Thermal Management in batteries with innovative Thermal Interface Materials

A. Wiessler, Polytec PT GmbH – Dürr Gluing Symposium, Bietigheim, 10.10.2019
Outline

- Motivation
- Why Thermal Interface Materials (TIMs)?
- Selection of TIMs based on performance and process parameters
- Methods for testing and assessing TIMs
- Outlook – ongoing R&D goals
Motivation

- Longtime experience with electrically and thermally conductive adhesives
- Increased demand for customized materials
- since 2012: serial supply of a thermally conductive adhesive for hybrid batteries
- Since 2015: New development of gapfillers for numerous battery projects
- 2019: SOP of several gapfiller & adhesive projects
About Polytec PT

- Development & manufacturing of specialty adhesives and Thermal Interface Materials
- Customer-specific formulations (>50% of sales)
- Flexibility in production 0,1 kg … 1200 kg batches
- Active in funded and joint research project
Why thermal management in EV-Batteries?

- Electrical performance depends on operating temperature
- Li-Ion cells degrade when exposed to too high temperatures
- Typical requirements for operating conditions:
  - Operating temperature ideally at 30-40°C
  - Cell temperature never above 80°C
  - Charging/Discharging only between 0 and 60°C

Lit.: Thomas Wetzel – Thermisches Design von Lithium-Ionen-Batteriezellen, KIT Institut für thermische Verfahrenstechnik, 2010

Picture: Wikipedia/Heatlord, CC BY-SA 3.0
Why Thermal Interface Materialis (TIMs)?

- Active components (battery cells, semiconductors etc.) generate heat losses
- Mechanical connection with cooling structures feature small air gaps
- Air is a very poor thermal conductor
- Consequently air gaps need to be filled with an interface material

\[
\text{Silicon } \lambda = 150 \text{ W/mK} \\
\text{Air } \lambda = 0.026 \text{ W/mK} \\
\text{Aluminum } \lambda = 237 \text{ W/mK}
\]
What is a TIM at all?

**Organic Matrix**
- Oil
- Polymer
- Adhesive

0.2 - 0.3 W/mK

**Thermally conductive fillers**
- Ceramics
- Metals
- Graphite

30 -> 300 W/mK for the bulk material
Modeling of thermal conductivity

Lewis-Nielsen model

\[ \lambda_C = \lambda_M \cdot \frac{1 + (A - 1)B\phi}{1 - \psi B\phi} \]

1.) Volume fraction of the filler (Φ)
2.) Conductivity of the matrix (λ_M)
3.) Maximum packing density (Ψ)
4.) Particle shape factor (A)
5.) Filler conductivity (determines B)


- www.polytec-pt.com
# Types of Thermal Interface Materials

<table>
<thead>
<tr>
<th></th>
<th>Conductive Pads</th>
<th>Conductive Pastes</th>
<th>Conductive Adhesives</th>
<th>Gapfillers</th>
<th>Speciality: PCM*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemically curing</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Reworkable</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Advantages</td>
<td>Pre-fabricated „Part“-character</td>
<td>Ease of use</td>
<td>Mechanical and thermal connection</td>
<td>Broad range of material properties</td>
<td>Latent-heat storage</td>
</tr>
<tr>
<td>Short-comings</td>
<td>Difficult to automate Compressive force necessary</td>
<td>Suitability depending on installation situation Only high viscosity grades</td>
<td>Limited conductivity Curing time needed</td>
<td>Curing time needed</td>
<td>Mostly available as pads</td>
</tr>
</tbody>
</table>

*:phase change material
Examples for Thermal Interface Materials

Thermally conductive epoxies for bonding prismatic Li-Ion cells to cooler

Thermally conductive paste/gapfiller for thermal connection of battery modules to cooling structure
Fundamental properties of TIMs

- **Material properties**
  - Composition (Silicone yes/no)
  - Consistency
  - Density

- **Process properties**
  - Shelf life
  - Viscosity, flow properties
  - Metering / dispensing properties
  - Abrasiveness

- **Operation properties**
  - Thermal conductivity
  - Isolation properties
  - Adhesion
  - Elasticity

- **Long-term properties**
  - Temperature resistance
  - Chemical resistance
  - Vibration resistance
## Example 1: thermally conductive adhesives

<table>
<thead>
<tr>
<th>Feature</th>
<th>Range of values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consistency</td>
<td>Self levelling… pasty</td>
</tr>
<tr>
<td>Curing conditions</td>
<td>24 h/23 °C … 60 min/80 °C</td>
</tr>
<tr>
<td>Therm. conductivity</td>
<td>0,8 …. 2 W/mK*</td>
</tr>
<tr>
<td>Density</td>
<td>1,5 … 2 g/cm²</td>
</tr>
<tr>
<td>Modulus</td>
<td>100 … 9.000 MPa</td>
</tr>
<tr>
<td>Lap sheer strength**</td>
<td>5 … 15 MPa</td>
</tr>
<tr>
<td>Elongation at break</td>
<td>up to ~20 %</td>
</tr>
</tbody>
</table>

* Up to 3 W/mK upon request (with compromises regarding mechanical properties)
** on untreated aluminum
Example 2: thermally conductive pastes

<table>
<thead>
<tr>
<th>Feature</th>
<th>Range of values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Konsistenz</td>
<td>pasty</td>
</tr>
<tr>
<td>Viscosity at 40 °C</td>
<td>150 ... 250 Pa s</td>
</tr>
<tr>
<td>Gap dimensions</td>
<td>0,2 … 2 mm</td>
</tr>
<tr>
<td>Curing</td>
<td>Non-curing</td>
</tr>
<tr>
<td>Therm. conductivity</td>
<td>2,0 …. 2,7 W/mK</td>
</tr>
<tr>
<td>Density</td>
<td>~2 g/cm³</td>
</tr>
</tbody>
</table>

Bild: Dürr System AG
Example 3: thermally conductive gapfillers

<table>
<thead>
<tr>
<th>Feature</th>
<th>Range of values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consistency</td>
<td>Self-levelling… pasty</td>
</tr>
<tr>
<td>Viscosity at 23 °C</td>
<td>50 … 250 Pa s</td>
</tr>
<tr>
<td>Gap dimensions</td>
<td>0,2 … 5 mm</td>
</tr>
<tr>
<td>Curing</td>
<td>Curing at RT</td>
</tr>
<tr>
<td>Therm. conductivity</td>
<td>1,5 … 3,2 W/mK</td>
</tr>
<tr>
<td>Density</td>
<td>2,0 … 3,1 g/cm³</td>
</tr>
</tbody>
</table>

Picture: Polytec PT
Testing of long-term properties of TIMs

- Accelerated ageing tests – Test Methods
- Goal: Validation of vehicle life time (10-15 years)

- Temperature- & humidity storage (THT)
- Temperature-cycling / -schocks (TC)
- Combined TC und THT storage, e.g. VW PV-1200
- Vibration tests (with temperature cycling), e.g. VW 82161
- Power cycling test (PC)
Testing of long-term properties of TIMs

- Accelerated ageing tests – Test Methods

Besides material properties and test conditions sample preparation is of essence

Bulk Material ≠ Lab tests ≠ Samples in module dimensions ≠ Dummy Modules ≠ Battery & vehicle testing (OEM)
Testing of long-term properties of TIMs

Accelerated ageing tests – Test Methods

PV1200 Temperature cycling + humidity -40…+80 °C in weeks
Testing of long-term properties of TIMs

- Accelerated ageing tests – PV 1200
  - Aluminum/glass substrate
    150 x 390 mm
  - 2 mm gap
  - Horizontal storage
  - 2 cycles/day -40 … +80 °C
    appr. 30 … 80 % r.F.
  - Duration 12 weeks
    (2000 hours)
  - Optical inspection

- Ok after 12 weeks (2000 h)
- No crack formation oder delamination

- Dismanteling
Testing of long-term properties of TIMs

- Accelerated ageing tests – Vibration

  - On the basis of VW 82161
  - Dummy-module 150 x 390 mm
  - Testing on shaker with temperature cycling
    at -20 ... + 65 °C
    5 ... 200 Hz
  - Duration 120 h
    (X, Y, Z 40 h each)
  - Optical Inspection

Example:
1-part conductive paste
Testing of long-term properties of TIMs

- Accelerated ageing tests – Power cycling

- Aluminum cylinder Ø 30 mm
- Upper cylinder periodically heated to 90 or 110 °C
- Low cylinder cooled
- Periodical measurement of thermal resistance $R_{th}$ in situ according to ASTM D5470

Example:
1-part conductive paste

Abbildung 1: Prinzipieller Aufbau des TIM-Probenhalters der DHBW Stuttgart
Outlook – R&D goals

- High thermal conductivities
- Suitability for respective processes (Flowability/Compressability)
- Low manufacturing cost
- Customized mechanical properties
- Reworkability
- Customer specific requirements
Thank you very much for your attention.