Measurement and Characterization of Thermoelectric Materials

Xiao-Yuan Zhou, Guo-Yu Wang, Hang Chi, Ctirad Uher*

Department of Physics, University of Michigan, Ann Arbor, MI 48109-1040, USA

I. INTRODUCTION

The efficiency of a thermoelectric device is fundamentally limited by the physical properties of thermoelectric materials, which can be quantified through the dimensionless *Figure of Merit*[1]:

$$ZT = \frac{S^2\sigma}{\kappa}T$$

Desirable novel thermoelectric materials should have a low thermal conductivity and a high power factor ($PF=S^2\sigma$) - so that ZT is high. Furthermore, investigation of the structure-property relationship through *Hall Effect* study can help in better understanding of optimization of thermoelectric materials.

Herein we outline the approches we use to characterize these important transport properties. Typical experimental set-ups and data can be found in the *Thermoelectric Materials Characterization* figure in the *Middle Panel*.

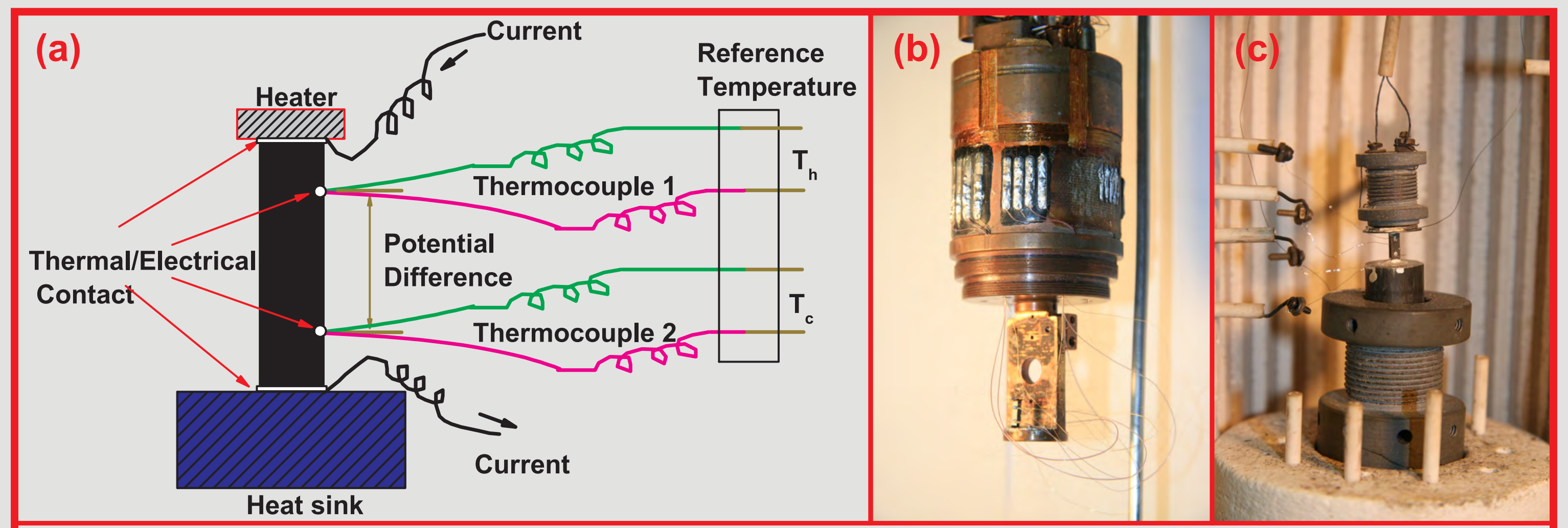


Figure 1. (a) Principle of measurement of electrical conductivity and Seebeck coefficient, together with experimental realization in case of (b) low temperature (2K-300K) and (c) high temperature (300K-800K).

II. FIGURE OF MERIT

Even though direct measurement of ZT is possible, it is often necessary for researchers to make independent measurements of the electrical conductivity, the Seebeck coefficient, and the thermal conductivity.

1. σ – Electrical Conductivity

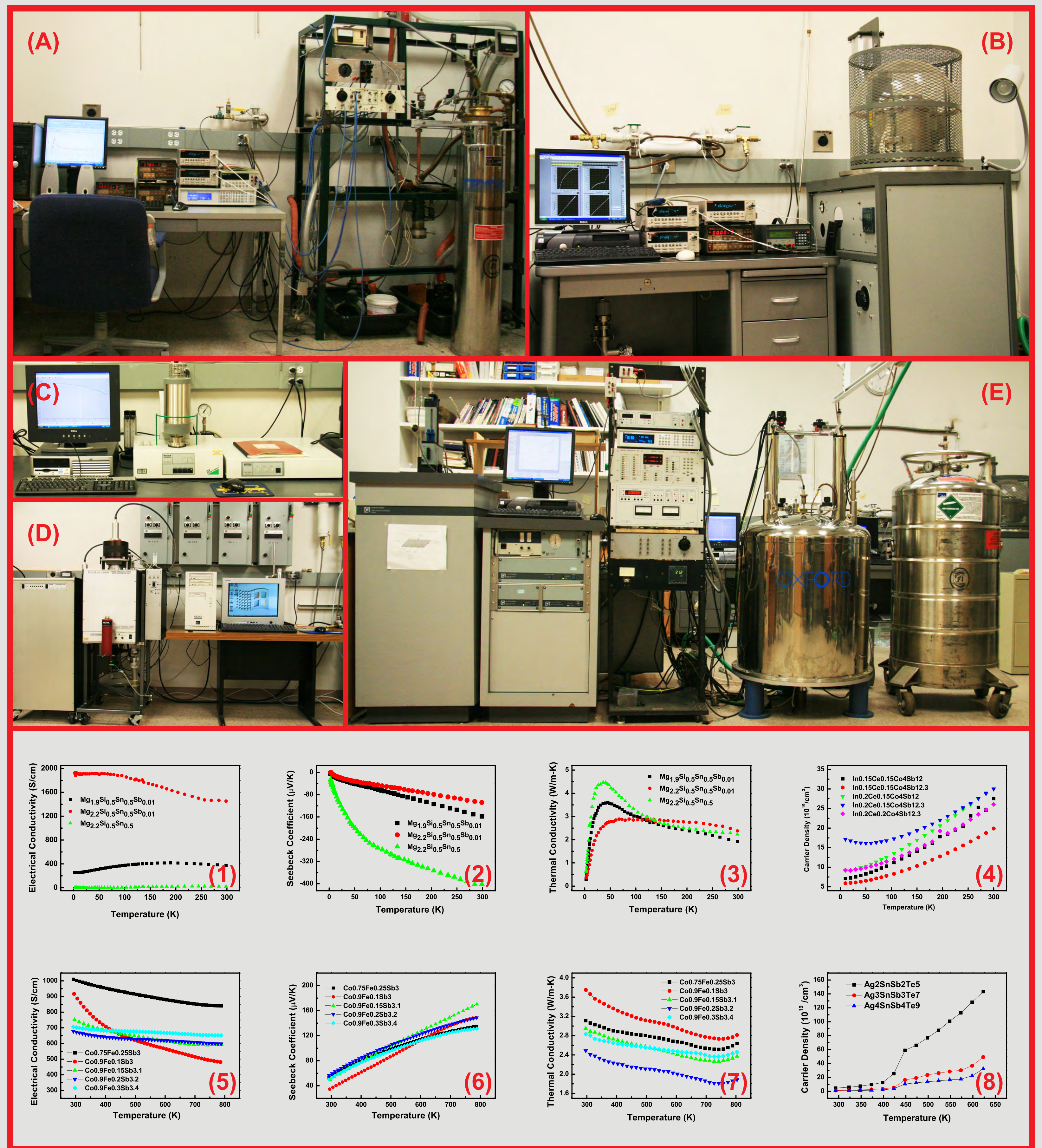
Considering the contribution to resistance from electrical contacts, the measurement of σ of thermoelectric materials is often conducted in a four-probe fashion. In order to avoid *Peltier Effect* contribution, a *Low Frequency AC Tenique* is highly recommended. As shown in Figure 1, electrical current I is introduced through large-area soldered contacts at either end of the sample. The potential difference ΔT is determined across point-contacts attached to the sample. In principle, σ can be given by (together with sample cross section A and probe seperation l):

$$\sigma = \frac{I}{\Delta V}\bullet\frac{l}{A}$$

2. S – Seebeck Coefficient

As illustrated in Figure 1, the temperature difference ΔT is determined by using a pair of thermocouples. And copper branches (for low temperature, 2K-300K), or legs of thermocouples (for high temperature, 300K-800K) are used to obtain the electrical potential difference ΔV. Hence the Seebeck coefficient can be calculated by:

$$S = \frac{\Delta V}{\Delta T}$$



Thermoelectric Materials Characterization from 2K to 800K

APPARATUS: (A) low temperature (2K-300K) test system for electrical conductivity σ, Seebeck coefficient S and thermal conductivity κ; (B) high temperature (300K-800K) test system for σ and S; (C) Netzsch DSC 404C system used for measurement of *Cp* (300K-1700K); (D) Flash Line 5000 system used for determination of diffusivity D using laser flash method (300K-800K); (E) temperature dependent (2K-300K, 300K-900K) Hall Effect measurement system.

DATA: (1-3) σ, S and κ (2K-300K) for solid solution $Mg_2Si_{0.5}Sn_{0.5}$ based materials[2]; (4) carrier density (2K-300K) for $In_xCe_yCo_4Sb_{12+z}$ materials[2]; (5-7) σ, S and κ (300K-800K) of $(Co,Fe)Sb_3$-$FeSb_2$ composite materials[3]; (8) carrier density (300K-650K) of TAST materials[4]

3. κ – Thermal Conductivity

At low temperature (2K-300K), the technique most frequently used to determine κ is the *Longitudinal Steady-State Method*. Researchers can use experimental set-up described schematically in Figure 1, as long as the heating power P and thermocouple seperation l are obtained (with l, A and ΔT which are previously known):

$$\kappa = \frac{P}{\Delta T}\bullet\frac{l}{A}$$

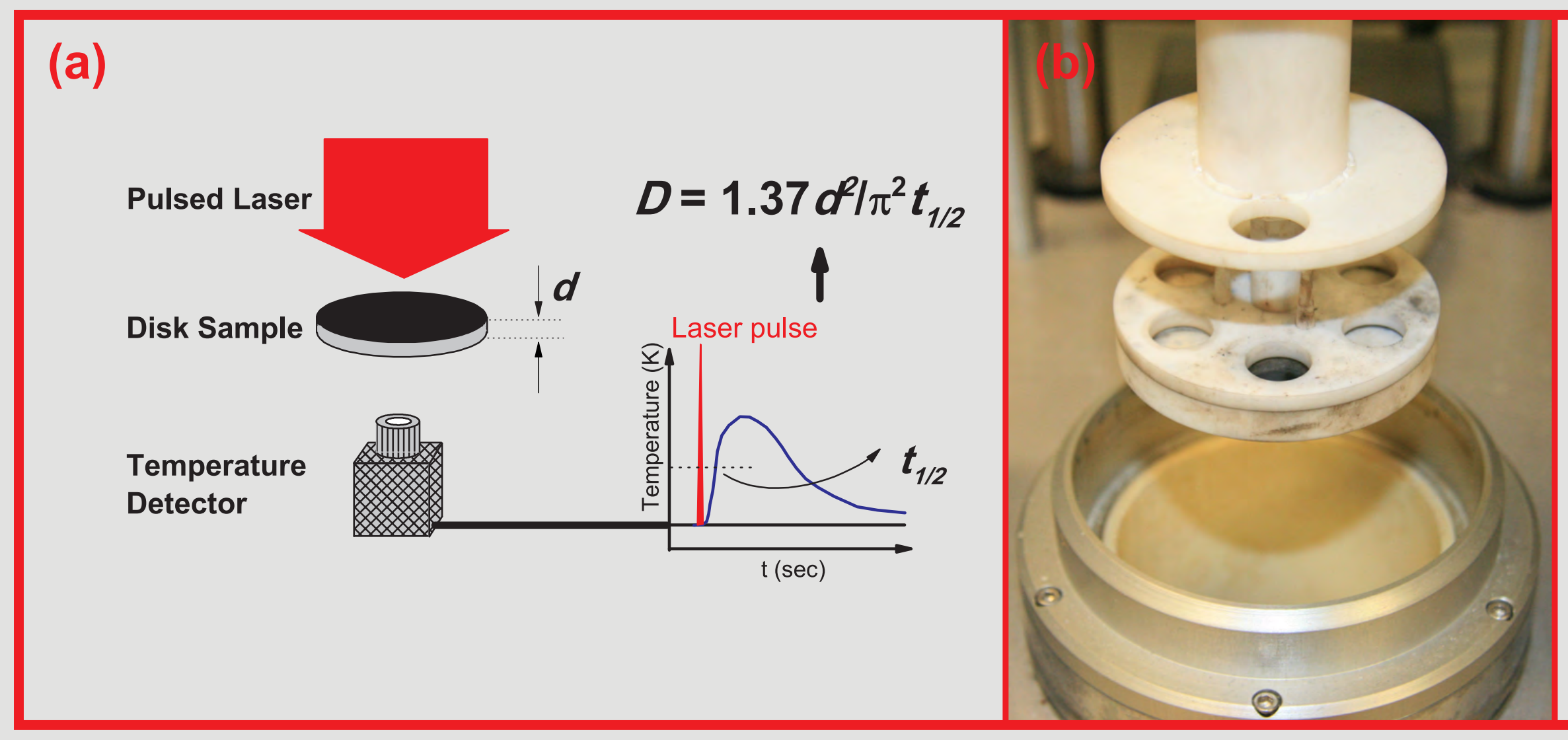
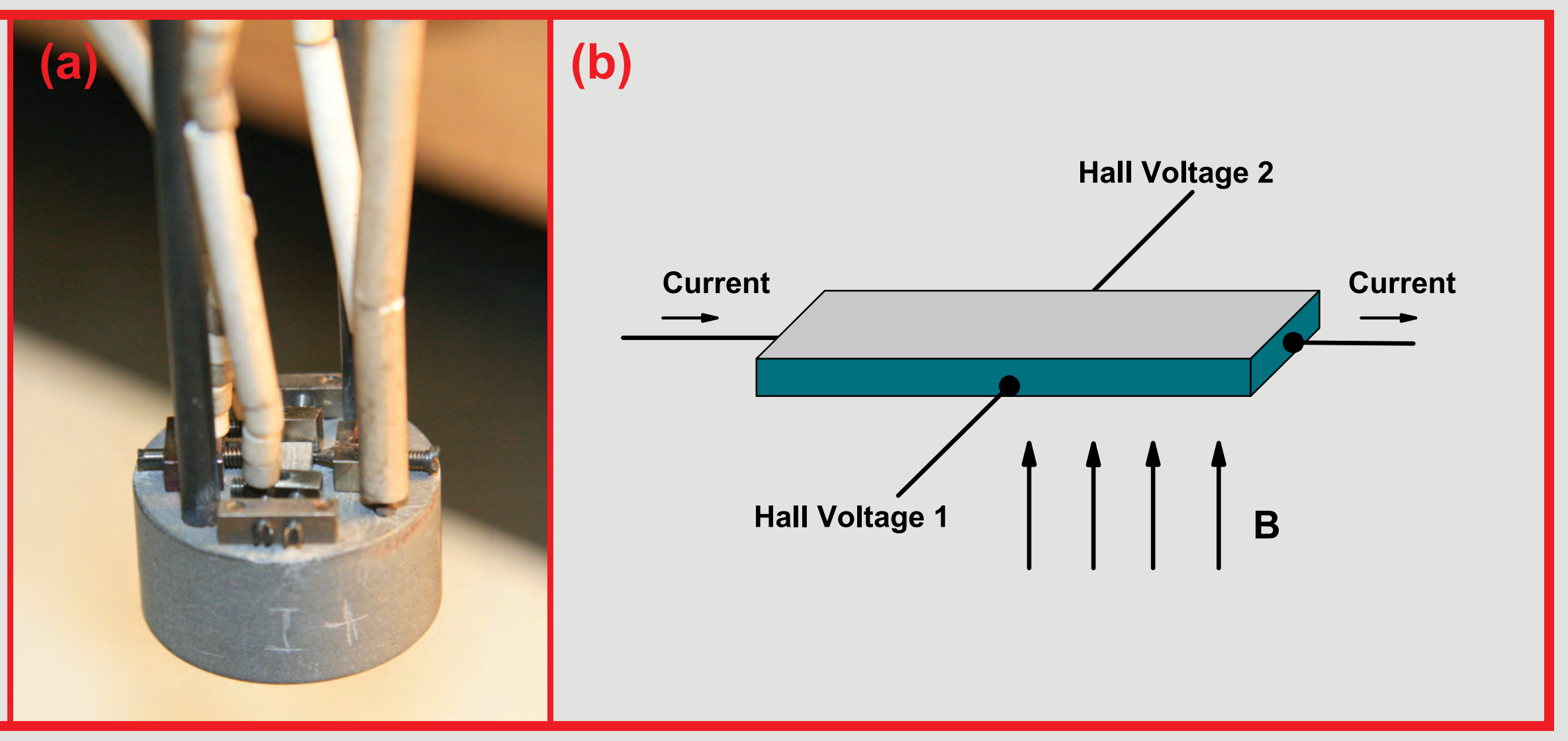


Figure 2. (a) The Laser Flash Method used in measurement of thermal diffusivity, along with (b) sample holder.

At high temperature (300K-800K), dynamic procedure may be preferred. It is common to obtain the thermal conductivity by measuring the density (ρ), the specific heat capacity (*Cp, see Middle Panel (C)*), and thermal diffusivity (*D, see Figure 2 and Middle Panel (D)*):

$$\kappa = \rho C_p D$$

Figure 3. (a) sample prepared with electrical contacts , ready for Hall analysis and (b) illustration of Hall Effect.



III. HALL EFFECT

Shown in Figure 3, Hall Effect can provide vital information about carrier density and mobility. Hall Effect study can be conducted in a broad temperature range in our lab. From 2K to 300K, a Quantum Design MPMS system combined with an AC Bridge is used for data acquisition. From 300K to 800K, a home-made apparatus, together with an Oxford air-bore superconducting magnet (up to 9T), is used for sample analysis. The whole system is shown in the *Middle Panel*.

IV. NOTES AND REFERENCES

[1] G. S. Nolas, J. Sharp, H. J. Goldsmid. Thermoelectrics - Basic Principles and New Materials Developments. Springer, 2001.

[2] In collaboration with Wuhan University of Technology, China.

[3] In collaboration with Michigan State University, USA.

[4] In collaboration with Northwestern University, USA.

DOE EFRC Summer 2010 Meeting, MSU, East Lansing, MI, USA, July 30, 2010

*Correspondence Email Address: CUher@UMICH.EDU