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Influence of temperature on microstructure, structural and ferroelectricity evolution properties with nano and micrometer grain size in multiferroic $HoMnO_3$ ceramics

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Abstract The influence of temperature on microstructural, structural and ferroelectric evolution properties of multiferroic holmium manganese oxide ($HoMnO_3$) ceramics were investigated. $HoMnO_3$ ceramics were synthesized using a mechanochemical reaction of Ho_2O_3 and Mn_2O_3 powders in a high energy ball milling machine. The powder were sintered from 600 to 1250 °C with 50 °C increments. The results shows the microstructural, structural and ferroelectric hysteresis loop were observed to be dependent on sintering temperatures. The XRD characterization suggests an improvement of crystallinity with increasing sintering temperature. The hexagonal $HoMnO_3$ were observed at temperature ≥1200 °C with the grain size of around 1600 nm. SEM micrographs showed larger grain size as the sintering temperature increased. The SEM results revealed a transformation of crystal structure occurs from orthorhombic to hexagonal at larger grain size regime. Polarization *P*—electric field *E* ferroelectric properties were observed to be enhanced with the increase of grain size through sintering temperature. The ferroelectric behavior was observed to change with the change of microstructure along with the structure transformation from orthorhombic to hexagonal. A complete systematic studies of the micron-nanometer grain size on microstructure-properties evolution of $HoMnO_3$ multiferrroic ceramics is higlighted.

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1 Introduction

The rare earth manganites, $RMnO_3$ are used in multiferroics and magnetoelectric devices applications. This class of material, in general exhibits strong magnetic exchange interactions between the magnetic moments of the manganese (Mn^{3+}) ions as well as some of the magnetic rare earth (R^{3+}) ions [1]. The magnetoelectric effect makes the magnetoelectric multiferroics interesting materials for future information-technology devices in which data can be written to magnetic memory elements by applied electric fields. The hexagonal manganites $RMnO_3$ (R=Sc, In, Y, Ho) are one group of magnetoelectricmultiferroics. In particular, $HoMnO_3$ (HMO) is a strong magnetoelectric material in the sense that its magnetic phase at low temperature can be controlled by an applied electric field [2]. The selection of an appropriate manufacturing process is the key to obtain nanocrystalline powders with high homogeneity and uniform structure. In the present work, the mechanical alloying technique is employed. This technique was chosen to benefit from its relatively higher yield of nanoparticles compared to that from any wet chemistry technique [3–16]. Normally, most researchers would tend to employ the lowest solid-state sintering temperature to obtain a controlled microstructure and fully dense polycrystalline materials. However, the cause-and-effect sequence that occupies the ferrite literature is an experimental sequence focused mainly on yielding the final outcome, i.e. the final composition-microstructure-magnetic properties relationship [17–20]. It is interesting to study theoretically