Development of a Thermoelectric Module Suitable for Vehicles that is Based on CoSb3 Manufactured Close to Production

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Introduction / Motivation

A actual area of interest is the increase of power train efficiency in future passenger and light duty vehicles through advanced technologies in the area of alternative energy conversion. In this case, the technology of using exhaust heat thermoelectrically through a thermoelectric generator (TEG) increa-singly meets the requirements of higher efficiency demanded of combustion engine power trains. In addition to overall TEG system design, the development of long-term stable, efficient thermoelectric modules (TEM) for high-temperature applications is a great challenge. This work presents the results of internal development activities done in three DLR departments and reveals an expedient module design for use in TEGs suitable for vehicles.

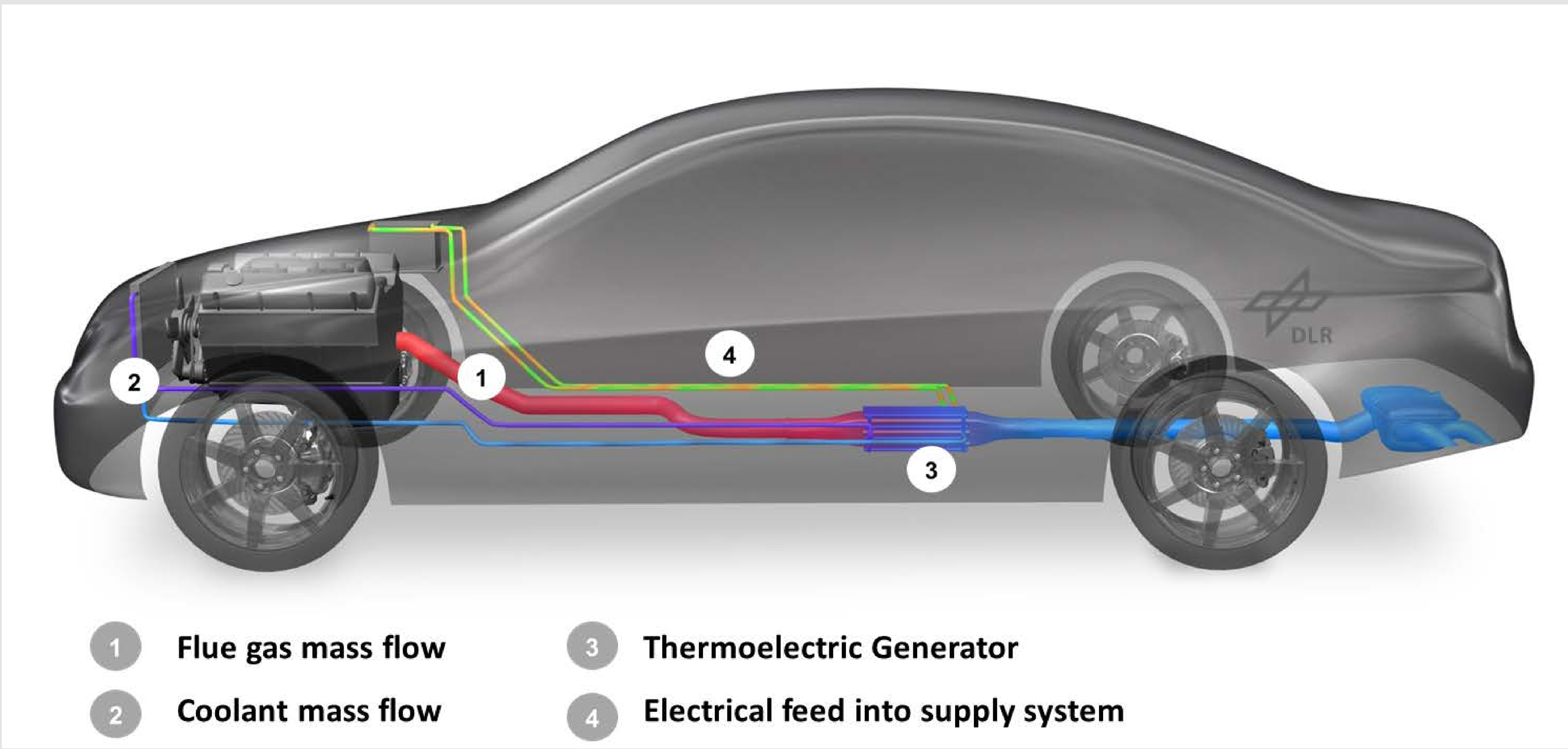

Fig. 1: Schematic integration of a thermoelectric generator (TEG) in the exhaust gas system of an IC engine powered vehicle

Vehicle-specific boundary conditions

- Most important on the design of a TEM ⇒ Boundary conditions at the exhaust end
- Exergetic and comprehensive system-wide studies ⇒ Ideal application temperatures $T_h = 550°C$ at the hot side with local temperature gradients of 70 K/s during driving

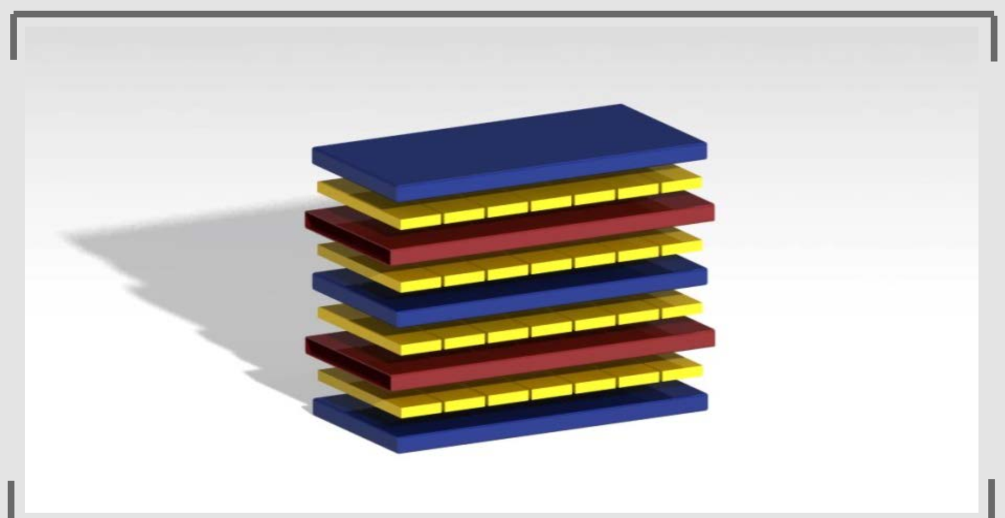

Fig. 2: Schematic view of a TEG layered compound structure with hot side heat exchanger (red), cooling water heat exchanger (blue) and TEM (yellow)

- Planar module design with a module area A=62 mm x 26 mm

Underlying design concept

- Depositing of an electrical isolation layer (yellow) on a metallic substrate with high thermal conductivity and minimal layer thickness (heat exchanger or metal sheet – light gray)
- Electrical connections (dark gray) ⇒ minimize temperature gradient from heat source to TEM by using thin layers

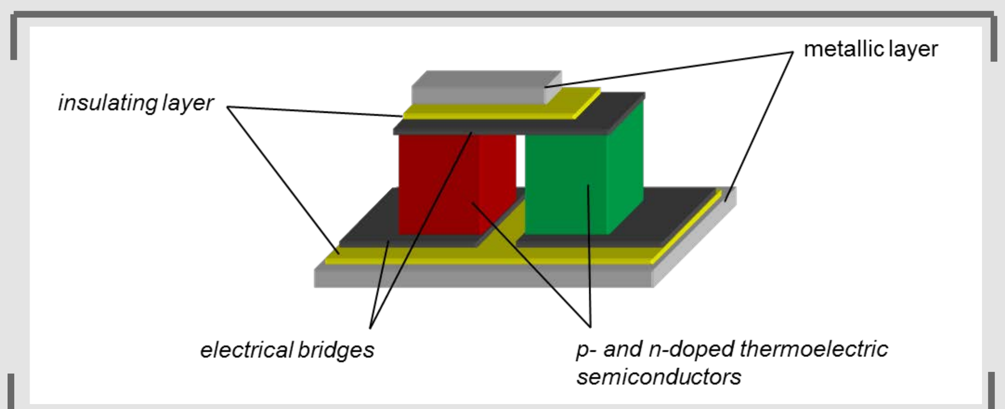

Fig. 3: Developed layer series for the production of TEM suitable for vehicles

CoSb3 manufactured close to production

- Skutterudite materials:
  - Fulfill temperature conditions
  - High efficiency
  - Long-term thermal and mechanical stability
  - Low cost
- Fabrication: gas atomization technique ⇒ fine-grain powder out of melt by dis-persing the material using a gas stream
- Sintering powder at 580°C with 50 MPa
- Cutting with a high speed dicing saw
- *ZT* value 0,45

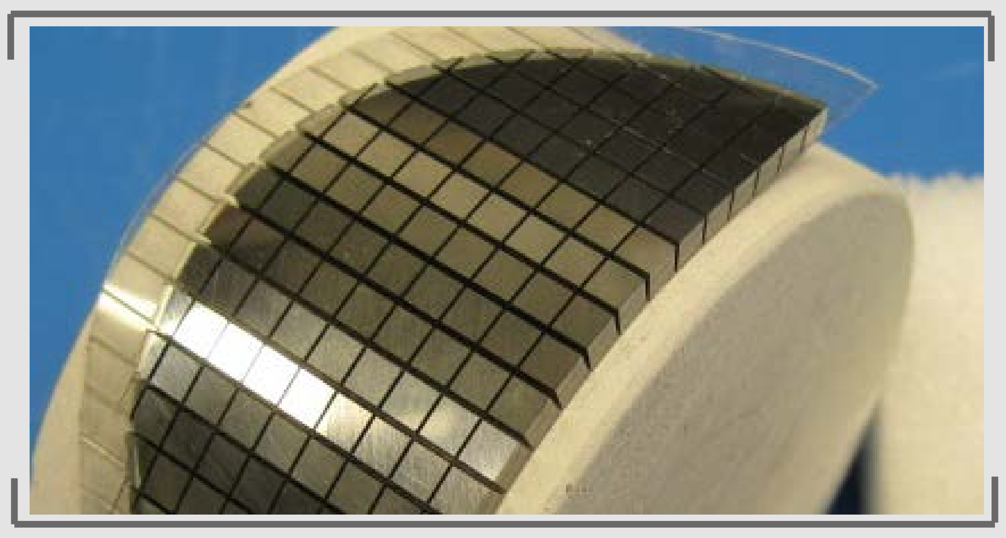

Fig. 4: Thermoelectric functional material

Simulative design of a TEM

- Thermoelectric performance: under ideal conditions optimal power output for one module (62 mmx 26 mm, 19 base units – pn couples) approximately 15W
- Thermomechanical simulations: highest mechanical loads at the area of the electrical isolation

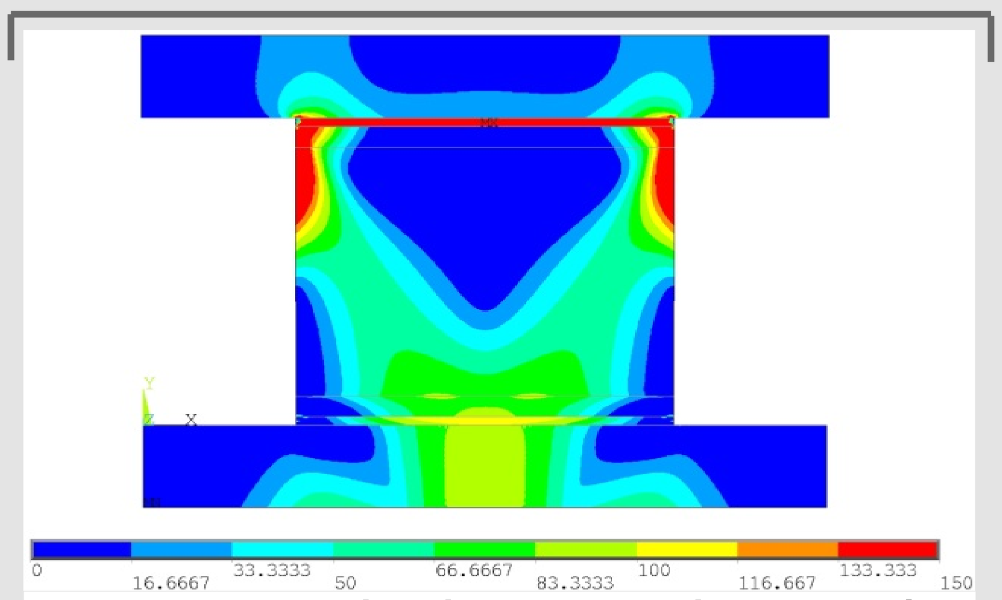

Fig. 5: Stress distribution in the exemplary functional layer compound in MPa

Plasma-sprayed multilayer films

- For the layer compound following or-dering is chosen:
  - Metallic substrate material
  - Plasma-sprayed thin film isolation $MgAl_2O_4$
  - Plasma-sprayed connections ⇒ gradient layer (nickel/silver)
  - Connection via diffusion bonding

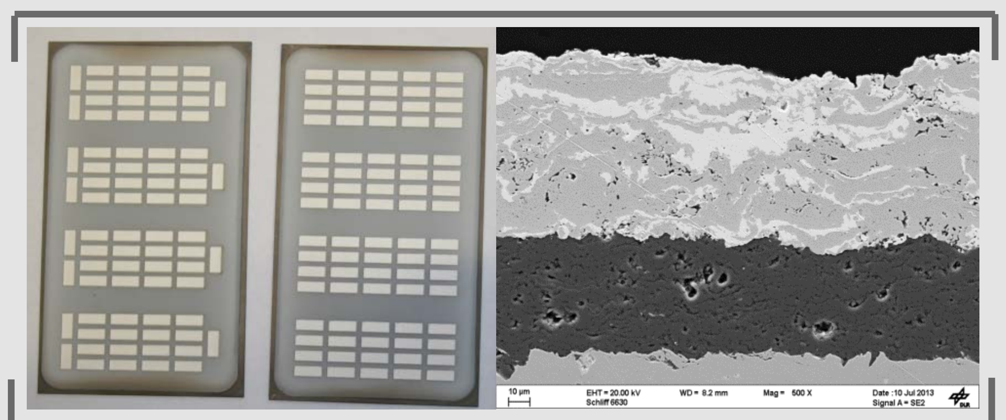

Fig. 6: (Left) Completely coated substrate mate-rial for the hot side of the module; (right) REM re-cording of the nickel and silver gradient layer

Conclusion / Outlook

- Application temperature approx. 550°C
- High thermal alternating loads
- Elongated module ⇒ ideal for usage of a TEG in a vehicle
- Production of $CoSb_3$ on a kg-scale
- Development of thin film contacting
- Next steps:
  - Praktical implementation
  - Simulative validation

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