The Electrical Conductivity of Post-Perovskite in Earth's D" Layer

Recent discovery of a phase transition from perovskite to post-perovskite suggests that the physical properties of the Earth's lowermost mantle, called the D" layer, may be different from those of the overlying mantle. A possible existence of a highly electrically conductive layer has been often suggested in the deepest mantle from geophysical modeling, where post-perovskite phase is dominant. The direct measurement of silicate post-perovskite has never been performed before.

We measured the DC electrical conductivity of $(Mg_{0.9}Fe_{0.1})SiO_3$ perovskite and post-perovskite phases at high pressure and temperature in a laser-heated diamond-anvil cell (DAC) (Fig. 1), up to 143 GPa and 3000 K corresponding to the condition at the D" layer of the mantle [1]. All the measurements were made at beamline **BL10XU** in order to identify the crystal structure from the XRD patterns. The resistance of starting material was ~10^9 Ω, and it dropped by several orders of magnitude after the synthesis of perovskite or post-perovskite upon heating at high pressure. The electrical conductivity was estimated from the measured resistance and sample geometry that is defined by the length between the electrodes, laser spot size, and thickness of the perovskite or post-perovskite layer. We have determined the electrical conductivity of perovskite phase to 117 GPa. The conductivity obtained at 37 GPa and ~2000 K was about 1 S/m (Fig. 2), which is reasonably consistent with the earlier measurements at 23 GPa in a multi-anvil apparatus [2]. The conductivity decreased remarkably between 58 and 104 GPa. This could be due to the high-spin to low-spin transition of iron in perovskite [3]. The conduction in the high-spin perovskite is dominated by a small-polaron process of electron hopping between ferrous and ferric iron sites. The unpaired electrons in the 3*d* orbital play important roles in this process, but the number of unpaired electrons of ferric iron decreases from five to one at this spin-pairing transition, thus resulting in a significant reduction in the conductivity. Similar reduction in the electrical conductivity has been observed for (Mg, Fe)O ferropericlase between 50 to 70 GPa at room temperature [4], and it has been attributed to the iron spin-pairing transition as well.

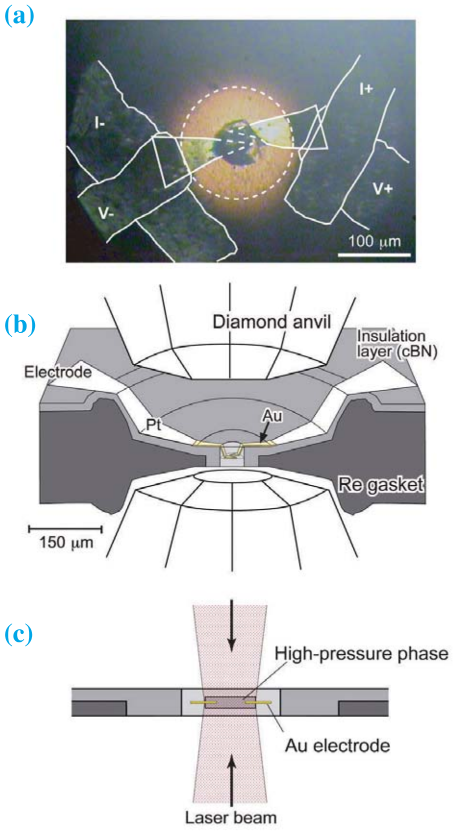

Fig. 1. **(a)** Microscopic image of the sample and electrodes. The quasi-four-terminal electrical resistance measurements were performed at high temperature (direct current of 1 mA was applied through I+ to I-, and the voltage drop between V+ and V- was recorded). **(b)** Schematic drawing of the configuration in a DAC. **(c)** Close-up view of the sample during heating by laser. About 30 or 50-μm areas of the sample and Au electrodes were heated from both sides. Only high-temperature part of the sample transformed to high-pressure phase.

The exceedingly high electrical conductivity of post-perovskite was observed in a couple of separate experiments (Fig. 2). The conductivity increased by three orders of magnitude when perovskite transformed to post-perovskite upon heating to ~2000 K for 20 min at 143 GPa. The sample showed the conductivity of >10^2 S/m (siemens per meter) with minimal temperature dependence. The high conductivity of post-perovskite was reconfirmed when post-perovskite was synthesized directly from the amorphous starting material by heating to 2000 K for 30 min at 129 GPa. After the complete pressure release, the sample was examined under both transmission electron microscope (TEM) and field-emission-type scanning electron microscope (FE-SEM) with a spatial resolution of 1.0-nm. We observed no metal-like phase throughout the sample. The post-perovskite phase has a stacked SiO_6-octahedral sheet structure with interlayer (Mg, Fe) ions. The high conductivity likely reflects the short Fe-Fe distance in the (Mg, Fe) layer, which is shorter than that in perovskite.

These results indicate that the electrical conductivity of (Mg, Fe)SiO_3 post-perovskite is much higher than that of perovskite (Fig. 2). A layer with a high electrical conductivity above the core-mantle boundary would enhance the electromagnetic (EM) coupling between the fluid core and solid mantle. It has been suggested that if the conductance of this layer is >10^8 S (at least 3×10^7 S), the resultant exchange of angular momentum between the core and mantle would be sufficient to change the length of a day on decadal timescales by a few milliseconds, as has been observed [5]. Our measurements indicate that the conductance of the D" layer may be 4×10^7 S (the conductance is related to the conductivity and thickness of the layer), which is marginally high enough to account for the decadal variations in length of a day. In addition, the EM coupling also affects the periodic precession of the Earth's axis of rotation (nutation). The high conductance of the post-perovskite-rich D" layer may explain the retrograde 18.6- and 1.0-year nutations that have been observed.

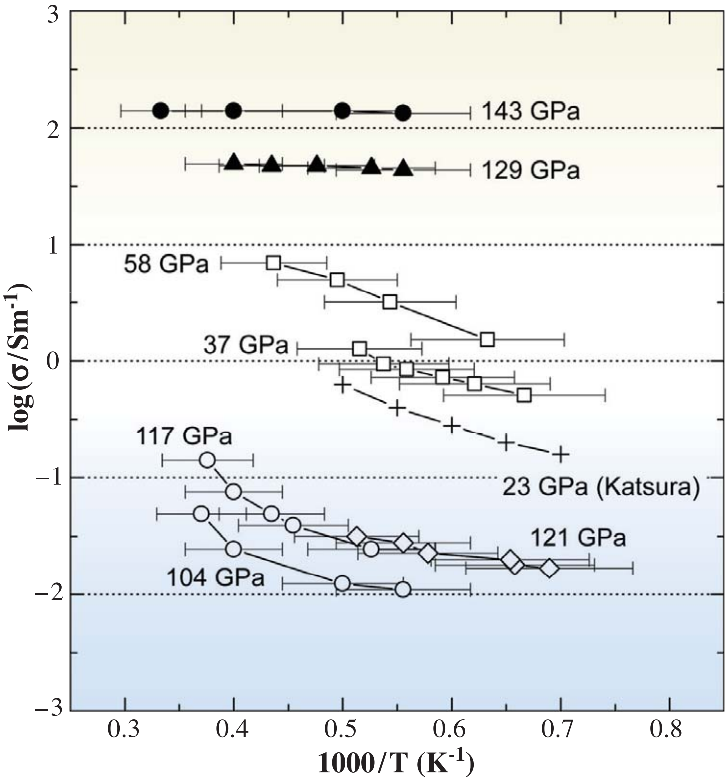

Fig. 2. Electrical conductivity (σ) of perovskite and post-perovskite as a function of reciprocal temperature. Different symbols show the results of different set of experiments. Open and closed symbols indicate measurements of perovskite and post-perovskite, respectively. Previous data on perovskite by Katsura *et al.* [2] are also presented by crosses.

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References

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