Structuration of LTCC & other ceramic modules for sensors and packages operating in harsh environments


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Outline

1. Introduction
2. Liquid level sensor
3. Jet engine AMB sensor
4. Microreactors
5. Conclusions & outlook
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Harsh environments

- **Aerospace**
  - Temperature fluctuations
  - Radiations, plasma, lightning, vacuum, …

- **Deep-well drilling**
  - Extreme pressures
  - High temperatures >200°C
  - Corrosive environment

- **Automotive, chemical, …**

**Ceramic modules**
Introduction - thick-film technology

- Thick-film circuit: series of layers
  - Screen-printing of layers with a mask
  - Direct dispensing (prototypes)

- Each layer comes as a paste:
  - Functional material (as powder)
  - Organic vehicle: binder + solvent

- Materials (usually mineral)
  - Conductors
  - Resistors: mechanical & thermal sensors
  - Dielectrics
  - ...and much more!

More info at: http://lpm.epfl.ch
Thick-film process

1 - Introduction

More info at: http://lpm.epfl.ch
LTCC - 'Low-Temperature Cofired Ceramic'

- **What is LTCC?**
  - Evolution of standard thick-film technology
  - Silicate material + $\text{Al}_2\text{O}_3$ - outstanding chemical & thermal stability

- **How is it made?**
  - Base material: «green» tape = ceramic in polymer binder
  - Each sheet shaped & printed with specific pastes (inks)
  - At the end: lamination & firing into a single circuit

More info at: [http://lpm.epfl.ch](http://lpm.epfl.ch)
LTCC application examples

More info at: http://lpm.epfl.ch
LTCC manufacturing process

1 - Introduction

More info at: http://lpm.epfl.ch
LTCC advantages

- $T_{\text{firing}} < 900^\circ C$: Ag-compatible
- High-density packaging
- 3-D structuration
- Hermetic structures
- Reliable performance
- High volume, low cost

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Thick-film liquid level sensor

Features:

• Absolute piezoresistive pressure sensor for continuous immersion in water & fluids
• Submersed
• 3 thick-film circuits
  1. Base
  2. Membrane
  3. Electronics
• Membrane side in fluid
• Electronics & cable protected by epoxy potting compound
Level sensor - module

Membrane free-standing to avoid stress induced by packaging
Level sensor - membrane

- Piezoresistors
- Conductive sealing glass
- (Insulating) sealing glass
- Coarse offset adjustment
- Cut
Level sensor - seal

- Conductive sealing glass
- Conductor
- Insulating sealing glass
- Membrane
- Sealed reference cavity
- Base

Fluid Epoxy potting

2 - Level sensor

MAM’2011 - Micronarc Alpine Meeting, Villars-sur-Ollon, 2011-01-17 #15
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Jet engine AMB sensor

- **Active Magnetic Bearing (AMB) XY position sensor for jet engines**
- Magnetic position sensor - eddy currents in rotor
- No mechanical bearings (oil, wear, cooling,…)
- Increased reliability
- Decreased maintenance costs
- Operation @ 550…600°C in aggressive gases
- Thick-film circuit

* Luc Burdet, EPFL-LSRO
AMB sensor principle

- **X detection winding**
- **Excitation winding**
- **Temperature measurement wire**
- **Y detection winding**

**Wiring pads**
AMB sensor circuit build-up

Inductor build-up

Dispensed conductor paste

Wires

Conductor & dielectric 2

Conductor & dielectric 1

Conductor 3

Ceramic substrate

Windings

Pads

3 - Jet engine AMB sensor
Kirkendall effect @ high temp.

Result of long-term stability (>2’000 hours)

<table>
<thead>
<tr>
<th></th>
<th>Au pads (c3)</th>
<th>Ag pads (c3)</th>
<th>Ag:Pd pads (c3)</th>
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</thead>
<tbody>
<tr>
<td>Au lines (c1 &amp; c2)</td>
<td>OK</td>
<td>X</td>
<td>X</td>
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<tr>
<td>Ag lines (c1 &amp; c2)</td>
<td>X</td>
<td>OK</td>
<td>X</td>
</tr>
</tbody>
</table>

- Only (quasi) identical metals may be in contact!
- Silver selected for cost & high conductivity
Ag electromigration @ high temp.

- **Shorting of windings after operation at HT:**
  - Degradation only observed if voltage applied fluctuations
  - Creation of Ag conductive paths identified at pads …
  - No problems if covered

- **High-temperature Ag electromigration!**
Ag electromigration - mitigation

- Need modern migration-resistant crystallising dielectric!
- Demonstrated successful operation at 600°C!
- Use of resistive guard pad or ring to cancel electric field around pad also possible
- Extensive long-term qualification of these solutions still needed!
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Packaging of MEMS microreactor

(Ch. Alépée - LMIS, 2000)

- MEMS microreactor for methanol dehydrogenation into formaldehyde
- Reaction catalysed by Na around 800°C!
- Inlets / outlets must be at ca. 300°C (Na vapour)!
- Thick-film packaging

\[
\text{CH}_3\text{OH} \rightarrow \text{CH}_2\text{O} + \text{H}_2 \\
\text{[Na, 800°C]}
\]
4. Definition of channels (thick-film)

- Alumina bottom substrate
- Walls built-up by thick-film dielectric
- Final layer = sealing glass
- Glass sealing of top substrate
- Allows transparency

(M.-A. Schneider - 2004)
Microreactors - simple mixer

Alignment holes

Channels

Mixer channel

Bottom

I/O ports

Cover
Complex LTCC microreactor

Complex mixer by cutting

V. Mengeaud, EPFL 2002

- “Zig-zag” mixer
- Preserves integrity of LTCC layers
Chemical microreactor / calorimeter

Features:
- DIL-24 package
- Global heating track
- Inlet pre-heating zones (meanders)
- Thermally insulated reaction zone
- Microcalorimeter with calibration heater
- Separate flow sensor for each inlet

R. Willigens, 2005
Chemical microcalorimeter - layout

2 Inlets + 2 flowmeters + reaction zone + sensing & calibration resistors

4 - µ-reactors
Chemical microcalorimeter - channels

Top Al$_2$O$_3$ lid
Silicone glue
LTCC (isolated zone)
Silicone glue
Heated Al$_2$O$_3$ base

Global layers

5 LTCC layers

Pre-heating

Reaction zone

Flow meter

Exit channel

Top lid
Top fluidic layer
Separator
Bottom fluidic layer
Bottom (base)

4 - $\mu$-reactors
Chemical microcalorimeter - flow sensors

Flow meter response
Chemical microcalorimeter - HCl+H$_2$SO$_4$

Réactions chimiques: HCl + NaOH $\rightarrow$ H$_2$O + NaCl ; H$_2$SO$_4$ + NaOH $\rightarrow$ 2H$_2$O + Na$_2$SO$_4$

HCl + NaOH

H$_2$SO$_4$ + NaOH

Acid-base calorimetry
Micro solid-oxide fuel cells (µ-SOFCs)

The LTCC platform concept for SOFCs application

- Fuel inlet
- Exhaust outlet
- Air flow
- Wire bonds
- Sealing glass
- Pt meanders (temperature control)
- Gas processing unit
- Catalyst-filled channels
- Solder bonds
- Thick-film ceramic base

(Thermal Insulation)
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Conclusions & outlook

- **Proven materials (automotive, aerospace & telecom)**
  - Very good thermal & chemical stability
  - For both sensor & packaging applications

- **Many promising development areas:**
  - MEMS packaging & interconnects @ high temperature
  - Interconnects for high-temperature (sensor) electronics
  - LTCC structuration for micromechanical devices
  - LTCC fluidics
Thank you

Questions?