

# Transparente Keramik – Potentiale, Anwendungsfelder und Herausforderungen

Transparent Ceramic Materials – Challenges and Opportunities

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# Motivation

## Why Transparent Ceramics?

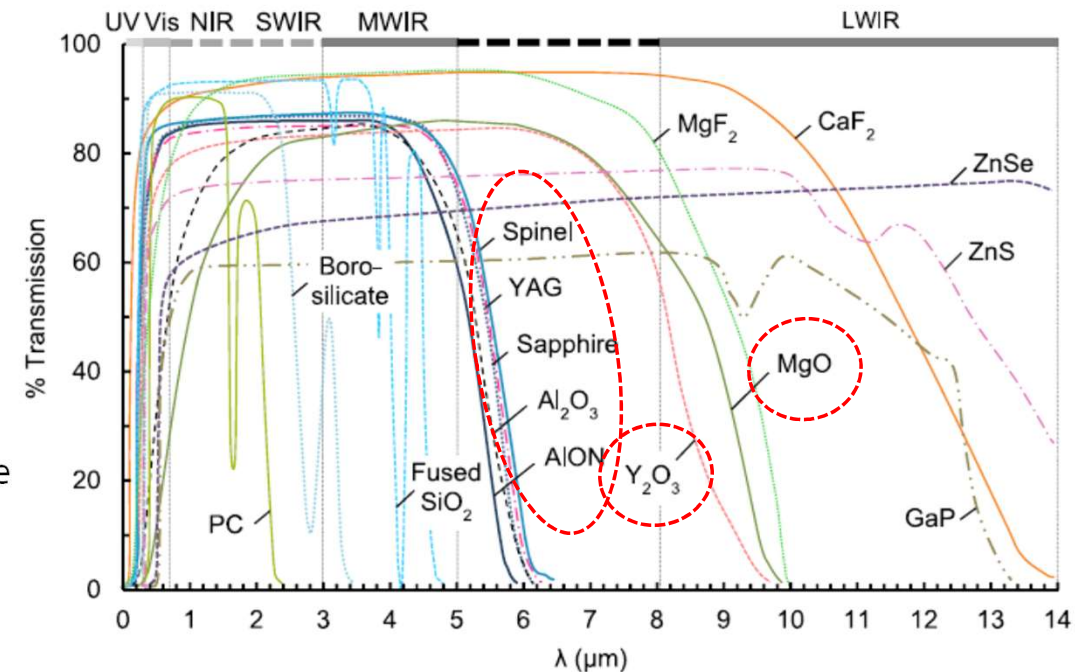
- Common transparent materials: glasses, polymers, glass ceramics
- Application of transparent materials:
  - Protective windows
  - Sensors
  - lenses with specified refraction indices
  - laser materials: gain material, saturable absorbers

### Advantages of ceramics

- Chemical stability
- Mechanical stability
- Thermal conductivity, application temperature
- Optical properties: Wider transmission window into IR range

### Challenges

- Thorough processing required



M. Du Merac, *Encyclopedia of Materials* 2021

# Transparent Ceramics – Transmission Physics

## Interaction of Light and Matter

- „Ceramic“: polycrystalline, anorganic  
e.g.  $ZrO_2$ ,  $Al_2O_3$ , ...

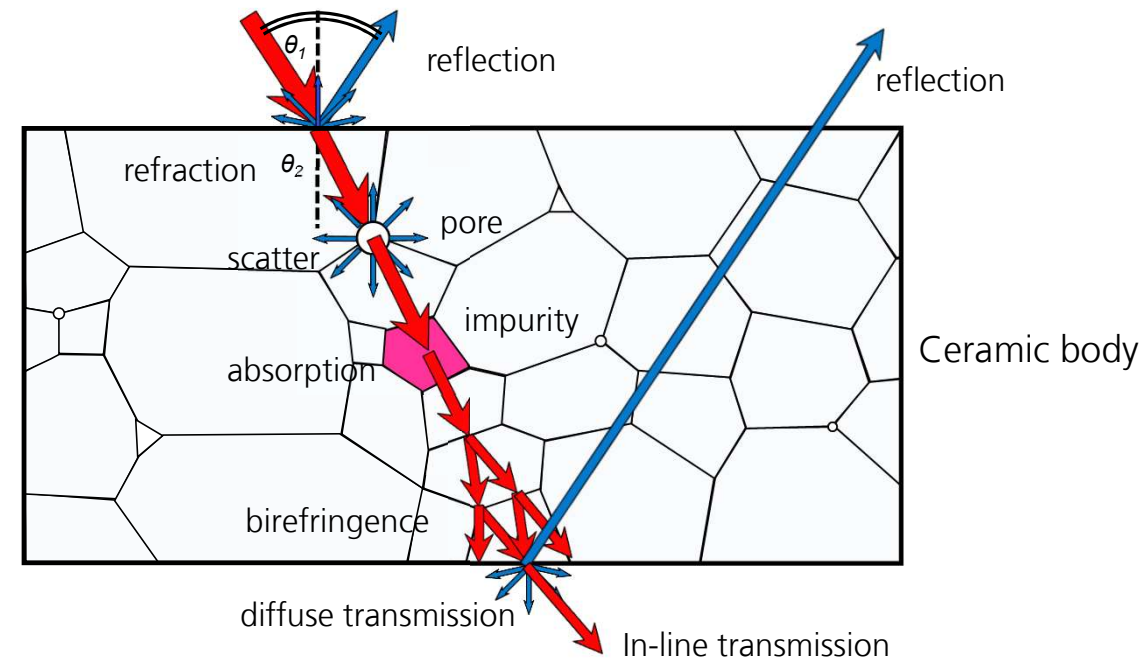
### Prerequisites for high transparency

No secondary phases and pores

< 0.01% (0.0001) porosity     < 10-1000 ppm impurities

Grain size < wavelength (only for non cubic structure)  
→ birefringence!

- Impurity-free powders or precursors required
- Thorough conduction of ceramic processing route



Adapted from: M. Du Merac: Interfaces in Transparent Polycrystalline  $MgAl_2O_4$  Spinel, PhD Thesis 2019

# Transparent Ceramics – Transmission Physics

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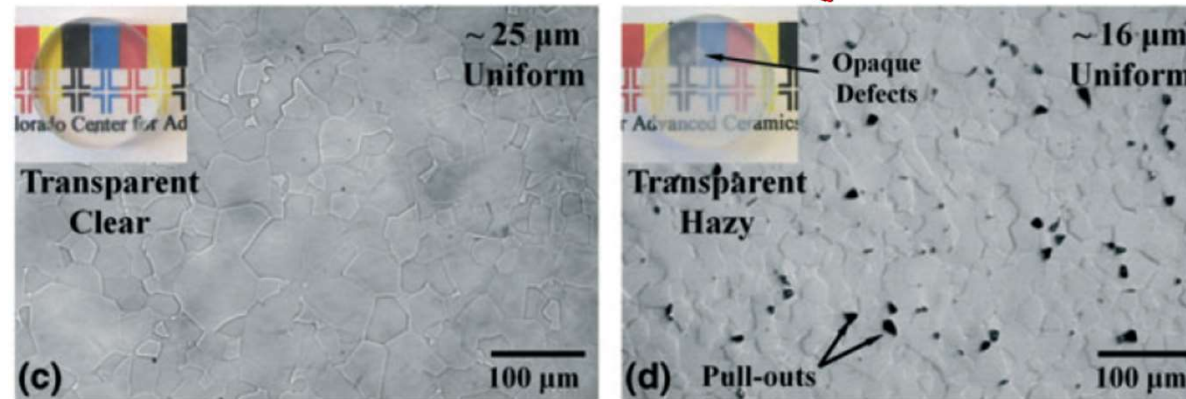
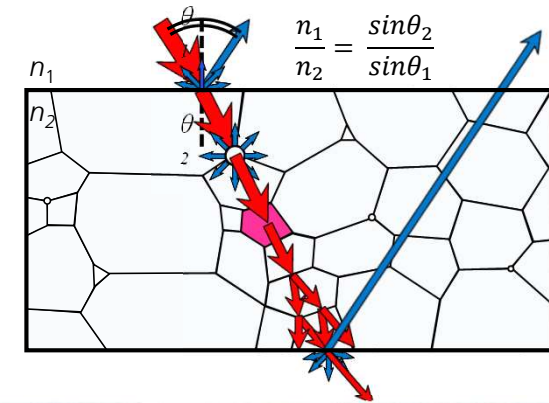
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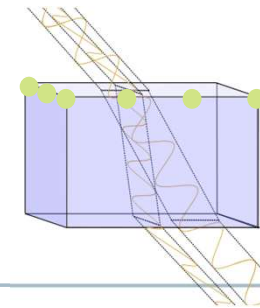
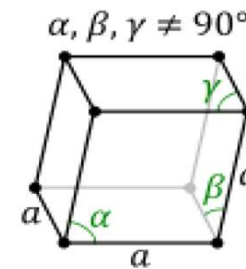
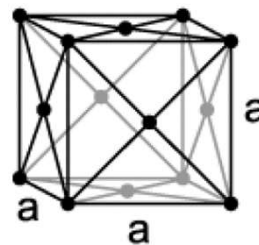
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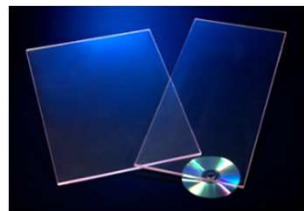


M. Du Merac et al., *Int. J. Appl. Ceram. Technol.* 10 (2013)



# Transparent Ceramic Materials

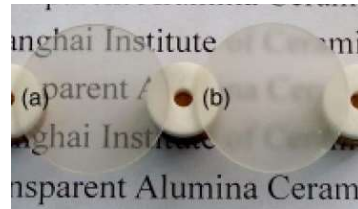
## Examples



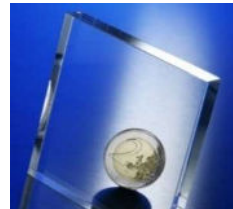
Al<sub>2</sub>O<sub>3</sub> (monocrystal)



Al<sub>2</sub>O<sub>3</sub> (polycrystal)



Al<sub>2</sub>O<sub>3</sub> (oriented, random)



MgAl<sub>2</sub>O<sub>4</sub>



MgAl<sub>2</sub>O<sub>4</sub>



Y<sub>2</sub>O<sub>3</sub>



ZrO<sub>2</sub>



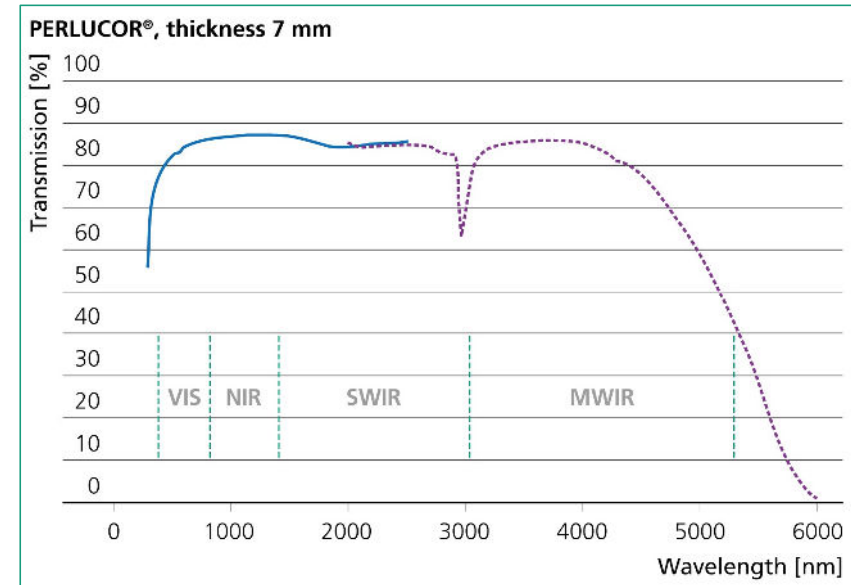
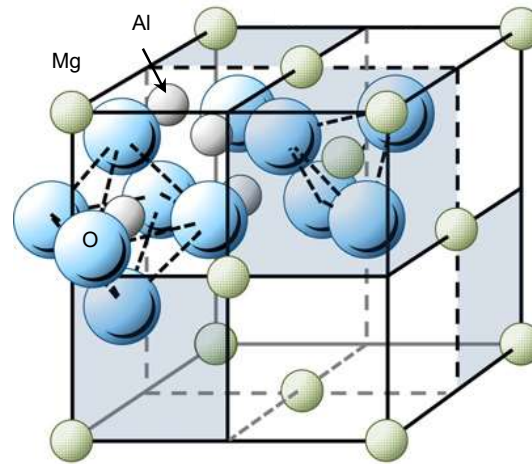
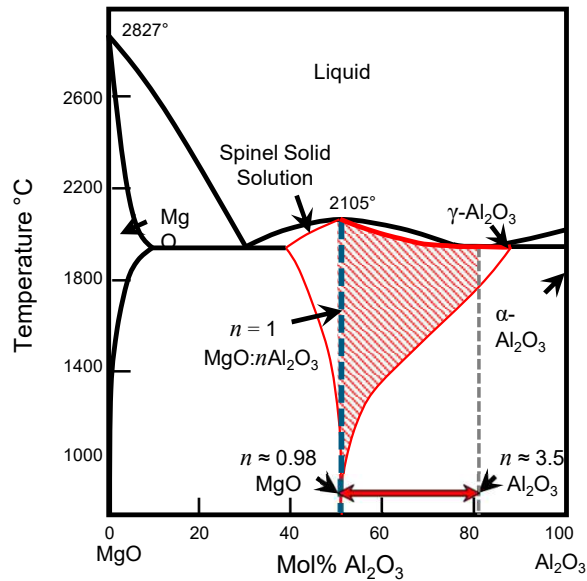
Nd<sup>3+</sup>:YAG

	optical properties					thermo-mechanical properties					
	refractive index n		transmittance [% max (calc)]	cut-off		density [g/cm <sup>3</sup> ]	Hardness [GPa]	flexural strength [MPa]	K <sub>1c</sub> [MPa·m <sup>-1/2</sup> ]	E [GPa]	κ [W/mK]
	n	λ [nm]		UV	IR						
Al <sub>2</sub> O <sub>3</sub> /Sapphire	1,77	633	86%	0,15	6,5	3,99	14-22	300-1000	2-3,5	345-400	24-36
MgO	1,74	633	87%	0,16	9	3,58	6-7	250	2	195-250	59
MgAl <sub>2</sub> O <sub>4</sub>	1,72	688	87%	0,21	6,5	3,58	12-16	350	2,2	220	15
Y <sub>2</sub> O <sub>3</sub>	1,92	633	82%	0,29	7,1	5,03	7	150-200	0,7	165	13,5
Y <sub>3</sub> Al <sub>5</sub> O <sub>12</sub>	1,83	633	84%	0,21	6,2	4,56	13-17	200	2,2	280	13,4
ZrO <sub>2</sub> (Y-stab.)	2,12	633	77%	0,38	6,7	5,94	13,5	300	2,8	230	2
Quartz	1,46	589	93%	0,16	4,7	2,2	4,5-5	50-60	0,8	70	1,4
Borosilicate Glass	1,52	589	92%	0,29	2,1	2,51	5	50	0,7	80	1,2

M. Du Merac, *Encyclopedia of Materials* 2021

# Transparent $\text{MgAl}_2\text{O}_4$ spinel

## Perlucor®



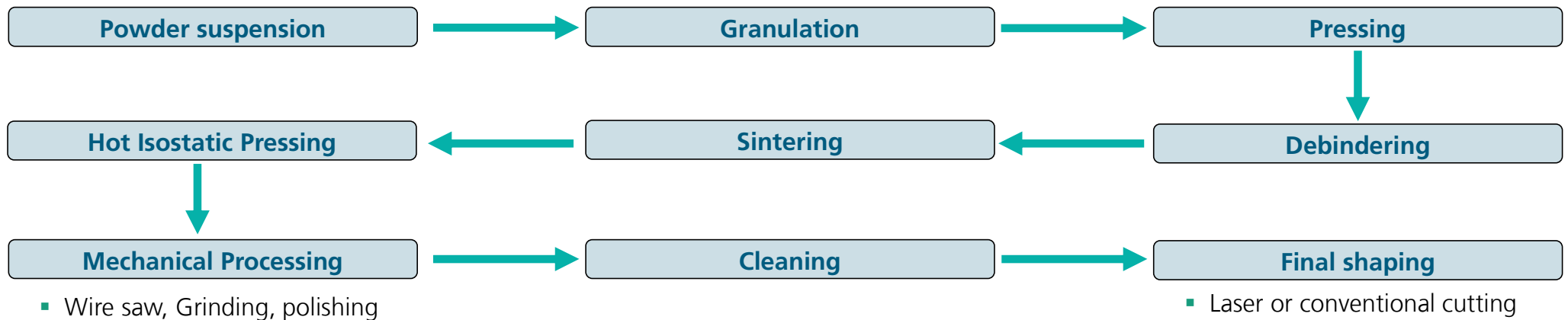
- Good trade-off between optical and mechanical properties
- Cubic crystal structure – no birefringence!
- Procedure for processing developed at IKTS in the past → further development is needed
- Will be main focus of further research activities at IKTS

# Production of Transparent Ceramic Components

## Technology Scheme

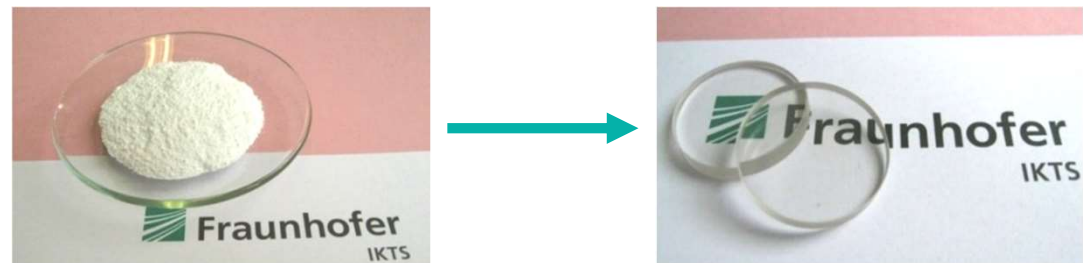
- Usage of commercial ceramic powders

- Impurity-free powders or precursors required
- Thorough conduction of ceramic processing route



## Current Targets

- Achieve high relative density >99,99%
- Establish reproducibility
- Establish pilot line for  $MgAl_2O_4$
- upscaling



# Transparent Ceramics at IKTS

Current work - pilot line PERLUCOR®

## Implementation of processing route

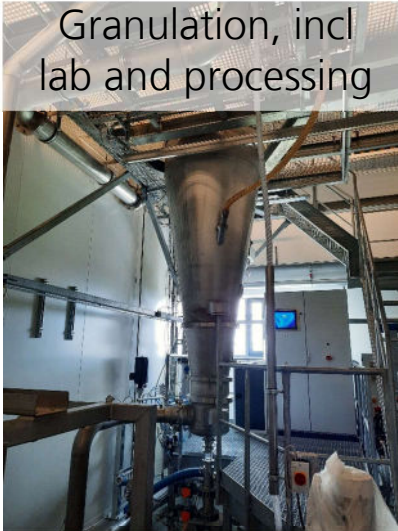
- Acquired from CeramTec-EETEC
- Focus on fabrication of  $\text{MgAl}_2\text{O}_4$  spinel first, different geometries
  - Processing of other materials will be established:  $\text{Y}_2\text{O}_3$ ,  $\text{MgO}$ ,  $\text{ZrO}_2$ , YAG, YIG



### Further devices:

- Press
- Diamond wire saw
- ...

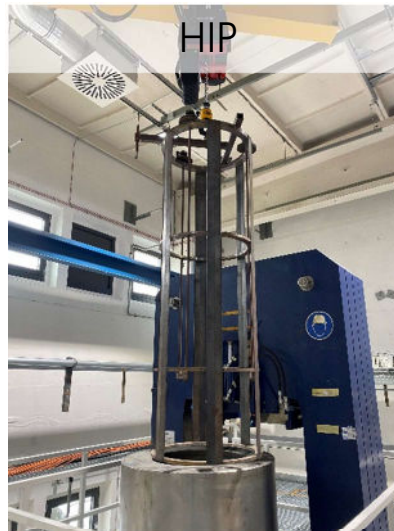
Granulation, incl lab and processing



2 electrical furnaces



HIP



Grinding and polishing machines



Ultrasonic cleaning





# Research and Development Center for Transparent Ceramics

Examples for Application of MgAl<sub>2</sub>O<sub>4</sub> PerLucor®



*Electronic device with spinel cover*



*Optical lens made of spinel ceramics*



*Active microimplant with housing made of spinel*

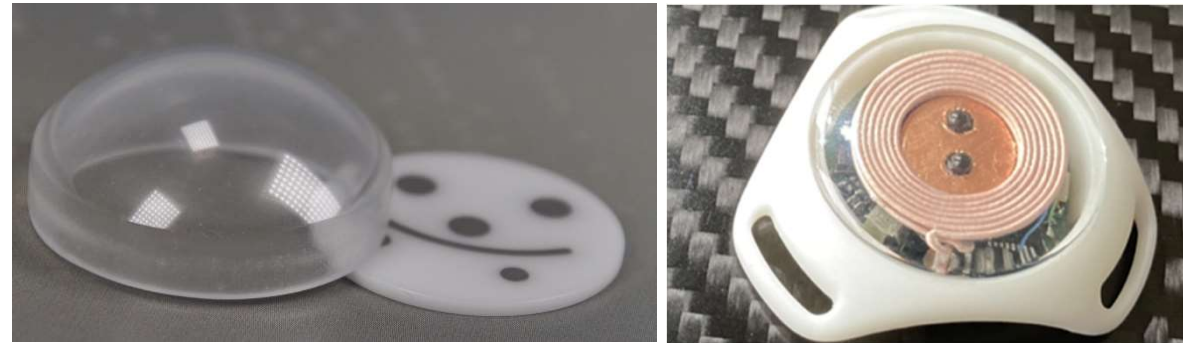


*Complex shaped components (watch parts)*

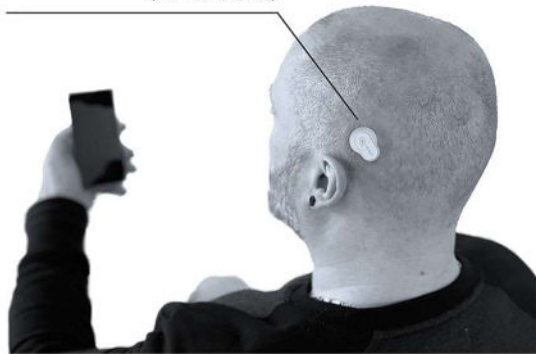
# Examples from Present Research

## Implant housing with transparent ceramic optical window

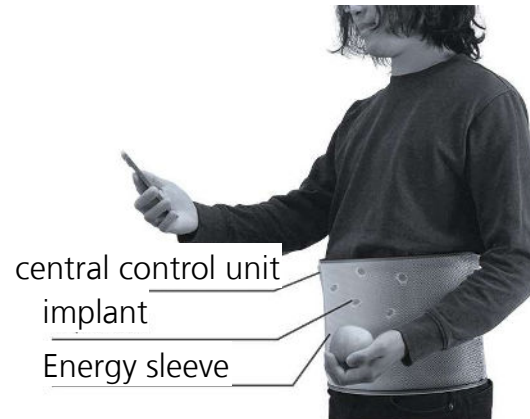
- Development of actively networking micro-implants, communicating with doctor or patient via external interfaces  
→ Optimal treatment of patients
- Development of manufacturing process for semi-spherical geometries, shaping processes
  - powder processing ceramic slurry
  - Sintering and polishing



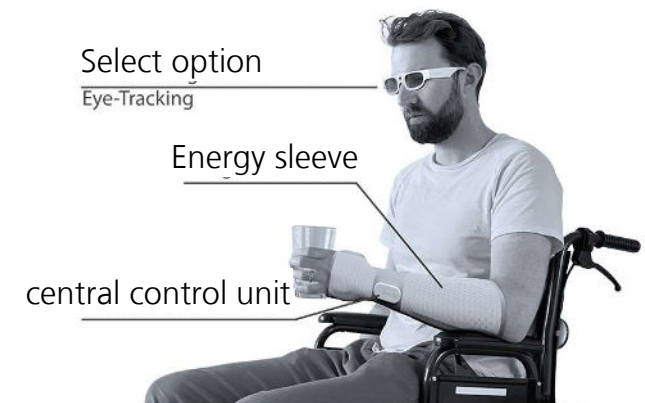
Coil element (Ear-Wearable)



Tinnitus suppression



Treatment of gastrointestinal dysfunctions



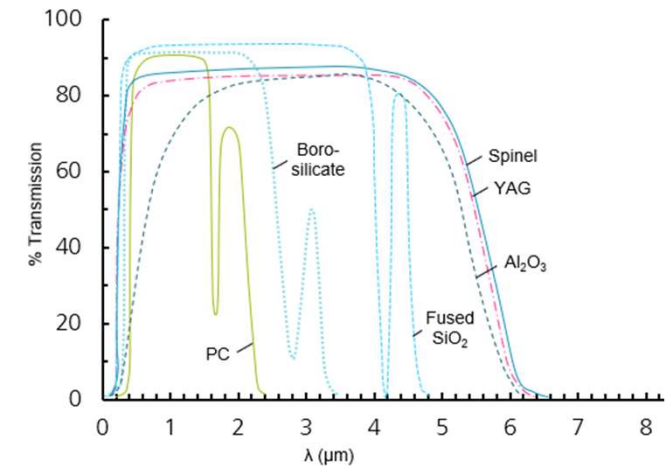
Restoration of grasping functions

# Examples from Present Research

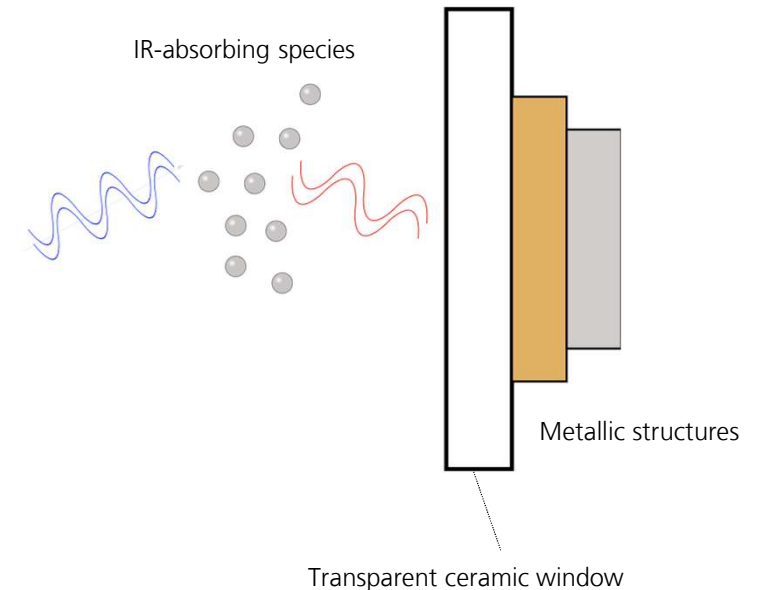
## IR-transparent Windows

### Gas sensors based on IR absorption

- detection of gases:  $\text{CH}_4$ ,  $\text{CO}_2$ ,  $\text{NH}_3$ ,...
- Glass not suitable in harsh environments
- IR-transmittance not sufficient
- Application of spinel and other ceramics
  - Figure out ceramic processing for establishing production of transparent ceramics
- Attachment of metallic structures necessary via CVD processes  
→ ceramics with high density required



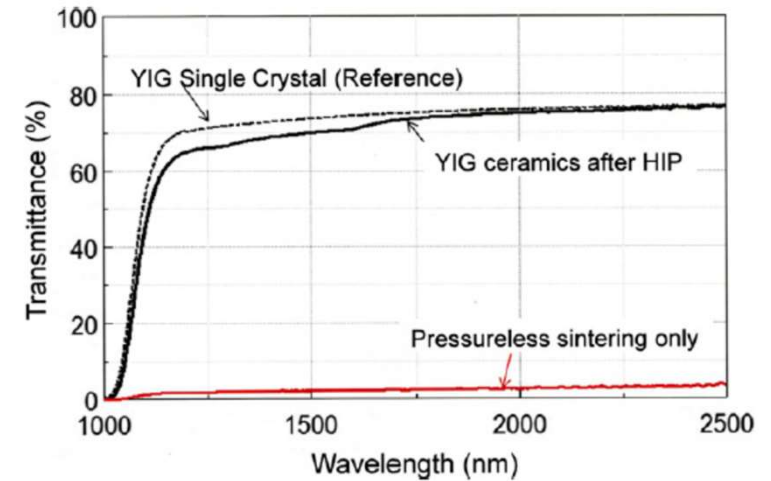
M. Du Merac, *Encyclopedia of Materials* 2021



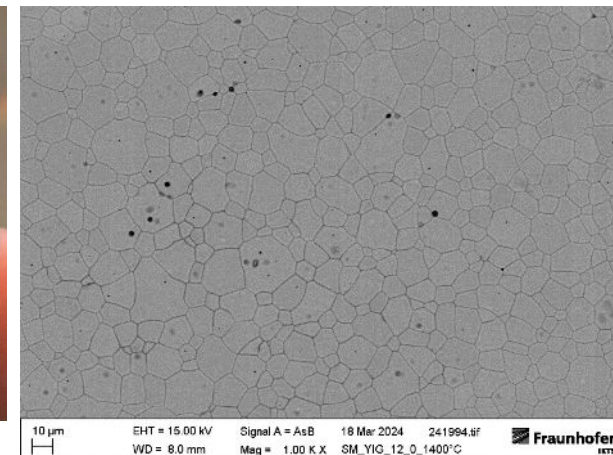
# Examples from Present Research

## Functionalized Transparent Ceramics

- Yttrium Iron Garnet  $Y_3Fe_5O_{12}$  (YIG)
- Transparent  $>1000\text{nm}$   $\rightarrow$  infrared light
- Good host for dopants: Nd, Er, Ho, Yb...
  - $\rightarrow$  Tuneable absorption and emission spectra
  - $\rightarrow$  Potential application as luminescent material, in sensors, lasers
- Work focused on:
  - Materials processing
  - Sintering process
  - Porosity reduction, densification
  - Microstructure optimization
  - Post-Processing



A. Ikesue et al., *J Am Ceram Soc* 101 (11), 2018



# Summary and Outlook

## Transparent Ceramic Materials at IKTS

### Establishing of pilot line for $MgAl_2O_4$ production

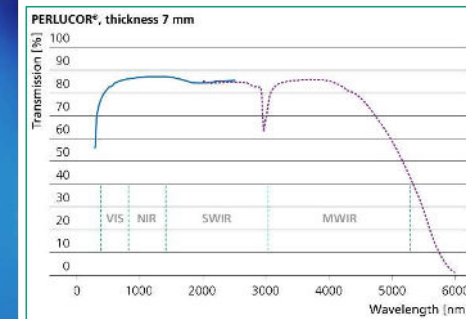
- Complete production chain for transparent ceramics at IKTS

### Development center for transparent ceramics

- Present research activities on  $MgAl_2O_4$  and YIG, to be extended

### Outlook

- Production of transparent ceramic components at the pilot scale
- Further research on  $MgAl_2O_4$ : e.g. production of larger parts, bonding....
- Extend research to other transparent ceramic oxide materials
  - $Al_2O_3$ ,  $MgO$ ,  $Y_2O_3$ , YIG,.... different dopants possible
  - Laser materials, ceramics for optical systems, Q-switches



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