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Phase transitions and electrical properties of High-Pressure High-Temperature treated bismuth oxide based material

A. Szpakiewicz-Szatan[1]*, T. K. Pietrzak[2], Sylwester J. Rzoska[1], Jerzy E. Garbarczyk[2], Jan Mizeracki[1], Witold Łojkowski[1]

[1]Institute of High Pressure Physics, Polish Academy of Sciences, Warsaw, Poland
[2]Faculty of Physics, Warsaw University of Technology, Warsaw, Poland

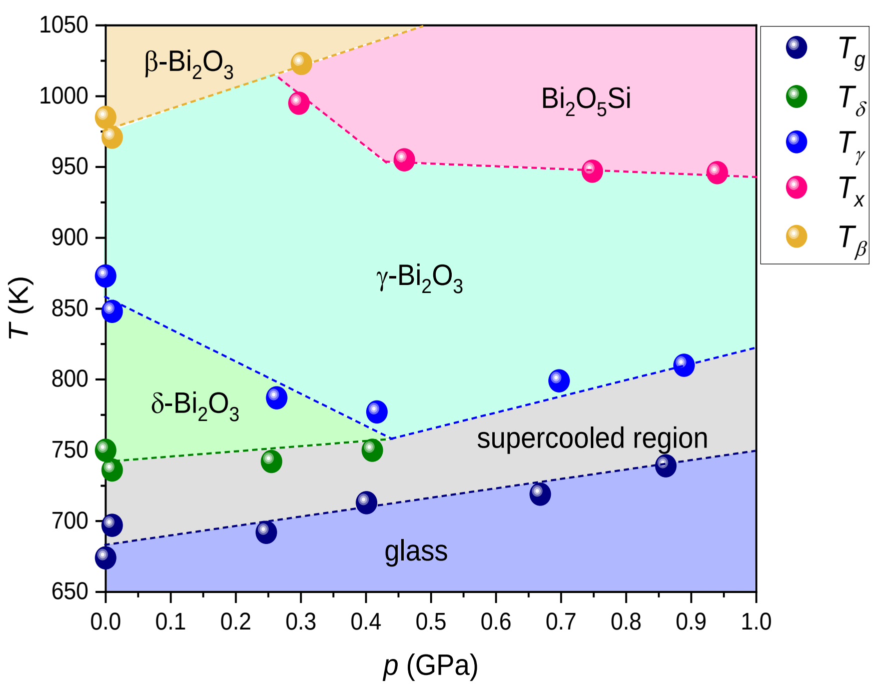
*Corresponding Author: aszpasza@unipress.waw.pl

1. Introduction

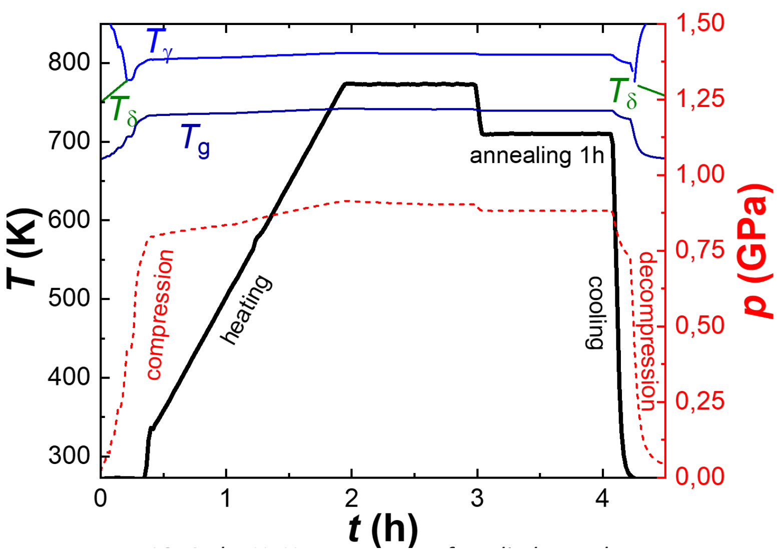
HPHT (high pressure high temperature) annealing slightly below the glass temperature (T_g) at pressure of just 1 GPa may lead to unusual properties, that are preserved after decompressing. In IHPP PAS there are HPHT processors operating at pressures up to 2.2 GPa at temperatures up to 1600°C with volumes up to 1 dm^3(1). In our previous studies(1) HPHT treatment of electron conducting glassy materials lead to simultaneous increase of electrical conductivity of 1-2 orders of magnitude and reduction of activation energy.

Bismuth Sesquioxide is a polymorphous material exhibiting properties of either an oxygen (super)ionic conductor or a semiconductor(2). It is potential candidate for use in Solid Oxide Fuel Cells due to δ-Bi_2O_3 superionic conductor properties(2)(3). Previously properties of bismuth oxide (III) have been studied either at near atmospheric pressure or on already crystalline material(4). **Aim of this study** was to observe whether HPHT treatment of Bi_2O_3 based glass could improve it's electrical properties.

2. Phase transitions

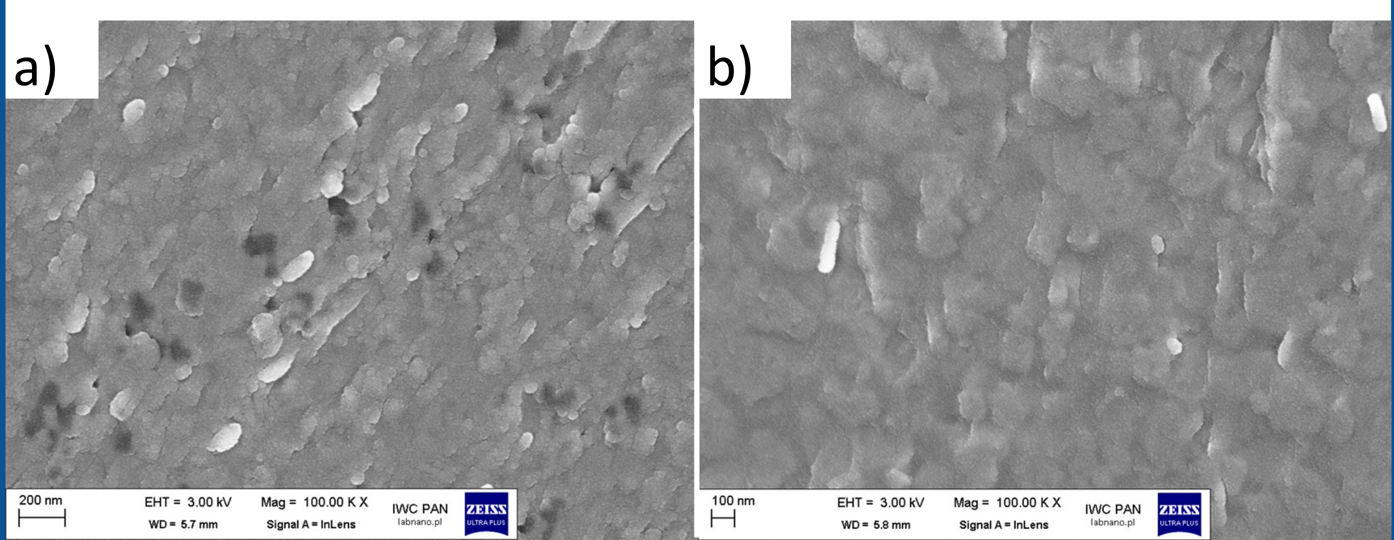


(Differential) Thermal Analysis at different pressures was utilized in conjunction with ex-situ X-Ray Diffraction to identify phase transitions. Based on those results *P-T* map of phase transitions was proposed.

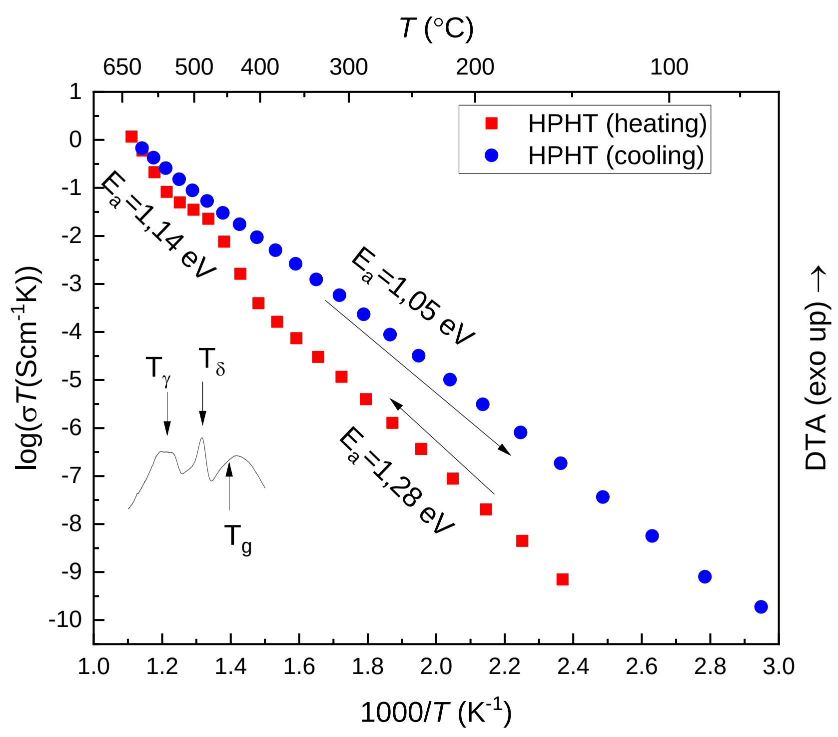


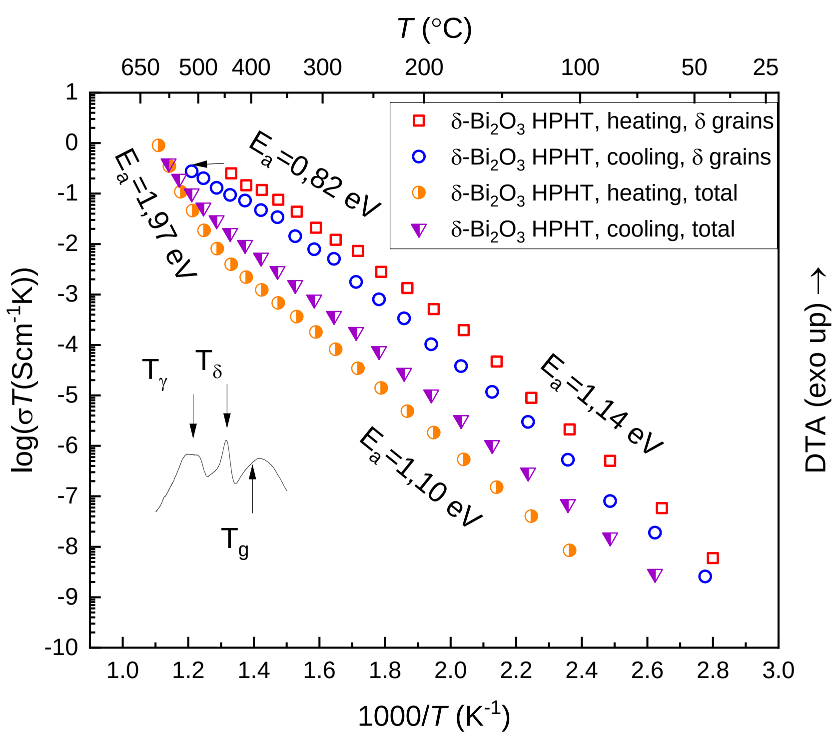
HPHT treatment was performed on glass ternary system and on thermally nanocrystallized at atmospheric pressure (HT) δ-Bi_2O_3.

Scanning Electron Microscopy was performed on material a) before and b) after HPHT.



3. Electrical properties





Electric conductivity was measured with Impedance Spectroscopy.

Two HPHT treated samples were compared:

1. Glass Bi_2O_3, HPHT treated for 1h at 250 MPa.
2. Nano δ-Bi_2O_3 further HPHT treated at 800MPa.

HPHT treated glass formed nanocomposite consisting of δ−Bi_2O_3 and Bi_2O_5Si with γ−Bi_2O_3 admixture embedded in SiO_2−Al_2O_3 glassy matrix.

In HT nano-δ-Bi_2O_3 phase conductivity of δ grains was clearly distinguishable from conductivity of whole sample.

In both cases further thermal treatment permanently increased total conductivity of the samples.

However, intra-grain conductivity of nano-δ-Bi_2O_3 was reduced.

4. Conclusions

- *P-T* map of phase transitions was obtained and utilized for HPHT treatment of selected crystalline phase (δ-Bi_2O_3).
- HPHT treatment allowed for better separation of polarization processes in nanocomposites containing δ-Bi_2O_3 grains and for easier determination of intragrain O^{2-} conductivity.
- The values of O^{2-} conductivity equal to: $4{\cdot}10^{-3}$ S/cm (grains of δ phase) and $4.5{\cdot}10^{-4}$ S/cm (total) at quite moderate temperature (600ºC) are very promising from applications point of view.

5. Acknowledgements

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6. References

(1)S. Starzonek, et al. *J. Non Cryst. Solids* **605** (2023) 122163
(2)E.D. Wachsman, K.T. Lee, *Science* **334** (2011) 935
(3)A. Szpakiewicz-Szatan, et al., *Materialia* **33** (2024) 101975
(4)H. Taniguchi, et al. *Angew. Chem. Int. Ed Engl.* **52** (2013) 8088