Electrical cell assembly for reproducible conductivity experiments in the multi-anvil

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Abstract

Electrical conductivity experiments under pressure and temperature conditions relevant to planetary interiors are a powerful tool to probe the transport properties of Earth and planetary materials as well as to interpret field-based electrical data. To promote repeatability and reproducibility of electrical experiments among multi-anvil facilities that use this technique, we designed and developed an electrical conductivity cell for multi-anvil experiments based on the 14/8 assembly that was developed to allow access to high temperatures. Here we present the details of design and parts developed for this cell that is available via the Consortium for Material Properties Research in Earth Sciences (COMPRES). The electrical cell has been tested up to 10 GPa and about 2000 °C on different materials (silicates and metals, both in the solid and liquid state).

Keywords: Multi-anvil, electrical conductivity, cell assembly, melts, silicates, metals

Introduction

Laboratory measurements of the electrical properties of Earth and planetary materials benefitted directly from the knowledge gained in material science and, in particular, electrochemical studies on aqueous solutions (e.g., Noyes et al. 1907; Fogo et al. 1954; Quist and Marshall 1968) and on solids (e.g., Bauerle 1969) that have been conducted since the beginning of the 20th century. Among the different setups developed, a common challenge consisted of avoiding polarization of the electrodes and in the sample, which can be accomplished by applying a small alternating current through the cell. Because semi-conductor materials present a frequency-dependent electrical behavior, efforts were also made to conduct electrical measurements over a scan in frequency (e.g., Koops 1951). The abundance of semi-conductor silicates in the crust and mantle of the Earth (and other terrestrial bodies) (e.g., Knight 1984; Sato 1986) motivated geoscience studies to develop setups allowing measurements of the dispersion in the frequency of rock samples under ever-increasing pressure and temperature. Among the different methods to visualize the electrical response of a semiconductor, the graphic representation of the sample’s complex impedance (e.g., Roberts and Tyburczy 1991; Huebner and Dillenburg 1995) has become the most commonly used, and experimental petrology facilities show a widespread usage of the impedance spectroscopy technique. In contrast, electrical studies of conductors (such as metallic core analogs) under pressure and temperature do not require measurements to be conducted over a range in frequency (e.g., Secco and Schloessin 1989; Deng et al. 2013; Silber et al. 2017); conductors present a very low capacitance and the frequency where induction equals zero is temperature independent (Constable 2015).

Different technical challenges arise from in situ and real-time electrical measurements under pressure and temperature, such as minimizing noise from the furnace on the electrical data and avoiding the breaking of the electrodes during compression. Among the different pressure device used in experimental geosciences, the multi-anvil apparatus is a relevant tool to conduct electrical investigations. First, by covering a broader pressure and temperature range than piston-cylinders and internally or externally heated pressure vessels, it reproduces the pressure conditions of the Earth’s crust and upper mantle as well as the entire interior of several small terrestrial bodies (such as Mars, Mercury, Ganymede, and the Moon). Furthermore, the recent development of high-pressure techniques using a Kawai-type multi-anvil press suggests that the maximum attainable pressure can reach up to 60 and 120 GPa using WC anvil and sintered diamond anvil, respectively. Second, multi-anvil investigations can be conducted on larger sample volumes than in very high-pressure devices such as diamond-anvil cells (DAC) and provide better constraints on temperature than DAC experiments.

The success of high-pressure and high-temperature electrical experiments to address geoscience questions depends on the quality and reproducibility of the measurements, as well as precise inter-laboratory comparisons. The Consortium for Material Properties Research in Earth Sciences (COMPRES) supported this study that consists of designing a 14/8 electrical assembly for the multi-anvil apparatus that can be used at pressure (up to about 10 GPa) and temperature (up to about 2000 °C) conditions relevant to terrestrial bodies, including the Earth. Here we present the development and testing of this electrical cell, which is adapted from the COMPRES cell assemblies (Leinenweber et al. 2012), and document the materials used as well as the calibration. This cell is available through COMPRES and interested experimentalists should be able to reproduce and adapt the cell with the designs and descriptions provided in this paper.