Catalytic Mechanism of Hydrogen Peroxide Decomposition by Redox-active Manganese Oxide Nanocrystals

Oleksandr Samoilov[1], Pavel Maksimchuk[1], Vladyslav Seminko[1], Mykyta Lupan[1], Ganna Grygorova[1], Andrey Onishchenko[2], Volodymyr Klochkov[1], Svetlana Yefimova[1].

[1]Yu.V.Malyukin Department of Nanostructured Materials, Institute for Scintillation Materials NAS of Ukraine, Kharkiv, Ukraine. [2]Department of Physics, Kharkiv National University of Radio Electronics, Kharkiv, Ukraine

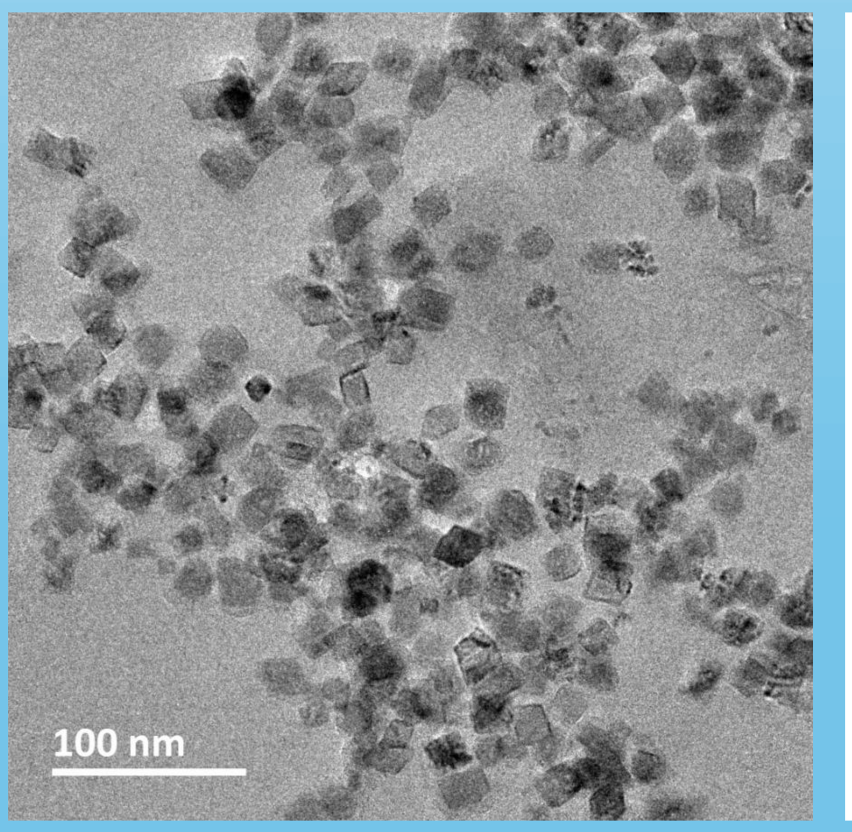
Rationale & Motivation

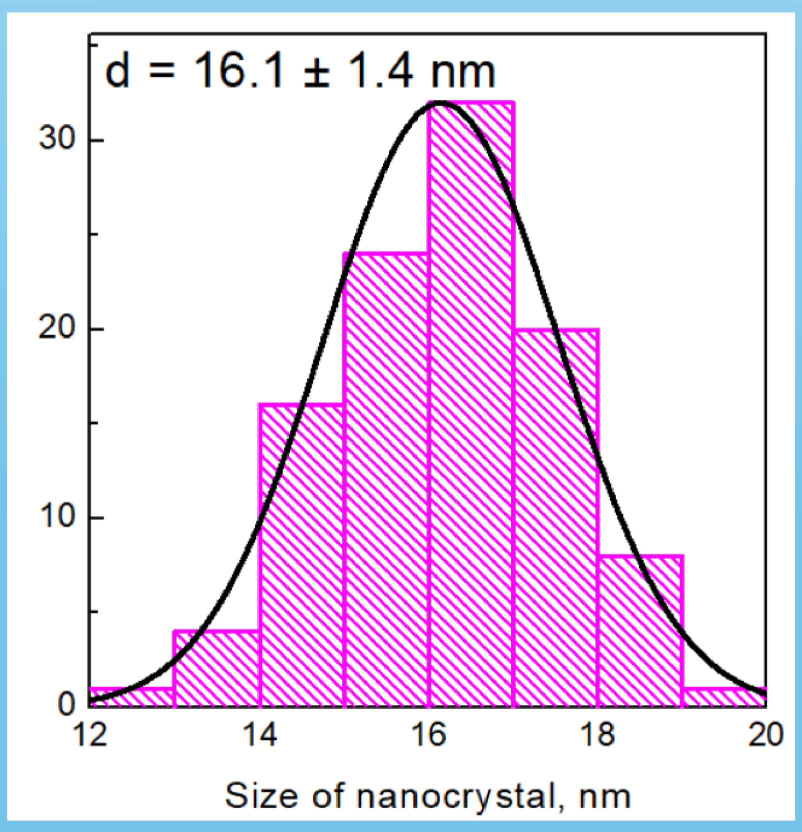
The Problem: Physiological ROS levels are essential for cellular signaling and metabolism, but their overproduction triggers disease-associated oxidative stress and biomolecular damage. Conventional regulation using low-molecular antioxidants or enzyme mimetics is severely limited by poor stability, rapid clearance, and low selectivity.

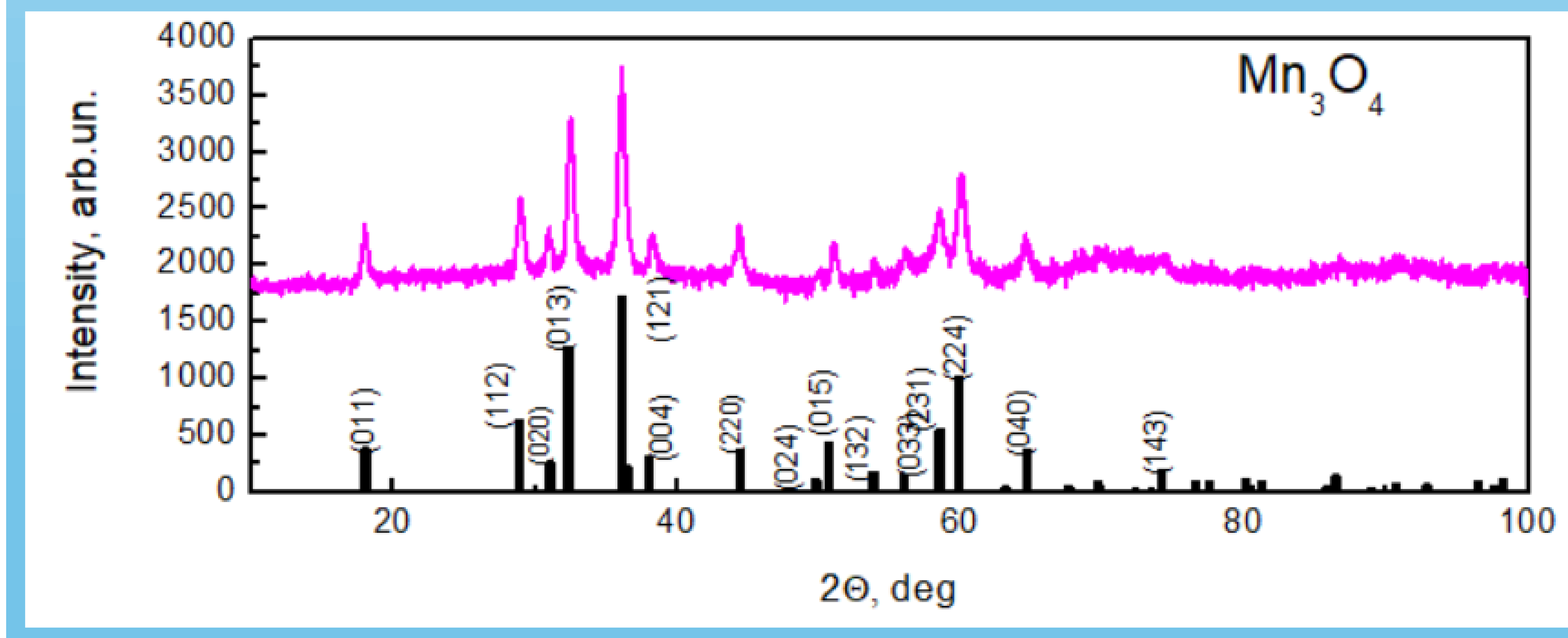
The Solution: Inorganic nanocrystals have emerged as highly efficient ROS regulators due to their high surface area, tunable composition, and enzyme-like catalytic activity. They can act as either scavengers or generators while maintaining exceptional chemical stability and prolonged activity.

Our Focus: Proposing and evaluating manganese oxide nanocrystals as robust ROS-modulating platforms capable of inducing controlled ROS elevation for the selective elimination of oxidative stress-sensitive cancer cells.

Morphological & Structural Validation

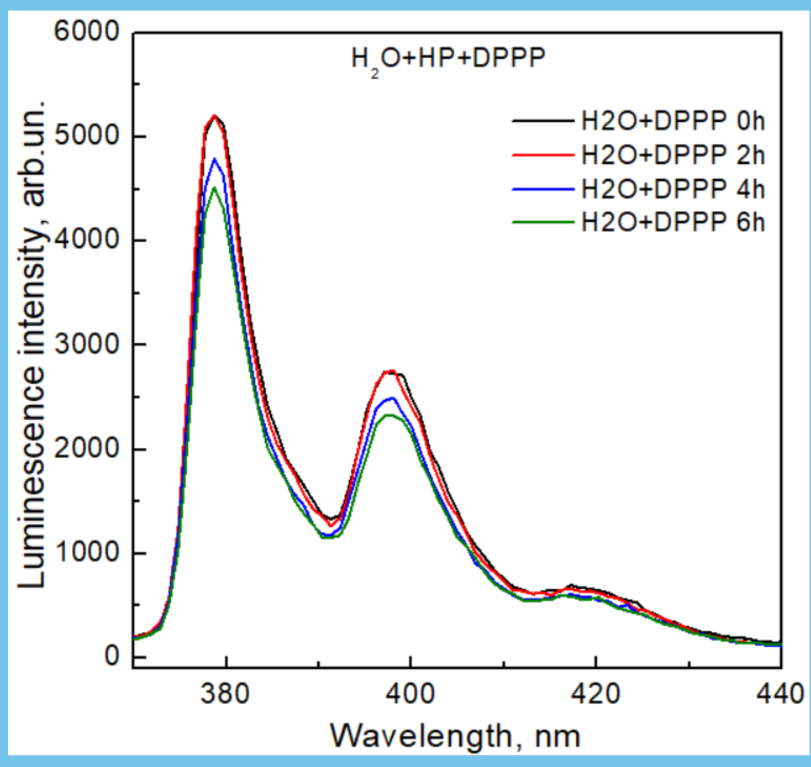


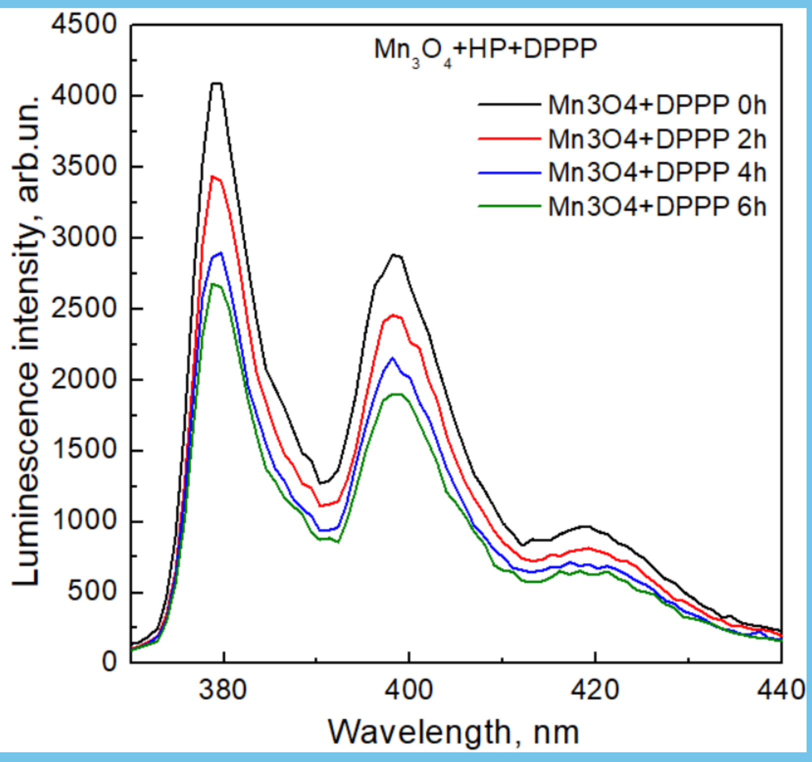




High-resolution TEM, size distribution, and X-ray diffraction jointly confirm the successful synthesis of stable Mn_3O_4 nanocrystals.

Catalytic Degradation of H_2O_2 (DPPP Molecular Probe)

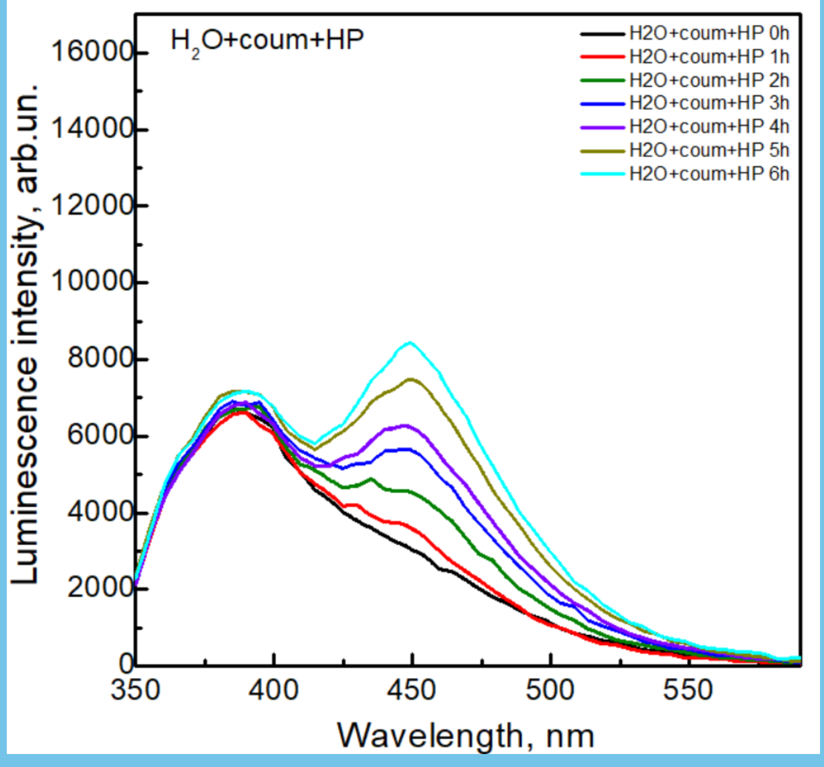


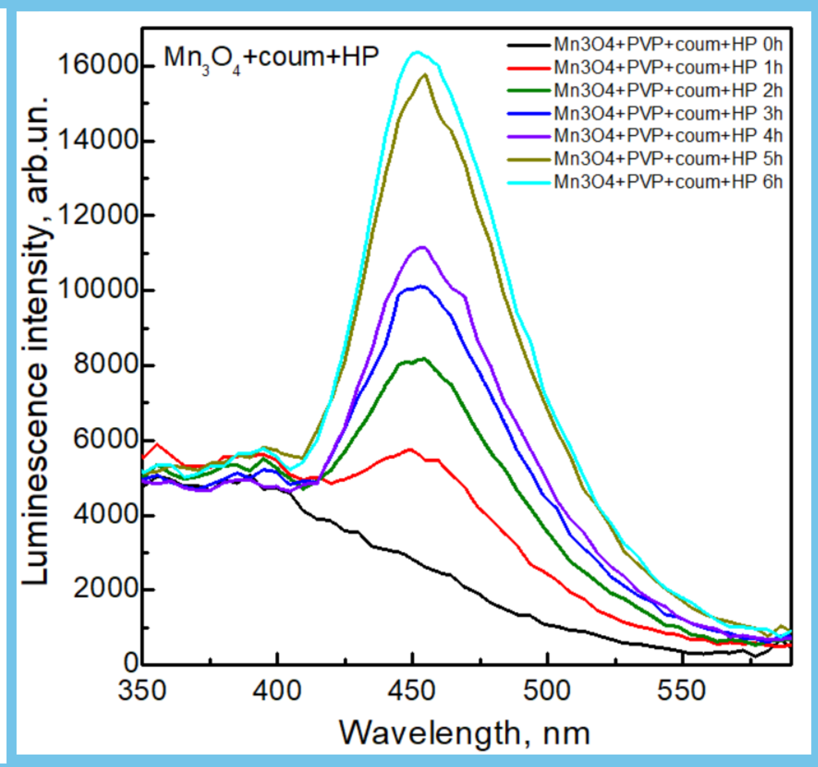


H_2O_2 Decomposition

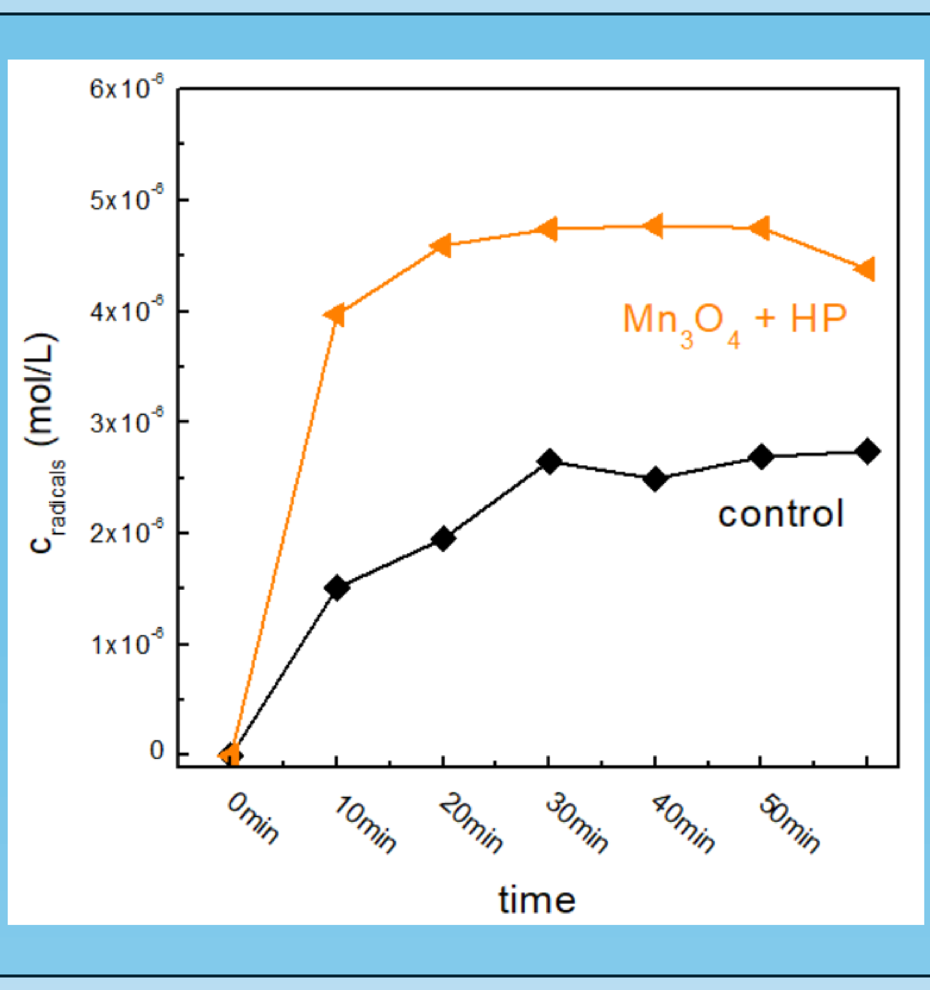
The DPPP probe effectively tracks hydrogen peroxide. The progressive lowering of the luminescence band over 6 hours in the Mn_3O_4 system precisely indicates the depletion of residual H_2O_2 compared to the stable control.

Hydroxyl Radical (•OH) Generation via Fenton-Like Reaction





•OH Formation (Coumarin) - A higher intensity ratio of the 460 nm band relative to the 380 nm band directly correlates with increased generation of cytotoxic •OH radicals.



•OH Formation (EPR) - Electron paramagnetic resonance definitively confirms the accelerated formation of •OH radicals in the presence of Mn_3O_4.

Summary & Clinical Implications

Mn_3O_4 nanocrystals demonstrate exceptional enzyme-like efficacy in catalytic ROS regulation. By actively converting H_2O_2 into highly damaging •OH radicals, these nanozymes show significant promise for advancing targeted, oxidative stress-based therapeutic interventions against malignant cells.

Acknowledgments

This research was supported by National Research Foundation of Ukraine, Grant № 2025.07/0093