

## Transparent Yttria-Based Nanocomposites

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### ABSTRACT

New materials with improved mechanical properties and high optical transmission in the full 3-5  $\mu\text{m}$  mid-wave infrared (MWIR) region wavelength are required. Commercially available polycrystalline transparent yttria, with  $> 100 \mu\text{m}$  average grain size, does not perform satisfactorily in demanding applications because of its modest strength. One way to improve strength is to develop an ultra-fine grained material with acceptable optical transmission properties. To realize a fine-grained ceramic, one approach is to develop a duplex-phase or composite structure, in which one phase inhibits the growth of the other phase during processing. In this study, mechanical and optical properties of a uniformly fine-grained ceramic composite, comprising a 50:50 vol% mixture of  $\text{Y}_2\text{O}_3$  and  $\text{MgO}$ , are measured and correlated with structure.

**KEY WORDS:** powder synthesis; hot pressing; ceramic composite; mechanical and optical properties.

### INTRODUCTION

Future IR sensor windows and domes are likely to be subjected to harsher mechanical and thermal environments than those that are used today. Sapphire ( $\text{Al}_2\text{O}_3$ ) is the current material of choice for many window applications, since it is readily available in high optical quality. A comprehensive review of commonly used window materials can be found in the literature (Harris 1993; Savage 1985). Yttrium oxide ( $\text{Y}_2\text{O}_3$ -yttria) has excellent optical properties in visible, near IR and full 3-5  $\mu\text{m}$  MWIR band and has been used for windows and domes. However, the current processing methods yield materials with  $>100 \mu\text{m}$  grain size (Harris, 1993) and inferior mechanical properties relative to that of sapphire. Increased strength can be achieved by reducing the grain size of the final sintered product to submicron range, while maintaining clean grain boundaries (Bamba 2003; Li 1999; Rice 1997).

Over the last two decades, nanostructured materials have been the subject of intensive research worldwide, since exceptional mechanical and functional properties can be achieved (Bamba 2003; Li 1999; Rice

1997). Moreover, high-strain-rate superplasticity has been observed (McFadden 1999, Wan 1999) in nanocomposite ceramics, which opens new opportunities for the near-net shape fabrication of such materials. Success in processing nanocomposites depends on the ability to mitigate grain growth during powder consolidation. This is readily achieved in nanocomposite ceramics, since the presence of one phase naturally impedes the growth of an adjacent phase(s) (Kear 2001, Liao 1999). The effect is particularly pronounced when two or more nanophases in the composite have comparable volume fractions, so that they form a thermally stable interconnected or co-continuous structure.

Consolidation of nanocrystalline powders is challenging because of their low apparent density, high amounts of chemi- and physi-sorbed gases, admixture content, severe inter-particle friction, and exaggerated grain growth during consolidation. Limited success has been achieved with additions of grain growth inhibitors. In many cases, the addition of such inhibitors degrades properties of the sintered compacts. Moreover, the uniform dispersion of a nanoscale grain growth inhibitor in a matrix phase is a formidable task.

In this paper, we describe the fabrication of a duplex-phase or composite structure, comprising a 50:50 mixture of  $\text{Y}_2\text{O}_3$  and  $\text{MgO}$ , in which the grain sizes of the constituent phases are  $\sim 250 \text{ nm}$ . The material displays improved mechanical properties while maintaining high optical transmission in mid-IR region.

### EXPERIMENTAL METHODS

Metastable powder of a 50:50 vol. %  $\text{Y}_2\text{O}_3$ : $\text{MgO}$  composition (80 mol%  $\text{MgO}$ , Figure 1) was obtained via proprietary processing. X-ray diffraction analysis showed that the powder consisted of three phases: cubic  $\text{Y}_2\text{O}_3$ , monoclinic  $\text{Y}_2\text{O}_3$ , cubic  $\text{MgO}$  (Figure 2a). The average particle size for each phase was  $\sim 30 \text{ nm}$ . Small samples of the powder were heat treated at  $700^\circ\text{C}$  and  $1400^\circ\text{C}$ . There was no significant change in the diffraction pattern at  $700^\circ\text{C}$ , while at  $1400^\circ\text{C}$  a two phase mixture of cubic  $\text{Y}_2\text{O}_3$  and cubic  $\text{MgO}$  was obtained, Figure 2b.