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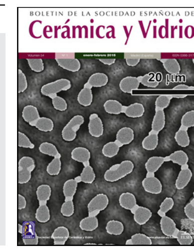

Ceramics with photonic and optical applications

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A B S T R A C T

There is a fast growing interest in new applications for advanced ceramic systems in the field of functional materials and in particular for optical materials. Ceramics are entitled to fulfil the gap between glasses and single crystals in the area of photonic materials. The processing versatility and unpaired resistance to high temperature corrosive environments of some ceramics make them good candidates for such applications. However, the critical dependence of the material optical properties on microstructure makes the deep understanding of the processing conditions even more necessary than before for the fabrication of well ordered, transparent, efficient optical ceramics.

This review is directed towards ceramists interested in new applications. In the paper we address some fundamental aspects of the relationship between processing, microstructure and optical properties that are illustrated with some examples related with transparent ceramics, glass ceramics, luminescence, random lasers, thermo-emissive applications, scintillators and dielectric metamaterials.

Cerámicas con aplicaciones ópticas y fotónicas

Palabras clave:
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R E S U M E N

Existe un creciente interés en el desarrollo de nuevas aplicaciones basadas en cerámicas funcionales, en particular para aplicaciones como materiales ópticos. Los materiales cerámicos están destinados a cubrir el hueco entre los vidrios y los monocristales en el campo de los materiales fotónicos. La facilidad de procesado junto con su inigualable resistencia en medios corrosivos y de alta temperatura, hacen de las cerámicas buenos candidatos para ser utilizado en las aplicaciones ópticas. Sin embargo, las propiedades ópticas de un material, dependen muy fuertemente de su microestructura. Por ello la fabricación de cerámicas con microestructuras ordenadas, cerámicas transparentes y con eficientes propiedades ópticas requiere más que nunca, conocer profundamente las condiciones de procesado y de su influencia en la microestructura.

Esta revisión está dirigida a ceramistas interesados en nuevas aplicaciones. En el artículo, tratamos brevemente algunos aspectos fundamentales de las relaciones entre procesado,

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Centelleadores cerámicos
metamateriales dieléctricos

microestructura y propiedades ópticas que hemos ilustrado con algunos ejemplos relacionados con las cerámicas transparentes, las vitrocerámicas, luminiscencia, láseres aleatorios, aplicaciones termoemisivas, centelleadores, y metamateriales dieléctricos.

Introduction

Advanced ceramics find greater than ever utilization in a wide range of applications. There is an increasing interest for ceramics in the health area, for example in bioceramics[1] and in drug delivering systems based on nanoceramics. In the energy field, ceramics are very important not only in the nuclear industry as fuel ceramics or for waste immobilization but also for electricity generation, transport and storage.[2] Impressive research effort is being done in the study of new electroceramics for Solid Oxide Fuel Cells[3] and rechargeable batteries and supercapacitors. In the transport industry it is well known the use of ceramics in spark plug insulators, valves, oxygen sensors or catalyst supports. Furthermore, ceramic magnets such as the hexaferrites, are component part of motors, filters, or in devices for communication technologies.[4] In addition to current attention devoted to the synthesis of new ceramic materials new applications require, on the one hand improvement in the traditional processing techniques and implementation of advanced processing techniques on the other hand.[5]

The discovery and development of new processing techniques widens out the range of application of ceramics to the area of optical and photonic devices. Most common optical materials are silica glass, SiO_2, and silicon, Si, thin films and substrates together with some semiconductors and oxide single crystals. Optical materials are shaped in the form of fibres, thin films or bulk pieces. Recently, ceramics are taking more and more relevance in optical technology. In Table 1 we present a summary of optical devices made with some oxide materials. One reason for it is that from the point of view of their electronic structure, ceramic compounds are insulators with a wide optical gap very convenient for optical applications. In addition the response of ceramics to light propagation strongly depends on their microstructure. Consequently, its transparency can be adapted by processing conditions.

In addition, compared to single crystals (SC) production of ceramics is less complicated. Accordingly, large ceramic pieces with arbitrary shape and size can be fabricated which is not possible to achieve in the case of SC. Also, ceramic composites can be doped with higher impurity concentration levels than SC made from melt solidification and ceramics with impurity concentration gradients can be easily fabricated. In recent years, the discovery of new sintering techniques allows the production of ceramics with high temperature of melting eluding the need for costly crucibles and contamination. On the other hand, compared to glasses, ceramics have better mechanical resistance, hardness and toughness. In general they also offer higher thermochemical stability than glasses.

Conversely, ceramics are opaque and light hardly propagates through them. Fortunately, as we will see later on this statement is not completely accurate and some ceramics fabricated using small size particles, with homogeneous grain size distribution and very low porosity may present transmittance values close to these of glasses and SC (Fig. 1). Transparent ceramics combining excellent mechanical and good optical properties are used as passive optical components. In particular as waveguides, lenses, mirror supports, optical filters for high power optical beams, etc. Transparent ceramics can be found displacing glasses as a part of armours, house appliances, lamps, LED's, etc. Increasing number of active optical devices incorporate ceramics as phosphors, scintillators, optical amplifiers, in high power lasers and multifunctional materials in general.

In the present paper we compile updated information on the use of ceramics as optical materials. In particular we will briefly describe the fabrication and application of transparent ceramics, of luminescent ceramics and their use in random lasers. Also, we will pay attention to selective thermo-emissive and scintillator ceramics.

Table 1 – Ceramic materials more often used in optical devices.

Material	Waveguide couplers	Lasers amplifiers	Detectors modulators	Filters attenuators	Polarizers	Protective barriers
SiO_2	X	X		X	X	X
Glasses	X	X				
YSZ, Ta_2O_5				X		X
$LiNbO_3$	X	X	X	X	X	
$CaCO_3$	X			X		
Al_2O_3	X	X				X