Synthesis and Characterization of Platinum Nanoparticles on Reducible Metal Oxide Supports for Catalytic Applications and Hydrogen Sensing

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Introduction

The reduction of 4-nitrophenol (4-NP) to 4-aminophenol (4-AP) and the detection of hydrogen (H_2) are crucial for environmental protection when it comes to water and air pollution. 4-NP, a toxic and persistent pollutant from industrial waste, is efficiently converted to 4-AP using platinum nanoparticles (PtNPs) on metal oxides such as SnO_2, α-Fe_2O_3 and MnO_2. This reduces the toxicity of the wastewater and at the same time produces a valuable chemical for pharmaceuticals and dyes. H_2, a clean energy source, must be reliably detected due to its flammability. PtNPs on reducible oxides improve the adsorption of H_2 and change the electrical resistance for accurate detection. The interactions between Pt and oxide improve the sensitivity, response time and stability of the sensor, ensuring real-time monitoring and long-term usability in industrial and environmental applications.

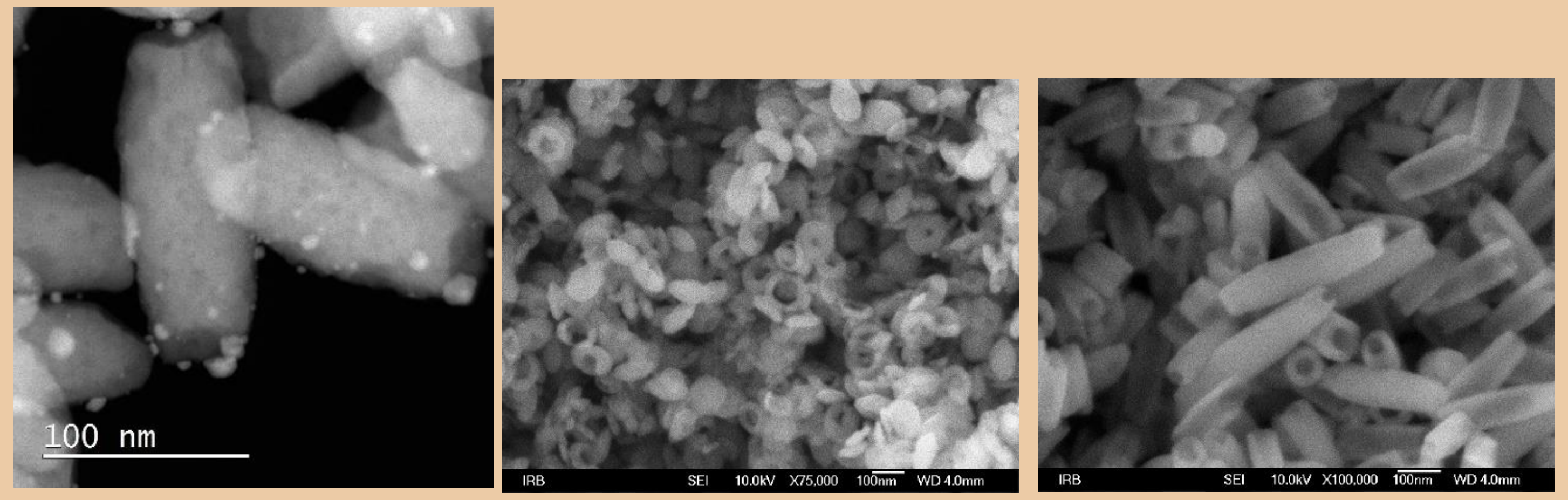

Figure 1. STEM dark-field image of FePt5 nanotube sample, SEM image of α-Fe_2O_3 nanoring and nanotube morphology.

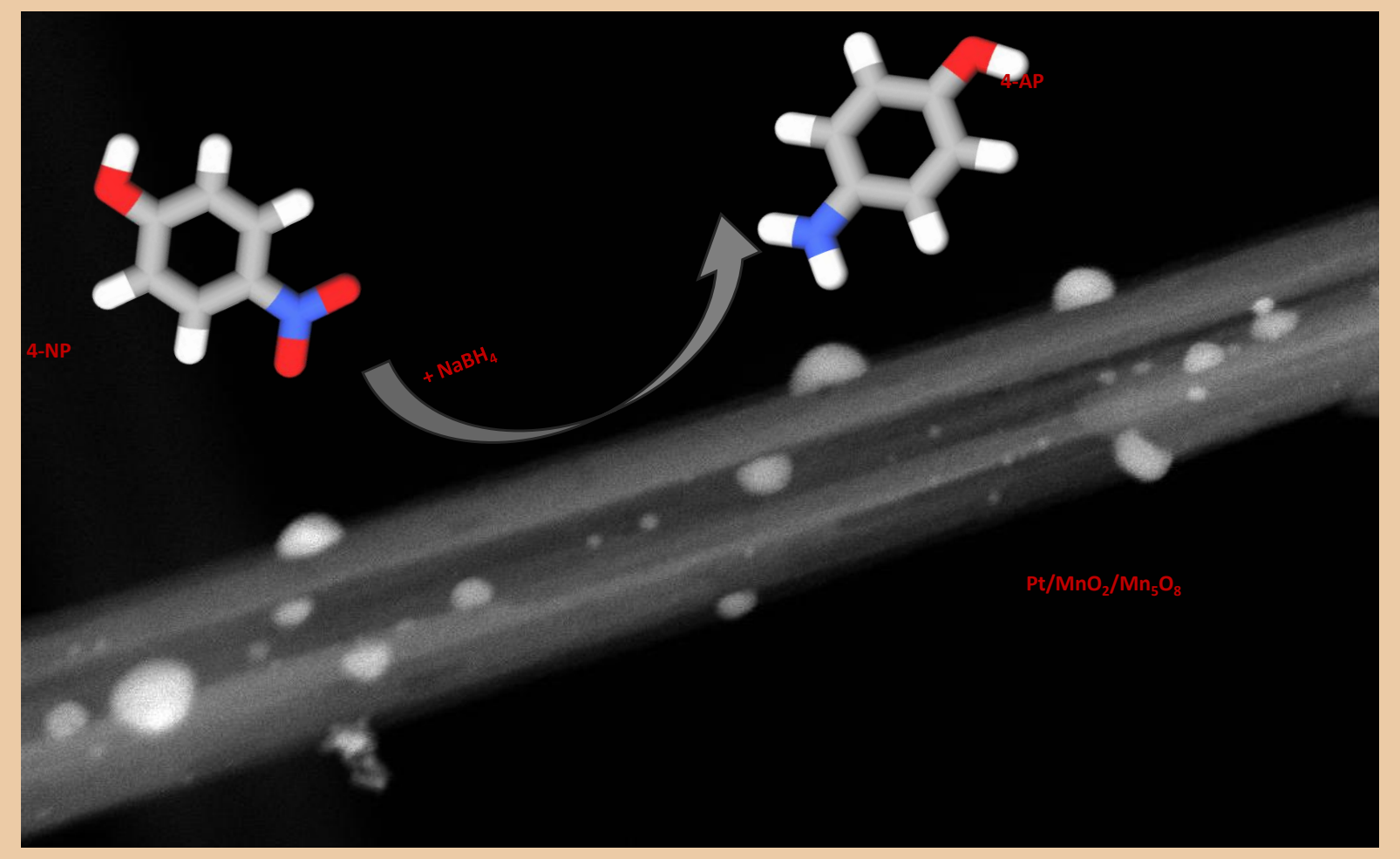

Fig. 2 Platinum transforms α-MnO_2 nanorods into monoclinic Mn_5O_8 and enables exceptional catalytic activity for reduction of 4-nitrophenol to 4-aminophenol.

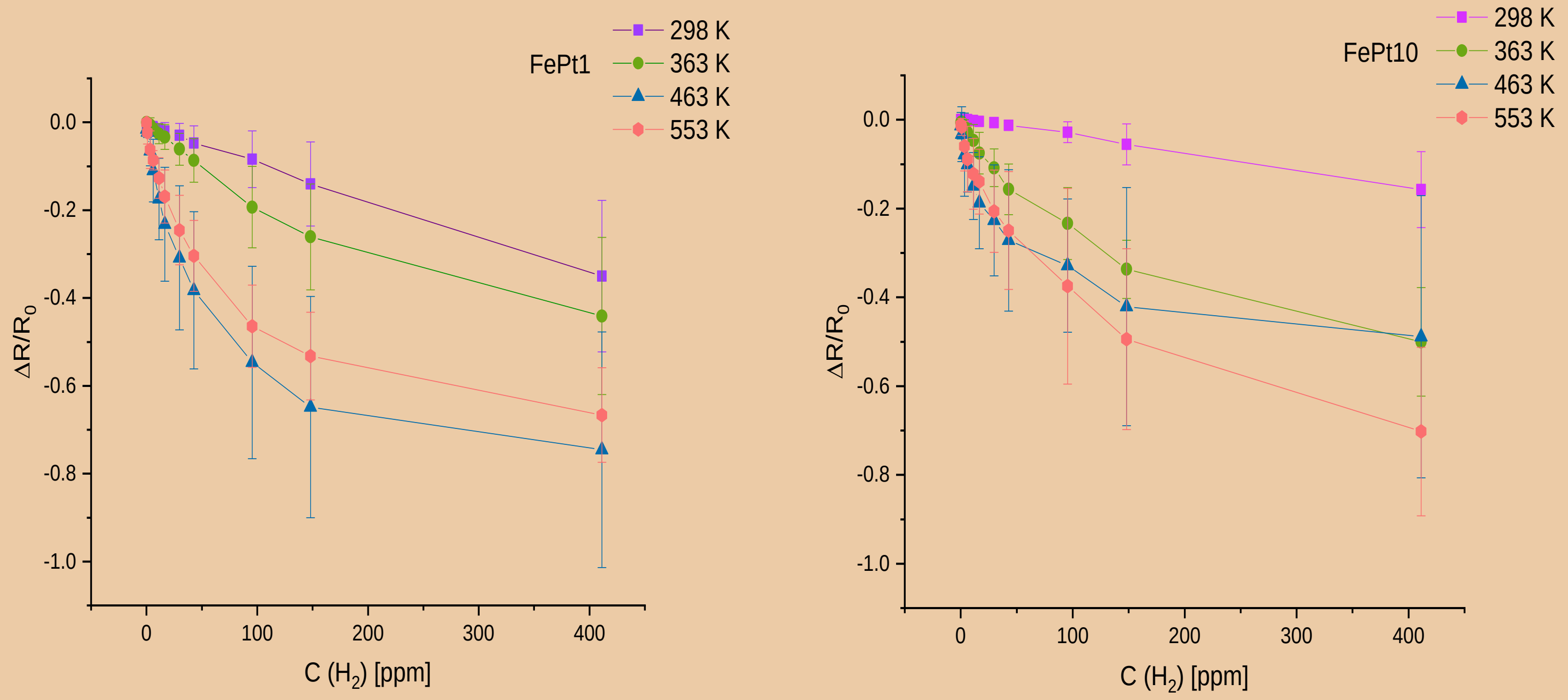

Figure 4. Response vs. H_2 concentration of FePt1 and FePt10 at different temperatures.

Results

In this study, platinum (Pt) nanoparticles on SnO_2 and α-Fe_2O_3 and MnO_2/Mn_5O_8 nanorods were synthesized and characterized for catalytic applications [1-4]. The mechanochemically synthesized Pt/SnO_2 and Pt/α-Fe_2O_3 catalysts exhibited ultrasmall Pt nanoparticles, which were well dispersed on SnO_2 and α-Fe_2O_3 supports and showed high catalytic activity in the reduction of 4-nitrophenol (4-NP) to 4-aminophenol (4-AP). Pt/MnO_2 nanorods synthesized by wet impregnation showed Pt loading-dependent effects on nanorod morphology and catalytic performance, with the relatively highest catalytic efficiency observed at a lower Pt loading (1 mol%). These results emphasize the importance of Pt dispersion and support morphology for catalytic applications. The hydrogen (H_2) sensing ability of pure α-Fe_2O_3 and Pt/α-Fe_2O_3 samples was also investigated.

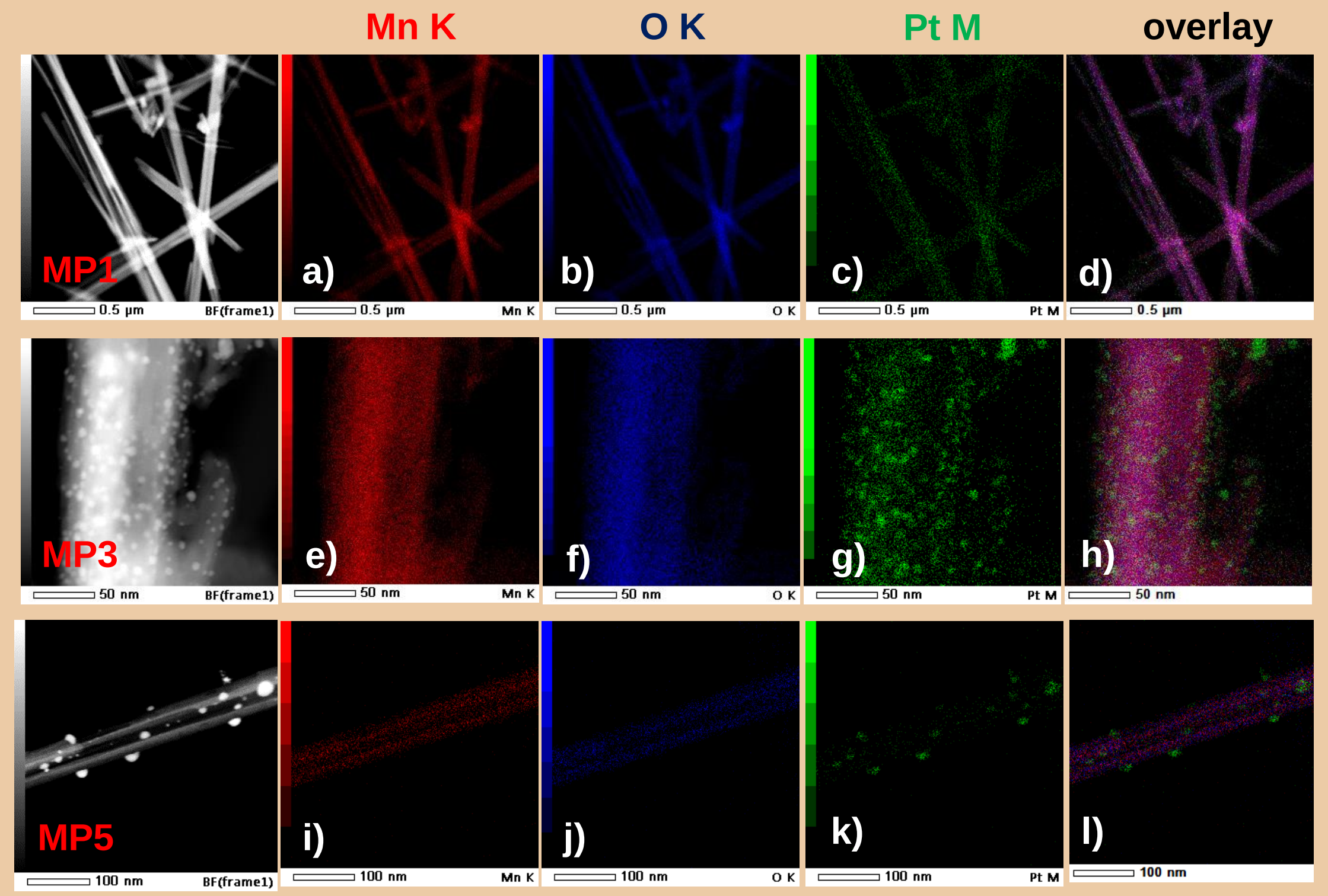

Figure 5. STEM image of sample MP1 (top row), MP3 (middle row) and MP5 (bottom row) and the corresponding EDXS elemental mapping images of the Mn K edge (a, e, i), O K edge (b, f, j), Pt M edge (c, g, k), and the overlay of the Mn K, O K, and Pt M edges (d, h, l).

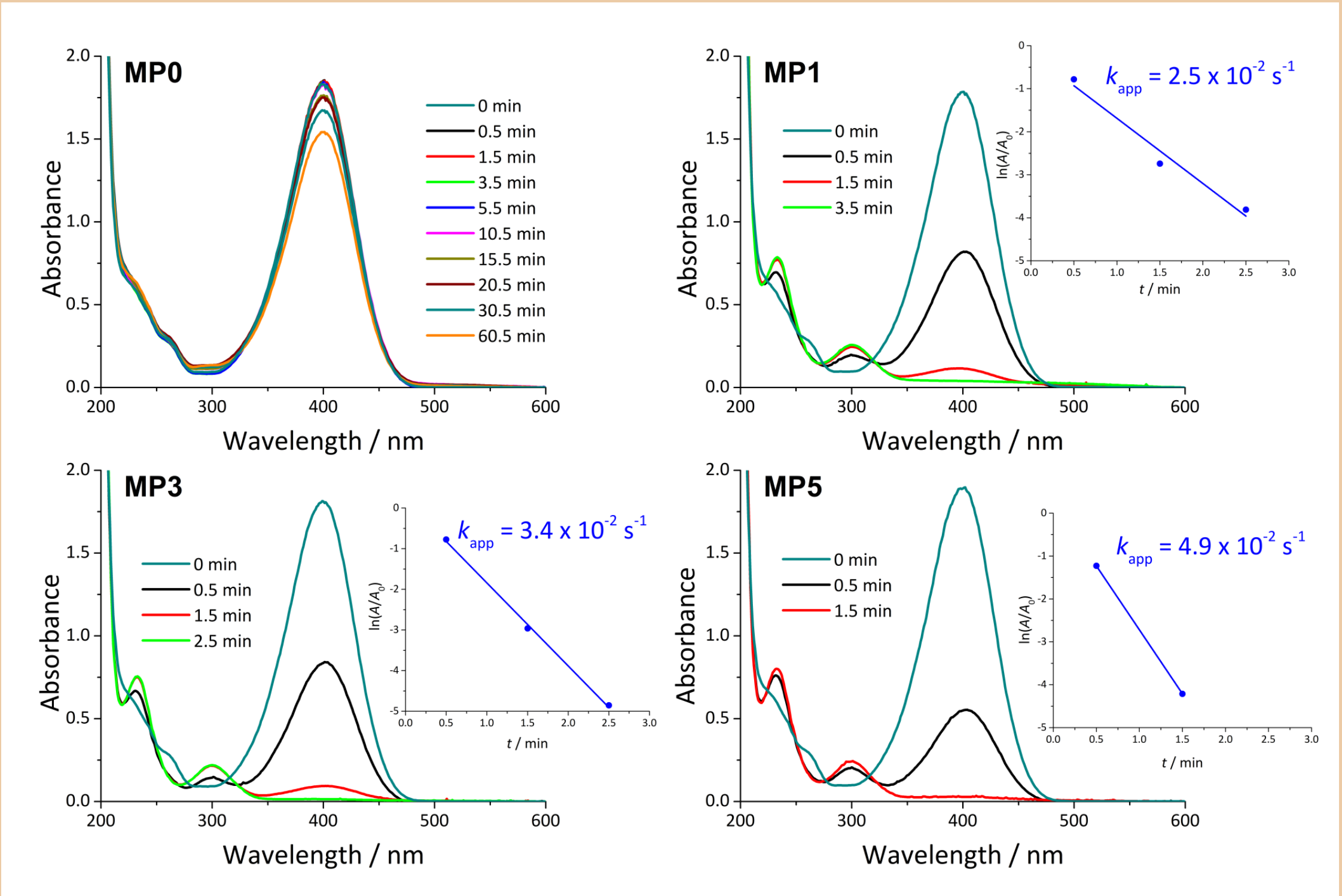

Figure 3. Catalytic reduction of 4-nitrophenol (4-NP) to 4-aminophenol (4-AP) as a function of time for sample MP0, which contains no platinum, and samples MP1, MP3, and MP5, which contain around 1%, 3%, and 5% platinum, respectively. The insets show the calculated apparent rate constants assuming pseudo-first order kinetics.

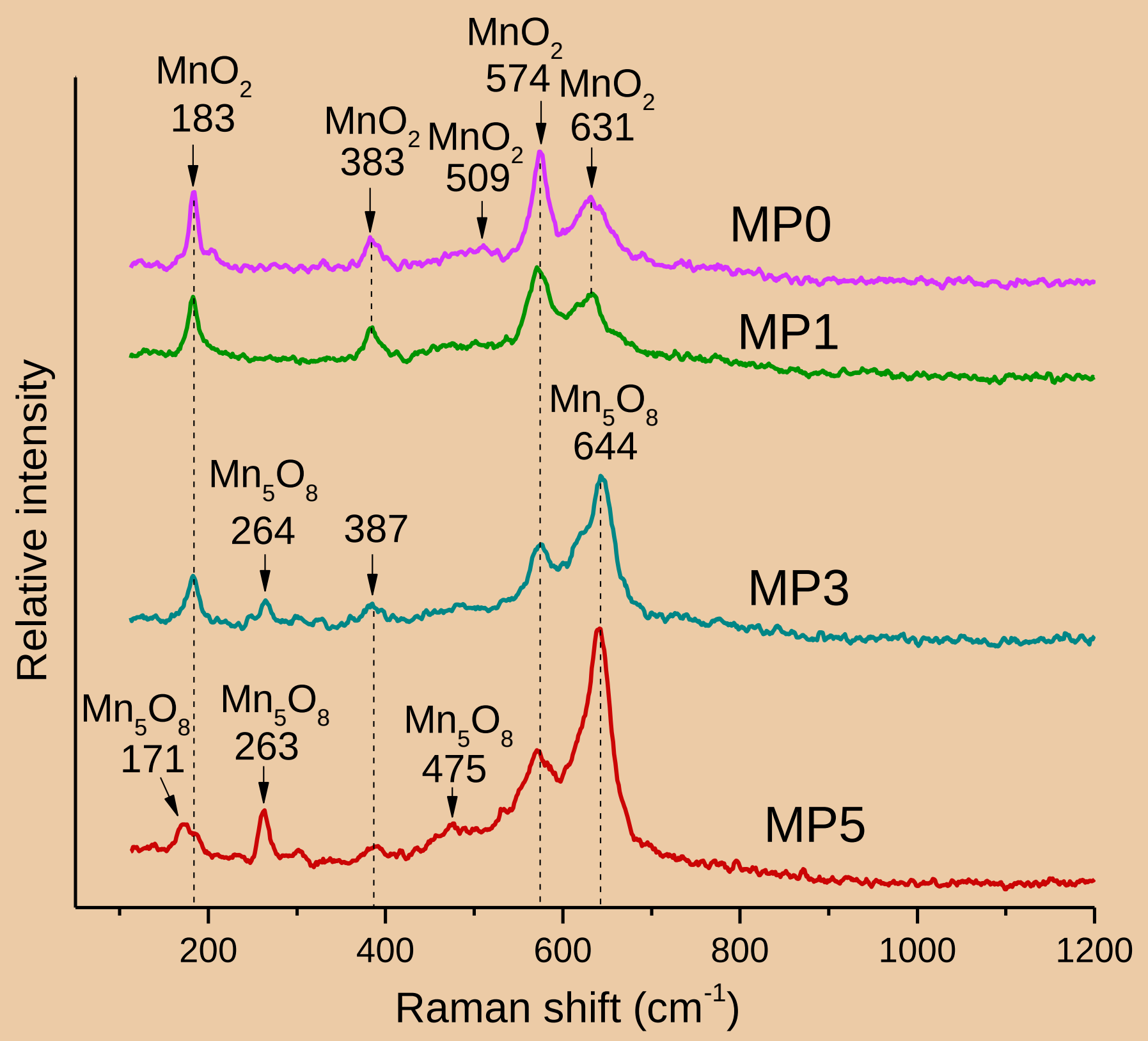

Figure 6. Raman spectra of samples MP0, MP1, MP3 and MP5

Conclusion

Mechanochemical synthesis yielded Pt/SnO_2 and Pt/α-Fe_2O_3 catalysts with well-dispersed ultrasmall Pt nanoparticles (PtNPs), confirmed by STEM analysis. XPS revealed Pt in all oxidation states, varying with Pt loading and support type [1-3]. Catalytic activity in 4-NP reduction was attributed to highly dispersed PtNPs, promising for environmental applications. Besides, it was found that dispersed platinum nanoparticles exhibit increased sensitivity to H_2 regardless of concentration, as well as increased sensitivity at higher temperatures and a reversible response to H_2 in ambient air, suggesting avenues for future research on optimal platinum concentrations and support morphologies. MnO_2/Mn_5O_8 nanorods supported Pt nanoparticles, showcasing varying crystalline phases and PtNP dispersions [4]. XPS and NEXAFS indicated changes in Pt oxidation states with loading, alongside the presence of Mn(II). Low Pt loading samples exhibited superior catalytic performance in 4-NP reduction, emphasizing the importance of Pt loading and support interaction. Both the catalytic reduction of 4-NP and H_2 detection have a direct impact on environmental protection. The use of highly dispersed PtNPs on metal oxide supports significantly improves catalytic performance and gas sensing and offers practical solutions for environmental protection and industrial safety..

References

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