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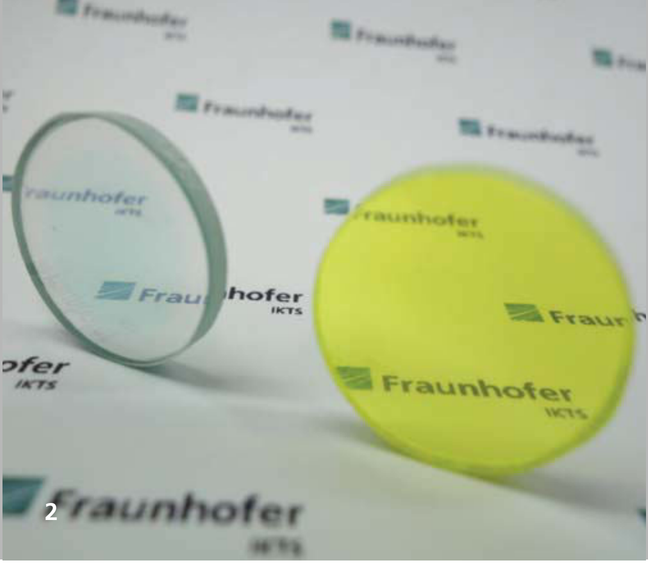

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OPTICS

OPTICAL CERAMICS WITH SPECIFICALLY ADJUSTED SPECTRAL TRANSMISSION

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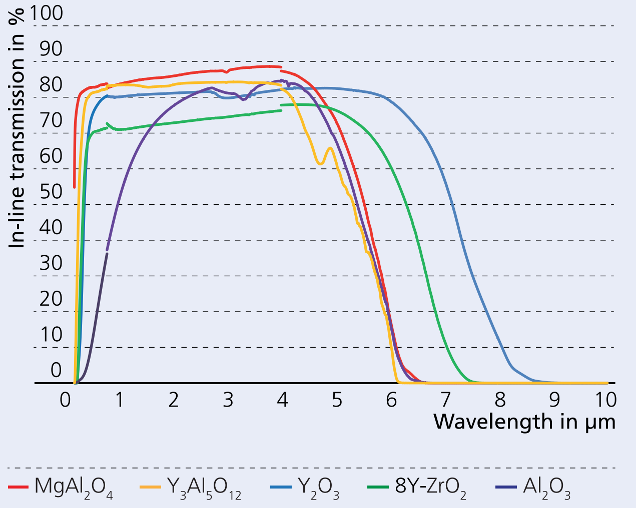
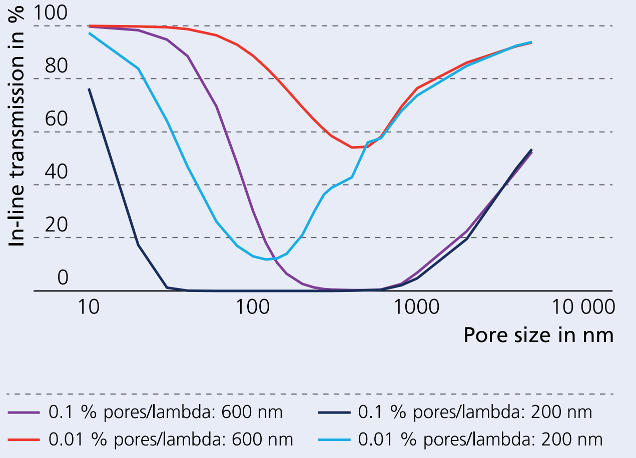
The light transmittance of solid-state bodies is determined by the atomic structure and can be described by the complex refractive index as a function of the wavelength. The real part of the refractive index detects the reflection on the surface and the imaginary part detects the absorption during the passage of the light beam. In the real crystal, the size of the light-transmitting area between the absorption edge in the short-wave and long-wave region of the spectrum is limited by the defect population and the purity of the material. The diagram below shows the transmission spectra of several different transparent ceramics from the UV to the IR region. The transparent ceramics can achieve spectral transmissions similar to single crystals but have special features to be discussed in the following.

Transmission spectra from UV to IR for transparent ceramics (thickness: 2–4 mm) developed at IKTS

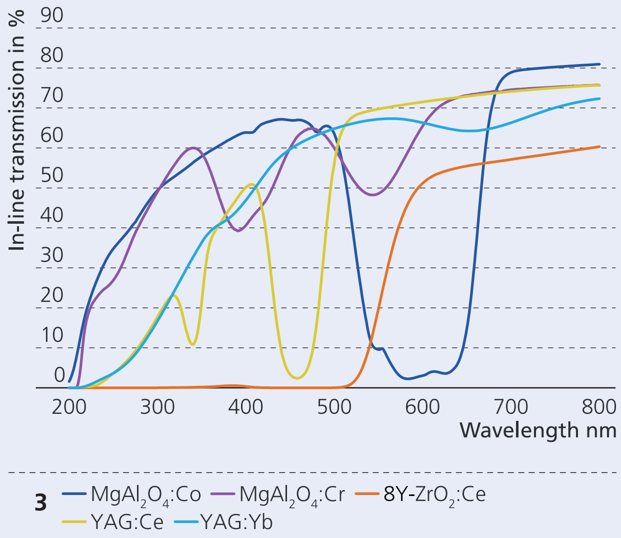


Due to their polycrystalline structure, the transmission in ceramics is influenced by stray light of pores and foreign phases. In anisotropic crystal systems (such as corundum and tetragonal ZrO_2), additional scattering of light by the directional dependence of the refractive index, which leads to a splitting of the light path of each crystallite, has to be taken into account. In order to achieve sufficient transparency, the scattering of light must be minimized. This is achieved by defect-avoiding manufacture of the ceramic green bodies and sintering methods that allow almost complete consolidation into pore-free ceramics. The strongest decrease of transmission by scattering can be observed for scattering centers, which correspond to the diameter of the wavelength of light. The influence of birefringence can be decreased by applying grain sizes smaller than the wavelength of light. Also, small pore sizes can contribute to a lower amount of light scattering. The diagram below shows a simulation of the reduction of transmission by Mie scattering of 0.1 % and 0.01 % spherical pores in spinel ceramic of 1 mm thickness as a function of pore diameter for the wavelengths of 200 nm and 600 nm.

Reduction of in-line transmission by scattering of pores in spinell ceramics



Microcracks, for example as generated during annealing in air, influence the transmission particularly in the short wavelength region of the spectrum. Individual coarser defects > 20 µm reduce the transparency on average only slightly but are perceived visually distracting and cannot be tolerated for optical



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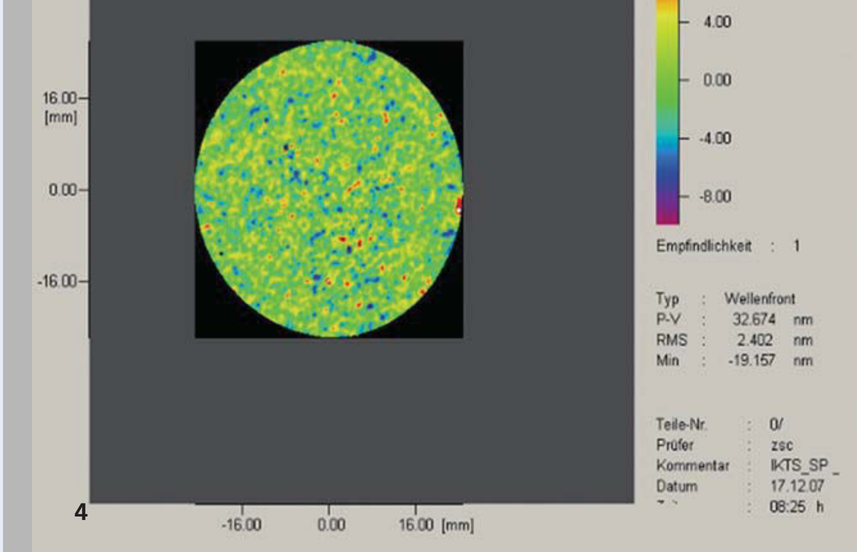

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applications due to the aberrations. A selective influencing of the spectral transmittance can be affected by the incorporation of dopants. Absorption states realized by specific dopants are the base for ceramic laser components, optical filters and ceramic scintillators for lighting technology and medical technology. Figure 1 shows transparent spinel ceramics (thickness 3.9 mm) with cobalt doping (blue), chromium doping (red), and a cerium-doped cubic 8Y-ZrO_2 ceramics (orange, thickness 1.9 mm). The absorption bands of the different ceramics are displayed in the UV-VIS spectrum (Figure 3).

Figure 2 shows YAG ceramics (thickness 2.7 mm), doped with ytterbium (light blue) or with cerium (yellow). The spectrum of the in-line transmission (Figure 3) shows that for 8Y-ZrO_2 the absorption band with cerium dopant is shifted to shorter wavelength. Both mechanisms, incorporation of absorption centers or scattering centers, open new possibilities in contrast to the classical transparent materials, such as glass, crystals and transparent plastics to create materials with new optical properties and to combine the excellent mechanical and thermal properties of ceramics with new optical properties. Compared to single crystals, transparent ceramics provide advantages due to the isotropic structure of polycrystalline microstructure, such as simplified manufacturing processes and new dopant opportunities, e.g. in higher concentrations.

Potential applications of transparent ceramics include mechanically, thermally or chemically stable windows for ballistic protection or for thermally or chemically stressed reactors and IR-transparent domes. The specific optical properties of ceramics, such as high refractive index and low stress-induced birefringence, make transparent ceramics interesting for optical lens systems. The requirements for the optical quality of ceramics depend on the respective applications. The following table defines development goals in terms of the criteria: loss factor k, in-line transmission, optical homogeneity and the number of visible defects at the wavelength of 600 nm for ceramic windows, optical lenses made of ceramics and laser ceramics. Partially, these parameters are highly ambitious because they are ultimately based on the task of producing perfect, i.e. in volume, completely defect-free ceramics. The necessary technologies for each crystal system and any impurity have to be developed starting from the ceramic raw materials followed by shaping and sintering.

Fraunhofer IKTS in Dresden has successfully met this challenge for the past 15 years, as the good optical homogeneity of IKTS spinel ceramics (see Figure 4, measurement Zeiss-SMT), which exceed the requirements of laser-suitable sapphire single crystals in terms of homogeneity, demonstrates.

Optical requirements of different application fields for transparent ceramics

Application field	Loss factor k in-line ~ 600 nm	In-line transmission ~ 600 nm, 4 mm thickness	Optical homogeneity Δn	Number of visible defects > 20 µm
Window	$\leq 0.05\ cm^{-1}$	$> 0.95\ T_{max}$	-	$< 100/cm^3$
Optical lenses	$< 0.01\ cm^{-1}$	$> 0.99\ T_{max}$	< 0.05 ppm	$< 10/cm^3$
Laser ceramics	$< 0.001\ cm^{-1}$	$> 0.999\ T_{max}$	0.01–1 ppm	~ 0

For further progress, a systematic investigation of the basic relationships between properties of ceramic raw materials and their compaction behavior, as well as the sintering mechanisms of ceramics at densities > 99.9 % of the theoretical density is required.

Acknowledgements

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1 *Doped $MgAl_2O_4$ and 8Y-ZrO_2 ceramics with specific absorption.*

2 *Doped YAG ceramics with specific absorption .*

3 *In-line transmission spectra of the ceramics from Figure 1 and Figure 2.*

4 *Homogeneity measurement of IKTS spinel ceramics.*

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