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TO: U.S. DEPARTMENT OF ENERGY

OFFICE OF BASIC ENERGY SCIENCES

MATERIALS SCIENCE DIVISION

***FINAL REPORT** for:*

OXIDE CERAMIC ALLOYS AND MICROLAMINATES

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PRINCIPAL INVESTIGATOR:

I-WEI CHEN

DEPARTMENT OF MATERIALS SCIENCE AND ENGINEERING
UNIVERSITY OF MICHIGAN, ANN ARBOR, MICHIGAN

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Major research conducted in this program falls into the following areas.

a. Microstructure and Micromechanics of Superplastic Ceramic Composites
b. Solute Segregation and Grain Boundary Kinetics of Ceramic Alloys
c. Sintering, Grain Growth, and Texture Development of Ceramics and Thin Films
d. In-situ and Microlaminate Oxide Composites.

The basic approach to the above research is to utilize the state of the art methods to process colloidal and green ceramics, to employ crystal chemistry and phase equilibria for microalloy and microcomposite design, to comprehensively characterize microstructure development and mechanical performance, to develop models, theories, and simulations to understand the energetics, kinetics and mechanics, and to explore novel microstructures and improved performance for practically important ceramics. Major accomplishments are summarized below.

a. Microstructure and Micromechanics of Superplastic Ceramic Composites

A strategy for alloy designs of superplastic ceramics has been developed. In applying this strategy to ceramic composites, transient phase processing is important. This approach is readily applicable to ceramics that have a tendency for anisotropic grain growth, and has been practiced to obtain ceramics that are superplastically formable at intermediate temperature but are creep resistant after post-forming heat treatment at higher temperatures. This has been demonstrated for zirconia/mullite, mullite/SiC_w, and Si_3N_4/Si_3N_{4w}. The deformation mechanics of ceramic composites have also been investigated using these ceramics, and analytical theories have been successfully developed.

Publications: See Nos. 1, 2, 5, 6, 7, 9, 11, 14, and 16 below.

b. Solute Segregation and Grain Boundary Kinetics of Ceramic Alloys

A comprehensive database for grain boundary mobility in solid solutions of oxide ceramics that have a fluorite or a fluorite-related crystal structure has been established. These ceramics all have an appreciable solubility range and are essentially cubic. Including zirconia, ceria, and yttria, they are important for nuclear, fuel cell, sensor, and structural applications. The solute segregation and drag mechanism has been modeled in the context of space charge concept, the dominance of interstitial mechanism for cation diffusion has been affirmed, the effects of ionic charge and size have been delineated, and the most effective dopants for suppressing grain growth have been identified.

Publications: See Nos. 2, 5, 8, 12, 15, 17, 22, and 23 below.

c. Sintering, Grain Growth, and Texture Development of Ceramics and Thin Films

Using very fine, highly sinterable powders of ceria and yttria, sintering behavior has been investigated to understand the concept of sinterability. These powders have a sintering temperature some 500°C below the prior art. For the initial and intermediate stage sintering, the existence of a universal microstructure in terms of normalized pore size distribution and particle size has been demonstrated, and the dominance of a particle coarsening/rearrangement mechanism that supercedes the pore/particle coordination mechanism has been established. For the final stage sintering, a Monte-Carlo simulation method has been developed to illustrate the evolution of realistic microstructures, and the scaling laws pertinent to this stage have been explored using the simulated data. An understanding of the drying, pyrolysis, and texture formation of thin films has also been obtained using practically important electroceramics of barium titanate and PZT.

Publications: See Nos. 3, 4, 13, 18, 19, 20, 22, 23, 24, 25, and 26 below.

d. In-situ and Microlaminate Oxide Composites

A novel, cost effective manufacturing method to obtain microlaminate oxide composites has been developed using high solid loading ceramic aqueous "doughs" that are repeatedly rolled and folded. Unlike conventional layer composites that start with tape casting, these composites can have easily variable layer thickness, and they can be pressurelessly sintered without hot pressing. The microstructure can be further manipulated to obtain a cellular structure by taking advantage of a novel instability of the planar phase interface of the rheologically mismatched two phase flow. High performance alumina/zirconia composites with an outstanding strength, toughness, and hardness combination have been obtained using this method. In addition, an in-situ alumina-aluminate platelet composite that has excellent sinterability has been obtained. This latter approach that explores the use of beta alumina and magnetoplumbite has since been followed by several other research groups.

Publications: See Nos. 10 and 27 below.

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