dG}{dt} \propto G^{-2} \]

- Cubic kinetics
  \[ G_t^3 - G_0^3 = Kt \]
Microscopy of Y-doped Alumina

Laboratory for New Ceramics, NIT Rourkela
Activation Energy of Grain Growth

Temperature (T) [°C]

Yttrium; $AE=407 \text{ KJ.mole}^{-1}$

Lanthanum; $AE=418 \text{ KJ.mole}^{-1}$

$\ln K$

Inverse Temperature ($T^{-1}$) [K$^{-1}$]
This presentation is incomplete.
Please speak to me for more information on the research results and area.

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Yttrium or Lanthanum (or large sized dopants) in alumina exhibit cubic grain growth kinetics.

Based on a simplification of Cahn’s model, it can be shown that the boundary velocity can be influence by dopant concentration and dopant distribution (segregation).

Velocity, thus, varies as inverse-square of grain size. This manifests in the cubic grain growth kinetics.

These dopants reduce the grain boundary mobility of polycrystalline alumina, lowest $M_b$ for La-doped alumina.

Submonolayer (Langmuir-McLean type) adsorption of the dopant atoms in the GB exhibit strong bond strength, reduced creep strain rate, reduced boundary mobility, and enhanced toughness (Hf in alumina).