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Mini Review

Relationship Between the Electrical Resistivity and the Band Gap for High-Temperature Piezoelectric Crystals

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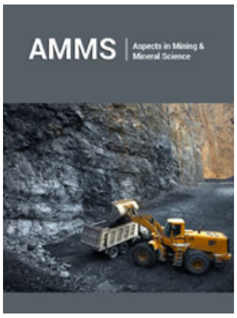
ISSN: 2578-0255



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Submission: December 30, 2019

Published: November 10, 2021

Volume 7 - Issue 5

How to cite this article: Shiwei Tian, Fapeng Yu, Xian Zhao. Relationship Between the Electrical Resistivity and the Band Gap for High-Temperature Piezoelectric Crystals. Aspects Min Miner Sci. 7(5). AMMS. 000673. 2021.
DOI: 10.31031/AMMS.2021.07.000673

Abstract

The electrical resistivity of piezoelectric crystals is a critical parameter for designing piezoelectric sensors working at elevated temperatures. In this report, the electrical resistivity as a function of band gap for different piezoelectric crystals is discussed and the potential relationship is presented.

Keywords: Piezoelectricity; Electrical resistivity; Electronic structure; Band gap; Sensor

Introduction

As a basic and critical parameter, the electrical resistivity of piezoelectric crystal determines the lowest usable frequency for piezoelectric sensors [1]. The electrical conduction of piezoelectric material is a complex process. It is known that the electrical conductivity (inverse of electrical resistivity) is dominated by the carriers, which are contributed from different factors, including ion migration, electron transition and micro crystal defects [2]. Considering the fact that the electrons motivated from the valence band to the conduction band contributes to the electrical conduction, the electrical conduction of piezoelectric crystals is believed to be associated with the band gap at elevated temperatures. To confirm this opinion, the electrical resistivities and electronic structures of high temperature piezoelectric crystals are studied comparatively.

Experiments

Different high-temperature piezoelectric crystals are selected for this study, including $LiNbO_3$ (LN), $La_3Ga_{5.5}Ta_{0.5}O_{14}$ (LGT), $Ca_3NbGa_3Si_2O_{14}$ (CNGS), $Ca_3TaGa_3Si_2O_{14}$ (CTGS), $Ba_2TiSi_2O_8$ (BTS), α-BiB_3O_6 (BIBO), $GaPO_4$, and $ReCa_4O(BO_3)_3$ (ReCOB) crystals etc. The band gap values for different high-temperature piezoelectric crystals are evaluated based on the transmission spectra recorded at ambient temperature. The Y-cut crystal samples with dimensions of $10\times10\times1mm^3$ are prepared to evaluate the electrical resistivity ρ_{22}. The electrical resistances are measured using a source meter (Keithley 2410C). The electrical resistivity is evaluated by equation (1)

$$\rho = UA/(It) \quad (1)$$

where U, I, A and t are applied voltage, measured current, area and thickness of the samples, respectively.

Results and Discussion

Among the investigated high-temperature piezoelectric crystals, the YCOB crystal is found to possess the largest band gap E_g being on the order of 6.17eV, while GdCOB and

PrCOB crystals show relatively lower E_g values, being around 6.15eV and 3.56eV, respectively. Interestingly, this sequence is in accordance with the electrical resistivity, which is determined to be $\rho_{YCOB}>\rho_{GdCOB}>\rho_{PrCOB}$, as can be seen in Figure 1. It is clear that the magnitude of the electrical resistivity shows a tendency with the band gap value for these high-temperature piezoelectric crystals. The variations of electrical resistivity (at 500 °C) as a function of band gap for other high-temperature piezoelectric crystals such as LN [3,4], LGT [5], CNGS, CTGS, BTS, BIBO [6,7], and $GaPO_4$ crystals [8,9] also obey this tendency, which strongly confirms the conclusion that the resistivity of the high-temperature piezoelectric crystals is associated with their electronic structure, the band gap of the crystal materials. The relationship between the electrical resistivity and band gap is further presented by data analysis. It is found that the order of magnitude of electrical resistivity for the electrical resistivity of high-temperature piezoelectric crystals is associated with the band gap value E_g.

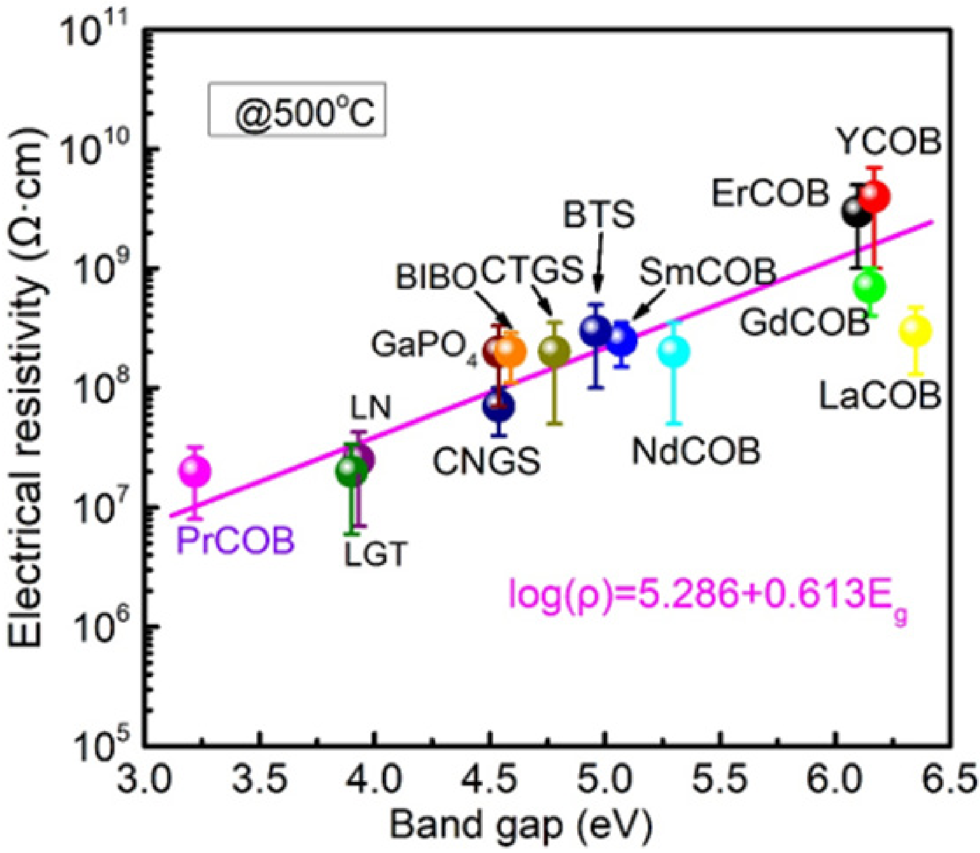

Figure 1: Electrical resistivity (at 500 °C) versus band gap for different high-temperature piezoelectric crystals.

Conclusion

The relationship between electrical resistivity and electronic structure for high-temperature piezoelectric crystals is studied and presented. The electrical resistivity is obtained to be associated with the band gap of piezoelectric crystals. It can be predicted that the piezoelectric crystals with large band gap values possess high electrical resistivity at elevated temperatures. This study is significant for designing and/or selecting piezoelectric crystals for high-temperature piezoelectric applications.

Acknowledgment

This work was supported by the National Natural Science Foundation of China (Grant No. 51872165), and The Primary Research & Development Plan of Shandong Province (2017CXGC0413).

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