

# Conduction mechanism transitions in ZnMgO and their implications for all-oxide heterostructures in low-cost solar cells

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## ABSTRACT

Zinc magnesium oxide (ZnMgO) is a promising n-type material for all-oxide heterostructure solar cells due to its favorable optoelectronic properties, earth-abundancy, non-toxicity and compatibility with scalable deposition techniques such as ultrasonic spray pyrolysis(1). While studying the effect of magnesium (Mg) on defect states and the conduction mechanisms can contribute to a comprehensive understanding of the thin film properties and thus mastering their tunability during the synthesis process. To date, ZnMgO has not been thoroughly investigated in the literature. Our research aims to address this gap and provide valuable insights into this underexplored area.

In this work, we investigate temperature-dependent conduction in  $Zn_{1-x}Mg_xO$  ( $x=0-3\%$  Mg) thin films deposited by ultrasonic spray pyrolysis and conductivity measured from 40–320 K. Pure ZnO exhibits Mott-Variable Range Hopping (VRH) at low temperature, with hopping energy 3.1 meV, hopping distance of 11.0 nm, and localized-state density  $5.7 \times 10^{19} \text{ cm}^{-3} \text{ eV}^{-1}$ . With 1–2% Mg, Nearest Neighbor Hopping (NNH) emerges and coexists with VRH process at lower temperature, reflecting a modified shallow-donor landscape and reduced carrier concentration. At 3% Mg, NNH dominates with an activation energy of 9.9 meV. While at higher temperature, thermal activation energy is the predominant mechanism across all Mg compositions and it increases from 26.9 meV to 70.2 meV as the bandgap widens from 3.264 eV to 3.308 eV(2). These results reveal a composition-driven VRH to NNH transition, providing understanding of charge transport in ZnMgO alloys, which are of significant technological importance for applications in all oxide solar cells.

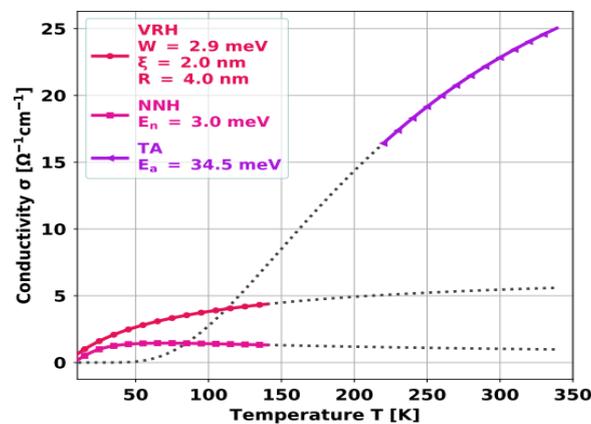


Figure 1 Illustration of the three conduction mechanisms in ZnO-based alloys

## References:

- (1) El Berjali, W.; Ould Saad Hamady, S.; Boulet, P.; Gries, T.; Horwat, D.; Pierson, J. F. High Quality ZnMgAlO Thin Films by Ultrasonic Spray Pyrolysis: Tuning of Optoelectronic Properties for Use as TCO, Window Layer, and Buffer Layer in All-Oxide Solar Cells. In *Oxide-based Materials and Devices XV*; Teherani, F. H., Rogers, D. J., Eds.; SPIE: San Francisco, United States, 2024; p 42. <https://doi.org/10.1117/12.3002565>.
- (2) Lone, K.; Colas, V.; El Berjali, W.; Ould Saad Hamady, S.; Hamzah, N. A.; Lim, W. F.; Ng, S. S. Shallow-Donor-Controlled Conduction in ZnMgO: Mg-Induced Transition Between Variable-Range and Nearest-Neighbor Hopping Mechanisms. *Phys. Status Solidi B* 2026, 263 (2), e202500596. <https://doi.org/10.1002/pssb.202500596>.