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Laser-modulated ac measurement of high temperature thermopower*

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An experimental set-up for ac-measurement of thermopower between room temperature and 1200K by using modulated laser-heating has been developed. The method shows many advantages compared with the conventional dc-measurements: convenience, applicability to small samples, possibility to measure the anisotropy of single crystals, and capability to continuously trace the temperature dependence of thermopower. The thermopower of a very short piece of pure Pt was measured with the present set-up to test the reliability and accuracy of our new method.

Keywords: high temperature, thermopower, experimental set-up, ac-measurement
PACC: 0720K, 0700, 0720

1. Introduction

Thermopower is one of the important electronic transport properties of conductors in both the application and basic research aspects. Although the high-temperature and low-temperature data are expected to be complementary to each other in understanding the physics involved in transport processes, reports on high-temperature measurements are considerably less than those of low-temperature measurements.[1] This is at least partly because the high-temperature experiment cannot be conducted as conveniently as in the low-temperature case.

In this paper, we present a set-up which uses modulated laser heating to realize the ac measurement of thermopower. By using the lock-in technology, the present method can continuously trace the temperature dependence of thermopower with much smaller temperature gradient than that in dc measurements, and hence will not lose any details, especially when some phase transition takes place.

The laser heating and the spring-driven mechanism allow for samples conveniently installed. The ac diffusion length can be adjusted by laser modulation frequency to match the sample size. Data obtained for pure-Pt thermopower is presented to confirm the reliability and accuracy of the apparatus.

2. Description of the set-up

The central part of the present set-up is schematically shown in Figs.1(a) and (b). A furnace together with the sample holder is placed inside a vacuum chamber which can be evacuated to 10^{-4}Pa. The high vacuum is of great help in reducing the thermal load and temperature fluctuation, which makes the temperature control and sweeping up to 1200K an easy task. An additional advantage is that the vacuum prevents the oxidation of the sample, the electrical leads, and the thermocouple.

An essential feature of the innovation is that the temperature difference along the sample is generated by a modulated laser beam of 808nm wavelength and the optical power is adjustable from 0 to above 40mW. The modulation frequency can be tuned from a few Hz to several hundred Hz, allowing the best match of the diffusion length to the sample size. The beam passes through a room temperature glass window 1 and a second quartz window 2 fixed to the stainless steel body 3 of the sample holder by a cap 4 with two screws, and finally falls onto the joint of a standard chromel-constantan thermocouple 5 pressed against the quartz window by the hot end of the sample 6. The joint end of the thermocouple is spot-welded with a copper wire 7 and compressed into a thin foil whose thickness is much smaller than the thermal diffusion length of the

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material. One face of the joint is painted black with carbon powder to obtain an efficient heating by the laser beam, while the other face makes good thermal contact with the hot end of the sample. The copper wire serves as one arm for the measurement of the thermopower of the sample. Since the heating is strictly restricted on the top face of the sample, it is easy to realize one-dimensional temperature gradient for our set-up. Therefore, the present set-up is very suitable for the measurements of the thermopower anisotropy of an anisotropic crystal. The sample 6 is placed in an alumina tube 8. The pressure between the sample and the thermocouple joint can be adjusted through the piston-like part 9, the spring 10, and the screw 11. The spring 10 is made of high temperature elastic alloy, ensuring good thermal and electrical contacts of the sample at both ends. A second chromel-constantan thermocouple with the hot end embedded in the sample holder body and the reference end placed in a flask at ice-point is used to measure the temperature of the sample holder. The control and sweeping of the temperature are realized by using a computer. The temperature difference between the two ends of the sample is kept at 0.2–0.3K, in contrast to the case of dc measurements where the temperature difference of several degrees is often needed to obtain acceptable accuracy. A small temperature difference is important especially for the case when a phase transition takes place. In this case large temperature difference may smear out the details of the thermopower behaviour upon crossing the transition. Thanks to the lock-in technology, satisfactory results are obtained in our ac measurement even at a temperature difference over an order smaller than in the dc measurements, as can be shown from the test measurement on Pt.

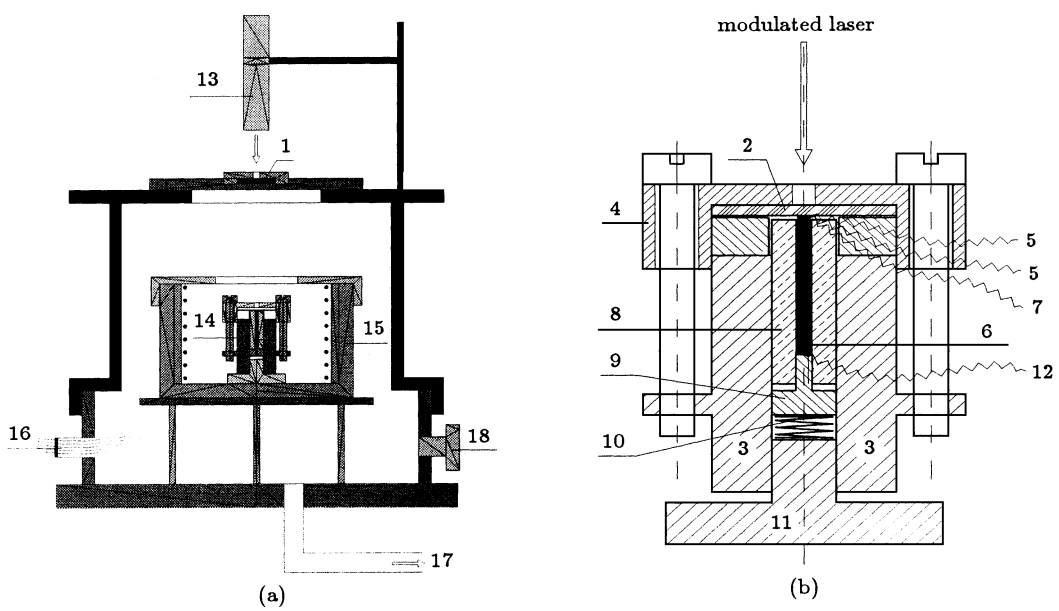


Fig.1. (a) general design of the set-up, (b) design of the sample holder. 1. glass window, 2. quartz window, 3. stainless steel body, 4. cap, 5. chromel-constantan thermocouple, 6. sample, 7. copper wire, 8. alumina tube, 9. piston-like part, 10. spring, 11. screw, 12. copper wire, 13. laser, 14. sample holder, 15. furnace, 16. measurement wires, 17. vacuum pump, 18. gas valve.

3. A test measurement

In order to test the reliability and accuracy of our set-up, we have measured the thermopower of pure Pt, and take Cu as a reference, as the thermopower data for both materials are available from the literature. Investigations of the thermoelectric properties of platinum and copper have been carried out by Berg,[2] Borelius *et al*,[3] Burkov and Heinrich,[4] Causack and Kendall,[5] Lander *et al*,[6] Roberts *et al*,[7] and Rudnitskii *et al*.[8]

The Pt sample is a piece of wire with 0.7mm in diameter and 4mm in length. The Seebeck voltage is measured by establishing a temperature difference of approximately 0.3K along the sample. Resultant temperature dependence of the absolute thermopower for Pt is shown in Fig.2. The thermopower measured with our set-up shows roughly a linear relationship with temperature. While the general behaviour is similar to that obtained by Rudnitskii *et al*,[8] Roberts *et al*,[7] and Burkov and Heinrich,[4] linear dependence was not observed in previous reports. Further investi-

gations are needed to clarify whose results are closest to the real property of the material.

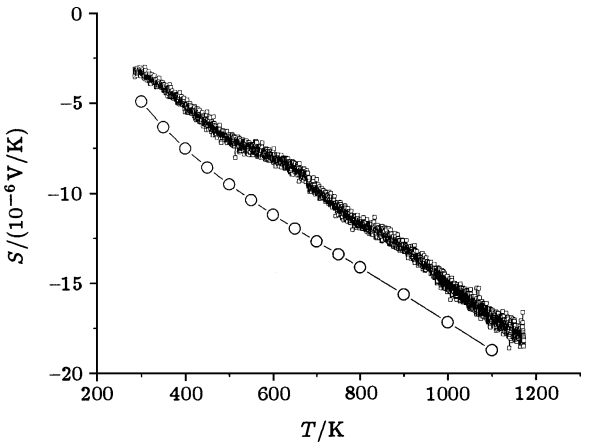


Fig.2. The absolute thermopower of Pt (circles represent the data of Burkov and Heinrich, and squares represent the data measured using our set-up).

4. Conclusion

In this paper we report a novel experimental set-up for the ac measurement of the high-temperature thermopower from room temperature to 1200K. The method shows many advantages compared with the conventional dc-measurements: convenience, applicability to small samples, possibility to measure the anisotropy of single crystals, and capability to continuously trace the temperature dependence of thermopower. Measurements on pure Pt sample confirm the reliability and accuracy of the set-up.

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