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3D Crystallographic Alignment of Alumina Ceramics by Application of Low Magnetic Fields

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ABSTRACT

Non-cubic crystals exhibit anisotropic physical and functional properties. Microscopic crystallites as constituents of polycrystalline materials are randomly oriented, thus polycrystalline ceramics lack the anisotropic properties of their monocrystalline counterparts. We propose a technology that exploits the synergy between magnetic alignment and colloidal ceramics processing, and enables to independently tune the orientation of grains in different sample regions by infinitesimal magnetic fields (<10 millitesla). The grain pivot mechanism enables the emulation of single crystals, as well as the creation of large complex-shaped ceramic elements with designed crystallographic landscapes and spatially and directionally tuned properties. Ultra-high magnetic response arises from magnetic shape anisotropy of platelet-shaped seed crystallites coated with small amounts of iron oxide nanoparticles. To control crystallographic growth directions during subsequent annealing procedures, the seeds are dispersed and aligned in a matrix of chemically identical, but much finer spherical particles. This technology opens an avenue to remarkably improve structural and functional properties of ceramic elements employed in numerous industrial applications.

KEY WORDS: Platelets, Gel casting, Magnetic, Alignment, Crystallographic, Texture

1. INTRODUCTION

1.1 Background

Ceramics constitute a broad class of materials defined generally as inorganic non-metallic solids whose ions are held together predominantly by covalent and ionic bonds. The degree of crystallinity may vary from highly ordered to amorphous. Functional engineering ceramics mostly have a crystalline structure, for example zirconium dioxide, silicon carbide, or aluminum oxide. Crystals consist of atoms forming near-perfect periodic arrangements. The microscopic atomic structure is often described in terms of its unit cell – an elementary building block of atoms that when repeated through translational and rotational symmetry create a bulk crystal. Unit cells determine a crystal's symmetry where the numerous symmetries possible in the 3D space are formally divided into 14 Braivais lattices.

Cubic systems are isotropic and possess the highest of crystal symmetries. Hexagonal, trigonal, rhombohedral, tetragonal, and monoclinic systems have anisotropic crystallography with preferred - or principal - axes that are intrinsically of higher symmetry over other axes. Many physical properties of such non-cubic crystals can often be anisotropic [1] – i.e., depend on crystallographic orientation; for example, thermal, optical and electrical conductivity, as well as mechanical properties such as strength, hardness, and toughness. This degree of anisotropy is crucial for many applications. Hexagonal boron nitride [2] crystals depict a striking illustration. Their thermal conductivity along the C (long axis) and A (short axis) planes differ by a factor of 20, the higher value in C plane exceeds the one of stainless steel by a factor of 30. This is