Tailoring magnetic properties of manganite nanoparticles via temperature, time, and pressure

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This work investigates how annealing temperature (t_{ann}), aging time (t), and external pressure (P) affect the structural and magnetic properties of manganite nanoparticles. Nanoparticles of $La_{0.8-x}Cd_xNa_{0.2}MnO_3$ and $La_{0.7}A_{0.2}Mn_{1.1}O_3$ (A = Na^+, Ag^+, K^+), with sizes ranging from 20 to 70 nm, were studied over a period of three years. Structural changes—most notable in smaller particles—included increased size, bandwidth, and microstrain. Phase transition temperatures increased with t_{ann}, t, and P. Aging time most strongly influenced the Curie temperature (T_C) in smaller, magnetically inhomogeneous nanoparticles, while pressure most affected larger, magnetically uniform ones. After three years, the largest particles showed the most stable phase transition temperatures and enhanced magnetocaloric effect ($-\Delta S_M$) near room temperature. These findings highlight t_{ann}, t, and P as key parameters for tuning functional properties and designing advanced spintronic and refrigeration materials.

Keywords: Annealing temperature; Aging time; High pressure; Phase transitions; Magnetocaloric effect

1. Introduction

Manganites with the general formula $R_{1-x}A_xMnO_3$, where R is a rare-earth cation and A is a mono- or divalent dopant, continue to attract significant interest due to their rich variety of physical properties. These include multiple magnetic phases—paramagnetic, ferromagnetic, superparamagnetic, phase-separated, ferri- and antiferromagnetic states—as well as insulator–metal transitions [1]. Additionally, they exhibit notable phenomenon as colossal magnetoresistance [2] and a pronounced magnetocaloric effect (MCE) [3]. Among the external factors influencing these properties, some are irreversible, such as annealing temperature (t_{ann}) and aging time (t), while others, as pressure (P), are reversible. Understanding how these parameters affect the functional behavior of Mn-based perovskites is essential for both fundamental research and technological applications. Here, we selected $La_{0.8-x}Cd_xNa_{0.2}MnO_3$ (x = 0 and 0.05) and $La_{0.7}A_{0.2}Mn_{1.1}O_3$ (A = Na^+, Ag^+, K^+) as model systems to investigate the combined effects of t_{ann}, t, and P on their structural and magnetic properties.

2. Results and discussion

The effects of annealing temperature (t_{ann} = 500, 700, and 900 °C), aging time (t = 0 and 3 years), and pressure (P up to 0.8 GPa) on the phase transition temperatures and MCE of Mn-containing perovskite nanoparticles were systematically investigated. All three parameters were found to increase phase transition temperatures—namely the T_C and the paramagnetic Curie temperature (θ)—with the exception of the blocking temperature (T_B), which decreased under P. Magnetocaloric characteristics, particularly $-\Delta S_M$, also improved. As an illustrative example, Figure 1 presents the evolution of phase transition behavior and MCE in $La_{0.8}Na_{0.2}MnO_3$. These findings not only deepen our understanding of the structure–property relationship in these systems but also provide practical pathways for engineering new functional materials. Such materials can be tailored for a range of applications, from biomedicine to aerospace, with particularly strong potential in magnetic refrigeration. Moreover, the study emphasizes aging time as a critical but often overlooked parameter in tuning the functional performance of perovskite materials, opening new directions in the study of time-dependent effects in them.

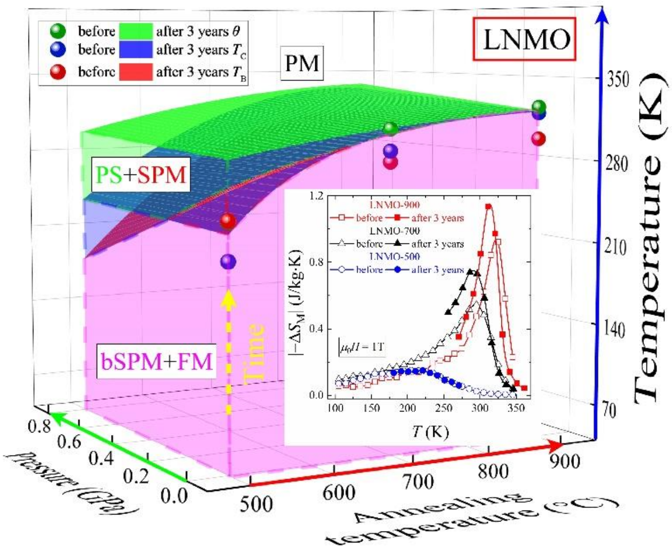

Figure 1: Schematic 4D pie chart illustrating the evolution of phase transition temperatures: paramagnetic Curie temperature (θ), Curie temperature (T_C), blocking temperature (T_B), as well as magnetocaloric effect ($-\Delta S_M$) in $La_{0.8}Na_{0.2}MnO_3$ (LNMO) at different t_{ann}, including paramagnetic (PM), phase separation (PS), superparamagnetic (SPM), blocked superparamagnetic (bSPM), and ferromagnetic (FM) phases.

References

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