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Electrical resistance measurement in lithium under high pressure and low temperature

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Abstract

Lithium is known as a 'simple metal' and the lightest alkaline metal in the periodic table. At ambient pressure lithium forms a body-centred-cubic structure and the conduction electrons are considered to be almost free from interaction with the atomic core. However, Neaton and Ashcroft (Neaton J B and Ashcroft N W 1999 *Nature* **400** 141) predicted that dense lithium at around 100 GPa will be found to transform to a low-symmetry phase and show a semi-metallic behaviour, in their calculation. Recently Hanfland *et al* (Hanfland M, Syassen K, Christensen N E and Novikov D L 2000 *Nature* **408** 174) reported the experimental behaviour of the existence of new high-pressure phase of lithium above 40 GPa which tends towards symmetry-breaking transitions. Here we report electrical resistance measurements on lithium performed at pressures up to 35 GPa at the temperature of 80 K.

1. Introduction

Lithium is the lightest metal among the elements and is regarded as a free-electron-like 'simple' metal; however, a calculation [1] shows that at high pressure near 100 GPa a pairing of lithium ions causes an insulating or semiconducting transition. Hanfland *et al* [2] recently also reported a new high-pressure phase: a 16-atom cubic phase of lithium above 40 GPa. The predicted tendency of the paired lithium to exhibit a *Cmca* structure (similar to the behaviour of dense hydrogen) was enough to motivate us to start making measurements of the electrical resistivity and searching for the onset of superconductivity in high-pressure conditions. In this paper, experimental results on transport properties of high-pressure lithium are reported for pressures up to 35 GPa at the low temperature of 80 K.

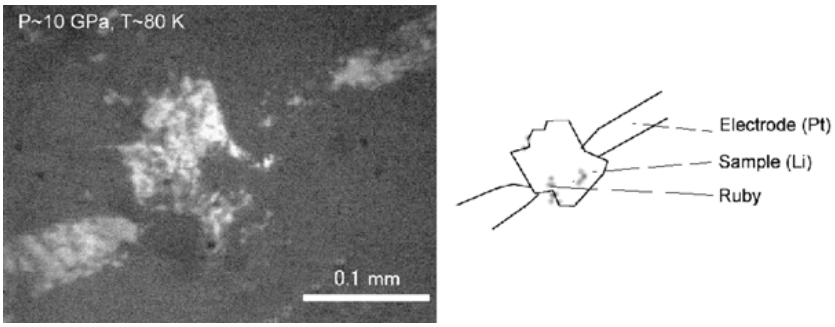

Figure 1. A photograph of the sample and electrode under pressure of around 10 GPa and at a temperature of 80 K. The shape of the lithium sample was slightly changed during application of the pressure. Two electrodes of platinum film are contacted on the sample. At just outside of this picture frame, two electrodes are divided into four probes and four-probe measurements are performed. Black dots are ruby chips on the sample surface.

2. Experimental details

The lithium sample, with a starting purity of 99.9%, was treated in an argon atmosphere in a water- and oxygen-free (<1 ppm) glove box. The sample was cut to a suitable size and put in a sample chamber in an insulated gasket. An Al_2O_3 powder layer covered the metal gasket (rhenium) surface and the sample chamber was approximately 5 μm in thickness and 70 μm in diameter. In order to prevent a chemical reaction reported in room temperature [4], the pressure was applied at low temperature. A membrane diamond-anvil cell (MDAC) was used to change the pressure during the low-temperature experiments. The pressure of the MDAC in a cryostat is controlled by a regulated gas pressure from the outside of the cryostat through a 15 MPa helium-gas cylinder. The pressure of the sample chamber was determined by a conventional ruby fluorescence method at low temperatures as well as room temperature. The typical assembling of the sample in the diamond-anvil cell (DAC) and the method of measurements of the electrical resistance under high pressure and low temperature are described elsewhere [3].

In the glove box the sample was pressurized to several GPa (not exceeding 10 GPa), then the MDAC was connected to the cryostat and cooled down to 80 K in a few hours. Figure 1 shows a typical photograph of the sample and electrode under pressure and at low temperature. In this case some of the lithium sample leaks out from the sample chamber; however, a reflected light from the sample surface is observed which demonstrates the continued existence of lithium—different from the case of a room temperature run.

The trial at room temperature is shown in figure 2. The sample and electrodes are arranged as for the low-temperature runs. At pressures above 20 GPa the lithium sample became rather transparent and the measured resistance showed a large increment. The increment of the resistance continued not only with increasing pressure but also with the passage of time. Moreover, some of the sample 'tried to escape' from the sample chamber through a small crack in the Al_2O_3 gasket used.

Figure 3 shows the pressure dependence of the measured electrical resistance of lithium at temperatures of 80 and 300 K. The large increment above 20 GPa in the curve for 300 K is not intrinsic and is due to deterioration and the chemical reaction of lithium. The resistance at 80 K was reproducible and showed a slight increment on applying pressure up to 35 GPa. There was no evidence of an abrupt change such as a metal-to-insulator transition.

Figure 4 shows the temperature dependence of the electrical resistance of lithium at pressures 20, 25, and 29 GPa and temperature down to 30 mK obtained with a clamp-type DAC.

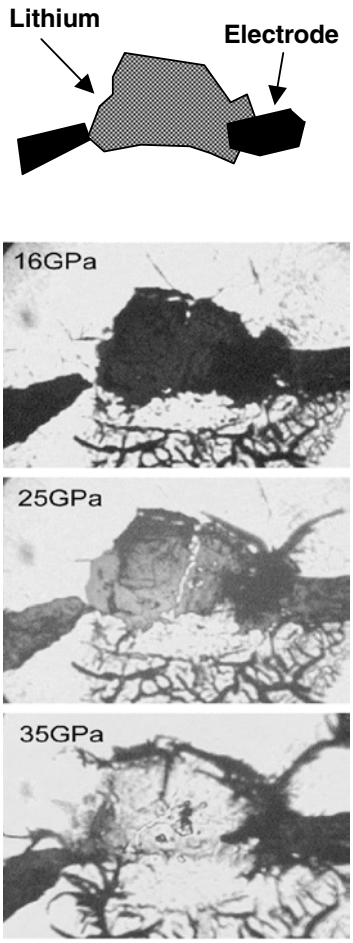

Figure 2. The trial at room temperature. The arrangement of the sample and electrodes as the same as in figure 1. At the pressure of 25 GPa the lithium sample became rather transparent; this continued with not only increasing pressure but also the passage of time. The sample 'tried to escape' from the chamber through the small crack in the Al_2O_3 gasket used.

In these pressure and temperature measurement regions lithium showed a metallic behaviour and no evidence of superconductivity. There may seem to be an anomaly at temperature around 100 K in these curves; however, it is not intrinsic, because between 70 and 300 K the temperature dependence is not shown very exactly. This is caused by the thermal expansion difference between parts of the DAC and the pressure decrease during cooling.

3. Results and discussion

The pressure dependence of the electrical resistance of lithium was measured at pressures up to 35 GPa at a temperature of 80 K. The resistance showed a slight increment with pressure and no evidence of an abrupt change such as a metal-to-insulator transition up to 35 GPa. In these pressure regions up to 29 GPa, the temperature dependence of the resistance was measured down to 30 mK. The resistance showed a metallic curve like those of typical metals and no

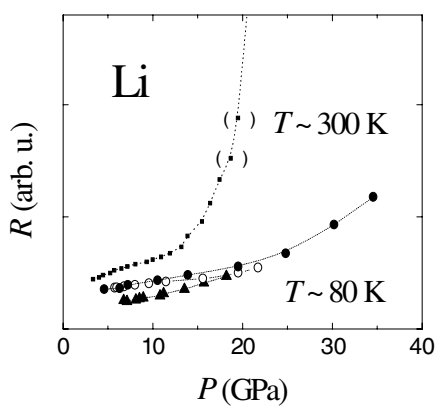

Figure 3. The pressure dependence of the scaled electrical resistance of lithium at a temperature of 80 K (●, ▲, ○) and 300 K (■). The large increment above 20 GPa at 300 K is not intrinsic, and is due to the chemical reaction of lithium. The resistance at 80 K showed a slight increment on applying pressure up to 35 GPa.

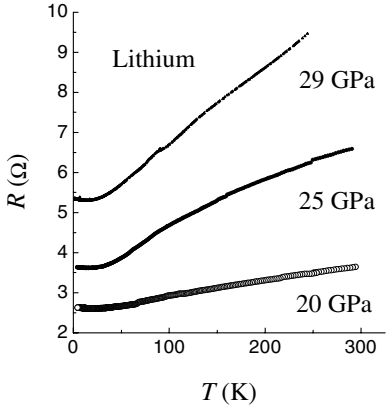

Figure 4. The temperature dependence of the electrical resistance of lithium under pressures of 20, 25 and 29 GPa. Lithium showed metallic behaviour at these measuring pressures. Note that in these experiments a clamp-type DAC was used; thus the data between 70 and 300 K do not show the temperature dependence very exactly.

onset of a superconducting transition. Experimental studies on the light alkaline metal lithium could show aspects of high-density hydrogen and its metallic state. Experiments at higher pressure are now proceeding.

Acknowledgments

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