Emerging Trends in Perovskite-Based Nanomaterials for Bacterial Inhibition and Antimicrobial Applications

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Introduction

- Perovskites are an important class of crystalline materials with a characteristic structure
- Metal oxide perovskites are commonly represented by the general formula **ABO_3**.
- Physical and chemical properties can be tailored by:
  1. Elemental composition and substitution.
  2. Metal-ion doping.
  3. Oxygen vacancies and structural defects.
- They exhibit interesting optical, electronic, catalytic and chemical properties.

Why nanoscale?

- High surface-area-to-volume ratio.
- Enhanced surface reactivity .
- Tunable properties
- Improved catalytic activity
- Reactive oxygen species (ROS) generation
- Antimicrobial potential.

Perovskite structure: the ABO_3 framework

- The A-site is generally occupied by a larger cation.
- B-site contains a smaller metal cation
- Oxygen anions form BO_6 octahedra around B-site cations
- Distortions and substitutions can alter structure and properties

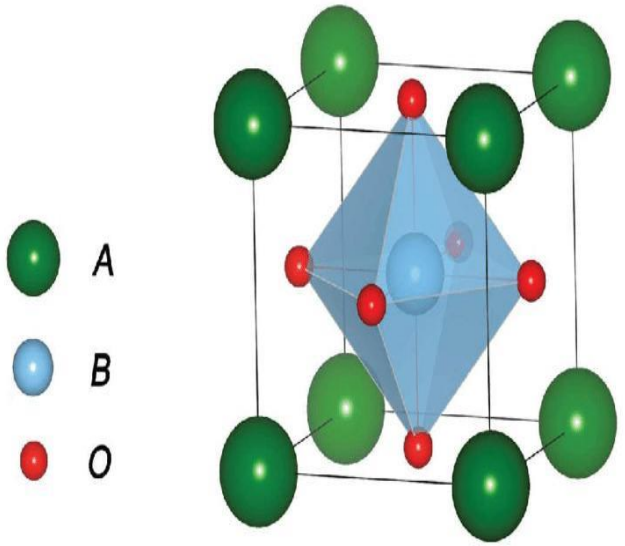


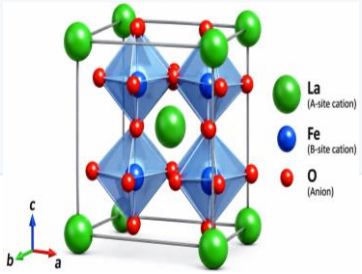
Fig 1: Structure of Perovskite

The ideal cubic model is a starting point; real compounds may be orthorhombic, tetragonal, rhombohedral or other distorted structures.

Perovskite Nanomaterials

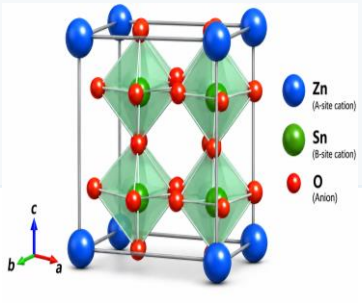
$LaFeO_3$ / W-type hexaferrite

$LaFeO_3$ combined with $BaCo_2Fe_{16}O_{27}$ in a nanocomposite.



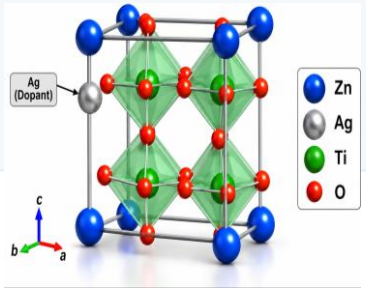
$ZnSnO_3$

Zinc stannate perovskite compared with ZnO and SnO_2.



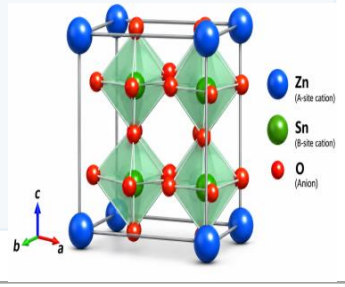
$ZnTiO_3$: Ag

Silver-doped zinc titanate nanocrystals.



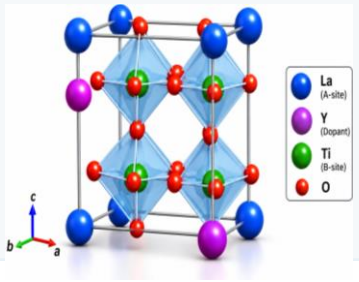
$ZnSnO_3$ (green route)

Fruit-extract-assisted synthesis of zinc stannate nanoparticles.



$LaTi_{1-x}Y_xO_3$

Yttrium-doped lanthanum titanate (x = 0, 0.05, 0.10).



Synthesis approaches

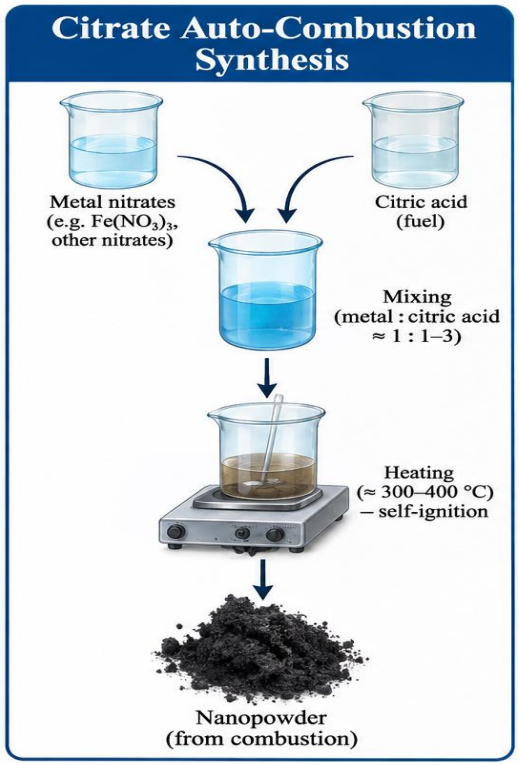


Fig 2: Auto- Combustion Method of Pervoskite Synthesis

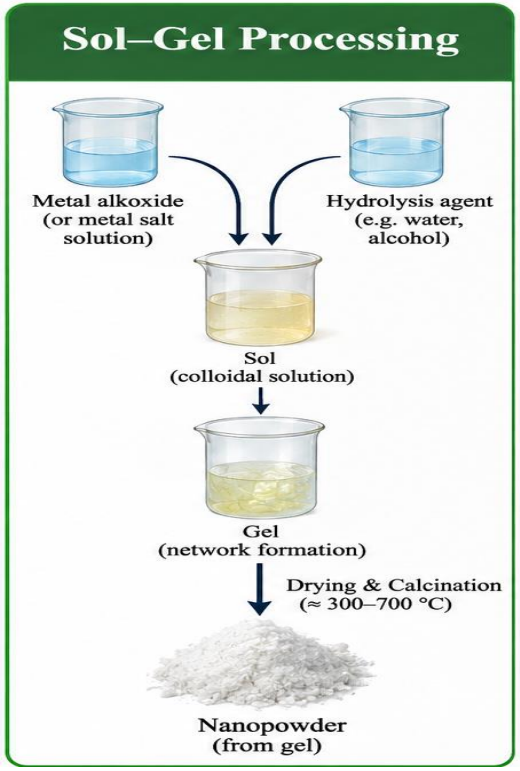


Fig 3: Sol- Gel Method of Perovskite Synthesis



Fig 4: Green Synthesis method of Pervoskite Synthesis

Structural, morphological and optical characterization

X-ray diffraction (XRD)

Identifies crystal phases, crystal symmetry and crystallinity; peak broadening can be used to estimate crystallite size.

SEM / FE-SEM and EDS

Visualizes particle/grain morphology and provides elemental-composition information.

UV–Vis / DRS

Evaluates optical absorption and estimates optical band-gap behaviour.

Synthesis and Antimicrobial Evaluation of $LaFeO_3$ and W-Type Hexaferrite

Synthesis and characterization

- Citrate auto-combustion route
- $LaFeO_3$ combined with $BaCo_2Fe_{16}O_{27}$
- XRD: orthorhombic perovskite + W-type hexaferrite
- SEM: spongy morphology; grains reported around 40–70 nm

Reported findings

- Direct / indirect optical gaps: 3.2 / 2.2 eV
- Antibacterial and antifungal activity evaluated
- Various Gram-positive and Gram-negative bacterial strains
- Potential application of the nanocomposite as an antimicrobial material

Synthesis and Antimicrobial Evaluation of $ZnSnO_3$ Nanomaterials

Study design

- Chemical synthesis of $ZnSnO_3$, ZnO and SnO_2
- Characterization using XRD, FE-SEM and UV–Vis
- Screening against Gram-positive and Gram-negative bacteria and a fungal strain

Main reported result

- $ZnSnO_3$ showed the strongest antibacterial efficacy among the materials tested
- SnO_2 showed no detectable antibacterial effect
- Different pathogenic microorganisms, including Gram-positive bacteria, Gram-negative bacteria and a fungal strain.

Synthesis and Antimicrobial Evaluation of Ag-Modified $ZnTiO_3$ Nanomaterials

Material preparation

- $ZnTiO_3$ and $ZnTiO_3$:Ag (x = 0.01, 0.02, 0.03)
- Sol–gel synthesis
- Annealing at 600–800 °C produced cubic-to-hexagonal phase transition
- XRD, FE-SEM/EDS and UV–Vis characterization

Functional properties

- Photocatalytic decolorization of methyl blue under UV irradiation.
- Antibacterial tests against Staphylococcus aureus and Vibrio.
- Ag doping enhanced photocatalytic and antibacterial performance.

. The 0.03% Ag-doped sample demonstrates the highest antibacterial performance

Green Synthesis and Antimicrobial Evaluation of $ZnSnO_3$ Nanomaterials

Green synthesis concept

- Limonia acidissima fruit juice used in an eco-friendly synthesis route
- $ZnSnO_3$ nanoparticles produced
- Study reports photocatalytic, electrochemical, antioxidant and antibacterial investigations

Reported functional scope

- Photocatalytic degradation of methylene blue
- Band gap energy 3.59 eV and 3.69 eV.
- Antibacterial activity investigated against Gram-positive *Staphylococcus aureus* and Gram-negative *Pseudomonas fluorescens*.

Synthesis and Antimicrobial Evaluation of Y-Doped $LaTiO_3$ Nanomaterails

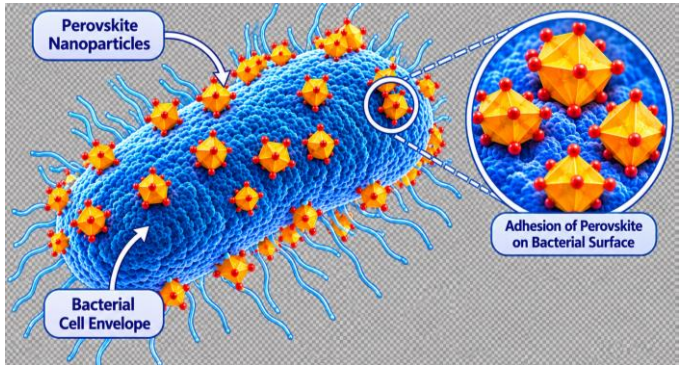
Composition and methods

- $LaTi_{1-x}Y_xO_3$ with x = 0, 0.05 and 0.10
- Auto-combustion followed by calcination
- XRD, UV–Vis DRS, FTIR, PL and FE-SEM/EDAX characterization
- Antibacterial tests: S. aureus and E. coli

Main reported findings

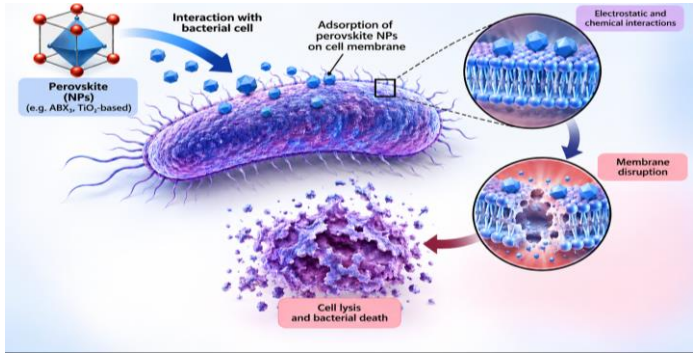
- Tetragonal crystal system reported
- 10% Y-doped sample showed 87.1% activity against S. aureus and 83.3% against E. coli at 500 mg/mL
- Antioxidant properties were also assessed

Antibacterial action of Perovskite Nanomaterials



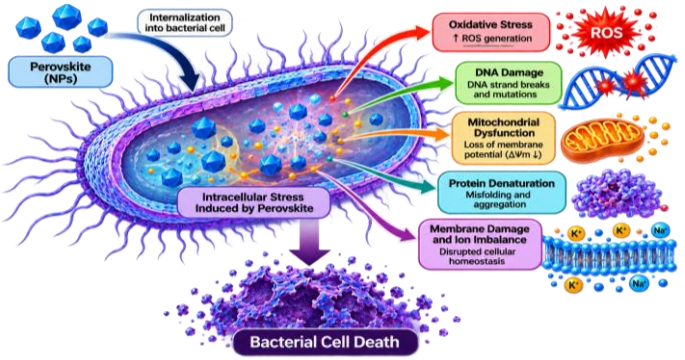
1. Cell-surface contact

Nanoparticles interact with the bacterial envelope; surface charge and chemistry may influence adhesion.



2. Membrane disruption

Contact may alter membrane integrity and permeability, causing leakage of cellular contents.



3. Intracellular stress

Reactive species or particle-associated effects may disrupt cellular components and metabolic processes.

Comparative Analysis & Limitations

Paper	Target bacteria	Key performance	Proposed mechanism	Key limitation
$LaFeO_3$ / W-type hexaferrite	Gram-positive and Gram-negative bacteria; notable targets: K. pneumoniae and P. aeruginosa. Antifungal activity also examined.	Promising activity, particularly against K. pneumoniae and P. aeruginosa.	Particle attachment to bacterial surfaces; possible membrane disruption and damage to cellular components.	Mechanism requires confirmation; scalability and long-term biological stability remain untested.
Y-doped $LaTiO_3$	Staphylococcus aureus (G+) and Escherichia coli (G−).	10% Y-doped sample at 500 µg/mL: 87.1% activity against S. aureus and 83.3% against E. coli.	Proposed nanoparticle penetration and cell-wall damage; smaller particle size may increase surface interaction.	Mechanism remains under investigation; only two bacterial strains were tested.
Green $ZnSnO_3$ (Limonia acidissima)	3 Gram-positive and 6 Gram-negative strains, including B. cereus, S. aureus, E. coli and P. fluorescens.	Antibacterial activity observed across a broad panel; strong responses reported for selected strains.	Specific antibacterial pathway was not experimentally established in the study.	Mechanism unclear; agar diffusion alone does not establish bactericidal action or performance in biological systems.
Ag-doped $ZnTiO_3$	S. aureus (G+) and Vibrio (G−).	Inhibition zones (S. aureus / Vibrio): pure 9/8 mm; 0.01% Ag 12/10 mm; 0.02% Ag 14/11 mm; 0.03% Ag 16/15 mm.	Ag interaction with bacterial membranes; ROS and interference with cellular functions are proposed contributors.	Only two bacterial groups tested; no MIC/MBC values; light contribution not clearly established.
ZnO, SnO_2 and $ZnSnO_3$	E. coli, Klebsiella sp., S. aureus, S. epidermidis and Candida albicans.	$ZnSnO_3$ gave the highest zone: 52 mm against S. epidermidis; ZnO showed moderate activity; SnO_2 showed no detectable inhibition beyond disc size.	Proposed ROS generation, cell interaction and membrane damage; possible metal-ion contribution.	Mechanism not directly verified; limited microbial panel and in-vitro testing.

Cross-study findings and interpretation

- Perovskite composition and dopant identity influence crystal phase, morphology and optical response.
- XRD and electron microscopy are central to confirming phase formation and nanoscale morphology.
- $ZnSnO_3$ and Ag-doped $ZnTiO_3$ studies report enhanced antimicrobial performance relative to selected comparators.
- The $LaTi_{1-x}Y_xO_3$ study reports concentration-dependent antibacterial behaviour.
- Reported antimicrobial results are specific to the strains, concentrations and assay conditions used in each paper.

Conclusion

Perovskite-based nanomaterials exhibit promising potential due to their tunable structural, optical, and surface properties. The studies demonstrate encouraging antibacterial and photocatalytic activities for selected compositions, highlighting their potential applications in antimicrobial materials. However, further research is required to establish their practical effectiveness through standardized antibacterial testing, mechanistic validation, and comprehensive safety assessments.

Future research should focus on optimizing dopant concentrations and composite ratios to enhance the antibacterial and photocatalytic performance of perovskite-based nanomaterials. Standardization of antibacterial testing methods and reporting procedures is essential for obtaining reliable and comparable results.

References

1. Ramadan, R. & Arman, M. M. (2025). Composition and antibacterial properties of newly developed layered perovskite/W-hexaferrite nanocomposite materials. Applied Physics A, 131, 375. https://doi.org/10.1007/s00339-025-08395-0

2. Abdalameer, N. K., Khalaph, K. A. & Jafar, A. M. (2025). Synthesis of ZnO, SnO_2, ($ZnSnO_3$) perovskite structure by chemical method and evaluation of antimicrobial activity. European Physical Journal Plus, 140, 294. https://doi.org/10.1140/epjp/s13360-025-06233-z

3. Kalaiselvi, C. R. et al. (2020). Synthesis and characterization of $ZnTiO_3$ and Ag-doped $ZnTiO_3$ perovskite nanoparticles and their enhanced photocatalytic and antibacterial activity. Journal of Solid State Chemistry, 281, 121019. https://doi.org/10.1016/j.jssc.2019.121019

4. Sunil Kumar, M. S. et al. (2024). Limonia acidissima fruit juice mediated eco-friendly synthesis of perovskite $ZnSnO_3$ nanoparticles: photocatalytic, electrochemical, antioxidant and antibacterial activities. Inorganic Chemistry Communications, 165, 112476. https://doi.org/10.1016/j.inoche.2024.112476

5. Prabitha, V. G. et al. (2023). Effect of Yttrium doping on antibacterial and antioxidant property of $LaTiO_3$. Discover Nano, 18, 155. https://doi.org/10.1186/s11671-023-03942-1

6. Soren, S., Chakroborty, S., Mahalik, R. R., Parhi, P., Pal, K., Behera, D., ... & Krishna, S. B. N. (2022). Evaluation of the antimicrobial potential of cerium-based perovskite (CeCuO3) synthesized by a hydrothermal method. *New Journal of Chemistry*, *46*(40), 19147-19152.

7. Abdalameer, N. K., Khalaph, K. A., & Jafar, A. M. (2025). Synthesis of ZnO, SnO2,(ZnSnO3) perovskite structure by chemical method and evaluation of antimicrobial activity. *The European Physical Journal Plus*, *140*(4), 294.

8. Mahmoud, A. M., Can, C., & Rabia, M. (2025). Lead-free perovskite KCsSnI1. 7Cl1. 3 material exhibiting superior photocatalytic antimicrobial activity. *Scientific Reports*, *15*(1), 32185.

THANK YOU