Low resistance and direction dependence on current of a pyromorphite compound doped copper

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Abstract

In our previous study[1-3], we reported various electrical properties of the Pb-Cu-P-O-S compound considering LK-99[4]. Through a series of structural analyses, we confirmed that the synthesized compound has a hexagonal pyromorphite structure. The chemical formula of oxide pyromorphite is known as $Pb_{10}(PO_4)_6O_2$, which has hexagonal system. In this study, we synthesized $Pb_{10-x}Cu_x(PO_4)_6O_{2-y}S_y$ (x: 0~3, y: 0~1). We doped this compound with copper and confirmed its low-resistance characteristics and the dependence on the direction of the current.

Keywords: Pyromorphite, Lead-Apatite,

1. Structure analysis

The X-ray diffraction (XRD) pattern of the synthesized pyromorphite-structured compound is presented in Figure 1. In this pattern, diffraction peaks corresponding to cuprite (Cu_2O) are observed (near $2\theta \approx 36.4°$), indicating the presence of cuprite as a impurity in the synthesized sample.

To eliminate this impurity phase, the sample was finely ground into powder and treated with ammonia solution, which is known to selectively dissolve cuprite. The XRD pattern of the sample after cuprite removal is shown in Figure 2. As seen in the figure, the diffraction peaks attributed to cuprite have disappeared, indicating that the cuprite phase was effectively removed through the ammonia. The result indicates that the ammonia-based purification method is effective for eliminating residual cuprite impurities from the synthesized product.

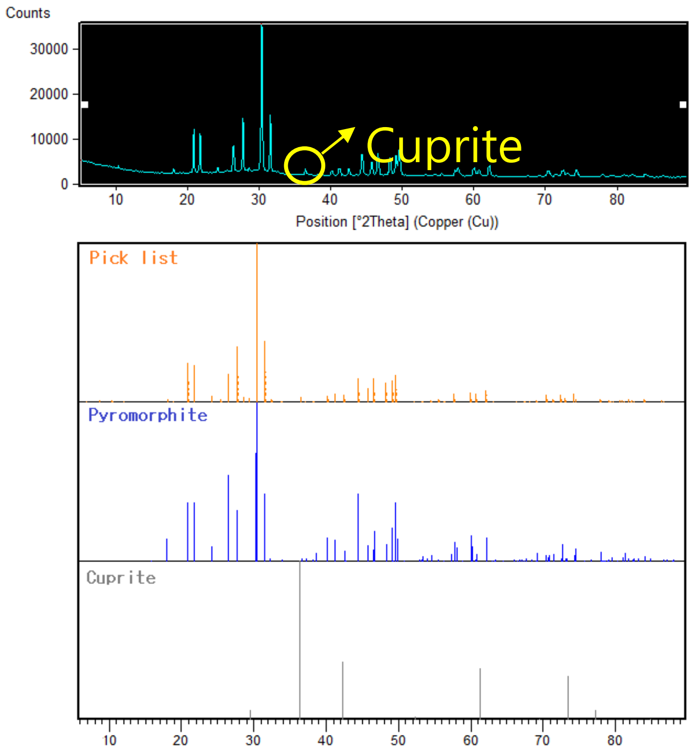

Figure 1. XRD pattern of the pyromorphite-structured compound with cuprite.

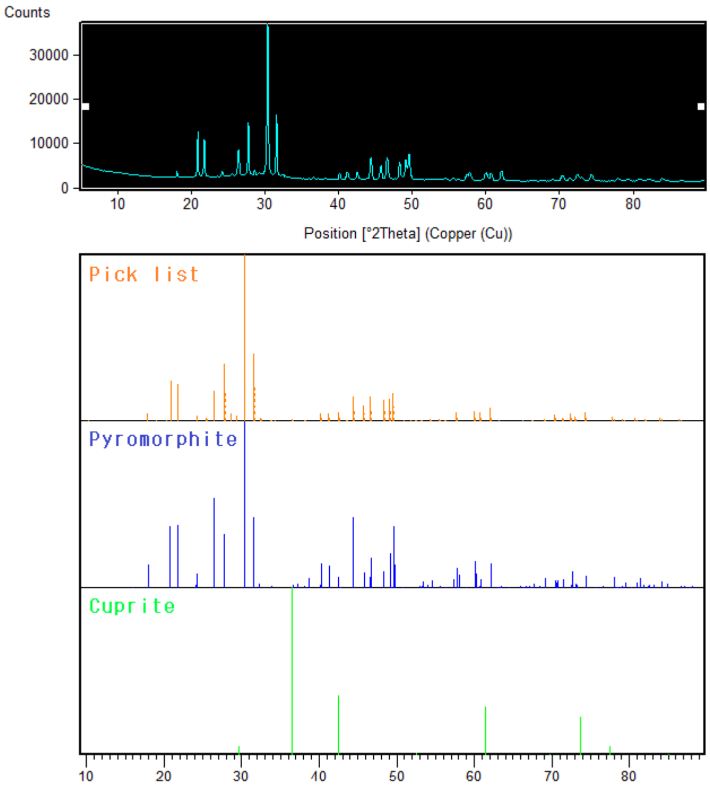

Figure 2. XRD pattern of the pyromorphite-structured compound.

2. Electrical properties of Pyromorphite and copper composite samples

We measured the voltage response to applied current on the sample using Keithley models 6221 and 2182A. The well-known four-probe method was employed, and the probe station used was the M.S.Tech M4P302 model with gold-plated probes. Figure 3 shows the measured voltage for applied current ranging from -100 to 100 mA in delta mode. Unlike commonly known metals, the copper doped with the compound sample showed current-direction-dependent behavior. It was observed that, depending on the direction of the applied current, the voltage remained near zero (0–100 mA), with variations in the range of only about 60 nV, suggesting possible noise. Moreover, when the voltage range is converted to resistivity, the value is approximately 6.3×10^{-9} Ω·m, which falls within the internationally defined zero-resistance range. In contrast, even in the direction where a slope is observed, the calculated resistivity is approximately 1.35×10^{-8} Ω·m, which is lower than the resistivity of copper (1.68×10^{-8} Ω·m).

This low resistance was also confirmed in the measurement of voltage for linear current sweep mode. Figure 4 clearly shows the current-direction-dependent characteristics. These results remained consistent even when the terminal directions were reversed. Using the synthesized samples, we will develop prototype low-resistance samples in the future to investigate these characteristics in more detail.

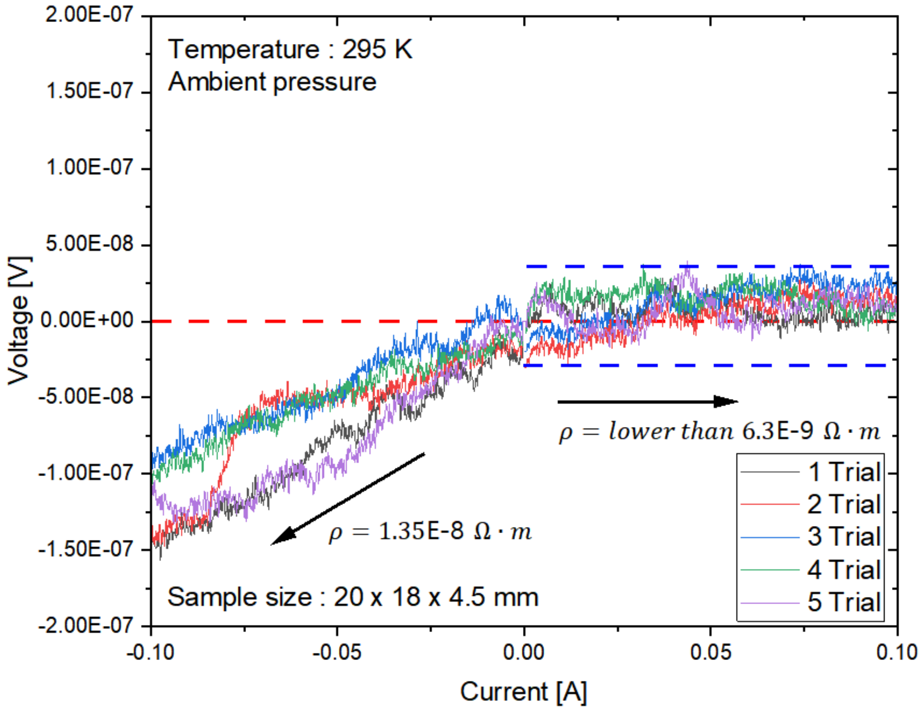

Figure 3. Measured voltages for applied current ranging from-100 mA to 100 mA (delta mode).

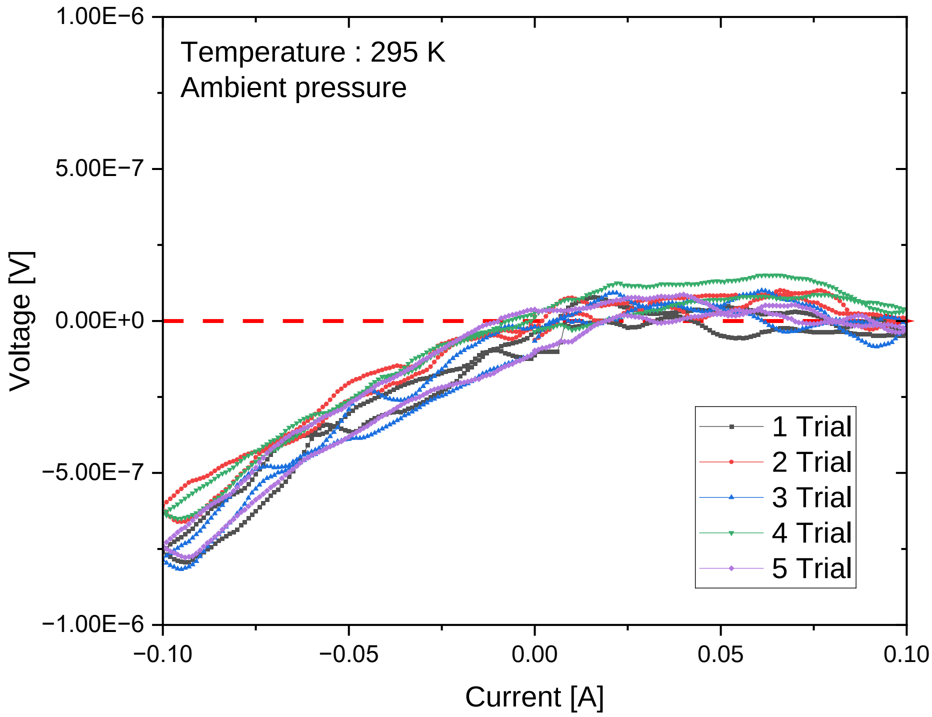

Figure 3. Measured voltages for applied current ranging from-100 mA to 100 mA (linear sweep mode).

3. Summary

In this study, we successfully synthesized $Pb_{10\text{-}x}Cu_x(PO_4)_6O_{2\text{-}y}S_y$ and investigated its electrical properties by doping into copper. Electrical measurements indicated a distinctive current-direction-dependent behavior, with extremely low voltage variations in one direction, corresponding to a calculated resistivity of approximately 6.3×10^{-9} Ω·m—within the internationally defined zero-resistance range.

These results showed low-resistance characteristics highlighting the potential zero resistance of this material for future applications. Further development of prototype samples will be performed to explore the mechanism and evaluate practical uses.

Acknowledgment

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Competing interests

Authors declare that they have no competing interests.

References

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