DOI 10.5162/SMSI2020/A5.4

Development of a new Measurement System for Electrical Conductivity and Hall Constant

Robin Werner[1], Jaroslaw Kita[1], Michael Gollner[2], Florian Linseis[2], Ralf Moos[1]
[1] Department of Functional Materials, University Bayreuth, 95440 Bayreuth, Germany
[2] Linseis Thermal Analysis, 95100 Selb, Germany
functional.materials@uni-bayreuth.de

Summary:

A new system to measure the electrical conductivity and the Hall constant for high temperature characterization is presented here. A new sample holder with a screen-printed platinum heater and four moveable electrodes allow measurements of any geometry according to van der Pauw's method up to 600 °C. The new design also enables the use of low-cost permanent magnets. Measurements of a gold thin-film and a boron-doped silicon-wafer demonstrate the functionality of the measurement system. Further developments will add the possibility to measure the Seebeck coefficient.

Keywords: measurement system, Hall constant, electrical conductivity, high temperature, low-cost

Motivation

The electrical conductivity, the Hall constant, and the Seebeck coefficient are among the important electrical parameters of material characterization. There is no existing measurement setup yet that combines all measurements in one apparatus. To the best of our knowledge, commercial measuring instruments can only measure either Hall constant and conductivity or Seebeck coefficient and conductivity. Usually these measurement systems are complex, expensive and they require very careful sample contacting. Oftentimes, expensive furnaces and electromagnets are required combined with a low flexibility in terms of sample geometry.

This contribution describes a new measurement setup that makes passive heating superfluous due to a directly heated sample holder in thick-film technology and allows the use of permanent magnets. A further advantage are the flexible, very small electrical contact points, which allow measurements of any lateral geometry with homogeneous layer thickness using van der Pauw's method. [1]

Description of the New System

The sample holder, shown in Fig. 1, consists of a 635 µm thick alumina substrate. A sample of any geometry with overall dimensions between 5 and 12.7 mm can be contacted by four moveable electrodes on the front side allowing Hall and conductivity measurements according to van der Pauw's method. On the reverse side, a screen-printed platinum structure is used to heat the sample area and the sample. The temperature on the upper side of the sample holder is controlled by the temperature-dependent resistance of the platinum heater structure.

The heater was designed by FEM analysis and validated by thermal imagining to guarantee a homogenous temperature distribution within the sample.

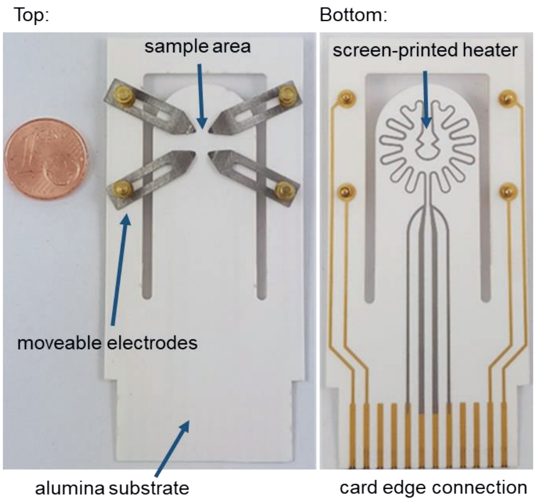

Fig. 1. Sample holder for Hall and conductivity measurements with a screen-printed heater

The four movable electrodes and the card edge connection allow a user-friendly exchange of the sample and sample holder and thus an easy installation and removal in the fixed gas floated measurement chamber. For Hall measurements, two counter-pole, moveable perma-

DOI 10.5162/SMSI2020/A5.4

nent magnetic yoke systems have been added. The measurement setup is shown in Fig. 2.

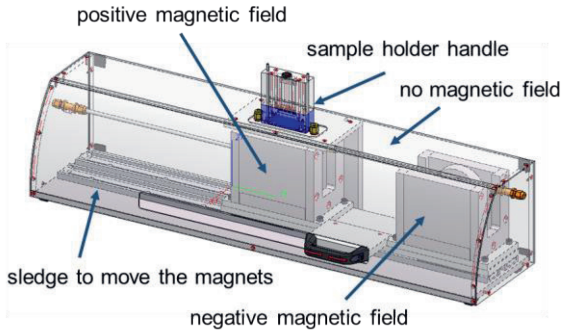

Fig. 2. Measurement setup with two moveable permanent magnetic yoke systems with +/- 760 mT

The magnets with a diameter of 90 mm and a distance of 20 mm ensure a homogeneous magnetic flux density of +760 mT or -760 mT within the sample area. This new measurement setup allows to do conductivity and Hall measurements according to van der Pauw's method.

Results and Discussion

In order to test the functionality of the new measurement system, a gold thin-film and a boron-doped silicon-wafer were measured at temperatures up to 600 °C. The results are shown in Fig. 3. All measurements are performed according to the guidelines of the ASTM International standard (F76-08). [2]

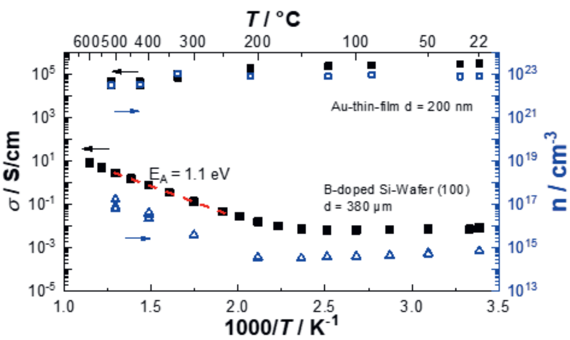

Fig. 3. Electrical conductivity and charge carrier concentration of a B-doped Si-Wafer and an Au-thin-film up to 600 °C

The measurements of a gold thin-film show a continuous decrease of the electrical conductivity while the charge carrier density remains nearly constant at increasing temperatures. This corresponds to a typical behavior of metals. It can be explained by the decrease of the mobility of the free electrons due to increased lattice vibrations with rising temperature. In contrast, the silicon wafer initially shows a slight decrease in conductivity up to a temperature of about 200 °C. After that, the conductivity increases by several decades, which can be explained by the typical formation of electron-hole pairs in the intrinsic region of a semiconductor. The charge carrier density in the intrinsic region above 200 °C also increases over several decades. The activation energy can be determined from these gradients. The calculated activation energy is 1.1 eV, which corresponds well to the band gap of silicon [3,4].

The measurements shown in Fig.3 can be seen as an evidence of the functionality of the new measurement system.

Conclusion and Outlook

The new measurement system allows measurements of the electrical conductivity and Hall constant up to 600 °C. The new sample holder with the screen-printed platinum heating structure can replace a furnace and enables the usage of permanent magnets even at high measurement temperatures.

In the future thermocouples and a second screen-printed heater for an additional temperature gradient for Seebeck measurements will be added. Furthermore, higher temperatures than 600 °C are envisaged.

References

[1] L.J. van der Pauw, A Method of Measuring Specific Resistivity and Hall Effect of Discs of Arbitrary Shape, *Semiconductor Devices: Pioneering Papers*, 174-182 (1991); doi: 10.1142/9789814503464_0017

[2] ASTM International, Test Methods for Measuring Resistivity and Hall Coefficient and Determining Hall Mobility in Single-Crystal Semiconductors, F76-08; doi: 10.1520/F0076-08

[3] C. Kittel, Introduction to solid state physics, Wiley, (2018), ISBN 978-1119454168

[4] G. Fasching, Werkstoffe für die Elektrotechnik: Mikrophysik, Struktur, Eigenschaften, Springer (2005); ISBN 3-211-22133-6