Fraunhofer IKTS

Fraunhofer Institute for Ceramic Technologies and Systems IKTS

Dickschicht-Pastenentwicklung für die Sensorik, die Leistungselektronik und die Hochfrequenztechnik

80. Treffen SAET, Fraunhofer IKTS, Dresden

Stefan Körner, Claudia Feller
stefan.körner@ikts.fraunhofer.de | www.ikts.fraunhofer.de

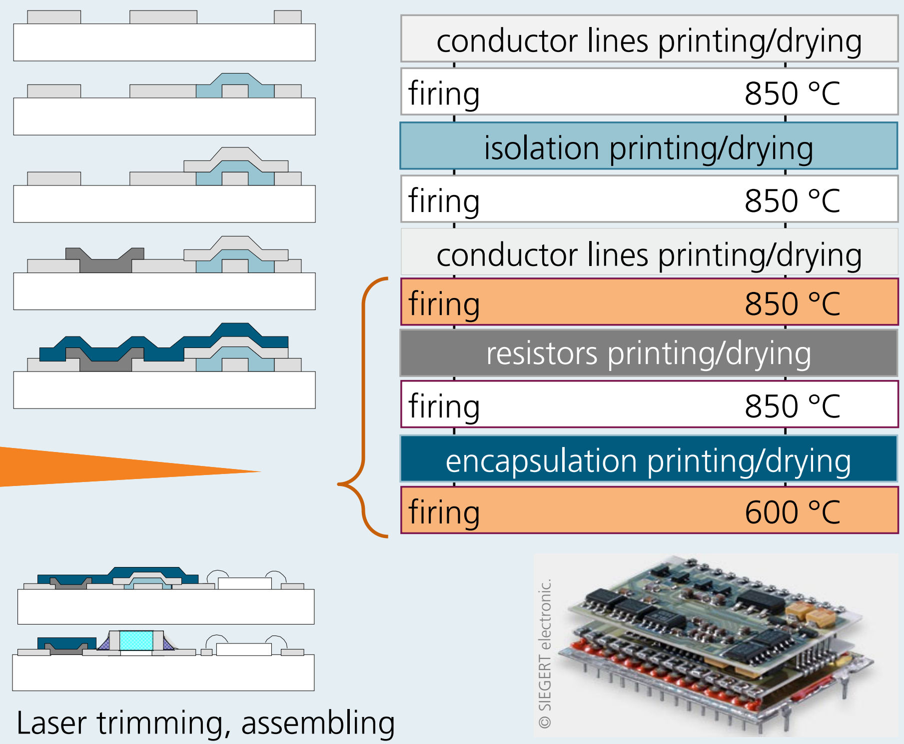
28.03.2023

Ceramic thick-film and multilayer technology

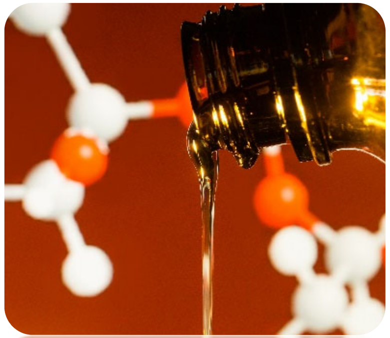
Process flow thick-film technology

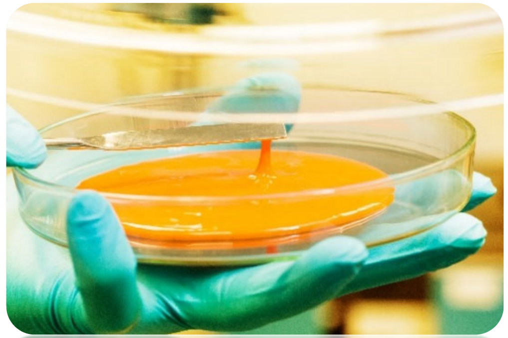
- **Sequential film** printing, drying, firing (on fired substrate)
- **Different functional pastes/inks**
  - Metallization – Ag, AgPd, AgPt, Au, Pt, Cu (contact pads, conductor lines; solder able, plate able, bond able)
  - Resistors – different decades (1 Ohm .. 1 MOhm/sq)
  - Glass layers
    - Type 1 – 850 °C isolation, overcrossing
    - Type 2 – 600 °C encapsulation

Volume shrinkage (multilayer) 35–50 %



How to make an ink/paste

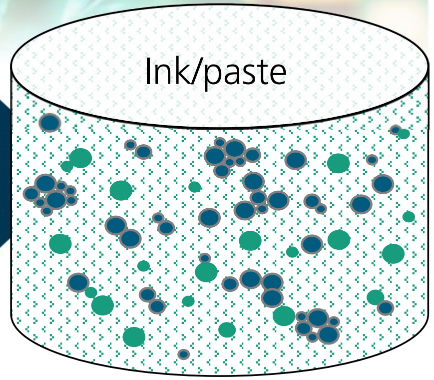




Glass, inorganics, additives

Solvent, polymer

Mixing, dispersing



How to make an ink/paste

Functional paste manufacturing process

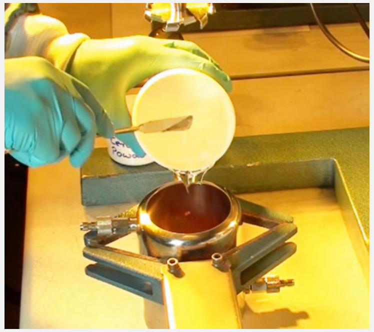
Powdering process

- Planet ball mill
- Measuring PSD/ specific surface

Mixing of solids

- Weight in
- Tumble mixer

Adding binder, dispersion (1)



- Weight in
- Dissolver

Final dispersion (2)

- 3-roll-mill
- Measuring viscosity

Printing

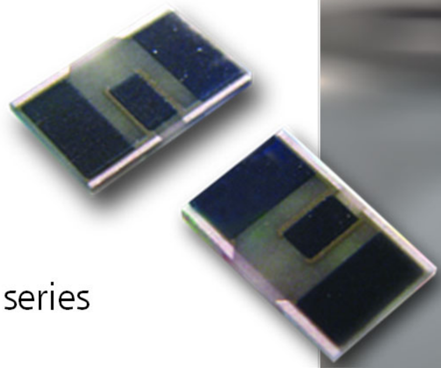
- Screen printing
- Dispensing
- …

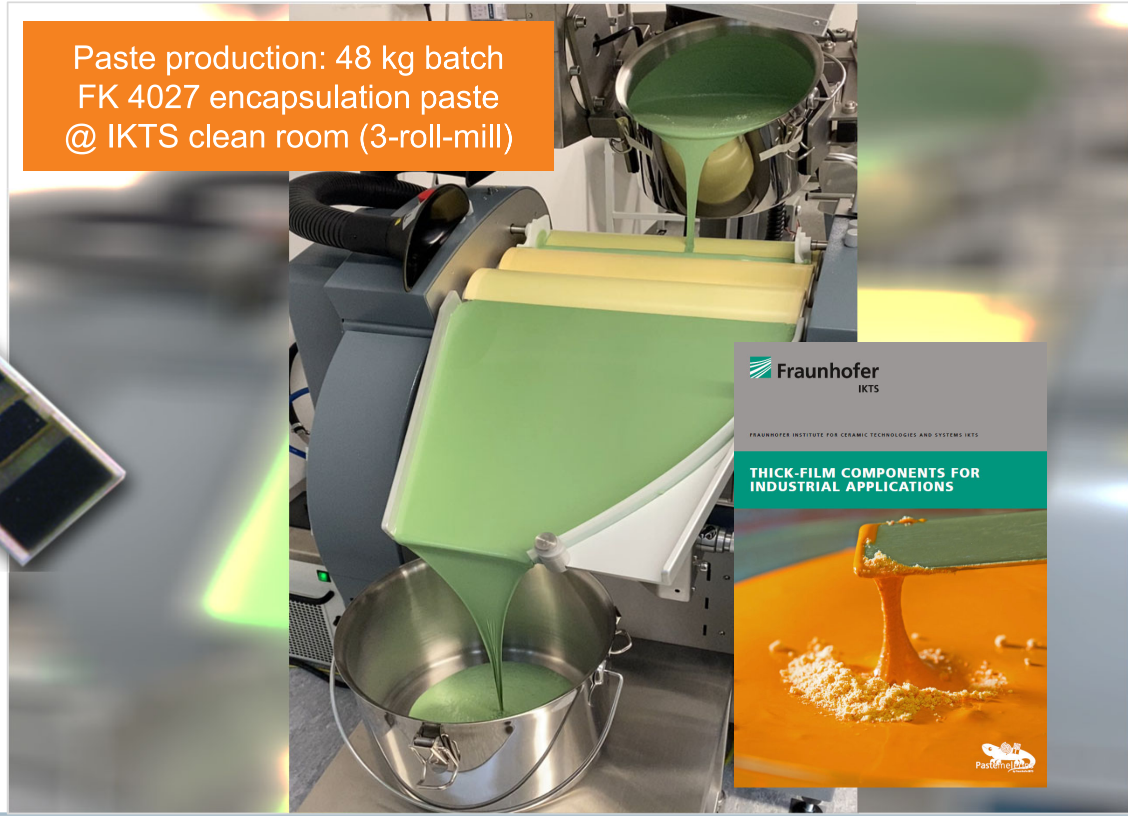
Main Research Topic **Power electronics**

Thick-film paste system for AlN-ceramics

Klick for further information

- **Topic**: **Unique paste composition for AlN-Substrates** (high thermal conductivity (180-200 W/m·K, CTE matches Si) **provided by IKTS** (DIN/ISO 9000 certified)
- **Resistor** paste series
  - **FK 96XX** (RuO_2), **FK 99XX** (AgPd)
- **Metallization** paste series
  - **FK 11XX/ 12XX** (AgPd)
  - **FK 10XX** (AgPt)
- **Glass encapsulation and marker** paste series
  - **FK 40XX**
- **Preliminary research**
  - **High ohmic resistors**





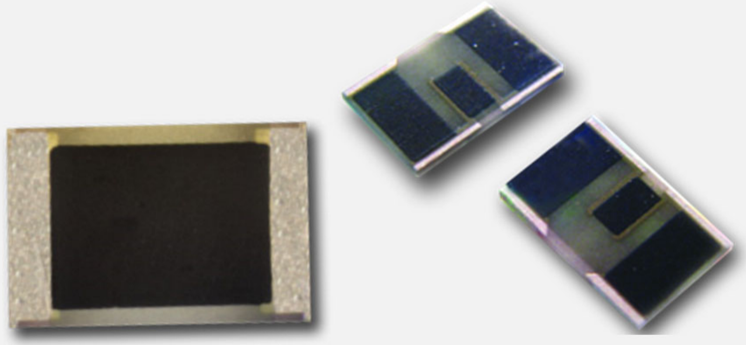
Application examples

Lead-free pastes for AlN substrates

- **Goal**
  - TFR, metallization and encapsulation pastes for AlN (standard pastes (alumina) not applicable because of strong interactions glass/AlN)
- **Approach**
  - Adapted glasses (no chemical interactions, suited glass viscosity)

Conductive chains (3D network)

- **AlN - advantages**
  - High thermal conductivity: 180…200 W/m·K
  - CTE: 4.8·10–6 1/K
- **High dielectric strength > 12 kV/mm**
  - Application fields
  - High power TFR
  - Attenuators



Source: https://ims-resistors.com/

Current research topics

Lead-free pastes for AlN substrates

- **Result: AlN compatible paste system**

Paste	Metal	R sq/mOhm/sq	Application
FK 1205	AgPd	< 25	R termination
FK 1220	AgPd	< 25	Acid stable
FK 1164	AgPd	< 25	Via paste
FK 1071	AgPt	< 6	Low resistance
FK 1282	AgPt	< 35	De-alloy stable

Paste	Cond. Phase	R sq/Ohm/sq	TCR/ppm/K
FK 9821m	AgPd	0.1	± 75
FK 9831m	AgPd	1	± 75
FK9611	RuO_2	10	± 100
FK9615	RuO_2	50	± 100
FK9621	RuO_2	100	± 100
FK9631	RuO_2	1.000	± 100

Resistor, conductor, encapsulation and heater pastes for AlN-ceramics, raw materials.

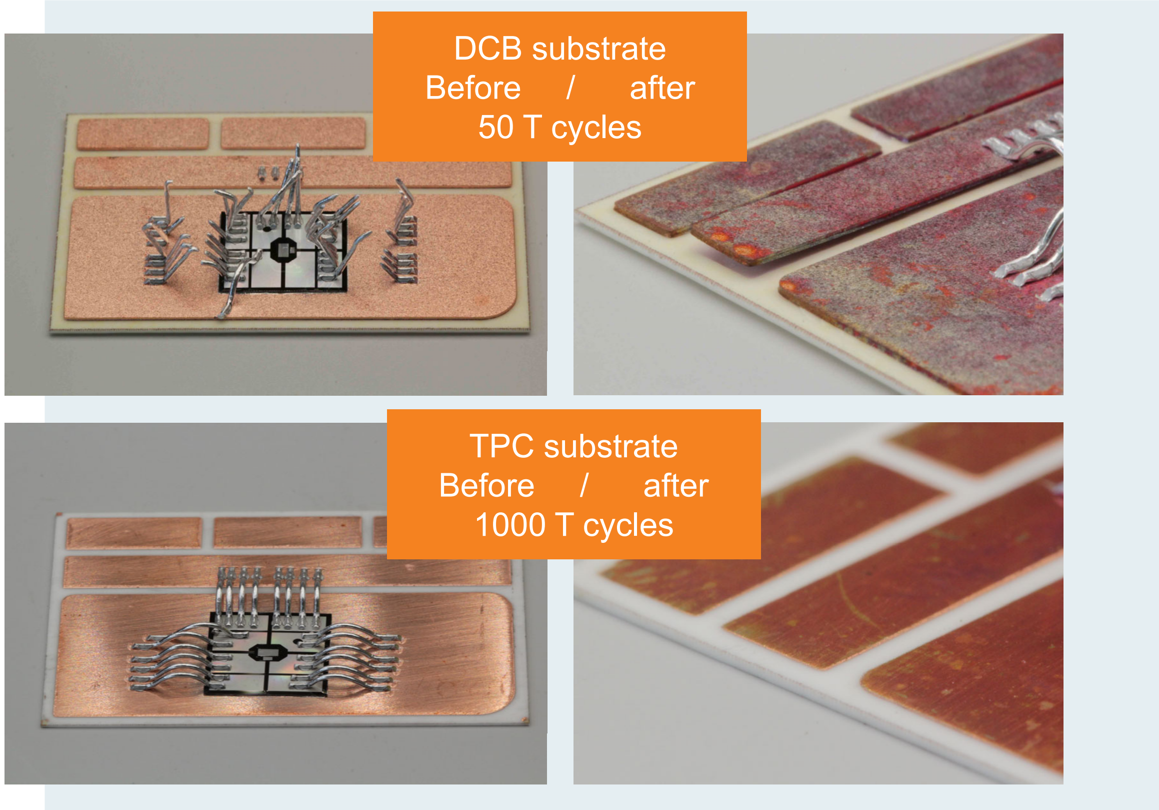
Further information/catalogue

Fraunhofer IKTS

Main Research Topic **Base metal pastes**

Fraunhofer funded internal project »**TPC LE** - Reliability of thick-printed copper on alumina substrates«

- **Topic**: Reliability of thick-printed copper metallisation vs. DCB (thermal/ power cycling)
- **Project partners**: Fraunhofer IISB, IKTS
- **Objectives**: Reliability comparison between DCB-, AMB- and TPC-metallized ceramic circuits
- **Thermal cycling**
  - Temperatures: -40 … +125 °C
  - Cycle time < 30 s
  - Dwell time > 15 min
- **Paste development**
  - **Metallization:** Cu, **CuNi**
  - **Resistor:** NiCr (under development)
  - **Encapsulation:** glass (under development)

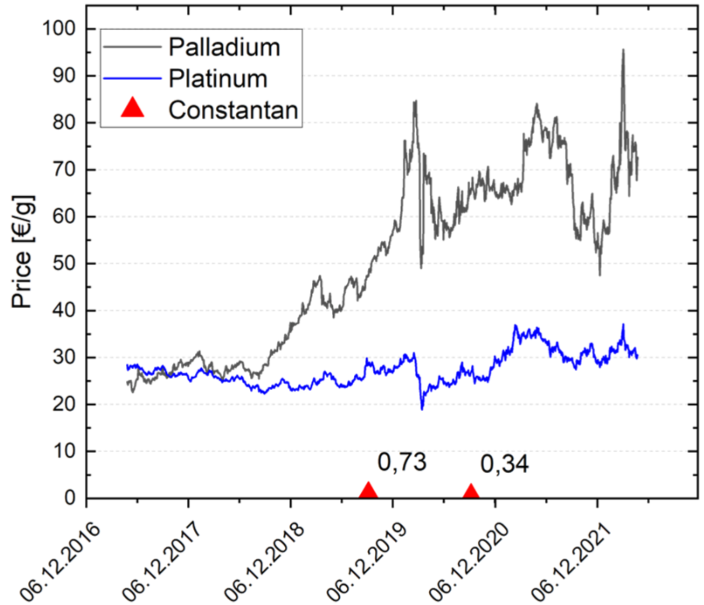


Current research topics

Base metal pastes

- **CuNi(Mn) pastes**

- Favorable properties
  - High electrical conductivity
  - Temperature coefficent of resistance close to zero
  - Temperature **stability up to 600°C**
  - **low metal price**

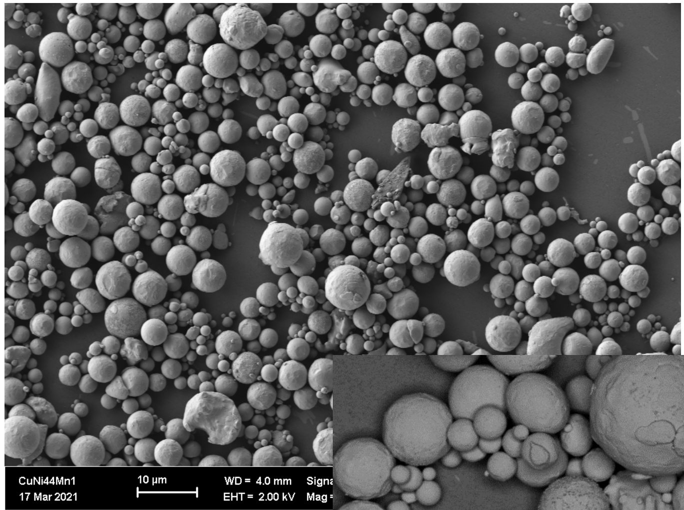


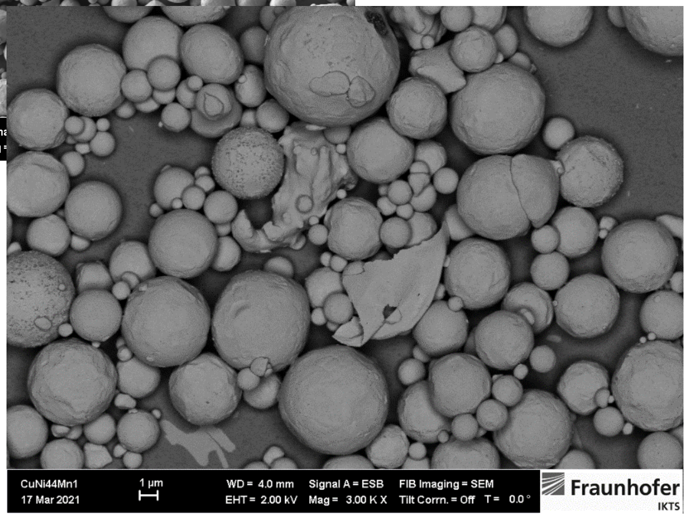
And still, there is **only one commercial paste supplier** with a Constantan paste.

https://www.mitsuboshi.com/english/product/material/resist.html [Accessed 02 July 2021].

Current research topics

Base metal pastes





- **Atomized Constantan powder (Cu55Ni44Mn1)**
  - Atomization atmosphere: Argon
  - Grain size roughly 15 µm
  - Classification to PSD

d_{10} = 3.1 µm
d_{50} = 7.3 µm
d_{90} = 13.2 µm

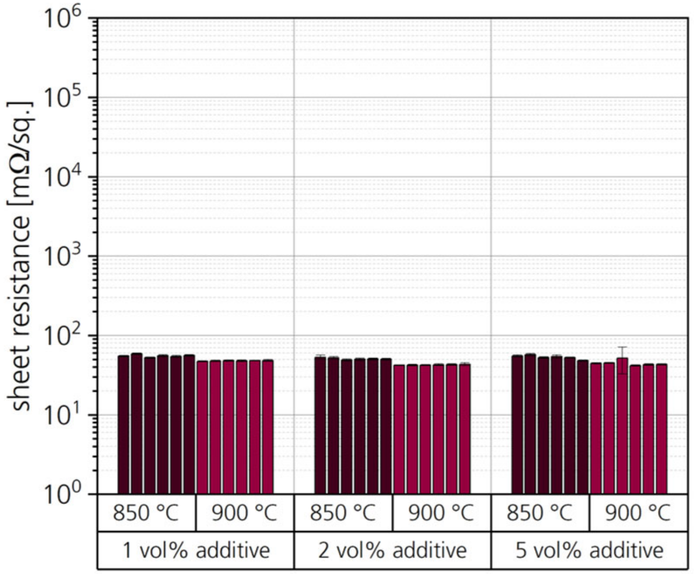
- **Glass powders (SiO_2-B_2O_3-Al_2O_3)**

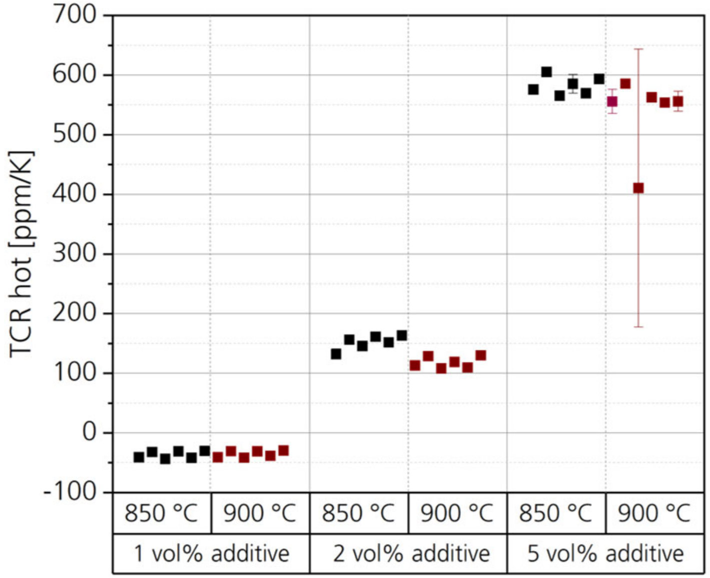
- At IKTS melted glasses
- Stepwise grinding to d_{50} ~ 2.4 µm

Fraunhofer IKTS

Constantan pastes

Sheet resistance and TCR





Sheet resistance

- Sheet resistivites in the range of 50-60 mOhm/sq
  - Independant of firing temperature or
  - oxygen scavanger content

Temperature coeffcient of resistance

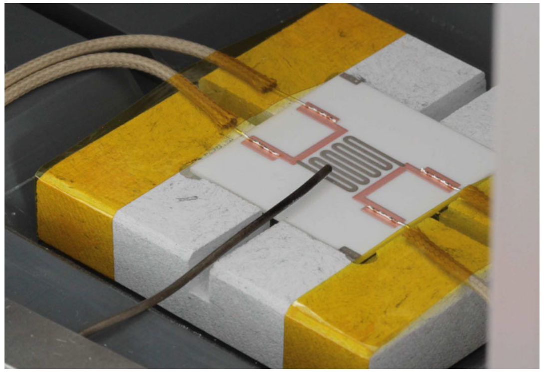
- TCR in the range of -50 up to 600 ppm/K
  - Dependant on oxygen scavanger content

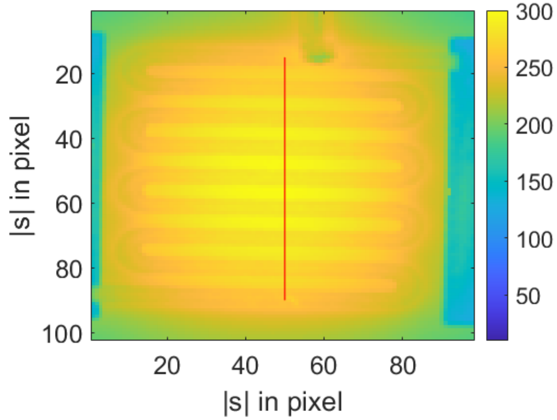
Fraunhofer IKTS

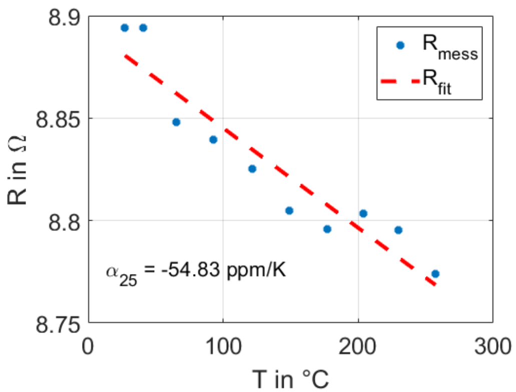
Current research topics

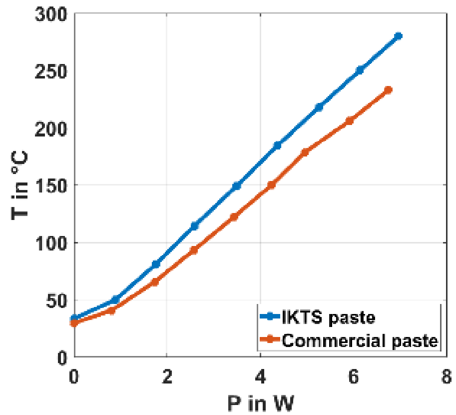
Base metal pastes

- **Testing as heater elements**
  - Power controlled: 1 … 8 W
  - Electric parameters are recorded with IR-data simultanously
- **Results**
  - Temperatures up to 300 °C reached
  - Homogenous temperature distribution
  - TCR 25…250°C is -55 ppm/K









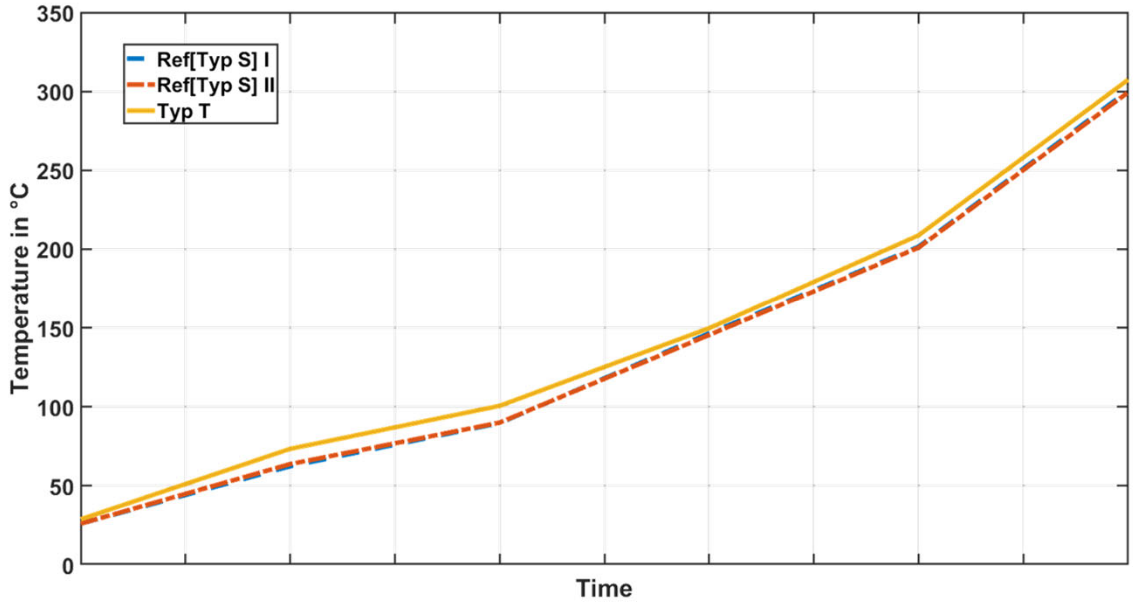
Public information

Current research topics

Base metal pastes

- **Testing as thermocouple**
  - Controlled temperature using a climate chamber
  - Comparison to a standard Type S thermocouple

- **Results**
  - Temperature sensitivity is given
  - Shape and progression of printed thermocouples are similiar to conventional system

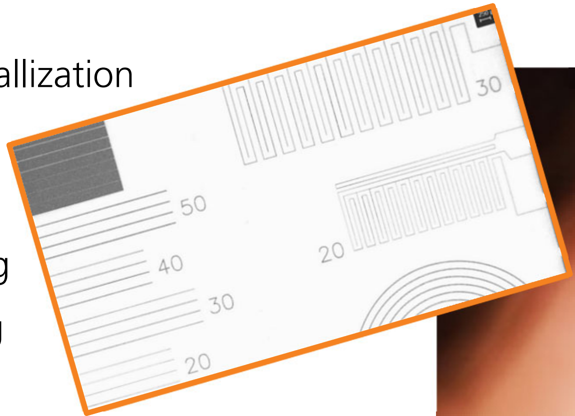


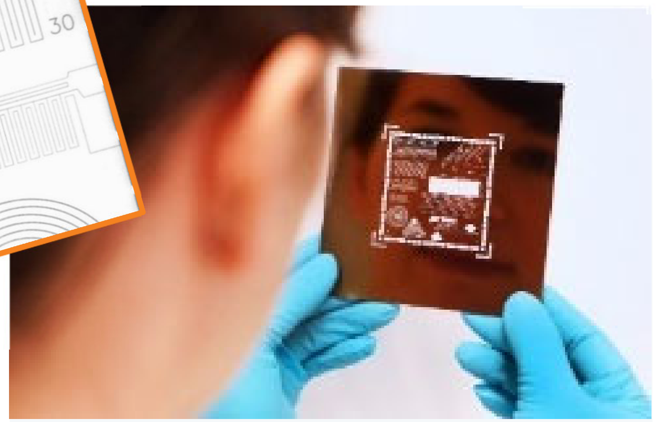
Main Research Topic **RF/ mmWave**

Photo-image able (PI) pastes

Klick for further information

- **Topic**: new lithography-based technology for fine-line metallization
- **Objectives**:
  - **Improved printing resolution** (<10µm),
  - **Improved surface quality, new features:** e.g. fencing
- **Process**: Screen printing – exposure – development – firing
- **Materials**: **Ag**, Au, Cu, glasses, **LTCC**

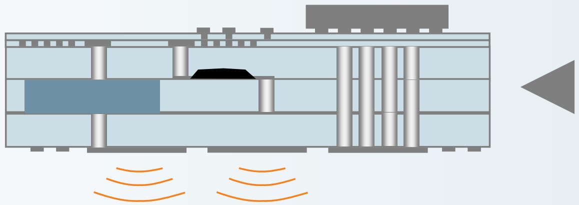




LTCC-PI
20µm l/s, 30 µm vias

LTCC-Standard core
75µm l/s, 75 µm vias

LTCC-PI
20µm l/s, 30 µm vias

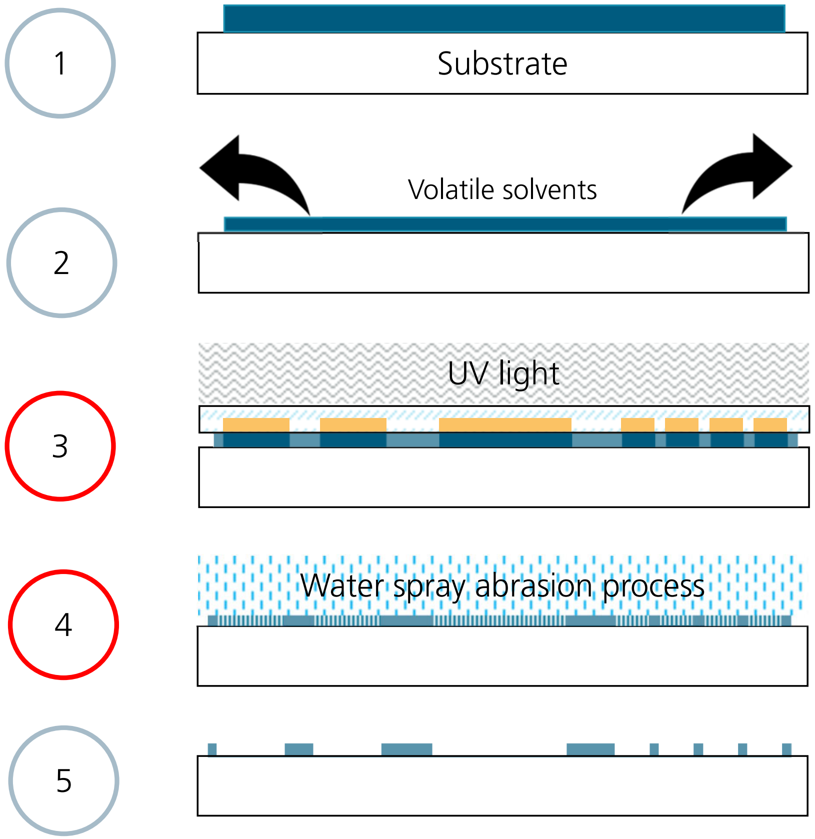


Embedded RLC
Embedded PI films
Thermal vias

Photo-imaging of thick-films

- Printing mask-based
- Exposure LDI, spray developing
- Max. resolution <10 µm

PI process
The look inside



(1) Screen Printing

(2) Drying

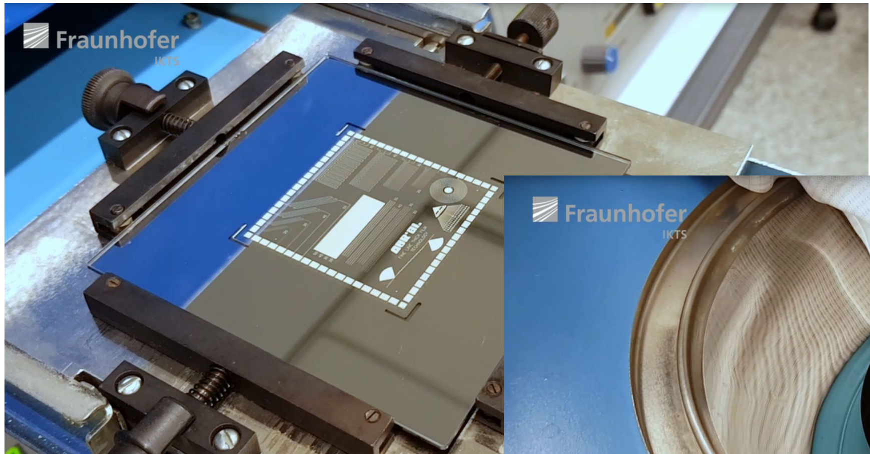
(3) First Additional Step (4-15 sec.):
Exposure with UV light through a photo mask or LDI (Laser Direct Imaging)

(4) Second Additional Step (4-12 sec.):
Imaging via Developing Step (water based chemical solutions)

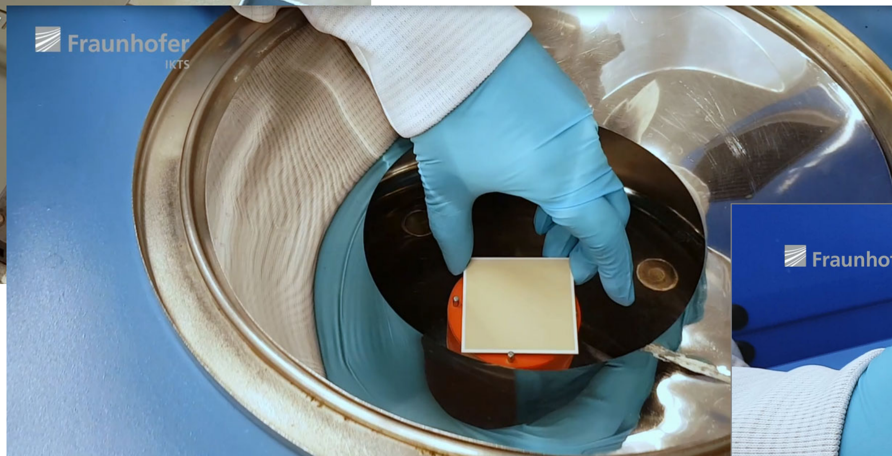
(5) Firing

PI process – The look inside

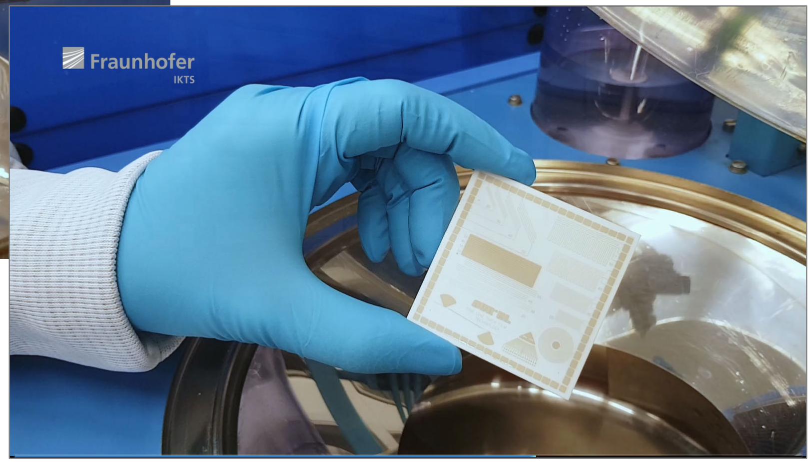
No Yellow room necessary!



Exposure (4-15 s)



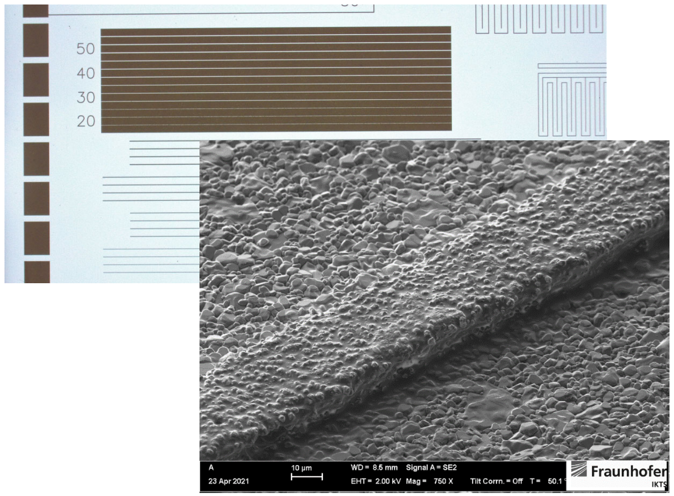
Developing (4-12 s)



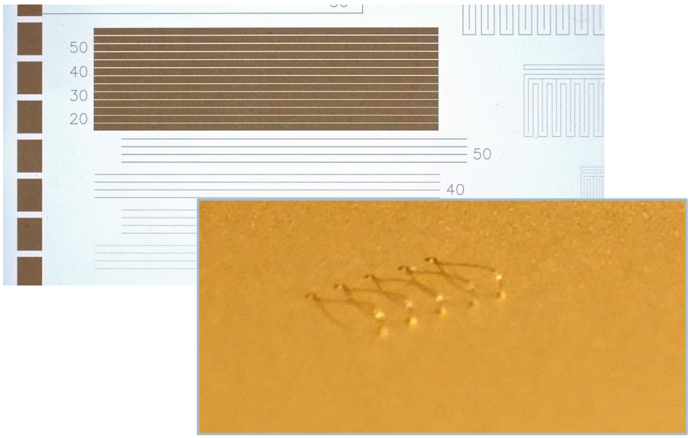
Structured substrate

PI process
Paste development

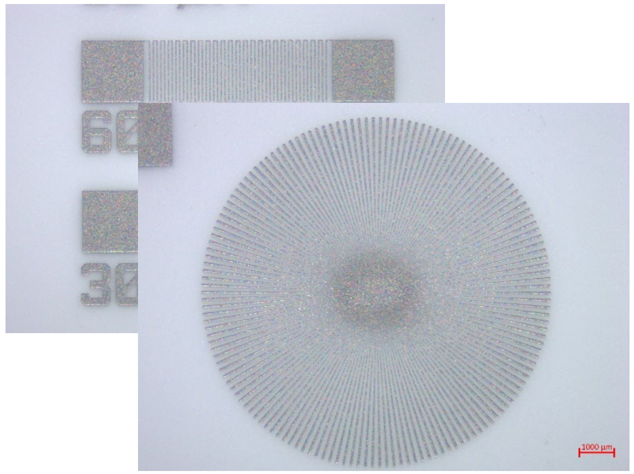
47
Ag
Silver
107.868

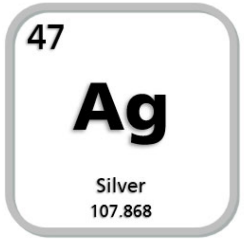


79
Au
Gold
196.967



78
Pt
Platinum
195.08



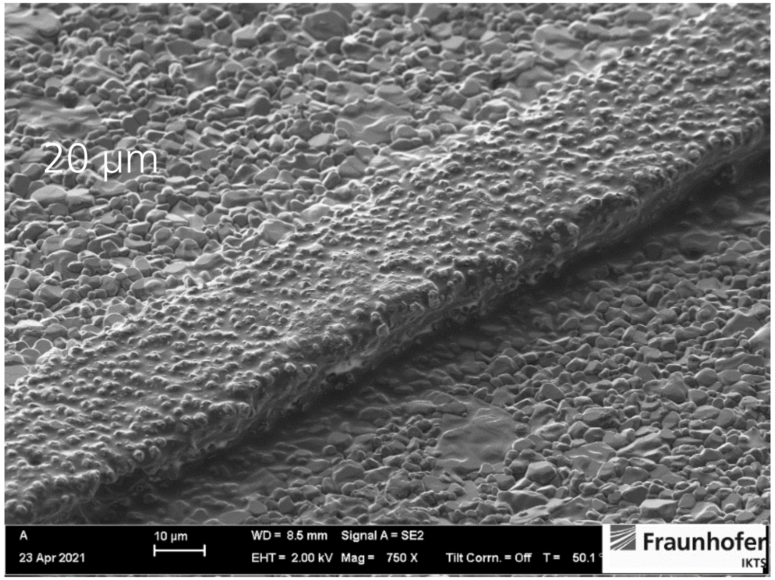


Paste development for PI

Al_2O_3

Characteristics	Unit	Value
Viscosity[1]	Pa·s	40…90
Sheet resistivity[2, 3]	mOhm/Sq	≤ 3.5
Fired film thickness[3]	µm	8…12
Line Resolution		
Line/space	**µm/µm**	**20/20**
Solder acceptance[3, 4]	%	≥95
Adhesion[5]	N/4 mm²	≥20

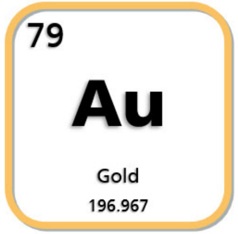
[1] *Rotational viscometer ARG2 with cone/plate combination (2 cm, 2°) at 10 s^{-1} and 22±0.2 °C.*
[2] *Sheet resistivity, calculated for a fired thickness of 10±1 µm.*
[3] *Firing profile: total cycle time 60 min, 10 min at 850 °C.*
[4] *Flux: Alpha 611, 220 °C, 5 s dip.*
[5] *90° wire-peel-test according to DIN 41850-2, 2 x 2 mm² pads, Sn/Pb/Ag 63/35,5/1,5 solder.*



PI1101A – Ag Paste

Paste development for PI

Al_2O_3

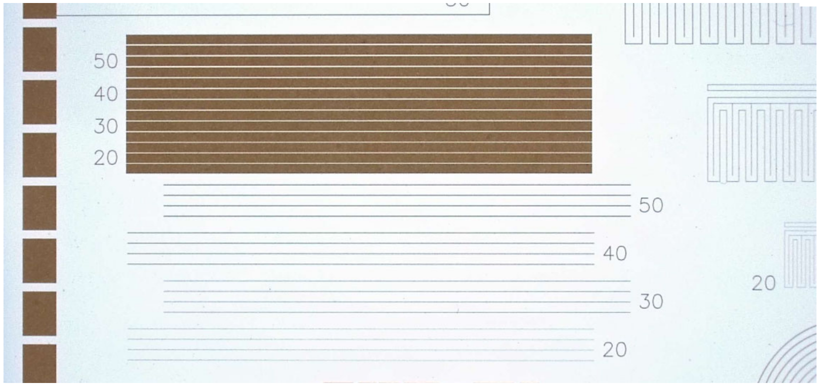


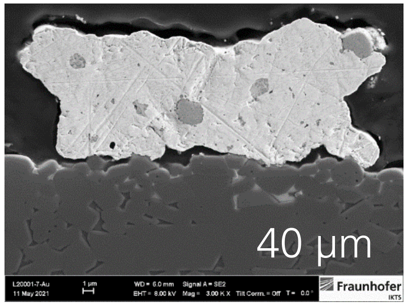
Characteristics	Unit	Value
Viscosity[1]	Pa·s	30…90
Sheet resistivity[2, 3]	mOhm/Sq	≤ 6
Fired film thickness[3]	µm	8…15
Line Resolution		
Line/space	**µm/µm**	**20/20**

[1] *Rotational viscometer ARG2 with cone/plate combination (2 cm, 2°) at 10 s^{-1} and 22±0.2 °C.*

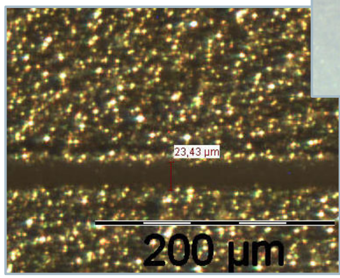
[2] *Sheet resistivity, calculated for a fired thickness of 10±1 µm.*

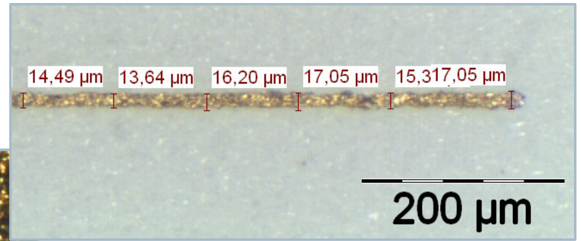
[3] *Firing profile: total cycle time 60 min, 10 min at 850 °C.*





PI2101 – Au Paste





Public information

Fraunhofer IKTS

Paste development for PI

Al_2O_3

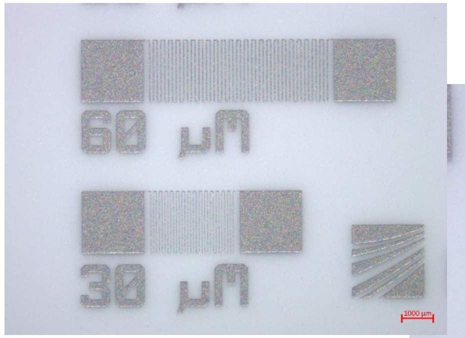
78
Pt
Platinum
195.08

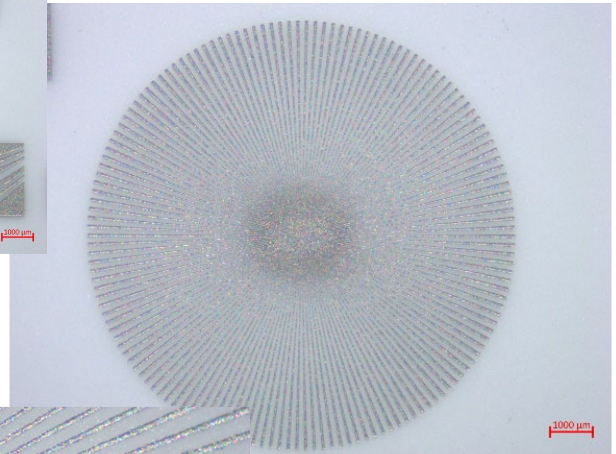
Characteristics	Unit	Value
Viscosity[1]	Pa·s	60…120
Sheet resistivity[2, 3]	mOhm/Sq	≤ 40
Fired film thickness[3]	µm	6…12
Line Resolution	**µm/µm**	
Line/space		**20/30**

[1] *Rotational viscometer ARG2 with cone/plate combination (2 cm, 2°) at 10 s⁻¹ and 22±0.2 °C.*

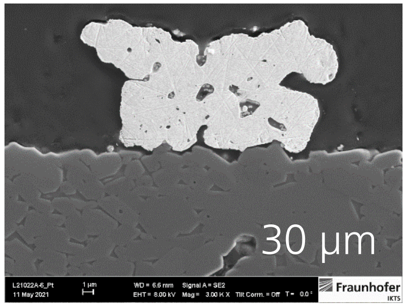
[2] *Sheet resistivity, calculated for a fired thickness of 10±1 µm.*

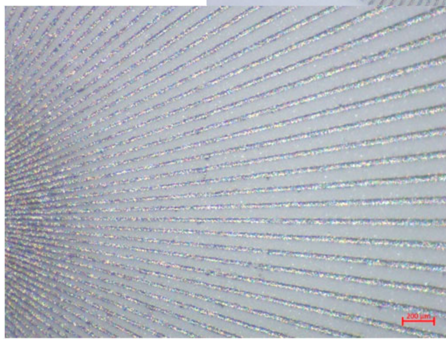
[3] *Firing profile: 10 min at 1200 °C.*





PI6101 – Pt Paste





Currently under development

Public information

Fraunhofer IKTS

Paste development for PI
Al_2O_3

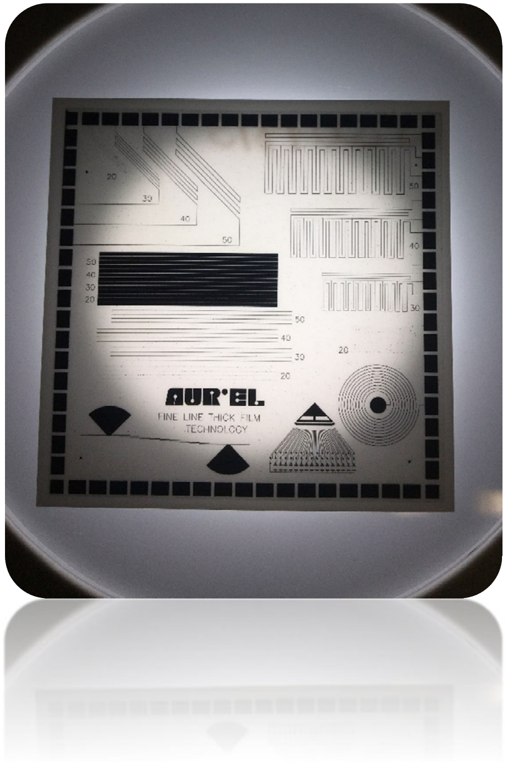
44
Ru
Ruthenium
101.07

Characteristics	Unit	Value
Viscosity[1]	Pa·s	90…140
Sheet resistivity[2, 3]	Ohm/Sq	3.5k
Fired film thickness[3]	µm	11…17
Line Resolution	**µm/µm**	
Line/space		**40/35**

[1] Rotational viscometer ARG2 with cone/plate combination (2 cm, 2°) at 10 s^{-1} and 22±0.2 °C.

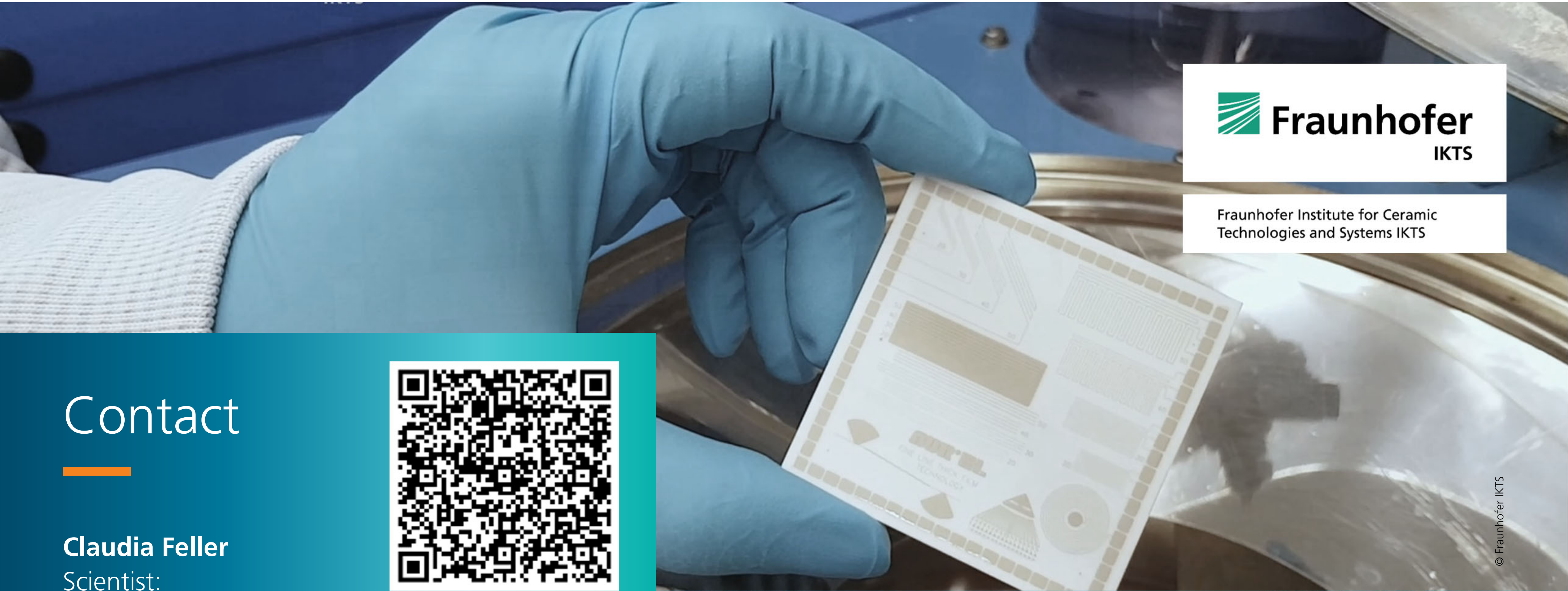
[2] Sheet resistivity, calculated for a fired thickness of 10±1 µm.

[3] Firing profile: 10 min at 850 °C.



W20024 – RuO Paste

Fraunhofer Institute for Ceramic Technologies and Systems IKTS



© Fraunhofer IKTS

Contact

Claudia Feller
Scientist:
Thick-film pastes, functional printing

Phone +49 351 2553-7788
claudia.feller@ikts.fraunhofer.de
www.ikts.fraunhofer.de

Thank you for your attention!

© Fraunhofer IKTS

01

Further information material

Public information
Fraunhofer IKTS

Department “Hybrid Microsystems”

Further research group information

Dr. rer. nat. Arno L. Görne

Functional Materials for Hybrid Microsystems

- Synthesis of functional ceramic materials (LTCC, ULTCC; magneto-ceramics, ferroelectrics, non-linear resistors (PTC, NTC), luminescent materials)
- Powder processing (high energy milling, spray tower, freeze drying)

Dr.-Ing. Stefan Körner

Thick-Film Technology and Functional Printing

- Functional pastes and inks, customized (conductors, TFR’s, glasses, heaters, sensors, LTCC …) adapted to different ceramics, LTCC, steel, different alloys, low T … high T firing, photo image-able; printing technologies
- Advanced rheometry of printable suspensions

Dipl.-Chem. Beate Capraro

Ceramic Tapes

- Functional tapes (HTCC, LTCC, ULTCC, metal, piezo, magnetic, glass, Li-battery electrodes, transparent)
- Application adapted solvent/ binder/ plasticizer systems
- 7 casting machines, doctor blade (DB), DB on roll, slot-die and triple slot-die casting

Dr.-Ing. Steffen Ziesche

Microsystems, LTCC and HTCC

- LTCC and HTCC based components and systems (ceramic PCB, sensors, mixing and micro-reactor devices, packages, actuators)
- Technology and process development
- Component and multilayer circuit design/ layout

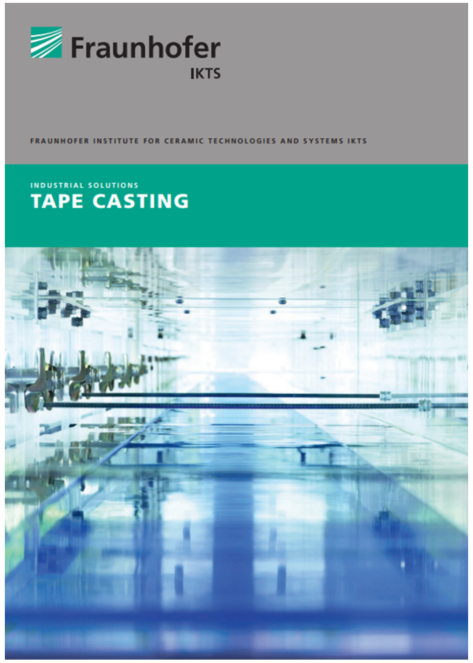
Dr.-Ing. Lars Rebenklau

Systems Integration and Electronic Packaging

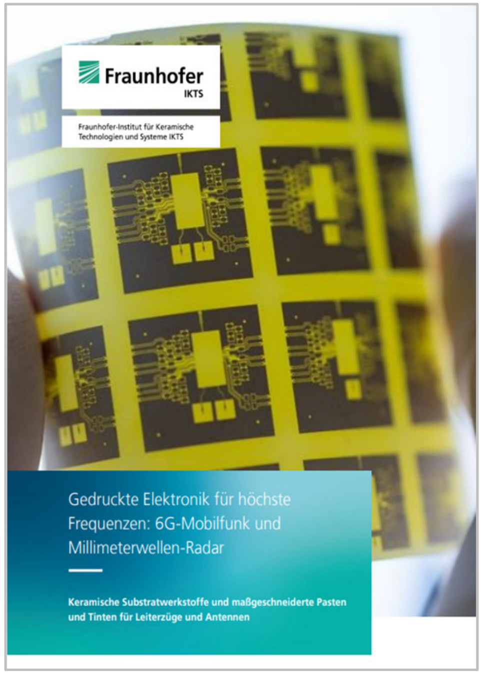
- Packaging technologies – wire bonding (thin, heavy, ribbon), welding, reflow/ selective soldering, Ag nano sintering
- Functional characterization and reliability (pull/shear force, IR, power cycling, ESD, isolation resistance, STOL, R_{sqr}/TCR, T shock, humidity, salt fog, mechanical shock)

Further information material

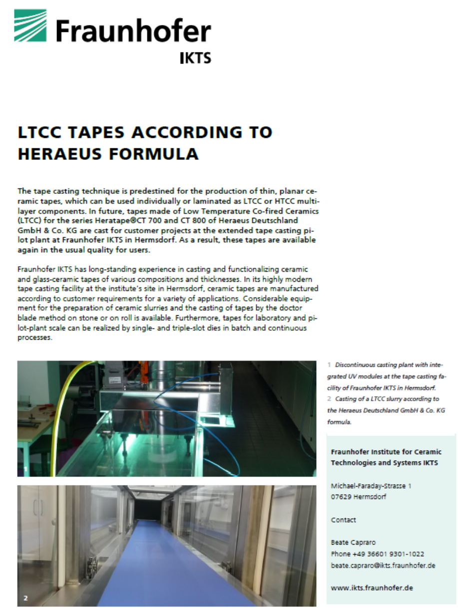
[Catalogue]



[Brochure]

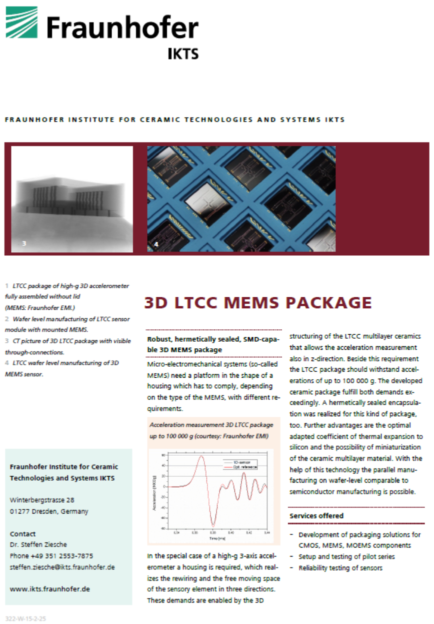


[White Paper]



[Information sheet]

Further information material


FRAUNHOFER INSTITUTE FOR CERAMIC TECHNOLOGIES AND SYSTEMS IKTS

3D LTCC MEMS PACKAGE

[Information sheet](#)


FRAUNHOFER INSTITUTE FOR CERAMIC TECHNOLOGIES AND SYSTEMS IKTS

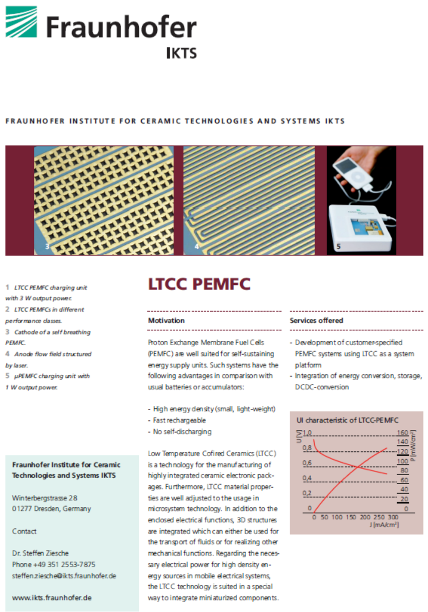
LTCC MEMS PACKAGING

[Information sheet](#)


FRAUNHOFER INSTITUTE FOR CERAMIC TECHNOLOGIES AND SYSTEMS IKTS

LAYER DEPOSITION TECHNOLOGIES

[Information sheet](#)


FRAUNHOFER INSTITUTE FOR CERAMIC TECHNOLOGIES AND SYSTEMS IKTS

LTCC PEMFC

[Information sheet](#)

Further information material

FRAUNHOFER INSTITUTE FOR CERAMIC TECHNOLOGIES AND SYSTEMS IKTS

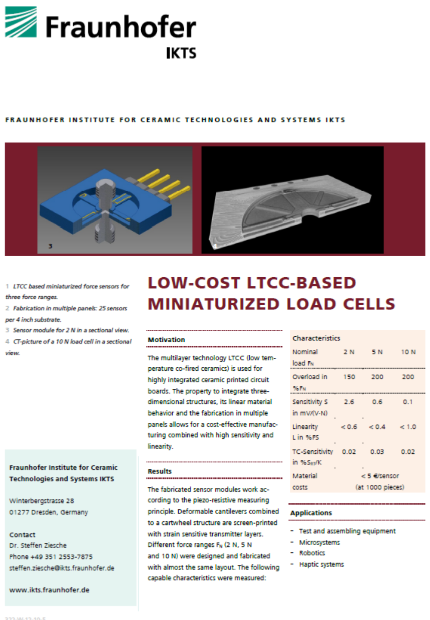
LTCC BASED PIEZO-RESISTIVE PRESSURE SENSORS

[Information sheet](#)

FRAUNHOFER INSTITUTE FOR CERAMIC TECHNOLOGIES AND SYSTEMS IKTS

LTCC-BASED INDUCTORS FOR EDDY CURRENT SENSORS

[Information sheet](#)



FRAUNHOFER INSTITUTE FOR CERAMIC TECHNOLOGIES AND SYSTEMS IKTS

LOW-COST LTCC-BASED MINIATURIZED LOAD CELLS

[Information sheet](#)

FRAUNHOFER INSTITUTE FOR CERAMIC TECHNOLOGIES AND SYSTEMS IKTS

T-SENSORS IN THICK-FILM AND MULTILAYER TECHNOLOGY

[Information sheet](#)