International Round-Robin on Transport Properties of Bismuth Telluride

Hsin Wang

Oak Ridge National Laboratory
Oak Ridge, TN USA

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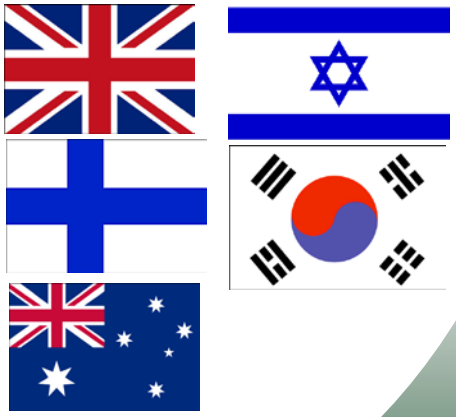
Annex VIII Participants

- **IEA-AMT Thermoelectric Annex**
  - Annex lead: Oak Ridge National Laboratory (H. Wang)
  - USA: Clemson (T. Tritt, S. Zhu); Marlow (J. Sharp); Corning (A. Mayolet, C. Smith, J. Senawiratne) and ZT-Plus (F. Harris)
  - China: SICCAS (S.Q. Bai, L. Chen)
  - Canada: Natural Resource Canada (J. Lo); University of Waterloo (Holger Kleinke); University of Quebec at Chicoutimi (Laszlo Kiss)
  - Germany: Fraunhofer IPM (H. Böttner, J. König)

- **IEA-AMT members countries:**
  - UK: NPL
  - Finland: VTT (discussion on October 20)
  - Israel:
  - Australia:
  - International Observer: Korea: KERI (H. W. Lee)



Annex VIII on Thermoelectric: Oct. 2009 - present:

- **Support DOE VT thermoelectric programs for vehicle applications**
- **Transport properties measurements**
- **Measurement standards and reliability**
- **Support the commercialization of thermoelectrics**
- **Annex VIII on thermoelectrics led by ORNL**
  - Round robin 1: 2009-2010 on n-type and p-type bismuth telluride
  - Round robin 2: 2010-2011 on p-type bismuth telluride
  - Round robin 3: 2012 at high temperatures n-type PbTe

IEA-AMT Focus: Bulk Thermoelectrics Used for Automotive Waste Heat Recovery

- Significant gaps exist between literature ZT values and scalable materials
- Possible Issues:
  - Measurement errors
  - No standards for calibration
  - Incomplete measurements
  - Data extrapolation
  - Materials non-uniformity
  - Orientation effect
  - Measurements on different samples

Marlow Materials Selected for Transport Properties Round-Robin Tests

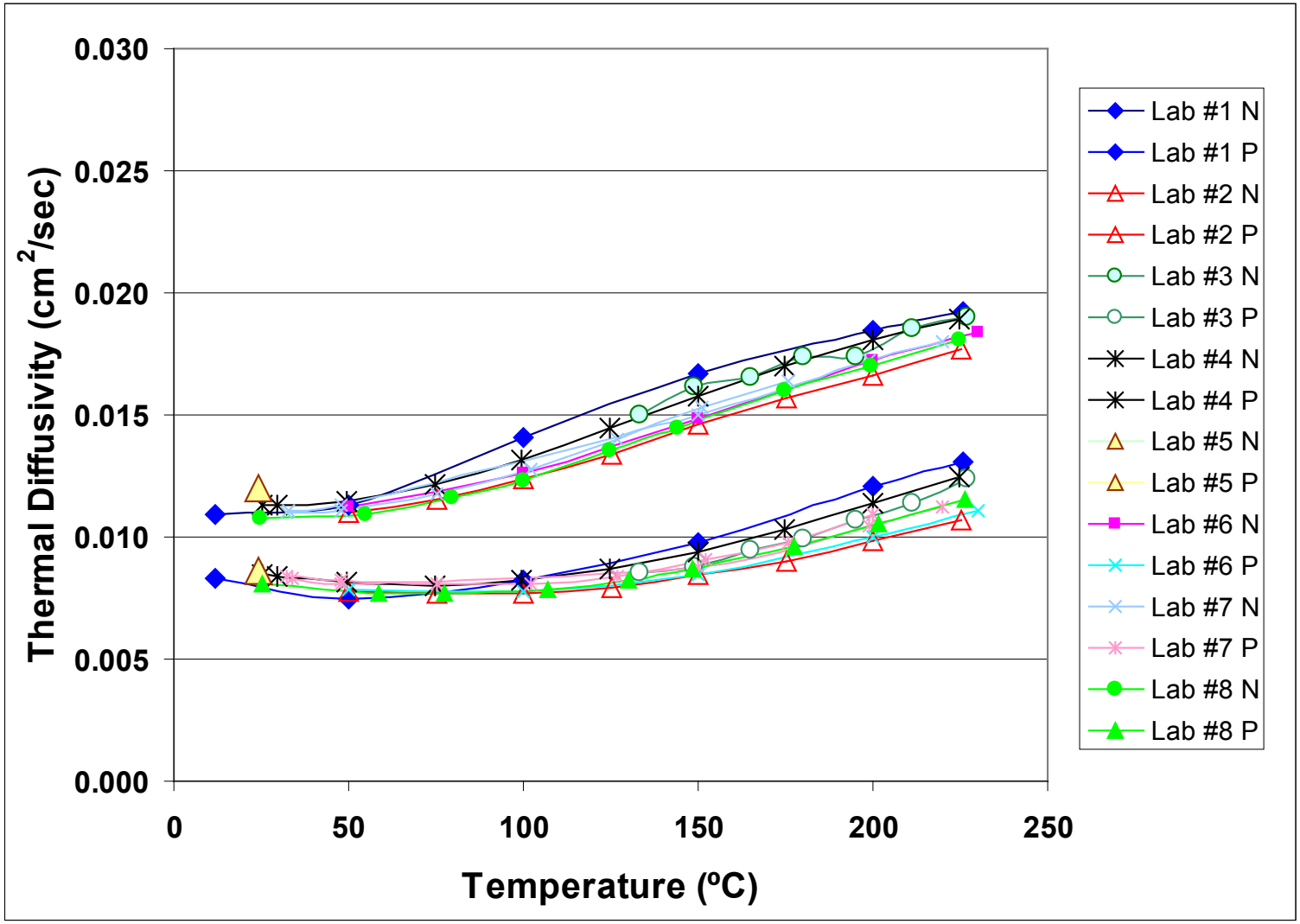
- Materials: $Bi_2Te_{3.005}$ (n-type) $Bi_{0.5}Sb_{1.5}Te_3$ (p-type)
- Four-sample Sets
  - Thermal diffusivity: 12.7 mm diameter disk
  - Specific heat: 4 mm diameter disk
  - Seebeck coefficient and electrical resistivity: 2 x 2 x 15 mm^3 bar, 3 x 3 x 12 m^3 bar
- Temperature range: 20-200ºC
- Round-robin plans:
  1. Use best practice in each lab
  2. Focusing on one specific material
  3. Develop test procedures

NIST Standards and Thermoelectrics

- **Five internationally recognized standards:**
  - **Temperature (K); Distance (m); Current (A); Frequency (Hz) and Mass (Kg)**
- **Thermoelectric properties for ZT:**
  - **Seebeck coefficient: V/K**
  - **Electrical resistivity: Ohm-m**
  - **Thermal conductivity: (W/mK)**
    - **Thermal diffusivity: m^2/sec**
    - **Specific heat: J/gK**
    - **Density: Kg/m^3**
- **All TE properties are "derived"**

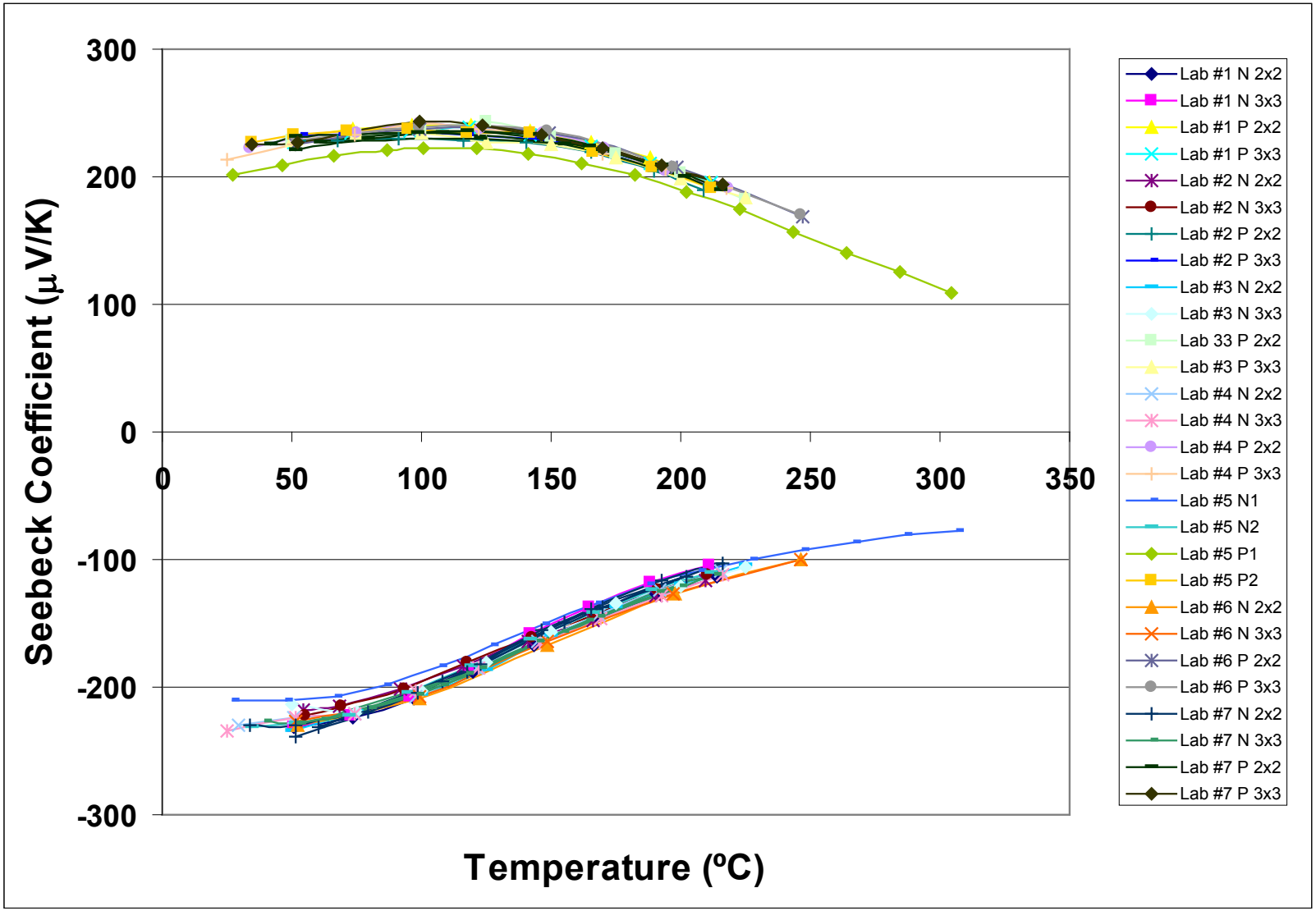
$$ZT = s^2T/\rho k$$
$$k = \alpha C_p D$$

Round-robin 1: Thermal Diffusivity

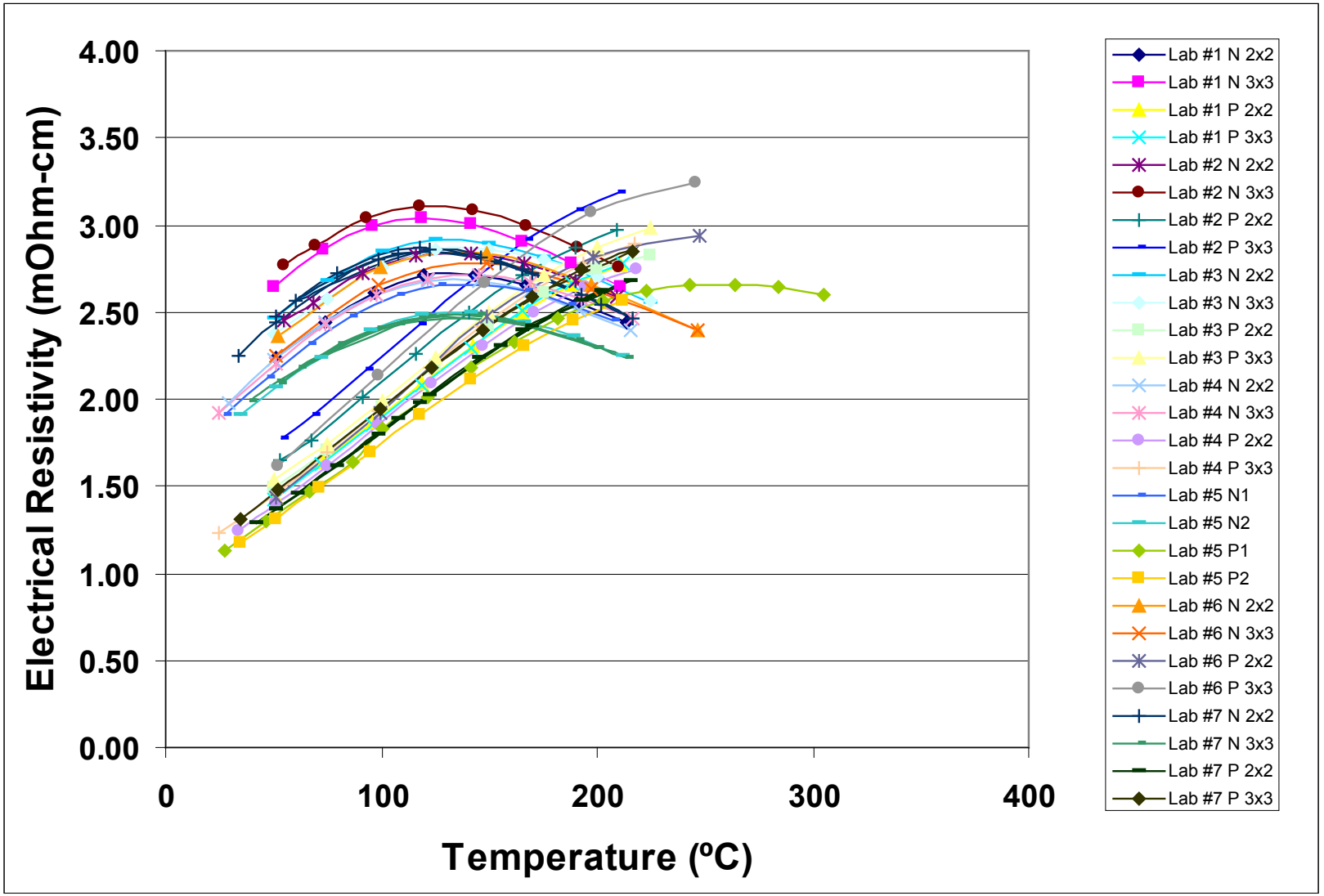


Results from 8 labs

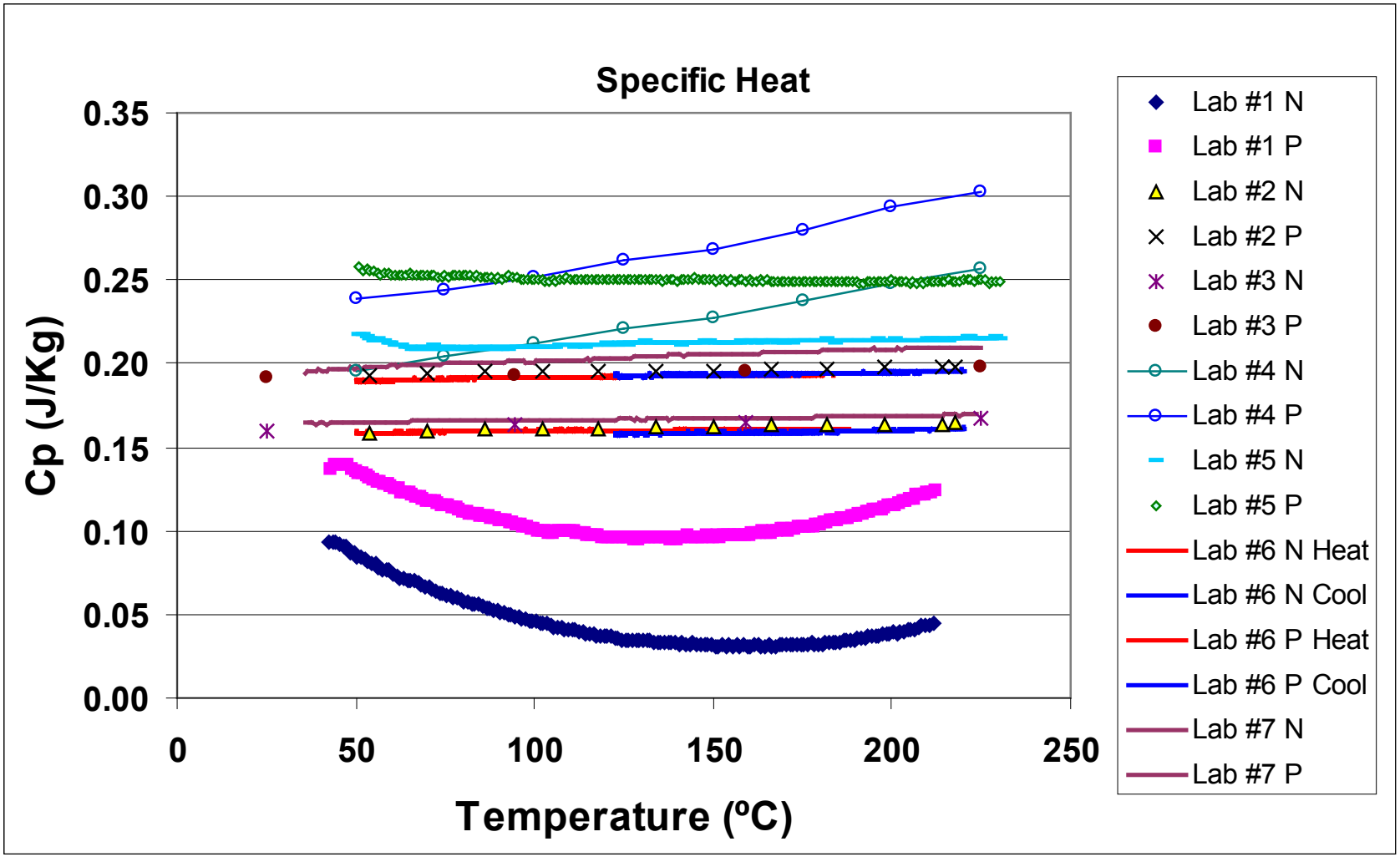
Round-robin 1: Seebeck Coeffieicnt



Round-robin 1: Electrical Resistivity



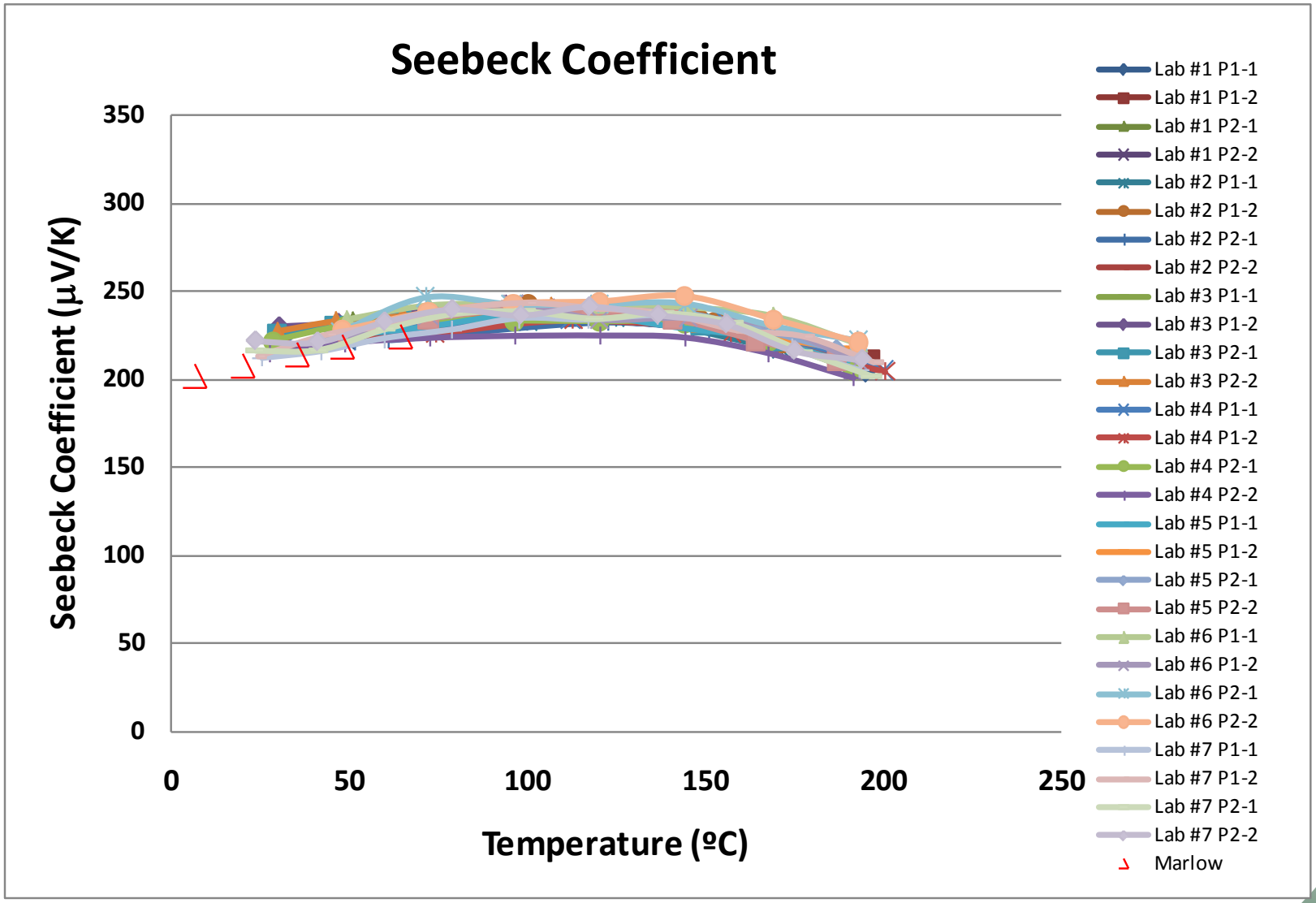
Round-robin 1: Specific Heat



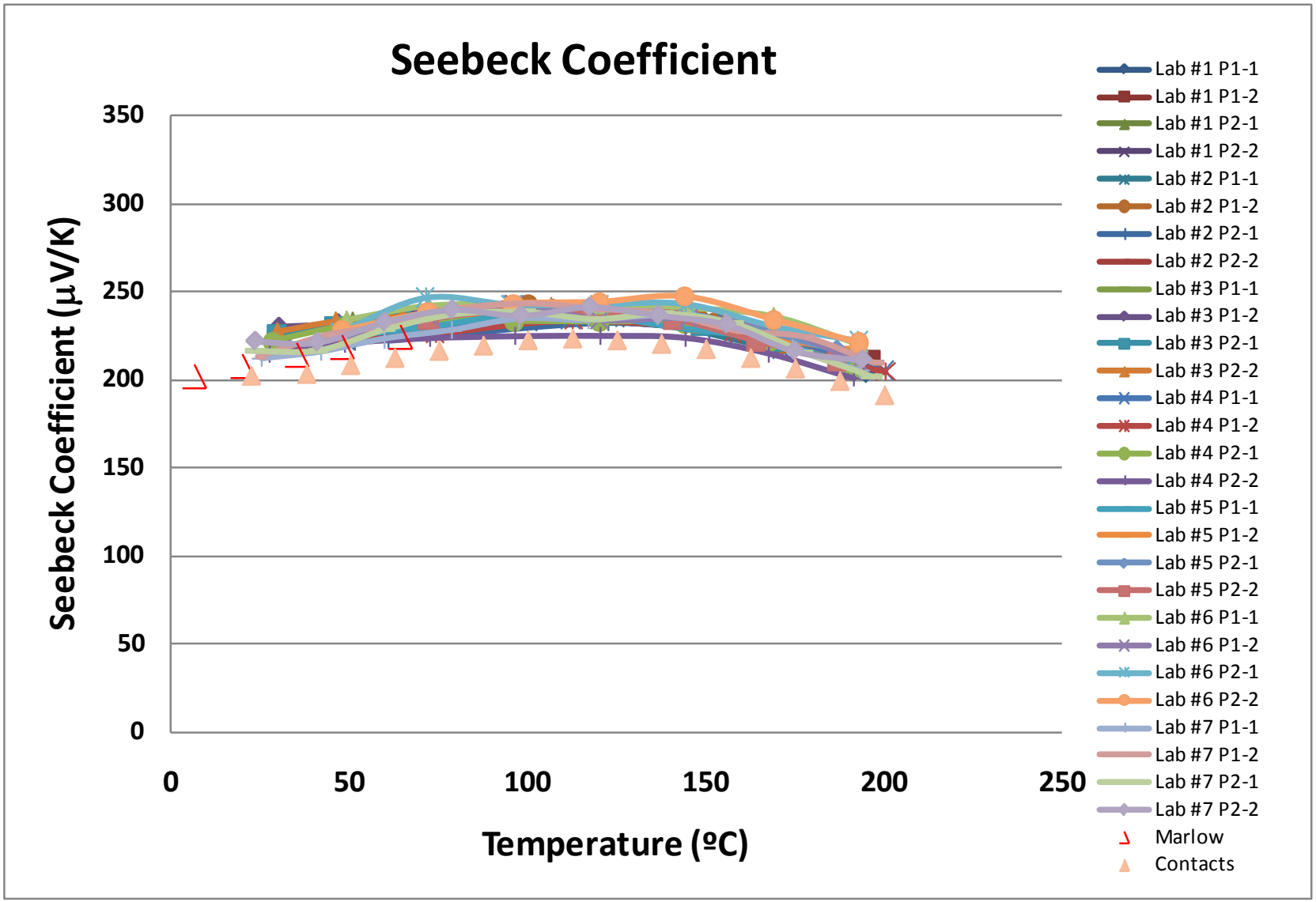
Round-robin #2 Started October 2010

- Procedures for DSC prepared by ORNL
- Two sets of p-type samples
  - Set #1: ORNL -> Clemson-> Corning -> ZT-Plus -> Germany -> China -> Canada
  - Set #2: China -> (Japan) -> Germany -> ORNL -> Clemson-> Corning -> ZT-Plus -> Canada
- Completed in September 2011
- Report to IEA-AMT: October 2011
- IEA-AMT Topical report November 2011

Round-robin 2: Seebeck Coefficient

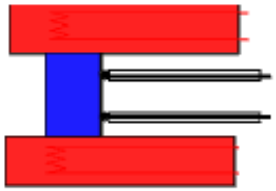


Discussion on Seebeck Measurements

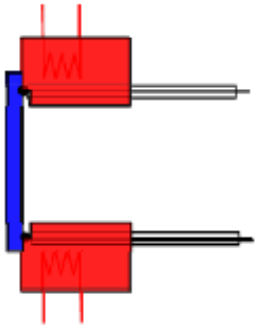


Comments on Seebeck coefficient measurement with ZEM 3 (M10) and IPM-SR1

- ZEM-3 (M10)
  Configuration of measurement:



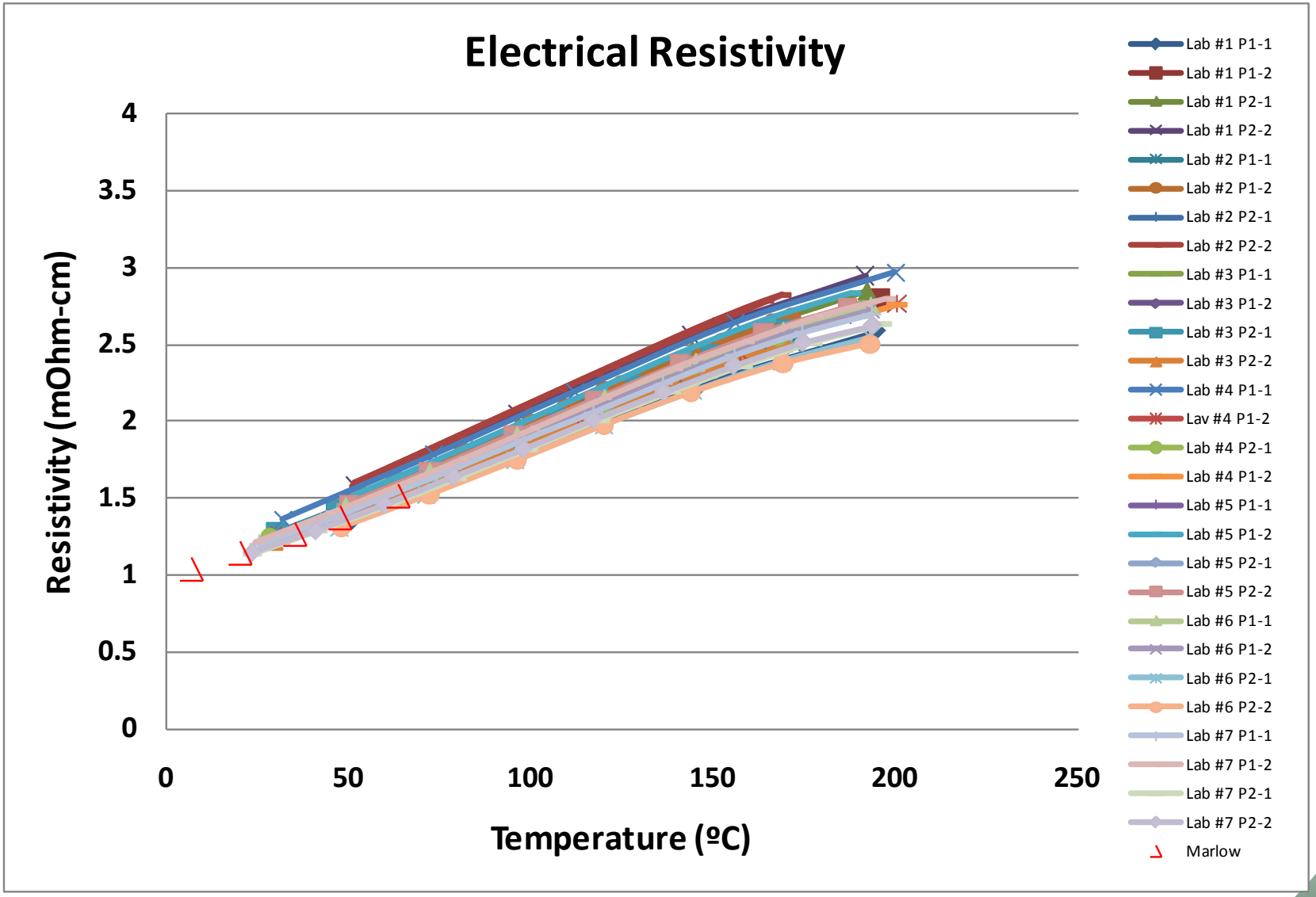
- IPM-SR1
  Configuration of measurement:



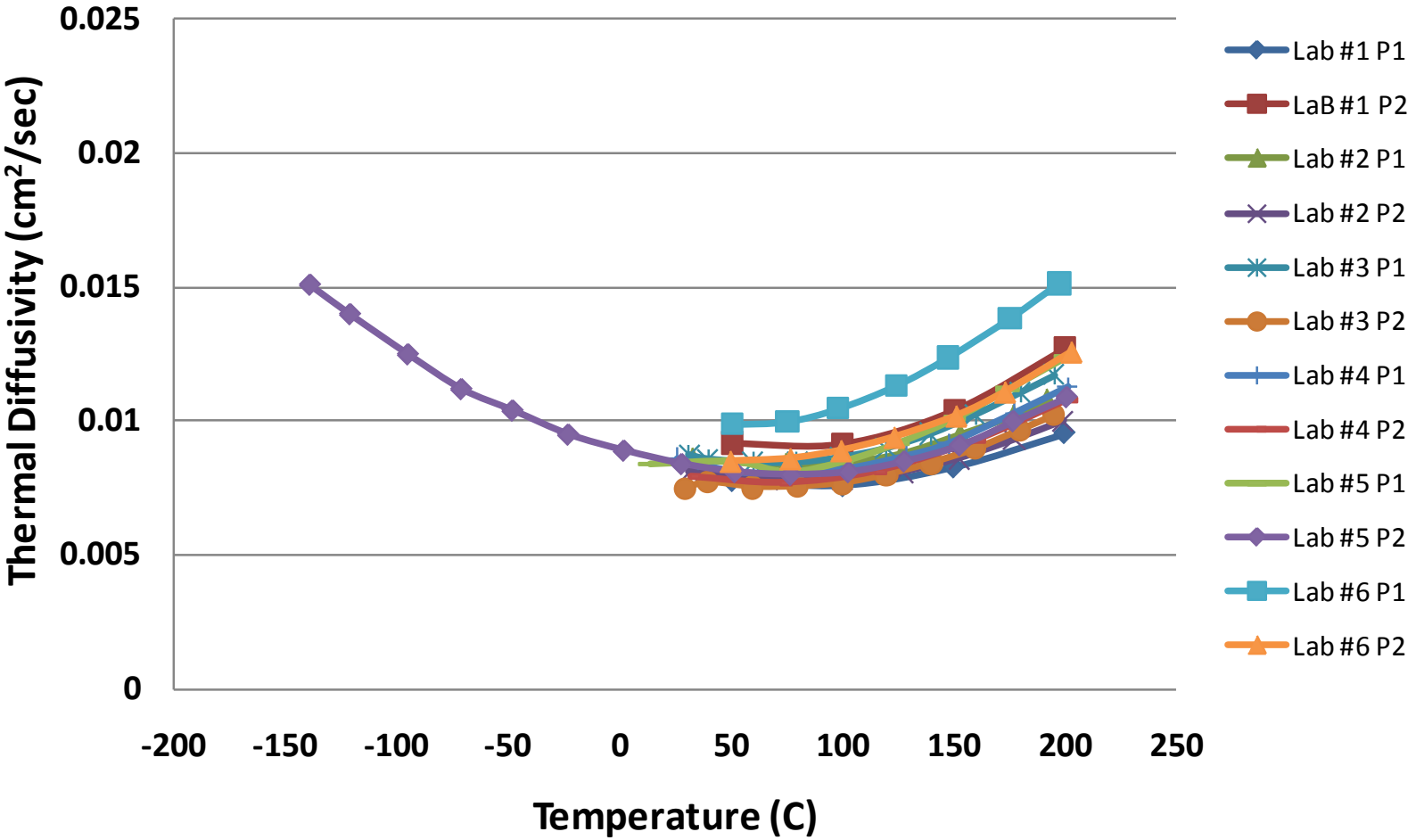
Assuming the real temperature gradient is the same, the temperature gradient measured with the ZEM-3 tends to be smaller than the one measured with the Fraunhofer IPM-SR1 because of the difference of configurations.

Fraunhofer IPM

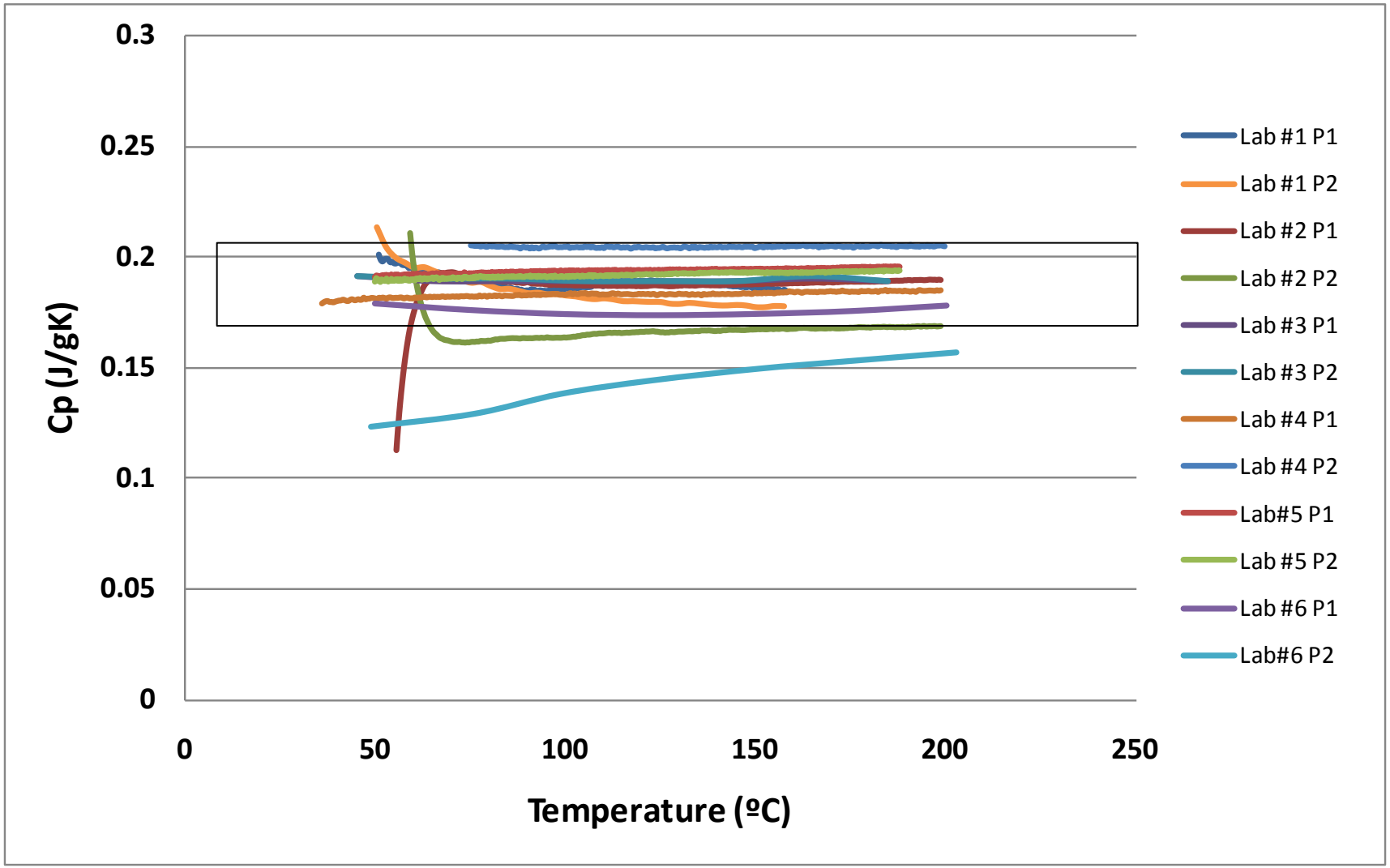
Round-robin 2: Electrical Resistivity



Round-robin 2: Thermal Diffusivity



Round-robin 2: Specific Heat



Round Robin 3 (Spring-Summer 2012)

- Temperature range: RT-500C
- Materials n-type: lead telluride
  - Difficult to machine, especially small disk for DSC
  - Professional cutting for thermoelectrics
  - Back-up materials is n-type skutterudite
- Test Plan: Germany-> China-> US (ORNL, ZT-Plus, GMZ, Clemson, Corning) -> Canada
  - Alternate methods: Marlow, ARL

Summary

- IEA-AMT is addressing the important issue of measurement standardization of thermoelectrics
- Significant measurement issues were observed, especially in specific heat and electrical resistivity.
- Good agreements in Seebeck coefficient, electrical resistivity
- Thermal diffusivity in good agreement expect for one test (data analysis)
- Specific heat remains an issue for reliable ZT
- Round-robin 3 underway