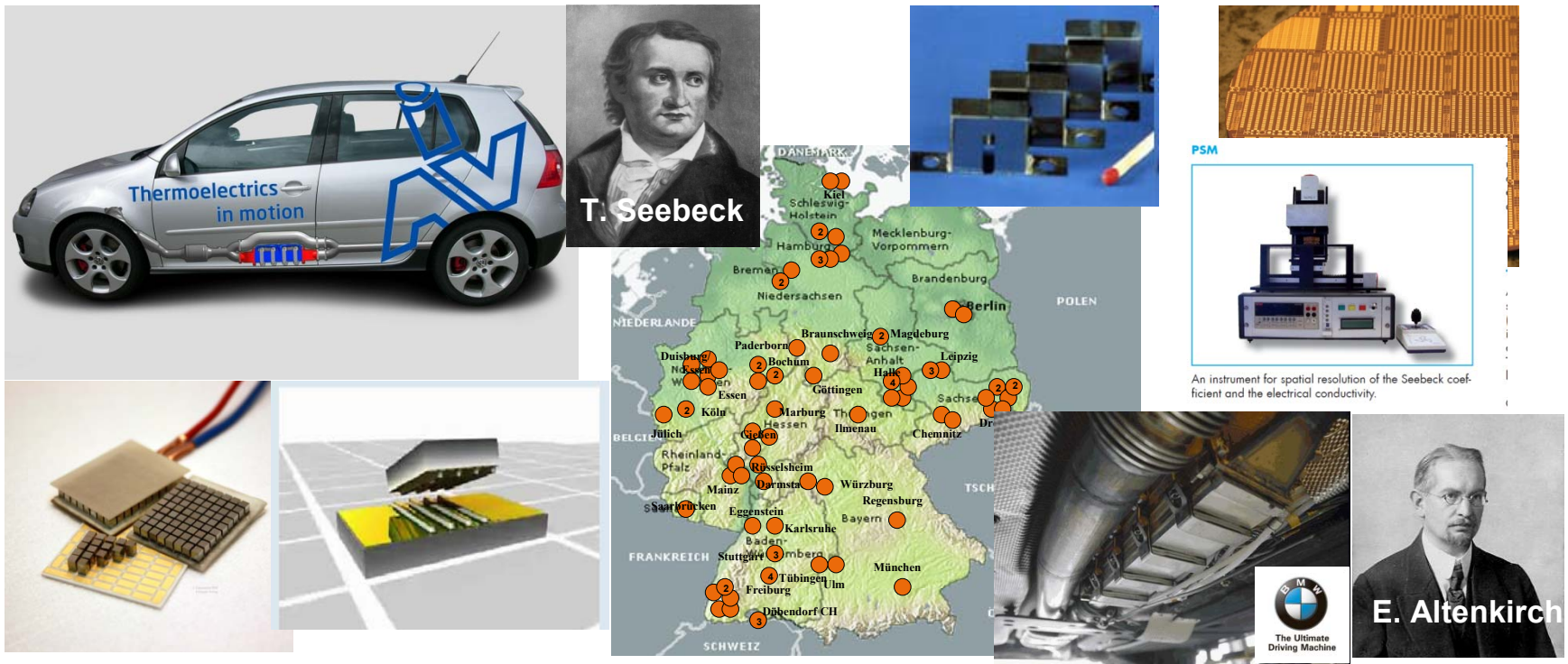


# Overview of Thermoelectrics in Germany

2009 DOE Thermoelectrics Applications Workshop  
September 29 - October 1, 2009 San Diego, CA

Harald Böttner, Fraunhofer IPM



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# CONTENT

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- History of Thermoelectric in Germany
- TE-research in Germany (Universities , MPG, DLR, FhG etc)
- TE-industry
- Companies interested in Thermoelectric
  
- TE-developments of international importance
- TE-funding situation
  
- Deutsche Thermoelektrik Gesellschaft
- TE-future in Germany

# History of Thermoelectric in Germany

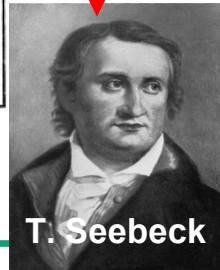
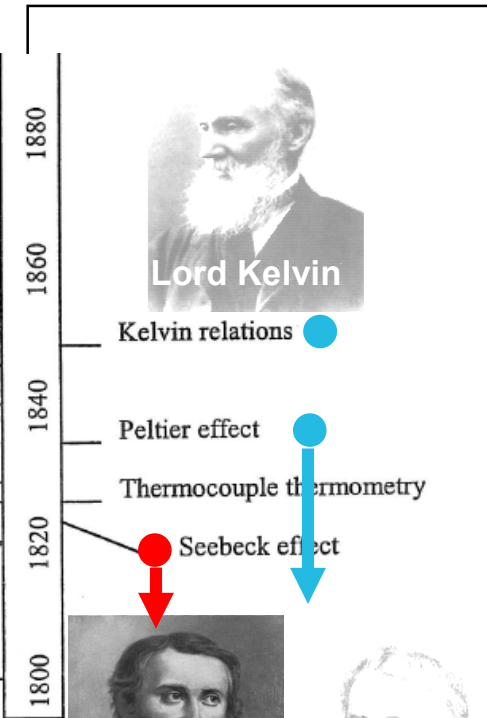


S. Ohm

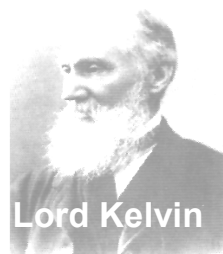
- Thermionic emission
- Entropy formalized
- Kelvin temperature scale
- Joule heat
- Ohm's law
- Carnot cycle
- Heat diffusion theory
- Galvanometer
- Voltaic cells



J. Fourier



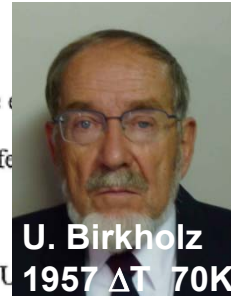
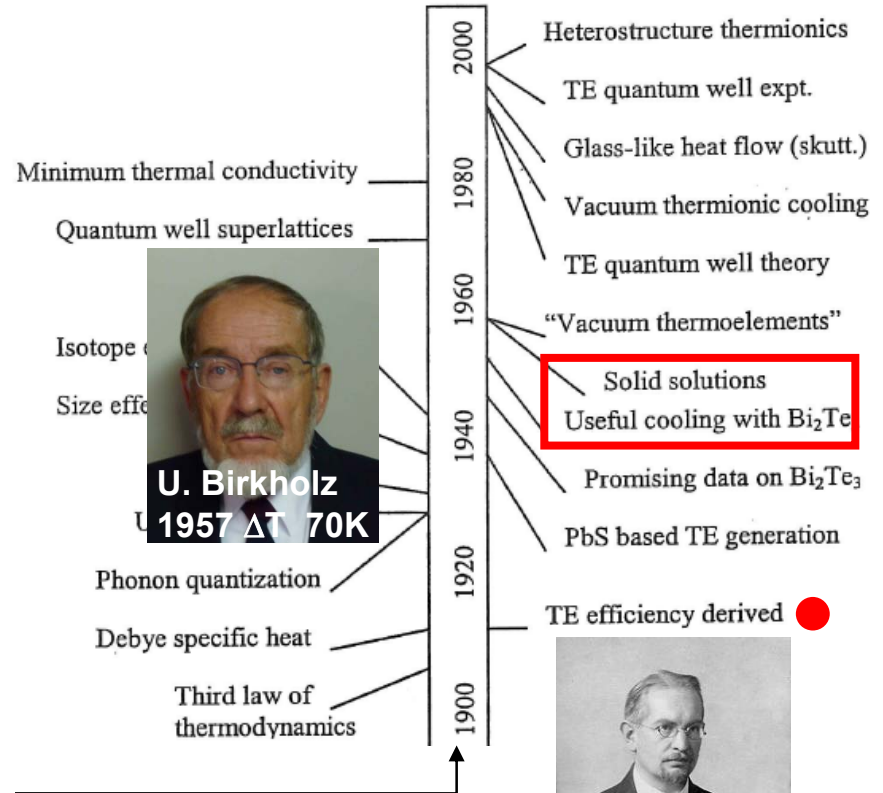
T. Seebeck



Lord Kelvin



Peltier



U. Birkholz  
1957  $\Delta T = 70K$



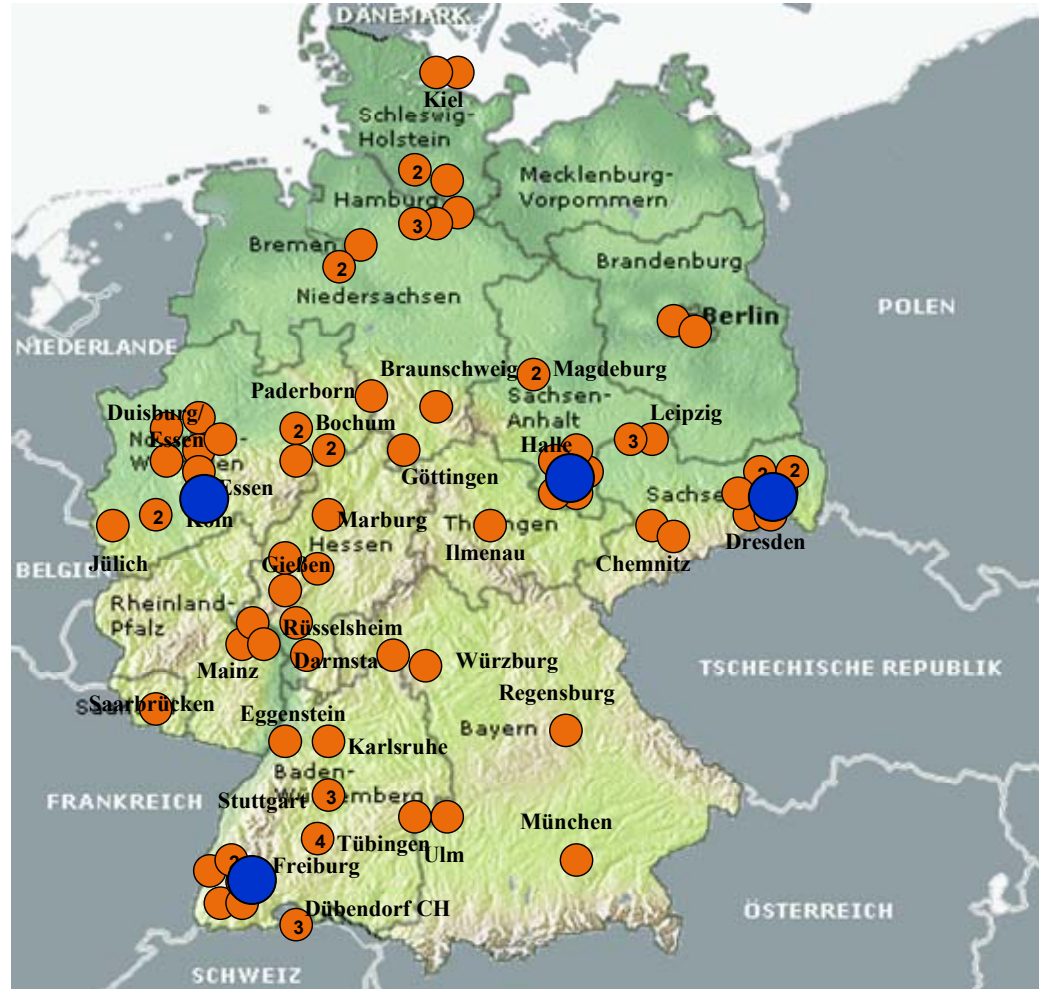
E. Altenkirch

$$Z \cdot T = \frac{S^2 \sigma}{\lambda}$$

# TE- in Germany

● Current (2009) activities  
basic and applied (R&D)

● Thermoelectric research  
situation ~ 2000



# TE-research in Germany (Universities , MPG, DLR, FhG etc)

## ■ Materials

$V_2VI_3$ , IVVI, IV-alloys; Half Heusler; Silicides, Scutterudies, Clathrates, Cobaltates

nanoscale materials,

melt spin, SPS, electrochemical deposition

<http://gepris.dfg.de/gepris/>

Projekt(e) thermoelectric

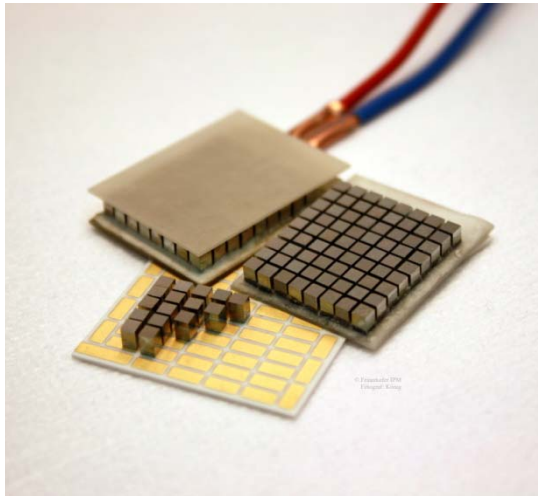
<http://gepris.dfg.de/gepris/OCTOPUS/;jsessionid=ht4LKCyWMIPkJQLMgtX8QVBvLDv1n1QL1hfXTgGxmy3zQpQ1LpdR!-576272848!1254240950042?task=doSearchSimple&context=projekt&keywords=thermoelectric&submitButton=1>



# TE-research in Germany (Universities , MPG, DLR, FhG etc)

## ■ Modules

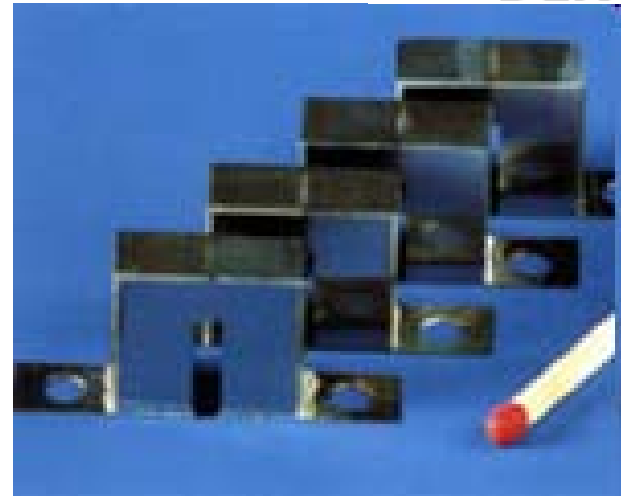
Fh IPM



**Partner**  
**Basis PbTe**



and DLR



# TE-research in Germany (Universities , MPG, DLR, FhG etc)

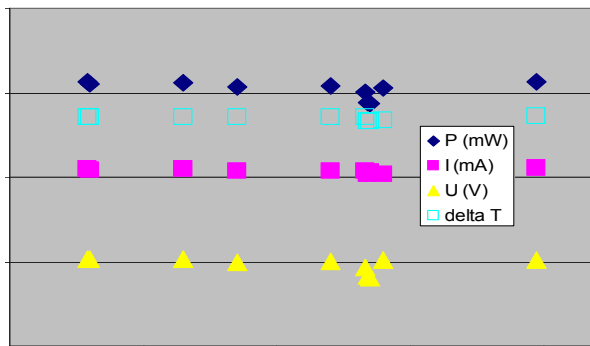
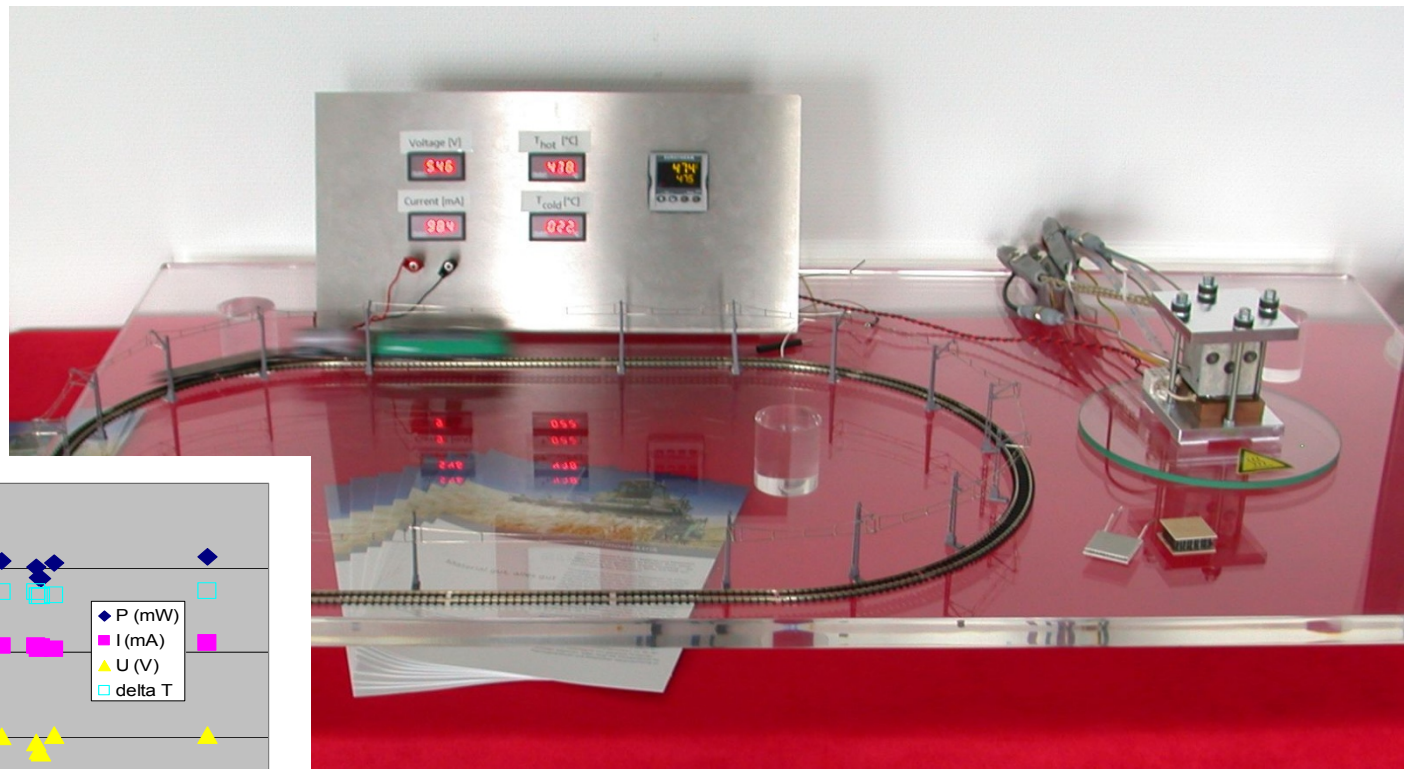
## Modules



Partner



**Tmax 550°C**

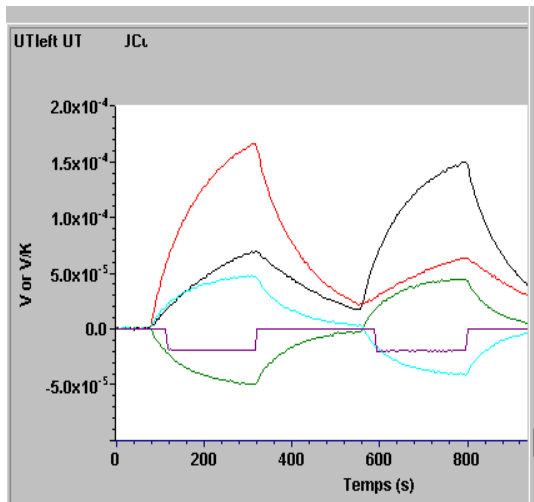


2007 05.09.2007 25.10.2007 14.12.2007 02.02.2008

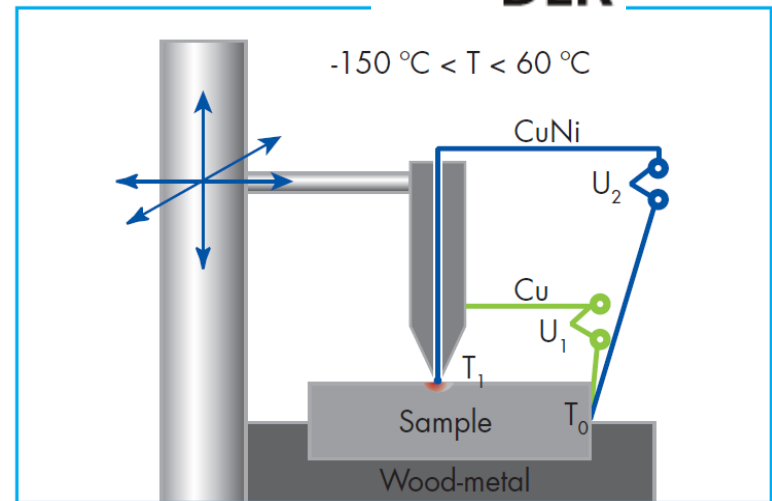
# TE-research in Germany (Universities , MPG, DLR, FhG etc)

## ■ Metrology

Fh IPM 



and DLR





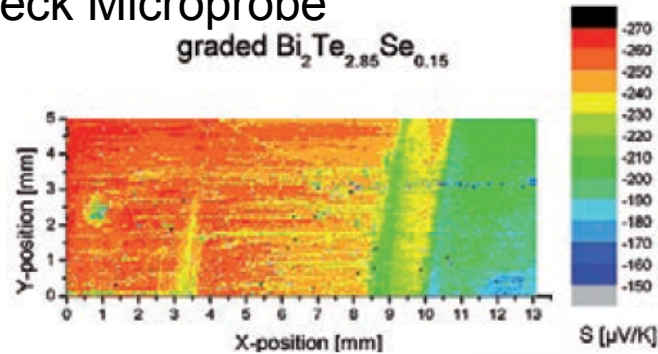
# TE-research in Germany (Universities , MPG, DLR, FhG etc)

## Metrology

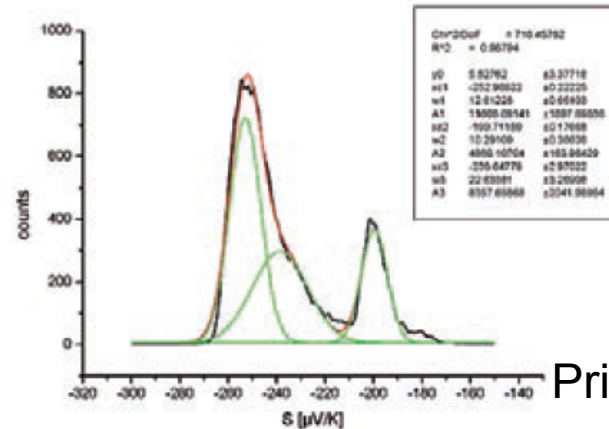
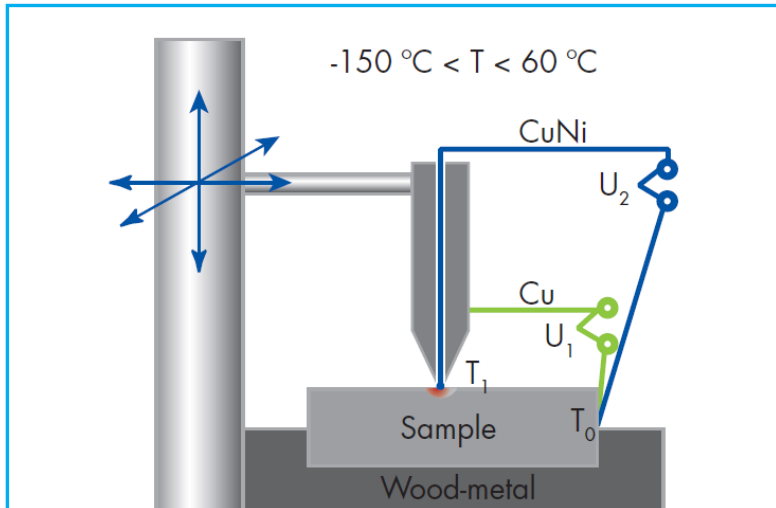


### Seebeck Microprobe

graded  $\text{Bi}_2\text{Te}_{2.85}\text{Se}_{0.15}$



### Principle



### Principle

### Seebeck coefficient in graded material

# TE-research in Germany (Universities , MPG, DLR, FhG etc)

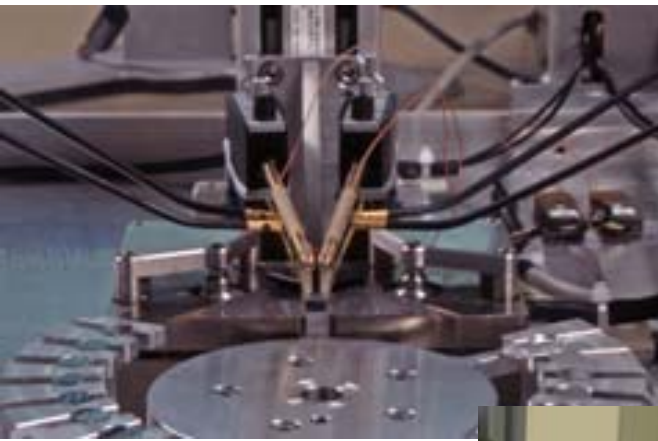
## ■ Metrology



- [Laser flash apparatus](#) for determination of thermal diffusivity
- [Thermogenerator test facility](#) for efficiency determination of thermoelectric energy converters
- Temperature dependent measurement of [Seebeck coefficient and electrical conductivity](#) from room temperature up to 700 °C
- [Hall facility](#) for the examination of electric transport properties
- [CTEM](#) – combined thermoelectric measurement (simultaneous measurement of the Seebeck coefficient, electrical and thermal conductivity, as well as the thermoelectric figure of merit)
- [Seebeck micro-thermoprobe](#) for spatially resolving determination of thermoelectric properties at surfaces of electrically conducting materials.

# TE-research in Germany (Universities , MPG, DLR, FhG etc)

## ■ Metrology



- automated screening-setup (S, s for RT)
- Seebeck, elec.cond. for thin films and bulk up to 500°C
- thermal conductivity of thin layers and bulk (3 Omega)  
4 systems in Germany



# TE-research in Germany Industry & Institutes

## ■ Systems



&



# TE-research in Germany Industry & Institutes

## Automotive

### Car manufactures

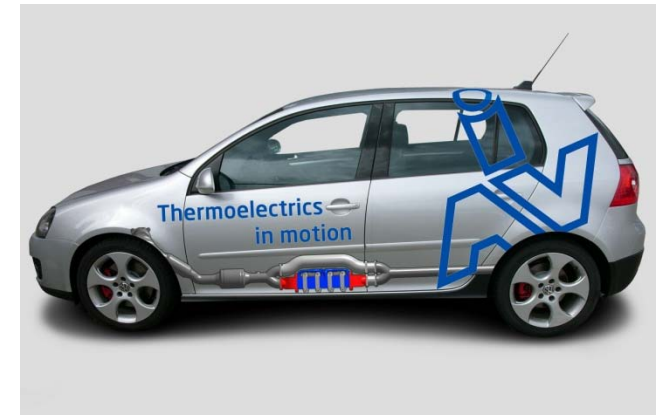
- BMW
- Daimler
- VW
- (Audi)
- OPEL (GM??)

### Tier one (exhaust systems)

- Behr
- Eberspächer
- Bosch

### Engineering companies

- IAV





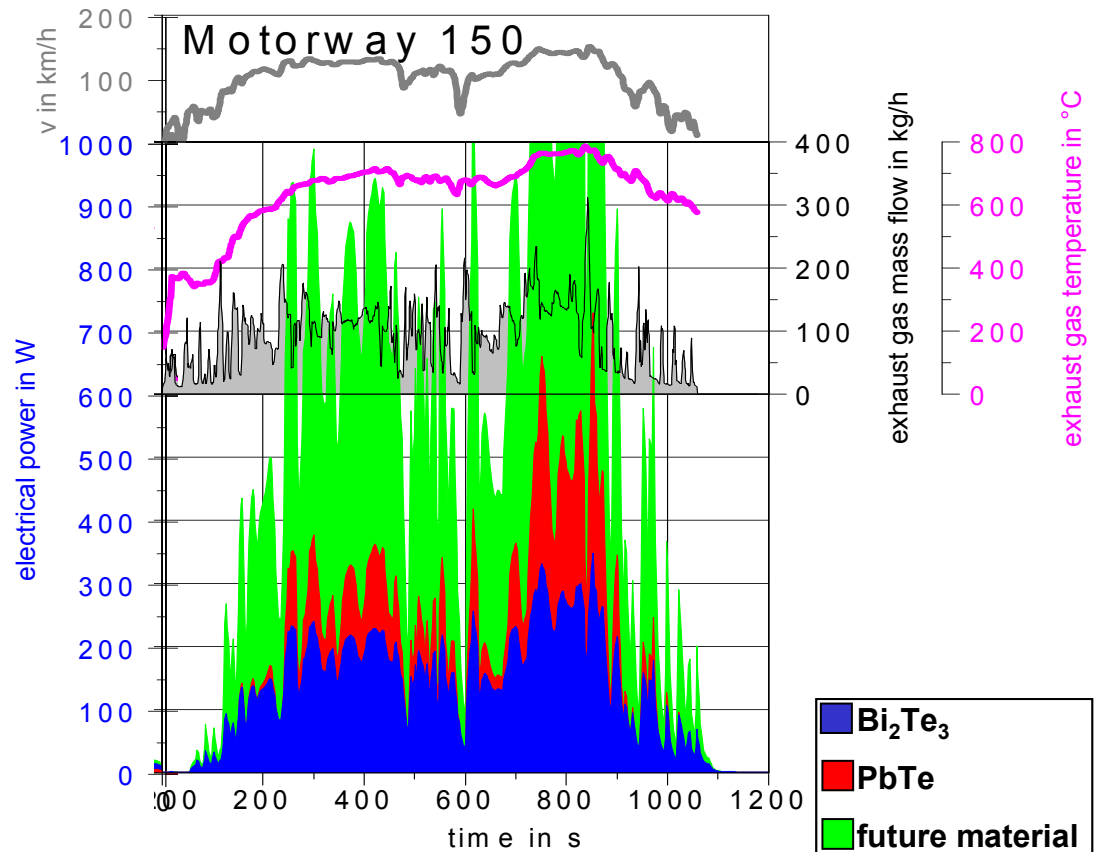
# TE-research in Germany Industry & Institutes

## Thermoelectric goes Automotive

Gerhard Buschmann, Daniel Jänsch,  
Jens Kitte

ICT/ECT, Freiburg July 27<sup>th</sup>, 2009

**IAV GmbH**  
Ingenieurgesellschaft Auto und Verkehr



# Companies interested in Thermoelectric

## Others

- Casting houses
- forges
- wood pellet furnaces
- Industrial facilities
- Glass manufactures

# TE-industry

## Materials, modules

### Materials

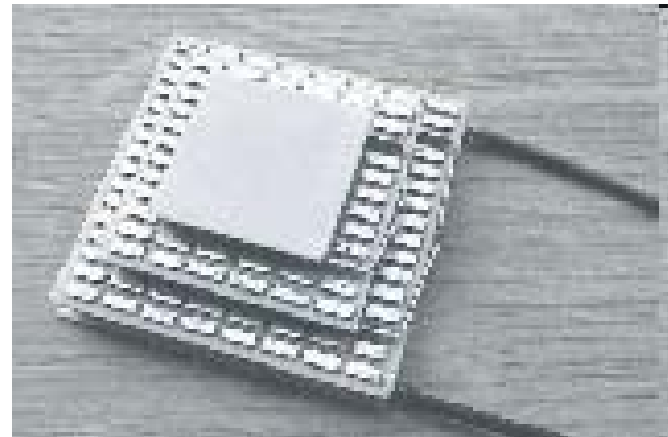
- BASF



### Modules

- Micropelt
- Peltron
- Teccom

all are small companies



# TE-industry

- Systems

  - Self powered wireless sensors



**Wireless sensors will soon be appearing by the thousands. Not only in our homes where they will control lighting and temperature or supervise domestic appliances, but also in industry to control manufacturing processes, in automobiles to check tyre pressure, or outdoors monitoring the environment. To ensure the required system reliability, maintenance-free solutions are in many cases absolutely essential.**

*Dipl.-Ing. Armin Anders, Co-Founder and head of product marketing EnOcean GmbH*

**Batteryless wireless transmitter modules – 300 meters range and absolutely maintenance free**

# TE-industry

## ■ Systems

### Self powered wireless sensors



#### DATA SHEET



#### Thermal Energy Harvester Kit ECT 100 perpetuum®

EnOcean has developed a thermal energy harvester which is able to power wireless sensor nodes from temperature differentials of only a few Kelvin.

This new energy harvester is based on a revolutionary DC/DC converter which automatically starts operation at 20mV. For comparison: the leading conventional DC/DC converters need at least 300mV to start operation - a factor of 15 more!

The output power is in the range from  $\mu\text{W}$  to mW at 3.5V and depends on the actual temperature differential and the Peltier element being used. Therefore it is designed for use with EnOcean radio technology in sensors and actuators. A typical thermo-driven sensor consists of a sensor element, a small Peltier element, the new DC/DC converter and an STM110 radio module from EnOcean. Powered by the thermo differential the



STM110 will wake up on a regular basis, e.g. every 10s, acquire sensor values and transmit them via a radio signal over a distance of up to 300m.

Type  
ECT100 Kit

Ordering Code  
S3004-P100



# TE-industry

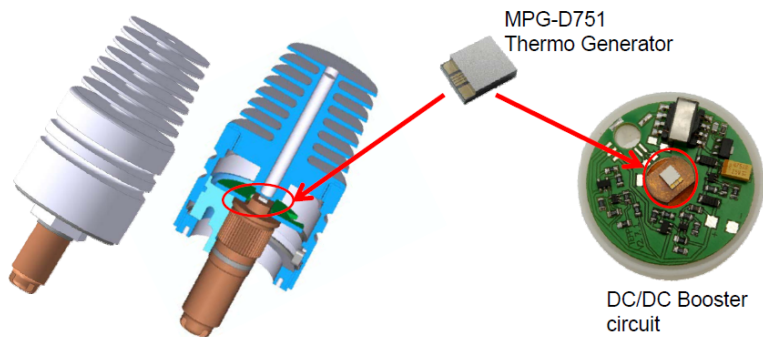
## ■ Systems

Self powered wireless sensors

TE-Power PROBE V2.7

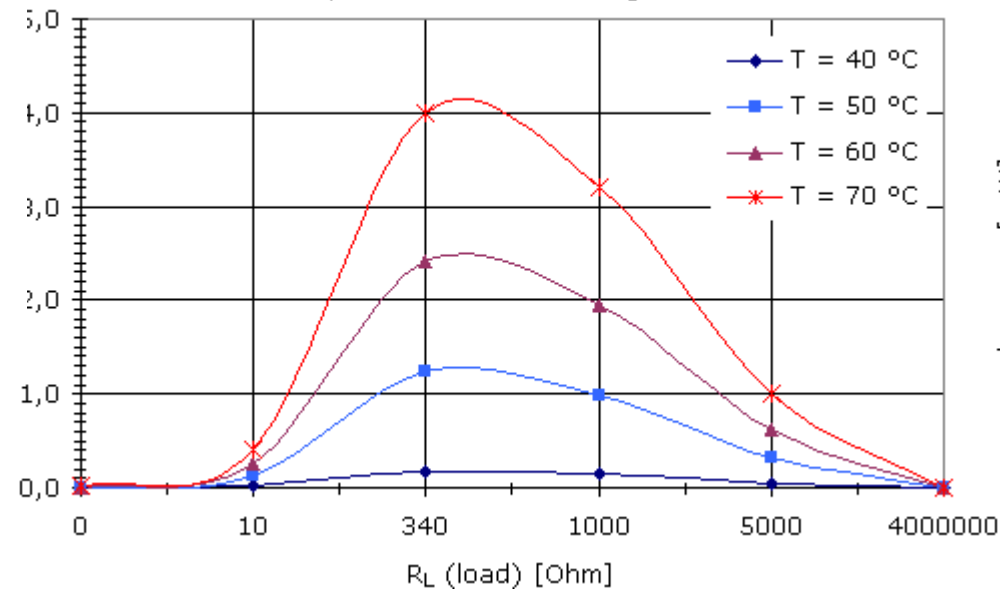
micropelt

Cross section & position of the TEG chip

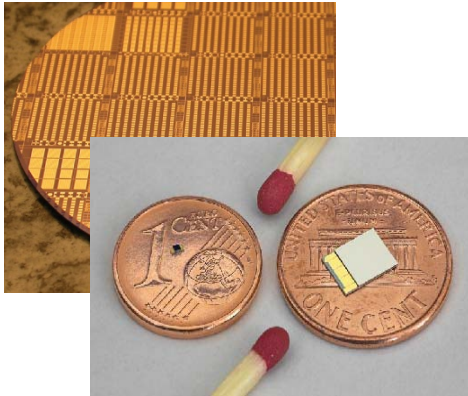


micropelt

power at load matching



# TE-developments of international importance



 **Fraunhofer**  
IPM

&

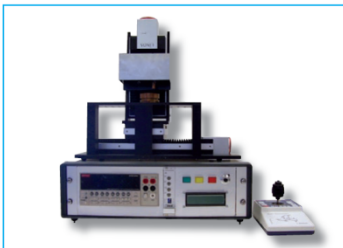
  
never stop thinking

# micropelt

## PSM – Potential-Seebeck Microprobe

A multidisciplinary measurement technique.

PSM



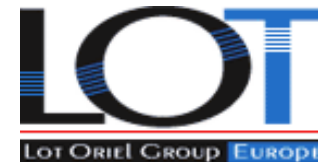
An instrument for spatial resolution of the Seebeck coefficient and the electrical conductivity.



&



distributed by



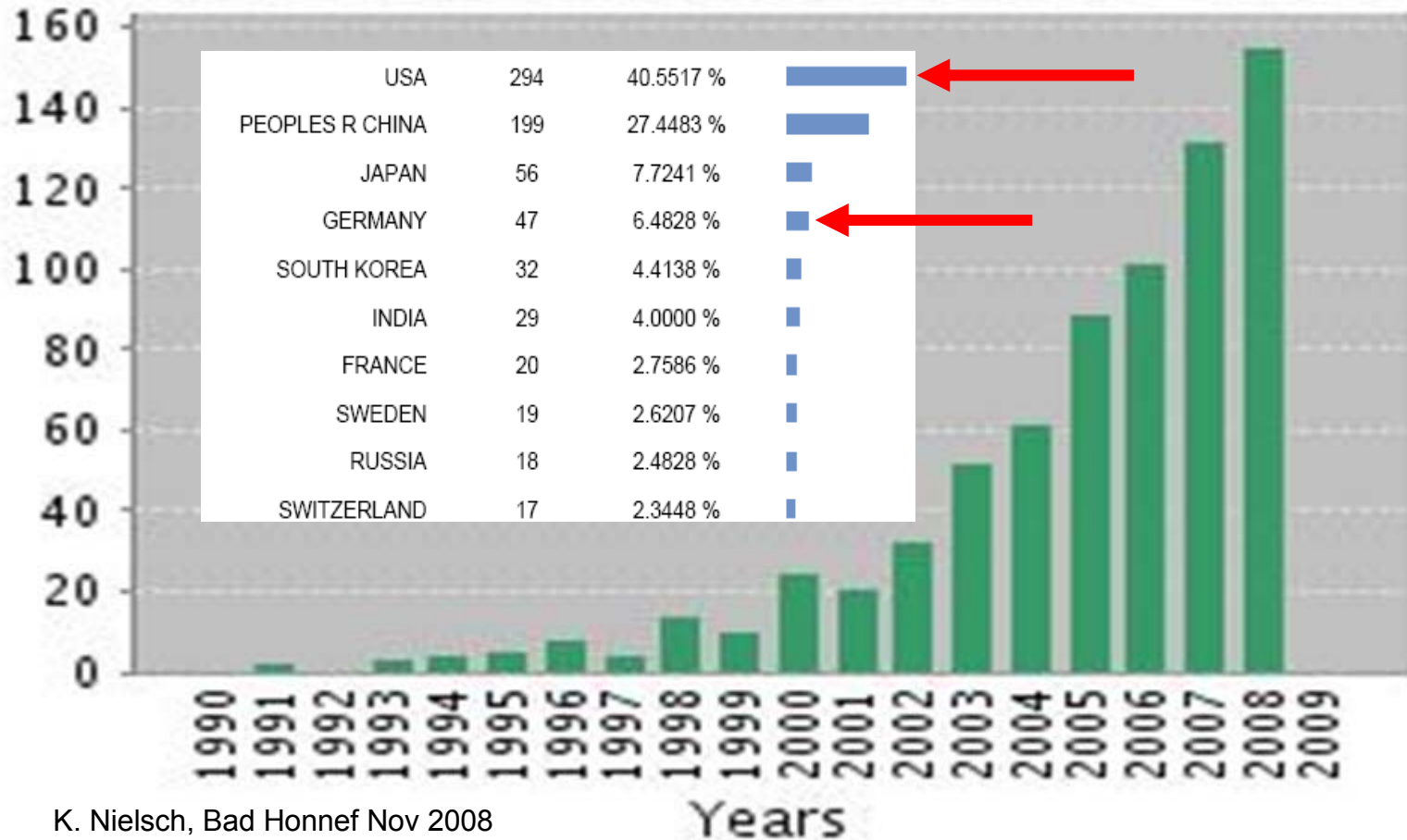
# TE-funding situation

- **DFG-program** (German Science Foundation )  
**„Nano-scale-thermoelectrics“**  
Idea end 2006, DFG proposal 2007, 40 groups were interested  
**June 2009 kick off** (up to six years)  
18 joint projects (8,7 Mio€ first 3-years periode)
- **BMBF-program**  
**„Thermoelektrika“**,  
Idea 2006, Proposal „HoTT“ 2007  
**summer 2009 kick off**: exclusively joint scientific projects  
- **HoTT1-** (up to three years)  
5 joint projects (~ 5Mio€)
- **BMBF-program**  
**„Thermopower“**  
autumn 2009 call for joint (industry/scientific) projects  
- **HoTT 2-** -(up to six years)  
NN joint projects ( ??Mio €)

# TE-funding situation

Thermoelectric Nanostructures, Web of science oct 2008

## Published Items in Each Year



K. Nielsch, Bad Honnef Nov 2008

Years

# TE-funding situation

## ■ DFG Program (German Science Foundation)

- Bi<sub>2</sub>Te<sub>3</sub> based Nanostructures
- IV-VI related Materials (e.g. PbTe)
- Skutterudites (e.g. Zn<sub>4</sub>Sb<sub>3</sub>)
- Heusler, Silicides and Clathrates
- Thermoelectric Oxides
- SiGe based Nanostructures
- Model Systems (GaAs, Graphene)
- Thermoelectric Measurements
- Theory and Modeling

<http://gepris.dfg.de/gepris/>

Projekt(e) thermoelectric



# TE-future in Germany



**Deutsche Thermoelektrik  
Gesellschaft  
German Thermoelectric Society**



Founded Nov. 2005

Registered in  
Freiburg

[http://www.thermoelektrik.org/englisch/index\\_en.html](http://www.thermoelektrik.org/englisch/index_en.html)

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**Thermoelek(c)trik(c) School  
(continuously)**

autumn 2006 (Tübingen), spring 2008  
(Freiburg), spring 2010 (Bremen)

Welcome to the home of the German Thermoelectric Society e.V.

# TE-future in Germany



## Submissions

■ 1 Germany	70
■ 2 Japan	69
■ 3 China	50
■ 4 USA	46
■ 5 France	18
■ 5 Taiwan	18
■ 7 South Korea	17
■ 8 Russia	13
■ 9 Austria	12
■ 10 Spain	10

## Attendees

■ 1 Germany	171
■ 2 Japan	91
■ 3 USA	63
■ 4 China	42
■ 5 France	36
■ 6 South Korea	32
■ 7 Russia	18
■ 8 Austria	17
■ 9 Spain	15
■ 10 Switzerland	12

# TE-future in Germany

- Current (2009) activities  
basic and applied (R&D)

Thank you for your attention and  
see you in Germany at

- Thermoelectric research situation ~ 2000

Heraeus Seminar: „Nanostructured Thermoelectrics“  
Physik-Zentrum Bad Honnef, 22. 24. 2010

<http://www.we-heraeus-stiftung.de/>





# TE-research in Germany (Universities , MPG, DLR, FhG etc)

Research facilities ranking  
in Germany ~ 2007

- **Fraunhofer IPM**
- **DLR Köln**
- **MPI Mikrostrukturphysik Halle**
- **MPI Dresden**
- **Freie Universität Berlin**
- **DLR Stuttgart**



# TE-research in Germany (Universities , MPG, DLR, FhG etc)

## ■ Metrology



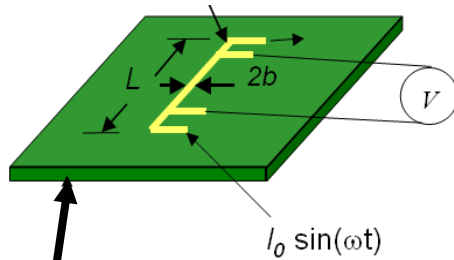
- contact resistance measurement set up (RT)
- modul characterisation (I, U)
- thermal conductivity of thin layers and bulk

(3 Omega)  
5 systems in Germany

### 3 $\omega$ – Methode

Cahill, *Rev. Sci. Instrum.* 61, 802 (1990)

metallic heater



- $I \sim \omega$
- $T \sim I^2 \sim 2\omega$
- $R \sim T \sim 2\omega$
- $V \sim IR \sim 3\omega$

Sample with insulating layer

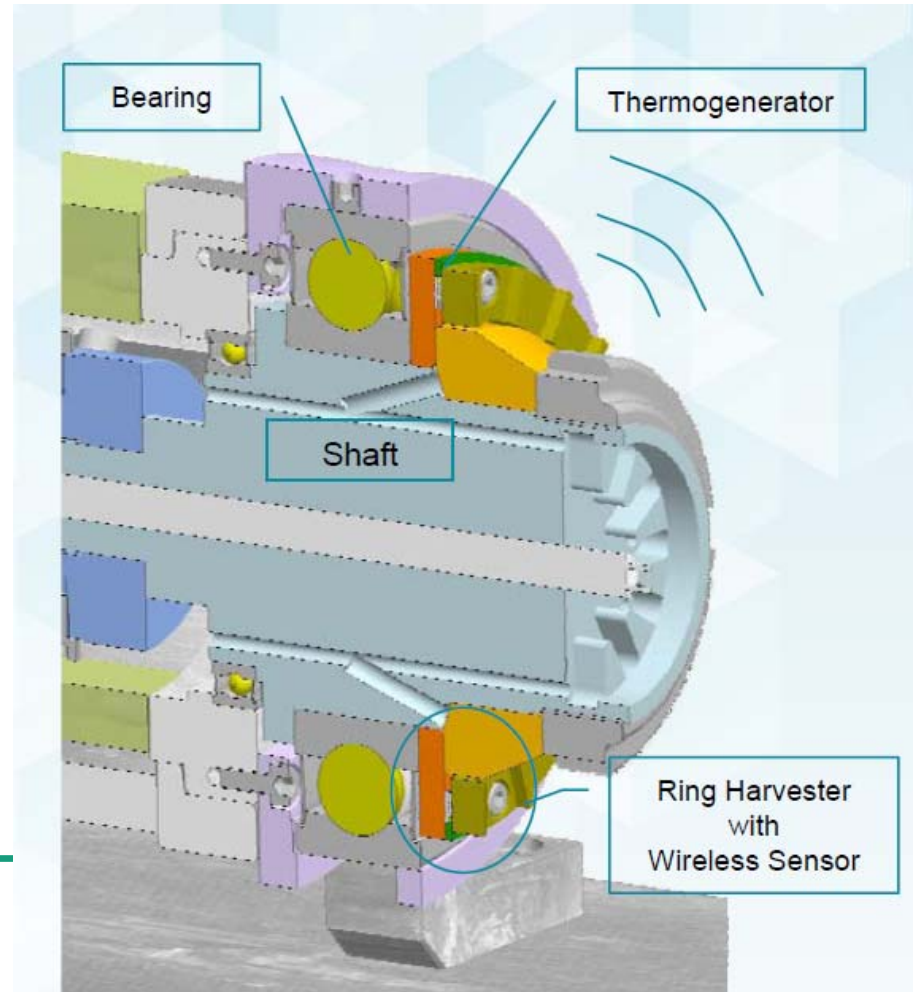
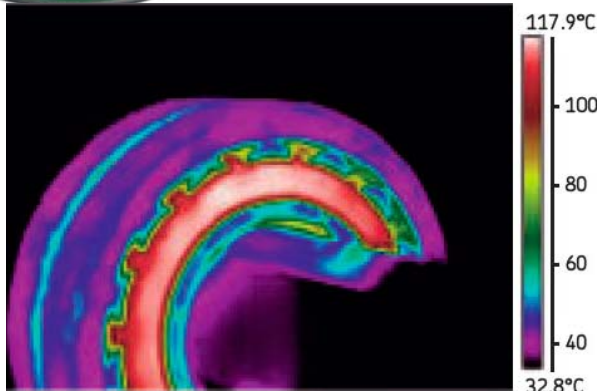


# TE-industry

## ■ Systems

Self powered wireless sensors

# micropelt



# TE-industry

- Systems

Self powered wireless sensors

# micropelt

