Fraunhofer IKTS

Fraunhofer Institute for Ceramic Technologies and Systems IKTS

Industrial solutions

Tape casting

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Cover image: Doctor-blade casting process for the efficient production of large-scale, flexible tapes.

Tape casting

Tape casting and coating is a highly productive technology, which allows the production of large-scale flexible tapes from functional materials in roll-to-roll processes, efficiently and at moderate cost. Fraunhofer IKTS has more than 70 years of experience in the field of ceramic and glass ceramic tapes.

The expert knowledge provided by Fraunhofer IKTS covers the development of slurries and processes for the manufacture of tapes, as well as their transfer into pre-series and small-series products. Many innovative products and developments are based on tape technology. They include classic ceramic microsystem technology, battery research, filtration and gas separation. Furthermore, various specific applications are available, such as transparent tapes for optical and analytical applications, bonding tapes for the production of pure ceramic composites as well as metal powder tapes for magnetic and electrocaloric applications.

Slot-die coater in the tape casting center at the Hermsdorf site.

Powder preparation

▼

Slurry development

▼

Process development

▼

Process optimization

▼

Technology development/upscaling

▼

Pilot production

Processing functional ceramic powders in a tape casting process is a challenging task. Our state-of-the-art tape casting center produces tapes with the most varied features and properties (e.g. LTCC, HTCC, defined porosity, UV-curing, transparent, permanent magnetic) according to the customer's requirements. The casting and coating machines enable the development and sample production of tapes with 50 µm to 1.5 mm thickness. The IKTS equipment is also available for companies for own test runs.

By using innovative printing processes and interconnection and packaging solutions, tapes can be functionalized and transferred into components and parts for diverse applications. We can support at these issues by our extensive experience in the development of specifically adapted thick-film pastes and inks, including their processing in the multilayer process.

Material and technology development

Overview

The tape casting process starts with the powder preparation. The powders are dispersed in a solvent and homogenized using binder and plasticizer. Casting starts once the slurry has been filtered and deaired. The slurry is cast onto a moving carrier tape using a doctor blade or slot die. Once dried, the tape, now called green tape, is cut to size, debindered and sintered.

Powder preparation

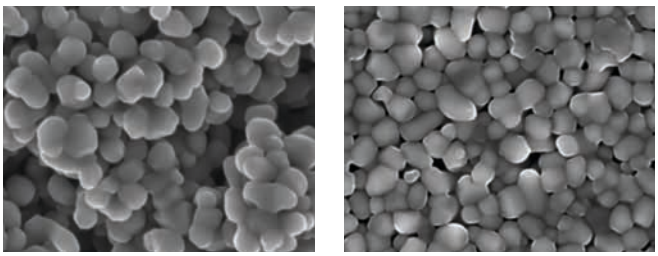
When developing castable slurries, the first step is the preparation of customized powders. The morphology and particle size distribution of the powders influence the quality of the casting slurry. Two main routes are available: commercially available or customer-specific powders are milled to the required particle size through mechanical treatment processes, or the morphology and grain size are configured through suitable synthesis processes during powder preparation.

Supporting analytics

- Particle size distribution
- Laser diffraction, sedimentation analysis
- Surface characterization, BET
- Morphology
- Light microscopy, electron microscopy
- Green density and sintered density

Dispersion

During dispersion, the prepared powder is finely dispersed in a solvent by adding a dispersing agent. The choice of dispersing agent depends on the surface chemistry of the powder to be processed, as well as the selected solvents. Very fine or nanoscale powders have a large specific surface, which means the ratio between surface and volume is high, resulting in high surface energy. Such ratios are not ideal from an energetic point of view, because the powder particles tend to agglomerate. Tape casting technology often uses non-foaming tensides and sterically acting (short-chain) polymers to separate and fully wet the powder particles. Based on their molecule properties, such polymers can be used as dispersing agents. Furthermore, it is important to prevent sedimentation in the slurry, in order to avoid density gradients in the tape.



Glass powder before and after the dispersion process.

Supporting analytics

- Viscosity measurements
- Zeta potential measurement
- Scanning electron microscopy

Dosage of slurry.

Homogenization

Binders and plasticizers are added to the dispersed solution for homogenization. Following that, the slurry is slowly mixed. The choice of binder and plasticizer depends on many different factors, such as powder morphology, solvent system, processing and thermal treatment of the green tape. Following homogenization, the slurry is filtered and deaired in several steps. First, a large sieve is used to remove the grinding media from the slurry. In a second step, the undissolved parts or residual agglomerations are separated from the slurry. The final step, the deairing of the slurry has a signifiant effect on the quality of the tape.

Air bubbles burst and come to the tape surface as the material dries, which produces small holes or bumps in the green tape. Perfect tapes can only be produced if the slurry is free from air bubbles.

Supporting analytics
- Viscosity measurements
- Slurry efflux time
- Grindometer

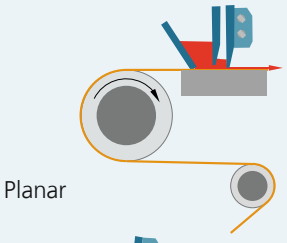
Tape systems

Solvent	Binder	Solid material/ slurry	Green tape
- Aceton - MEK - MEK/ethanol - MEK/toluol - Cyclohexanone - MIBK/ methanol - N-Methyl-2-pyrrolidon - Water	- PVB - PVA - PVDF - Alginates - Acrylates - Celluloses - UV-curing binders - Epoxy resins	- Medium particle size range from d_{50} 200 nm to 30 µm - Densities to 19.3 g/cm³ - Viscosities from 100 to 30,000 mPas	- Particle contents up to 91 wt% - Tape thicknesses 10 to 2000 µm - Larger thicknesses trough lamination

Tapes	
Tapes for porous supports	- Al_2O_3, ZrO_2, TiO_2
Magnetic powder tapes	- Absorber ferrite tapes - NdFeB tapes
Transparent tapes	- MgO, $MgAl_2O_4$
LTCC	- Basic tapes - Tapes anodically bondable to silicon - SiCer-capable tapes - Functional LTCCs
HTCC	- Al_2O_3, ZrO_2, Si_3N_4, AlN
Functional tapes	- Metal - Piezoceramics - Glass solders - Electrodes for Li batteries - Perovskite

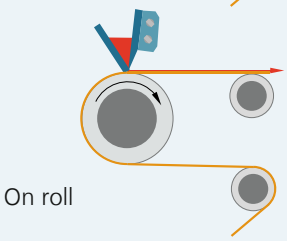
Technology development for multilayer coating using triple-slot-die coating.

Doctor blade process



Planar

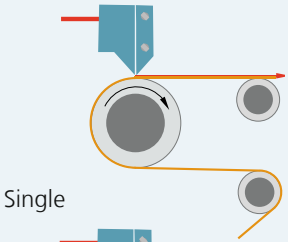
- Low to high tape thicknesses
- High precision (homogeneous thickness)



On roll

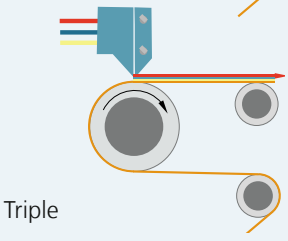
- Coating of very thin support tapes

Slot die process



Single

- High-viscosity slurries
- Low to high coating speeds
- Intermittent coatings



Triple

- Multilayer coatings
- Graded tapes
- Texturing

Tape casting

The tape casting center at Fraunhofer IKTS in Hermsdorf has available several casting machines, which use the conventional doctor blade method and differ from each other in terms of machine length, casting speed and drying method (convection, contact, UV, flotation).

Furthermore, two machines are available which add slot-die coating to the IKTS technology portfolio. With this process, the slurry is pumped into a slot die and applied to the moving carrier tape without contact. The so-called VALIBAT coater is used to realize tapes in the area of battery research. IKTS pursues a modular and ecological approach to tape casting. Following the application of the layer using the slot die, the cast electrode tape is dried contactless through suspension drying and then redensified in an integrated calendar if required.

The solvents contained in the tape casting slurry are then removed using thermal post-combustion and the resulting energy is reintroduced into the machine to dry the layers. The triple-slot-die coater allows multiple layers to be cast in one single casting step. Tapes with different functionalities or differently graded functionalities can be cast directly ‘wet-in-wet’ using triple-slot die coating. Both slot-die machines can be easily refitted to the conventional doctor blade process, whereby the slurry is applied directly to a steel carrier tape using the triple-slot-die coater.

Supporting analytics

- Green tape characterization
- Tape thickness
- Green density
- Hg porosimetry
- Field emission scanning electron microscopy

IKTS offers a combined process of optical and eddy current methods to monitor the tape casting process. It reliably measures in-line wet layer thickness, dry layer thickness, differences in density and optical defects.

Functionalization

Innovative printing, construction and connecting methods are essential when cast tapes are used for multilayer-based components and systems. They have a huge influence on the performance and strength of a component.

In many cases, ceramic tapes are functionalized with conventional screen printing and stencil printing methods. Other methods use digital printing technologies, such as inkjet or aerosol-jet printing. Fraunhofer IKTS has many years of experience in the development of client-specific functional pastes and inks for thick-film technology. This enables us to print the most varied materials on tape, such as precious metals, glass or functional ceramics.

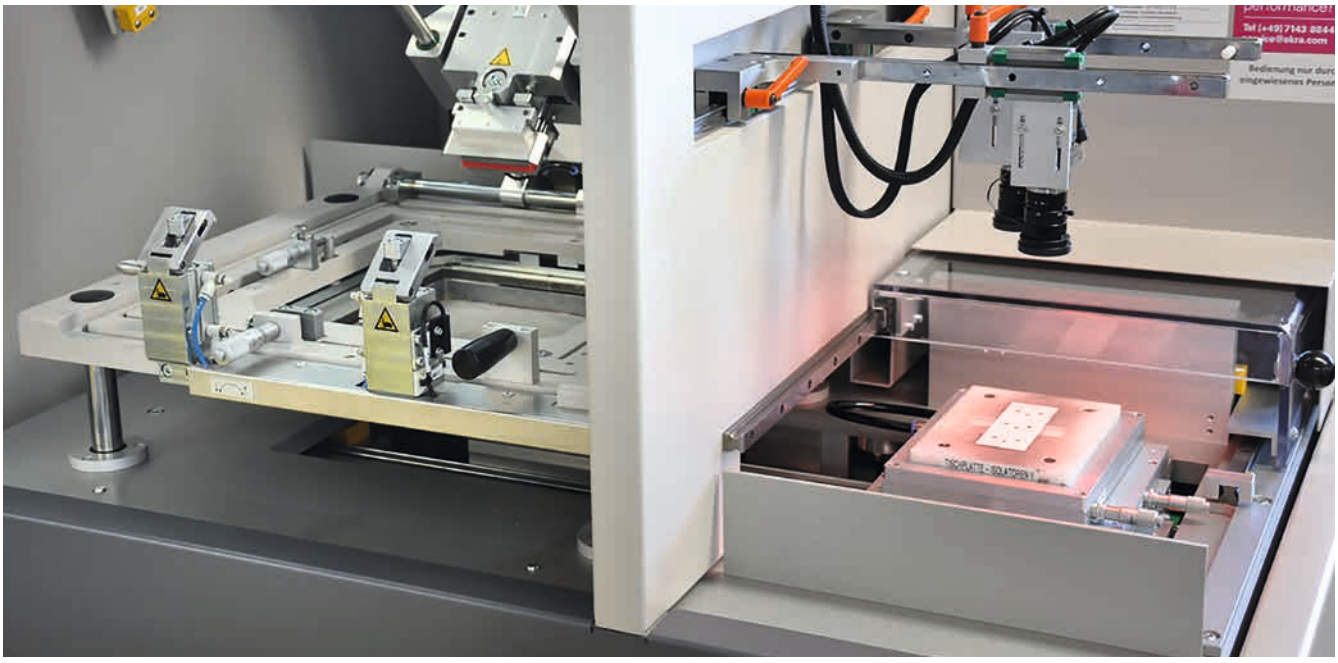
IKTS offers various technologies for joining and packaging, such as soldering, gluing or wire bonding based on polymeric and glass-bonded thick-film pastes.

Application examples

- Sensor housings
- Housings for reference electrodes with diaphragm
- Ceramic capillary bundles
- Internal metallizing of electroceramic honeycomb bodies
- Printed heater structures
- Ceramic components for ozonizers
- Ceramic basic components for thermally stable pressure sensors

Supporting analytics

- Thickness measurement
- Adhesivity
- Thermal characterization
- Field emission scanning electron microscopy
- Functional characterization



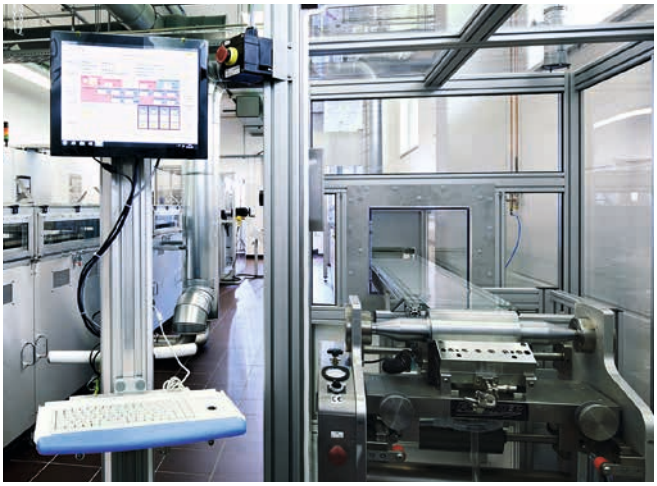
Functionalization of ceramic tapes with thick-film processes.

Equipment

Tape casting

Parameter	KMS lab facility	KWH casting facility	KWH/UV casting facility	KEKO tape caster	VALIBAT coater	Triple-slot die coater
Layer application	- Doctor blade on roll	- Doctor blade	- Doctor blade	- Doctor blade	- Doctor blade - Slot die	- Doctor blade - Slot die - Triple-slot die
Coating technology	- Single	- Single - Green/wet	- Single - Green/wet	- Single	- Single - Intermittent - Double-sided	- Single - Triple 'wet-in-wet' - Intermittent
Drying	- Passive at RT - IR drying	- Passive at RT	- UV curing	- Contact - Convection	- Flotation - Convection	- Contact - Convection
Machine length (m)	7.5	14.2	14.2	12.1	13.6	13.8
Curing channel (m)	6.0	12.8	12.8	10.0	6.25	11.6
Dry layer thickness (µm)	20–500	30–2000	10–1000	10–500	10–500	10–500
Casting speed (m/min)	0.1–10	0.1–10	0.1–10	0.1–3	1–4	0.25–1
Dosing	- Gravitation - Pressure	- Gravitation - Pressure	- Gravitation - Pressure	- Gravitation - Pressure	- Pressure	- Pressure
Carrier tape	- Mylar - Metal (Al, Cu)	- Mylar - Metal - Paper	- Mylar - Metal	- Mylar - Metal - Paper	- Mylar - Metal	- Mylar - Steel

Doctor blade pilot plant at Fraunhofer IKTS in Hermsdorf.

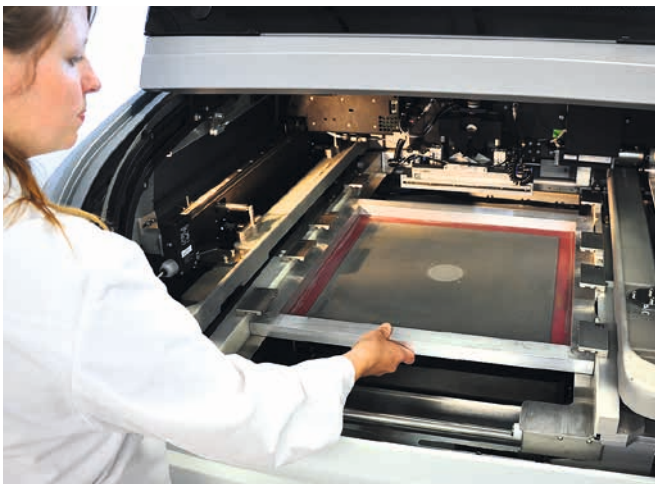


Slot-die pilot plant.

Screen printing

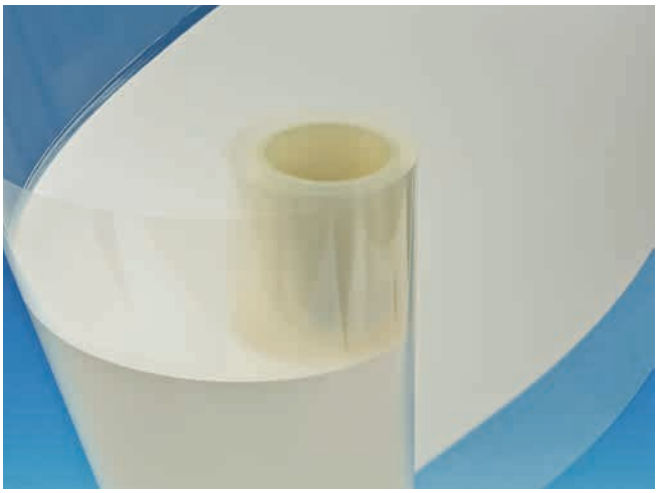
Teca-Print 70 pad printing machine	EKRA-M2 (I) screen printing machine	EKRA-M2 (II) screen printing machine	EKRA-Microelectronic 2H screen printing machine	DEK Type 03iX screen printing machine
Standard cliché length max. 100 mm	Printing format (x/y) max. 180 x 160 mm²	Printing format (x/y) max. 180 x 160 mm²	Printing format (x/y) max. 180 x 160 mm²	Printing format (x/y) max. 738 x 738 mm²
Process changeover to stamp printing	Printing material thickness max. 30 mm	Printing material thickness max. 30 mm	Printing material thickness max. 30 mm	Printing material thickness max. 40 mm
Cycles max. 300 cycles per hour	Screen frame 203 x 152 mm² to 305 x 305 mm²	Screen frame 203 x 152 mm² to 305 x 305 mm²	Screen frame 203 x 152 mm² to 305 x 305 mm²	Screen frame 40 x 50 mm² to 510 x 508 mm²
Printing pressure with 250 N centric load	Alignment accuracy ± 10 µm	Alignment accuracy ± 10 µm	Alignment accuracy ± 10 µm	Repeat accuracy ± 12.5 µm
Pneumatic drive	Squeegee speed 10–200 mm/s	Squeegee speed 10–200 mm/s	Squeegee speed 10–200 mm/s	Split optic for automatic stencil/screen alignment
230 V/50 Hz connection	Squeegee pressure 10–200 N	Squeegee pressure 10–200 N	Squeegee pressure 10–200 N	Humidity and temperature measurement inside printer
Compressed air 4–5 bar	Snap-off distance ≤ 5 mm	Snap-off distance ≤ 5 mm	Snap-off distance ≤ 5 mm	Printing with Pro Flow doctor blade
Air consumption per cycle at 5 bar: 0.25 liter	Table adjustment (x/y) ± 8 mm	Table adjustment (x/y) ± 8 mm	Table adjustment (x/y) ± 8 mm	
	Axis of rotation ± 3°	Axis of rotation ± 3°	Axis of rotation ± 3°	
		Manual optical positioning system	Automatic optical positioning system	

EKRA-M2H screen printing machine for functionalization of ceramic tapes.



DEK Type 03iX screen printing machine for large printing formats.

Tape systems



LTCC green tape for bonding to silicon.

LTCC tapes according to Heraeus formula

Low Temperature Co-fired Ceramic tapes (Heratape®CT 700 and Heratape®CT 800 series of Heraeus Deutschland GmbH & Co. KG) are available for customer projects at IKTS.

Parameter	IKTS-CT				
	702	**708**	**765**	**800**	**810**
Material	Pb-free LTCC tape for free sintering	Pb-free LTCC tape, low-loss tape, also suitable as basic tape for CT765	High K(~65) tape	Pb-free LTCC tape, suitable for sintering process with disposable protective layer	Pb-free LTCC tape, suitable for insulation on steel
Max. casting width (mm)	300	300	180	300	180
Max. tape thickness (µm)	180	180	180	180	180
Sintering temperature (°C)	870	870	870	870	870
Sintered density (g/cm³) (theoretical > 96 %)	3.2	3.0	5.5	3.3	3.3
Thermal expansion coefficient (ppm/K)	7.3 (25–300 °C)	7.6 (25–300 °C) 9.3 (25–800 °C)	9.1 (25–300 °C) 10.5 (25–600 °C)	5.1 (20–300 °C) 6.4 (20–Tg °C)	--
Thermal conductivity (W/mK)	4.3	4.3	--	4.3	4.3
Dielectric constant (at 25 °C)	7.5–7.9 (1 kHz)	6.4±0.1 (2.5 GHz)	65.0±4.0 (1.0 GHz) 96.7±0.1 (2.5 GHz)	7.5±0.1 (2.5 GHz) 5.3±0.1 (20.0 GHz) 5.2±0.1 (100.0 GHz)	8.7±0.1 (2.5 GHz)
Dielectric dissipation factor tan δ (at 25 °C)	3 x 10^{-3} (1 kHz)	0.3 (2.5 GHz)	< 0.2 (1.0 GHz) < 0.2 (2.5 GHz)	< 0.2 (2.5 GHz) < 0.8 (20.0 GHz) < 0.2 (100.0 GHz)	< 0.005 (2.5 GHz)

The measurements were conducted on sintered tapes or laminates.
We can provide detailed information on the debindering and sintering profile as well as sinter aggregates at your request.
Pastes compatible with tapes can also be recommended.

Tape casting of LTCC tapes according to Heraeus formula.

LTCC tapes for reliable MEMS integration

Silicon and LTCC (Low Temperature Co-fired Ceramics) are standard substrate materials for microsensors and microsystems technology. By combination of both materials into a common system, microsystems with significantly higher complexity might be produced. Established methods of microtechnology, such as photolithography and microstructuring, thick-film and thin-film technologies, as well as methods of assembly and connection technologies can be applied to both materials, resulting in efficient microsystems manufacturing options for various product areas.

BGK tape

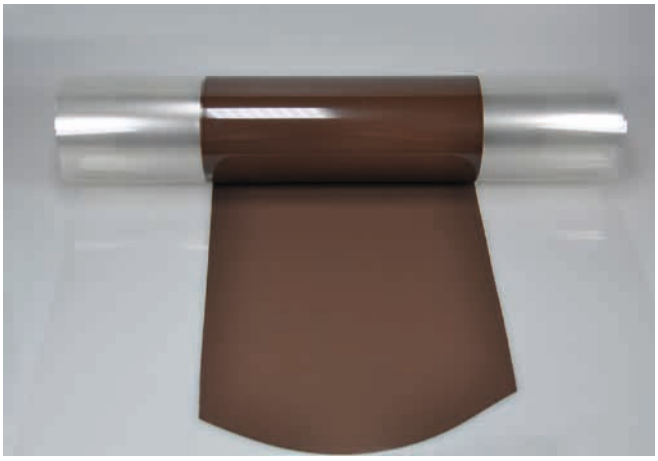
With its BGK tapes, Fraunhofer IKTS has developed a special LTCC material whose thermal expansion coefficient has been adapted to silicon and which is therefore ideal for anodic bonding with silicon. In this process, the fully processed and sintered multilayer is anodically bonded to silicon.

BCT tape

Fraunhofer IKTS has developed a special LTCC tape for the patented SiCer technology. The SiCer technology is based on a composite sintered substrate at wafer level, which consists of silicon and a glass-ceramic LTCC multilayer laminate. During the sintering process at 900 °C, the LTCC and the silicon are mechanically and electrically connected without any additives. Because of the zero-shrinkage in x- and y-direction a high fit between ceramic and silicon can be achieved. As a result, structures and components can be miniaturized.

Parameter	BGK tape	BCT tape
Characteristics	Anodically bondable to silicon	SiCer-capable
Tape thickness (µm) (green tapes)	50, 120, 180	120, 180
Shrinkage 6-layer laminate (x, y) (%)	16–17.5	18.7–19.2
Pressure during lamination (MPa)	20–25 (70–80 °C)	20–25 (70–80 °C)
Dielectric constant ε_r	5.35 (1 GHz)	8.29 (1 kHz) 5.42 (1 GHz)
Spec. volume resistance (Ω)	20.8×10^{12}	7.1×10^{15}
Spec. surface resistance (Ω)	127×10^{12}	411×10^{12}
Dielectric dissipation factor tan δ[1]	0.02 (25 °C, 1 kHz) 0.07 (25 °C, 1 MHz)	0.0014 (25 °C, 1 kHz) 0.0012 (25 °C, 1 MHz) 0.00196 (25 °C, 1 GHz)
Dielectric strenght[3] (kV/mm)	27.03	28.90
Thermal expansion coefficient (ppm/K)	3.4±0.2 (25–400 °C)	3.4±0.2 (25–400 °C)

The measurements were conducted on sintered tapes or laminates. Pastes compatible with this tapes can be recommended.
[1]VDE 0303 Part 4: 1969-12
[2]DIN IEC 60093
[3]DIN EN 60243-1



Functional ferrite tape.

Porous membranes.

Functional LTCC tapes

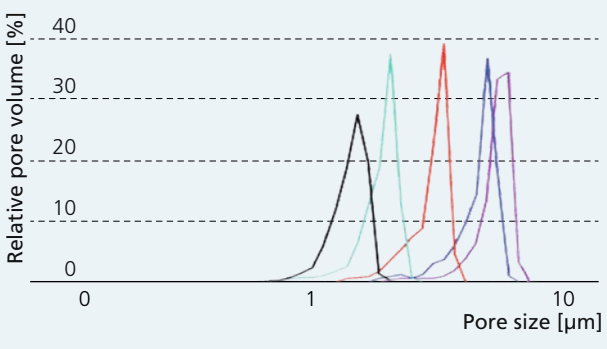
Currently, there is a growing demand to transfer the miniaturization and functionalization of electronic circuits from the chip level to the next higher integration level. The LTCC technology is a packaging concept with which electronic assemblies with a high scale of integration, microfluidic systems or modular electrochemical cells can be realized. The LTCC technology is a state-of-the-art technology allowing for the manufacture of integrated multilayer circuits that enable completely new interconnection and packaging solutions. The LTCC green tapes are structured, printed with metal thick-film pastes, laminated and sintered at about 900 °C. LTCC tapes developed at IKTS are used in pre- and small-series products.

Parameter	Value
NiCuZn ferrite tapes	
Green tape thickness µm	120
Sintering temperature °C	850–900
Permeability μ_r	200–800
MgCuZn ferrite tapes	
Green tape thickness µm	120
Sintering temperature °C	850–900
Permeability µr	300
HDK($BaTiO_3$) tapes	
Green tape thickness µm	5.35
Sintering temperature °C	850–900
Permittivity ε	> 2000
Dielectric dissipation tan δ	< 25 x 10^{-3}
Operating temperature °C	-55–125
Temperature characteristics	X7R

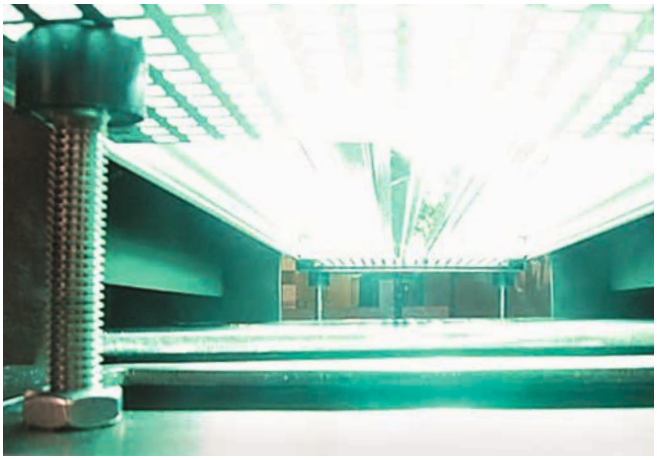
Porous support tapes

Ceramic tapes based on Al_2O_3, ZrO_2 and TiO_2 materials are the basis for substrates with defined porosity. The application is in the field of filtration technology and gas separation. They can be used for the manufacture of asymmetrically structured membranes with adjustable pore diameters between 3 µm and < 1 nm. An upscaling of the membrane preparation up to industrial scale is possible.

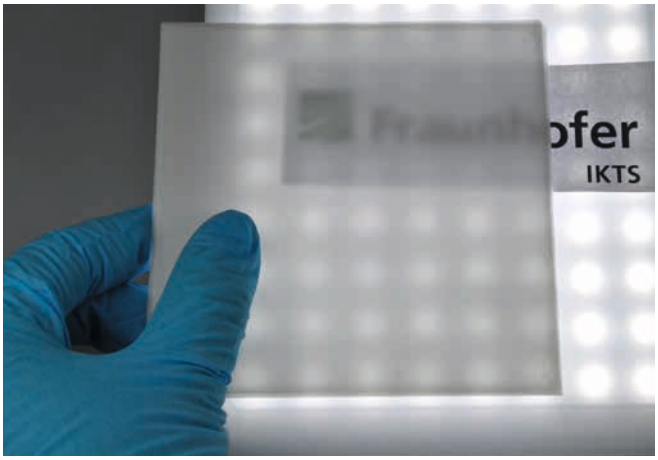
Material	Open porosity %	d_{50} µm	Casting width mm	Tape thickness µm
Al_2O_3	25	1.4		50–1000
	28	1.8		50–1000
	36	2.8	max. 300	50–1000
	42	4.0		50–1000
	43	5.0		50–800
ZrO_2	43	5.0	max. 300	50–1000
TiO_2	42	4.0	max. 300	50–800



Pore size distribution of different Al_2O_3 supports.



Processing of UV-curing slurry systems.



Highly translucent MgO tape, 8-layer laminate, not polished.

UV-curing tapes

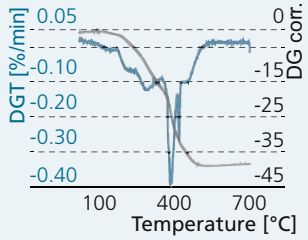
Because of the proven health and environmental hazards of organic solvents and phthalates used as plasticizers, as well as stricter legislation (ROHS/REACH), there are efforts to replace the conventional slurry systems by solvent-free alternatives. Investigations with two different ceramic and one hardmagnetic material have shown that UV-curing binder systems for the substitution of conventional, solvent-based systems are, depending on the application, suitable.

Composition

Ceramic materials	Al_2O_3, MgCuZn ferrite
UV binder	Darocur, Lucirin, Irgacure 500, 819
Photoinitiator	Desmolux 2299, U100
Dispersing agent	Ethylendiamine derivate
	Phosphoric acid ester
Organic burn-out	450 °C

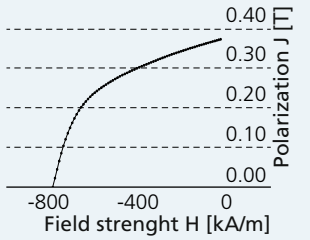
Al_2O_3

Curable thickness ≤ 2 mm



NdFeB

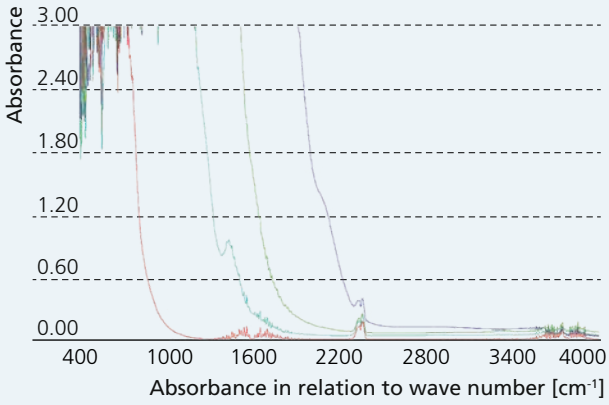
Curable thickness ≤ 220 µm



Debindering behavior of a UV-cured Al_2O_3 tape (left) and demagnetization curve of a UV-cured MQP-S tape (right).

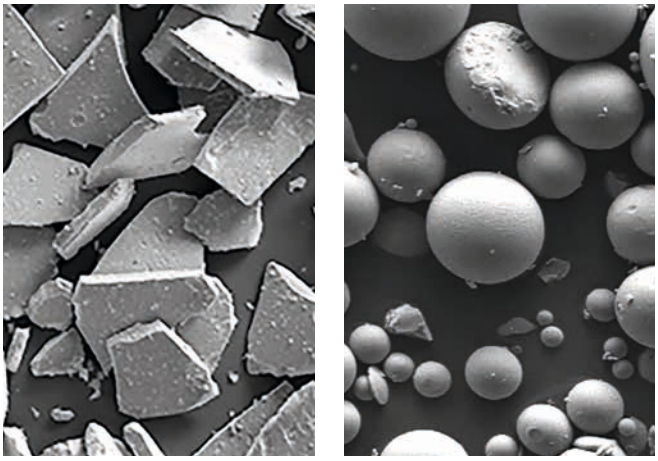
Transparent tapes

Transparent ceramic materials, with their special optical parameters combined with the typically ceramic properties such as high hardness, chemical and thermal stability or electric isolation, are interesting alternatives to conventional optical glasses or monocrystals. Transparent tapes are used as support materials for the analytical method of Raman spectroscopy, which is currently undergoing intensive development in the field of biophotonics.



Glass (blue, transparent up to 2400 cm^{-1})
Calcium fluoride (red, transparent up to 1000 cm^{-1}) and
Spinell (light green, 4 mm thick, transparent up to 2000 cm^{-1}
turquoises, 0,6 mm thick, transparent up to 1700 cm^{-1})
wave lenght 25–2.5 µm; spectral range 400–4000 cm^{-1}

IR transmission compared.



REM image of two NdFeB powders, MQP-B (left) and MQP-S (right).

VaLiBat coater for the production of battery electrodes.

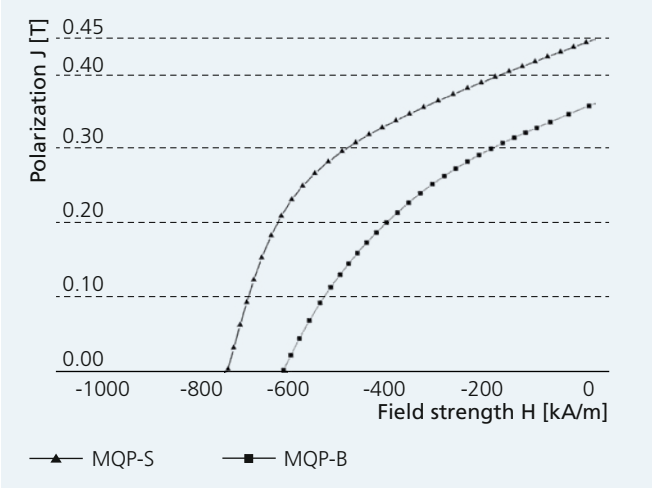
NdFeB tapes

For the miniaturization of actuators for micromechanical systems, microsystem technology or magnetic length or angle measurement, permanent magnetic thick films from highly remanent NdFeB with a magnetically hard phase $Nd_2Fe_{14}B$ are an interesting solution.

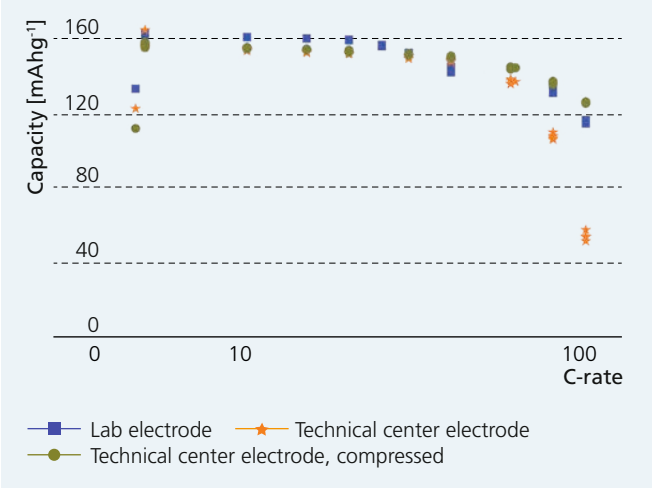
For these applications, commercially available NdFeB powders are used as functional material, processed while adding a thermally curing binder system and plasticizers, resulting in tape casting slurries. This enabels the production of green tapes with 100–500 µm thickness. After thermal curing, the tapes – depending on the NdFeB used – show remanence values of up to 500 mT and a coercive force of 600–800 kA/m. The tapes can then be multi-polar magnetized.

Tapes for batteries

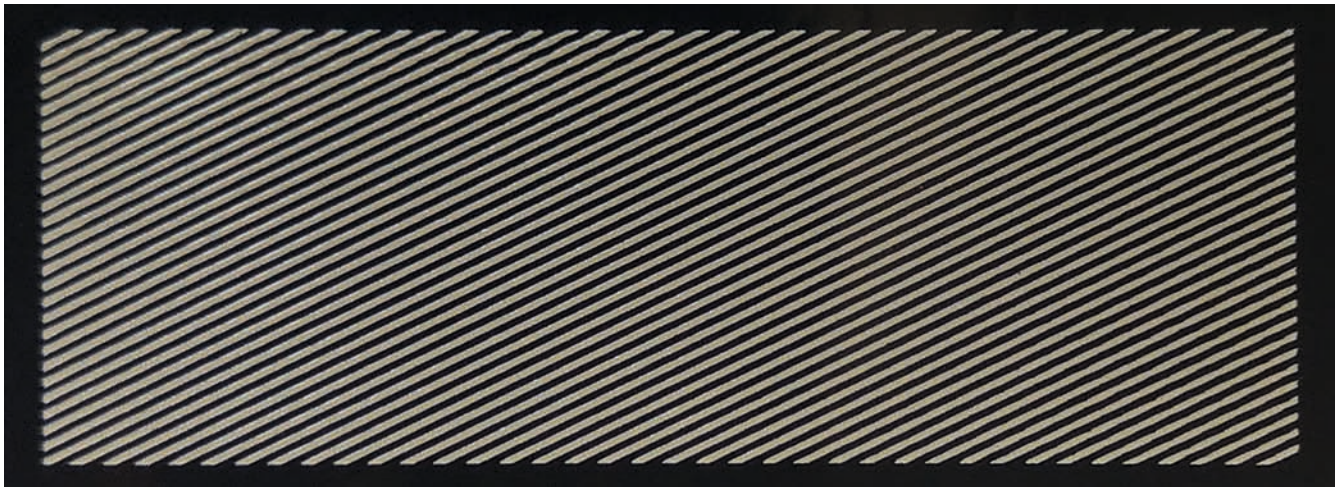
Powerful Li-ion batteries require cost- and energy-efficient manufacturing processes for the required electrodes. Tape casting technologies show enormous potential for this task. IKTS is experienced in the coating of metallic carrier tapes with active layers using the doctor blade method and slot-die coating. The core competence is the production of slurries from active powders with reproducible flow properties. Furthermore, developments in plant engineering are essential as well. Modern tape casting machines make it possible to apply active materials onto metallic carrier tapes and drying them while continuously coating large areas (strip coating). The focus of development activities and services is on experiments for material and technology optimization (e.g. current collector materials, casting and drying parameters) as well as developing upscaling processes.



Demagnetization curves of NdFeB thick films.



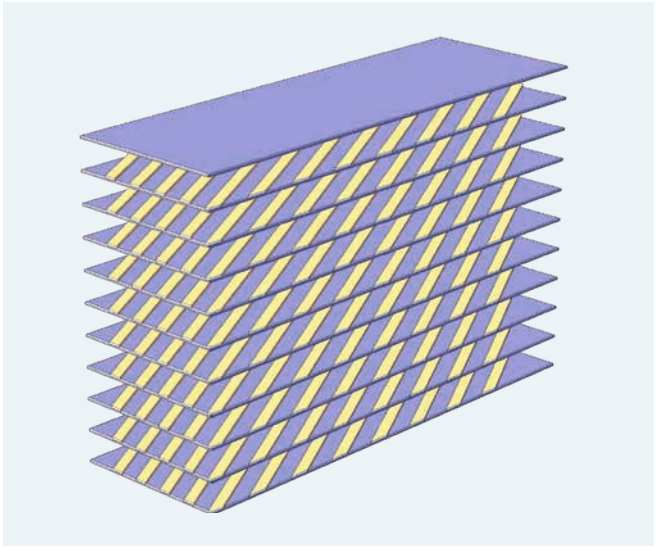
Capacity vs. C-rate of different battery tapes (in cooperation with Zentrum für Brennstoffzellen Technik GmbH).



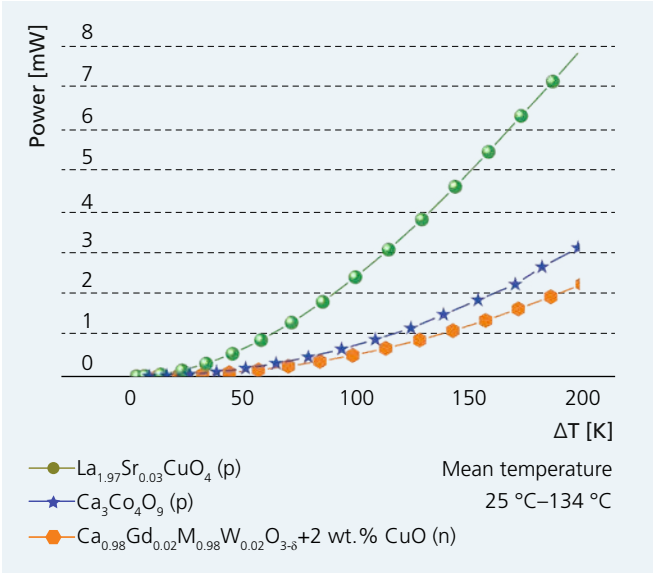
Green tape with printed metallization for the assembly of transversal multilayer thermoelectric generators.

Tapes for transversal thermoelectric generators

Ceramic multilayer technology is an interesting option for miniaturizing and batch-producing transversal thermoelectric generators. For this purpose, $Ca_3Co_4O_9$, La_2CuO_4 and $CaMnO_3$ powders are processed into green tapes and metallized via screen printing. In this process, the metal layers are printed at a specific angle to the direction of heat flow to produce anisotropic thermoelectric properties. Transversal multilayer thermoelectric generators (TMLTEG) are well suited for use in autonomous sensor systems with low power consumption.



Structure of a transversal TEG stack (source: EAH Jena).



Power vs. temperature difference for different transversal TEGs with Ag/Pd metallization (source: EAH Jena).

Fraunhofer IKTS in profile

For more than 30 years, Fraunhofer IKTS has been demonstrating the potential of ceramic materials in a steadily growing range of application areas. Our development activities are guided by the demands of nine market-oriented business divisions – supplemented by strategic preliminary research at the highest scientific level. As a research and technology service provider, we develop modern ceramic high-performance materials, industrially relevant manufacturing processes as well as prototypical components and systems in complete production lines up to pilot scale.

In addition, the research portfolio includes competences in materials diagnostics and testing. The testing methods in the fields of acoustics, electromagnetics, optics and microscopy contribute significantly to the quality assurance of products and systems. It is our motivation to develop holistic system solutions and services, but also to solve specific challenges within the processes of our partners from industry and science. Our expertise in the characterization and analysis of materials, components and systems along their life cycle provides us with a unique data pool to carry out new developments more efficiently and quickly.

All this qualifies Fraunhofer IKTS as a contact point for companies and research partners to make ceramic materials and non-destructive testing methods accessible to new industries, product ideas and markets.

Contact

Industrial solutions
Tape casting

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