Standardization of Transport Properties Measurements: Internal Energy Agency (IEA-AMT) Annex on Thermoelectric

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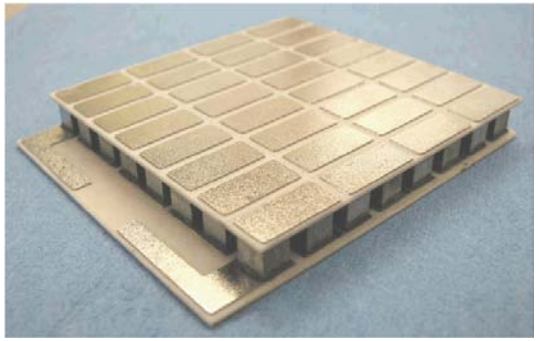
DOE 2011Thermoelectric Application Workshop
San Diego, CA
January 4, 2011



Acknowledgement

- IEA-AMT Collaborators
  - USA: Clemson (T. Tritt); Marlow (J. Sharp); Corning (A. Mayolet) and ZT-Plus (F. Harris)
  - China: SICCAS (L. Chen)
  - Canada: Natural Resource Canada (J. Lo)
  - Germany: Fraunhofer IPM (H. Böttner, J. König)
  - Japan: AIST (R. Funahashi)
  - Korea: KERI (H. W. Lee)
- ORNL: Edgar Lara-Curzio, Wallace Porter
- DOE VT Program support: Jerry Gibbs

DOE Supported Thermoelectric Materials Characterization

High Temperature Materials Laboratory, Oak Ridge National Laboratory
funded by the Vehicle Technologies Office

Main HTML functions in thermoelectric research

- **Transport properties measurements**
- **Thermomechanical properties and reliability**
- **Advanced materials characterizations:**
  - Atomic resolution microscopy (STEM)
  - X-ray and neutron scattering
- **HTML is leading a thermoelectric characterization project via the International Energy Agency (IEA) – Advanced Materials for Transportation (AMT)**

  Annex VIII on thermoelectrics led by ORNL
  - Participating countries: USA, Canada, Germany and China
  - Participating labs: more than 7

IEA-AMT and Organization

- IEA-AMT was established in 1985 and has organized 8 technical annexes
- Five On-going annexes: IV (Surface texturing), V (Magnesium corrosion protection), VI (Low-cost carbon fibers), VII (Nano-materials) and VIII (Thermoelectrics)
- Current organization: Led by DOE VT (Chairman: Jerry Gibbs)
- IEA-AMT Countries: USA, Canada, UK, Germany, China, Australia

Annex VIII Participants

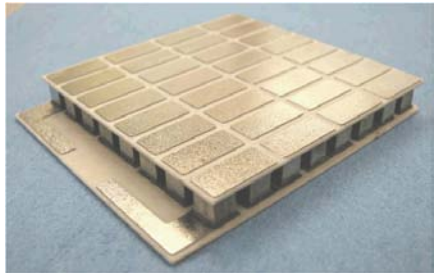
- IEA-AMT member countries
  - USA: ORNL (H. Wang); Clemson (T. Tritt); Marlow (J. Sharp); Corning (A. Mayolet) and ZT-Plus (F. Harris)
  - China: SICCAS (L. Chen)
  - Canada: Natural Resource Canada (J. Lo)
  - Germany: Fraunhofer IPM (H. Böttner, J. König)
- IEA member countries (initial observers to AMT)
  - Japan: AIST (R. Funahashi)
  - Korea: KERI (H. W. Lee)

Annex VIII Tasks

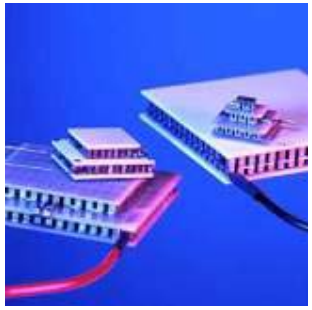
Goal: Help commercialization of TE materials for automotive applications

- **Develop testing methods and procedures for thermoelectrics (both bulk and low dimensional materials). Standardizing transport properties measurements**
- **Assessment of state-of-the-art thermoelectric materials and identify critical issue to improve performance**
- **International round-robin tests of selected thermoelectric materials**
- **Technical information exchange**
- **Characterizations of potential thermoelectrics for transportation applications**

Thermoelectric Applications on Vehicles



Power Generation



Cooling and Heating

Waste Heat Recovery

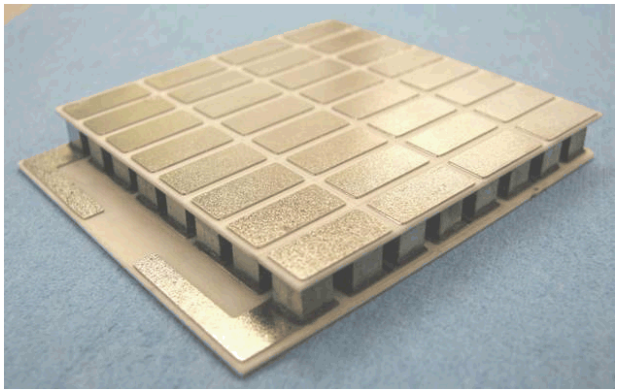
Zone/seat temperature control

TE Applications Require Accurate Transport Properties Measurements Over the Entire Temperature Range

TE Materials characterization:

- TE materials: Transport properties, ZT
- TE Modules: Efficiency, cost, reliability (cycle life)

Bulk Materials



Thermoelectric Module

Transport Properties Are the Keys to Thermoelectric Applications

Important issues to scale-up module production and thermoelectric generator design:

- **Are the literature values reliable?**
- **Can we validate or confirm transport properties?**
- **Are test standards available and being followed**
- **Are reference materials available?**

Bulk Thermoelectrics

- **Literature ZT values are sometimes not reproducible**
- **Possible Problems:**
  - **Measurement errors and no standards**
  - **Skipping measurements and extrapolation**
  - **Mis-conception about Cp**
  - **Materials non-uniformity**
  - **Measurements on different samples**

Marlow Materials Selected for Transport Properties Round-Robin Tests

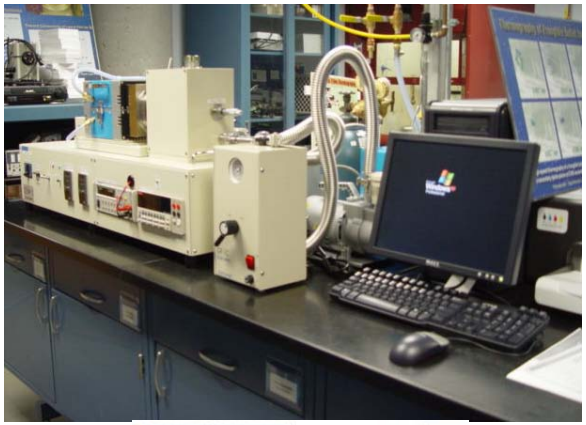
- Materials: $Bi_2Te_{3.005}$ (n-type) $Bi_{0.5}Sb_{1.5}Te_3$ (p-type)
- 75 μm powder -> hot pressed
- Four Transport Properties and Sample Geometry
  - Thermal diffusivity: 12.7 mm diameter disk
  - Specific heat: 4 mm diameter disk
  - Seebeck coefficient and electrical resistivity: 2 x 2 x 15 mm^3 bar, 3 x 3 x 12 m^3 bar
- Temperature range: 20-200ºC
- Rules: Use best practice in each lab

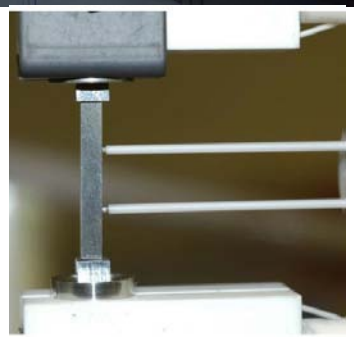
HTML Transport Properties Tests for Merit ZT

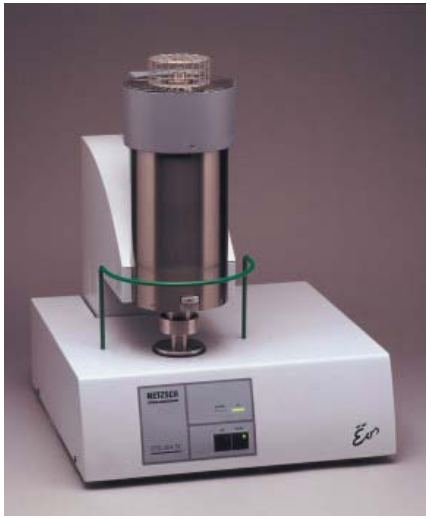
- **Seebeck and Resistivity: RT - 500ºC**
- **Thermal Diffusivity: RT - 500ºC**
- **Specific Heat: RT- 500ºC**

$$ZT = s^2T/\rho k$$

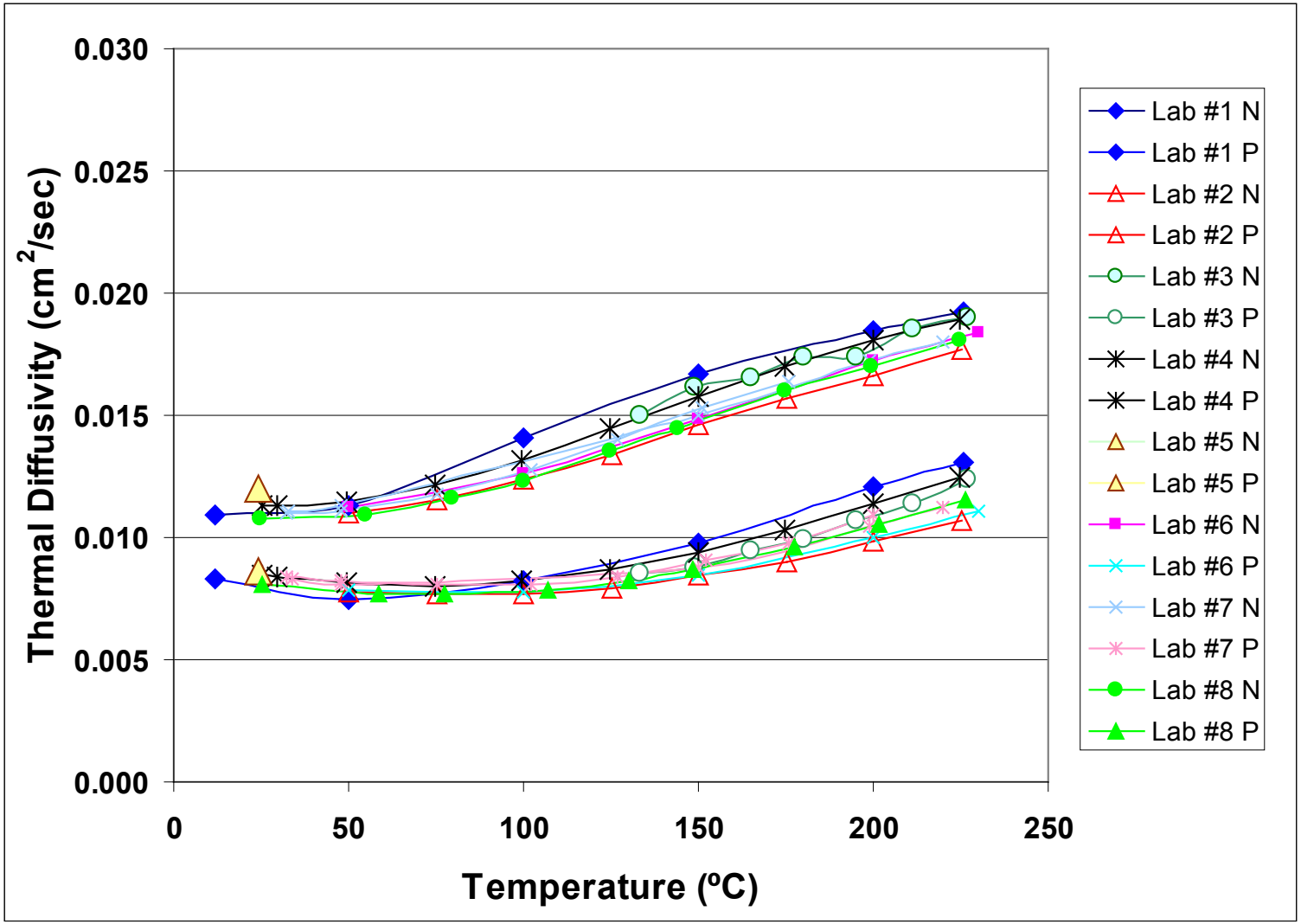
$$k = \alpha C_p D$$





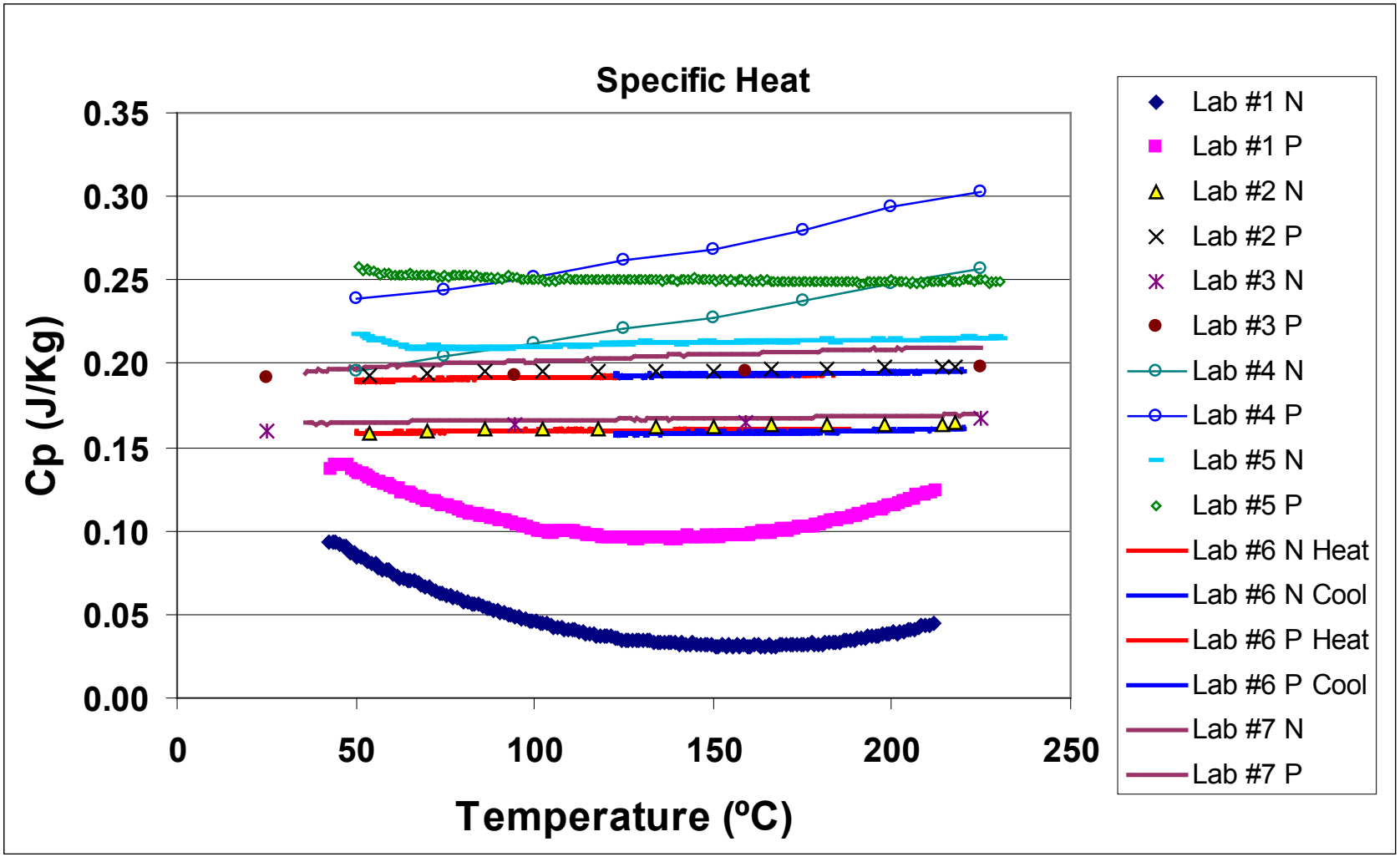


IEA-AMT Thermal Diffusivity Measurements



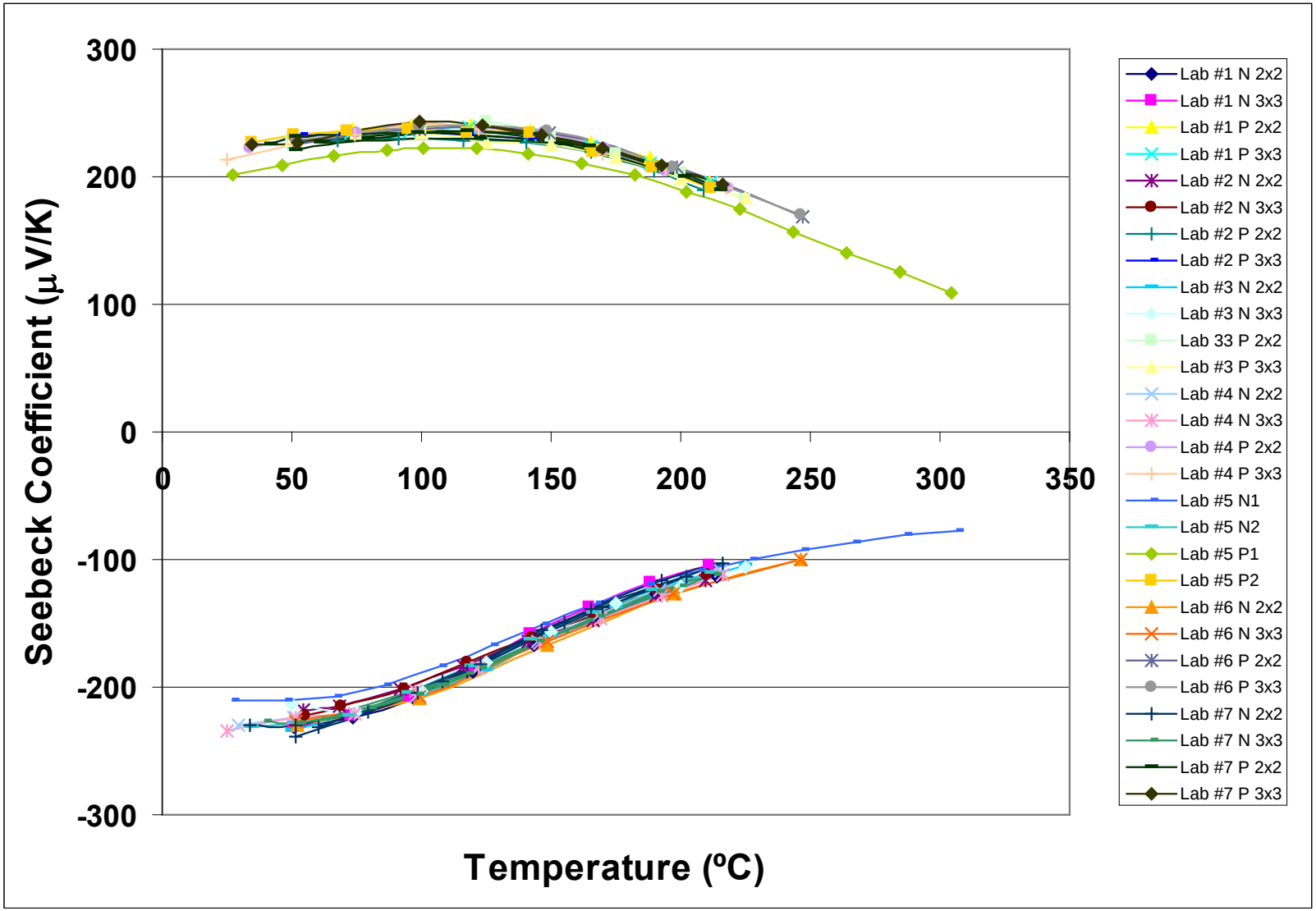
Preliminary results from 8 labs in 6 countries

IEA-AMT Specific Heat Measurements



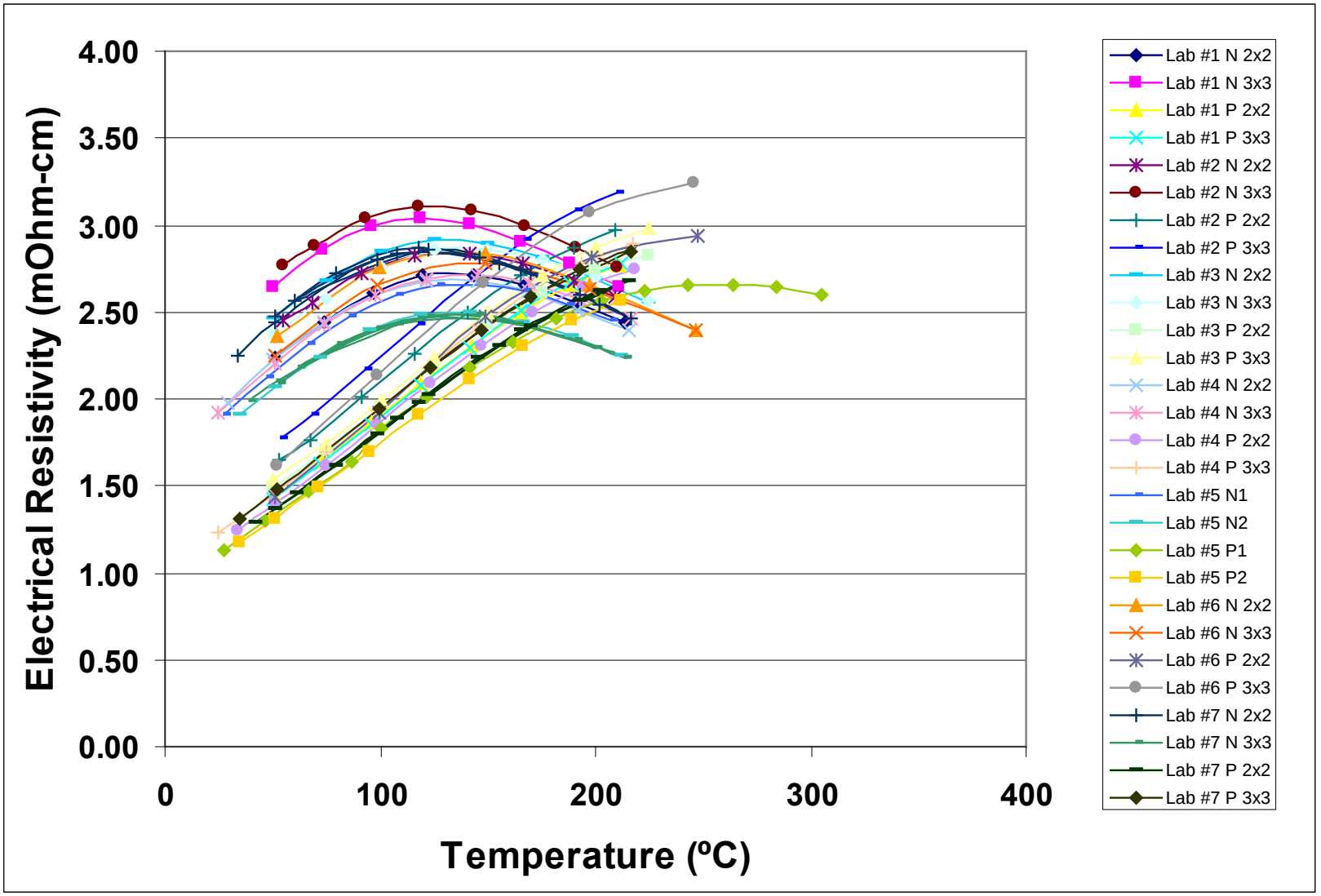
Preliminary results from 7 labs in 6 countries

IEA-AMT Thermopower Measurements



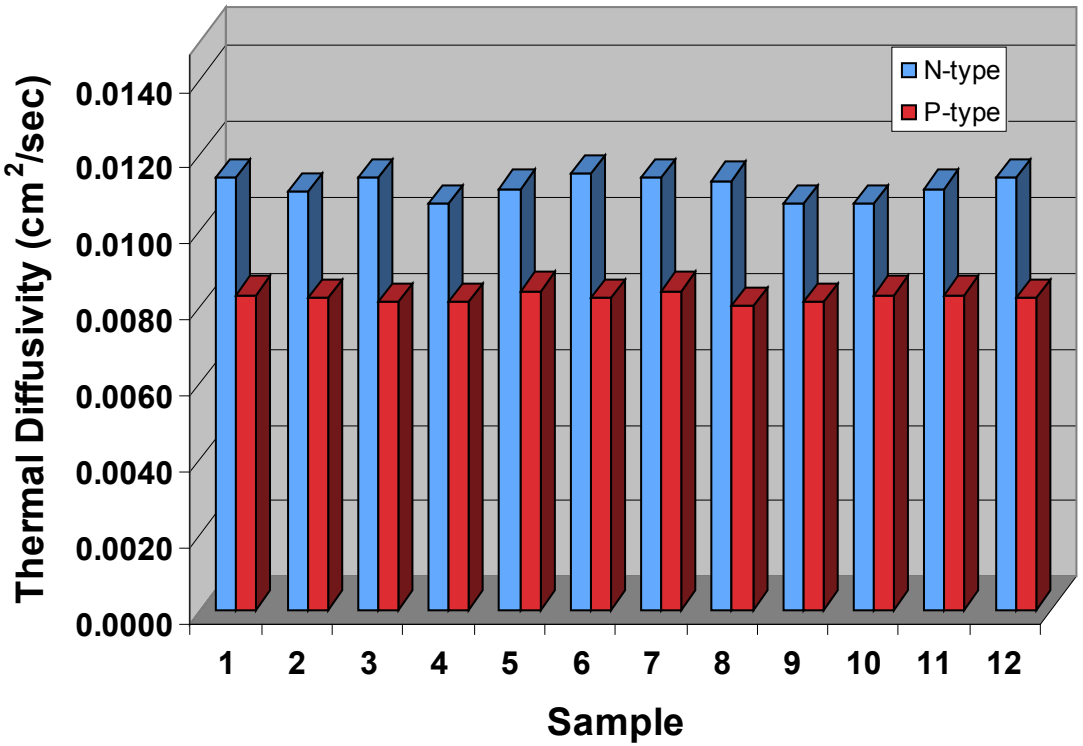
Preliminary results from 7 labs in 6 countries

IEA-AMT Electrical Resistivity Measurements



Preliminary results from 7 labs in 5 countries

Thermal Diffusivity: Room Temperature



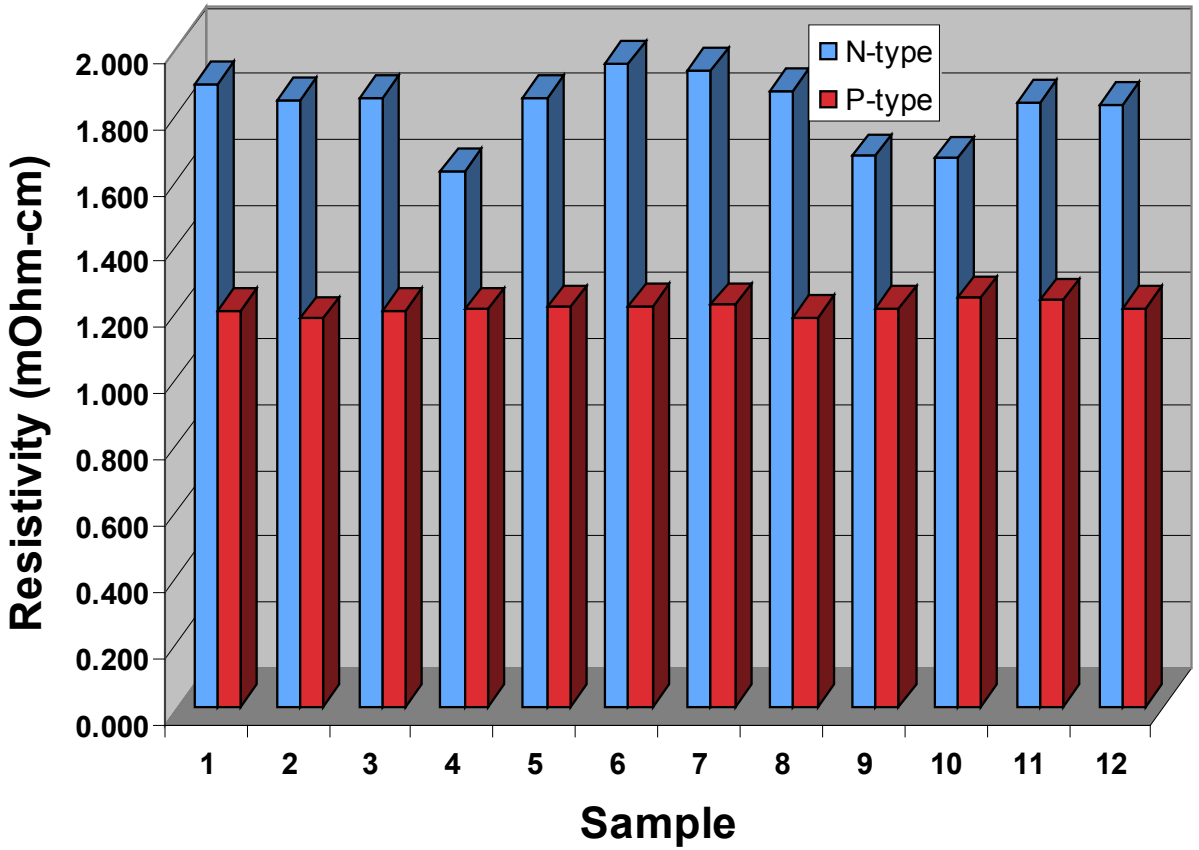
N-type: Average = 0.0111 cm^2/sec

STDEV = ±2.75%

P-type: Average = 0.0082 cm^2/sec

STDEV = ±1.54%

Electrical Resistivity: 4-point probe



N-type: Average = 1.820 mOhm-cm

STDEV = ±6.57%

P-type: Average = 1.208 mOhm-cm

STDEV = ±1.50%

Round-robin 2 Started in October 2010

- Two sets of P-type samples
  - Set #1: ORNL -> Clemson-> Corning -> ZT-Plus -> Germany -> China -> Japan -> Canada
  - Set #2: China -> Japan -> Germany -> ORNL -> Clemson-> Corning -> ZT-Plus -> Canada
- To complete in April 2011
- Report in ICT2011

Summary

- IEA-AMT is addressing the important issue of measurement standardization of thermoelectrics.
- First international round-robin was completed in 2010.
- Significant measurement issues were observed, especially in specific heat and electrical resistivity.
- P-type material was selected for 2nd round robin test.
- The IEA-AMT TE annex is working with the international community to produce more reliable transport data and promote the application of thermoelectrics in vehicles