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# Microstructure and Electrical Conductivity of (Y, Sr)$CoO_{3-\delta}$ Thin Films Tuned by the Film-Growth Temperature

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Perovskite-based rare earth cobaltates have been the topic of extensive research since they possess fascinating electrical and magnetic properties [1, 2]. $Y_xSr_{1-x}CoO_{3-\delta}$ (YSCO) compounds with room-temperature ferromagnetic properties were reported. In particular, the YSCO compound with x≈0.25 exhibits the highest Curie temperature ($T_c$≈335 K) among the perovskite-based cobaltates and the properties of YSCO could be modulated by its chemical composition [3]. In contrast to the considerable studies on the YSCO bulk materials, investigations on the microstructure and the properties of the YSCO thin films are limited. In this work, we report a detailed study on the microstructural and electrical properties of the $Y_xSr_{1-x}CoO_{3-\delta}$ ($x$=0.25) films, which were prepared at different growth temperatures on the $(La_{0.289}Sr_{0.712})(Al_{0.633}Ta_{0.356})O_3$ (LSAT) substrates.

The YSCO thin films are grown on single crystalline LSAT (001) substrates at 800 ℃ and 900 ℃, respectively, using a magnetron sputtering system. The flowing pressure is 1 mbar with the mixed ambient of Ar and $O_2$ at the ratio of 1:1. After the film growth, the films are annealed for 15 minutes in a mixture gas of Ar and $O_2$ (400 mbar) in a ratio of 1:1, and then cooled down to room temperature in 30 minutes. Cross-sectional specimens were prepared by focused ion beam (FIB) technique (FEI Dualbeam Helios NanoLab 600i). Transmission electron microscopy (TEM) observation and selected area electron diffraction (SAED) are carried out on a JEOL 2100 microscope, operated at 200 kV. Energy-dispersive X-ray spectroscopy (EDS) data and high-angle annular dark-field (HAADF) images are obtained in a JEOL ARM 200F. The electrical properties of the films are measured using a Physics Property Measurement System (PPMS, Quantum Design).

Figure 1 (a) and Figure 1 (b) shows a low-magnification bright-field TEM image of YSCO films grown on the LSAT (001) substrates at 800 ℃ and 900 ℃, respectively, viewed along the [100] zone axis of the substrates. From the image of the cross-sectional samples the thickness of the films is measured as about 100 nm. The films prepared at 800 ℃ show a homogeneous contrast and a sharp interface to the substrate, indicating a perfect epitaxy of the films. In contrast, In Figure 1 (b) nano-scale columnar contrast is evident in the YSCO films prepared at 900 ℃, which comes from second phase. The EDS spectrum of the second-phase particles is inserted in (b), which indicates that the secondary phase is $Y_2O_3$. Importantly, it can be seen that $Y_2O_3$ columns either start at the film-substrate interface or form within the film in a self-assembled manner. The size of the $Y_2O_3$ columns is typically in a range of 4−10 nm in the in-plane direction and 60−80 nm in the out-of-plane direction.

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Figure 2 shows the temperature dependence of the resistivity *ρ(T)* of the YSCO films grown at 800 ℃ and 900 ℃. It can be seen that the resistivity of both films increases exponentially with decreasing temperature in the measurement range from 300 to 95 K, which indicates that both films have semiconductor behavior. In comparison with the YSCO single-phase films grown at 800 ℃, the resistivity of the nanocomposite films grown at 900 ℃ decreases roughly by a factor of four over the entire temperature range of 95−300 K. To understand the electrical transport behavior in both films, the temperature dependent resistivity *ρ(T)* is fitted by Mott's variable range hopping (VRH) model [4]. In the case of $\rho(T)=\rho_0*\exp(T_0/T)^{-1/4}$ (where $\rho_0$ is the pre-exponential factor and $T_0$ is a characteristic temperature), a linear dependence of $\ln\rho$ versus $T^{-1/4}$ is obtained for both films, as shown in the inset in Figure 2, which indicates that hopping conduction is dominant in the measured temperature range for both films. Since the hopping energy is proportional to the slope of a plot of $\ln(\rho)$ versus $T^{-1/4}$, it is evident that the lower slope of the plot for the nanocomposite films indicates a lower hopping energy in comparing with the YSCO single-phase films. Our results indicate that the appearance of the $Y_2O_3$ columns in the $(Y,Sr)CoO_{3-\delta}$ films significantly decreases the resistivity of the films [5].

References:

[1] D Phelan, D Louca, S Rosenkranz, *et al*, *Phys. Rev. Lett*. **96** (2006), p. 027201.
[2] R Caciuffo, D Rinaldi and G Barucca, *Phys. Rev. B* **59** (1999), p. 1068.
[3] W Kobayashi, S Washiwata, I Terasaki, *et al*, *Phys. Rev. B* **72** (2005), p. 104408.
[4] F Hanic, M Hartmova, G G Knab, *et al*, *Acta Cryst.* **B40** (1984), p. 76.
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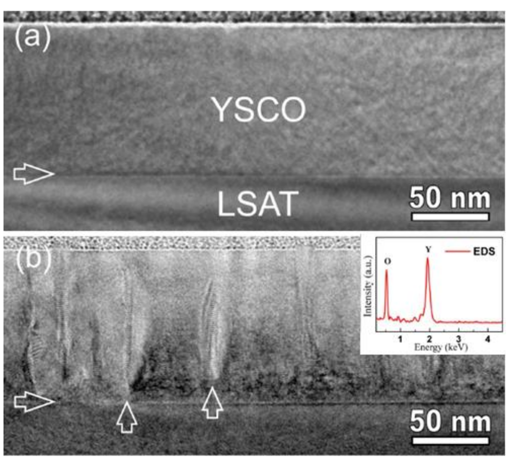


**Figure 1.** Low-magnification bright-field TEM images of the YSCO films grown at 800 ℃ (a) and 900 ℃ (b). The EDS spectrum of the second-phase particles is inserted in (b).

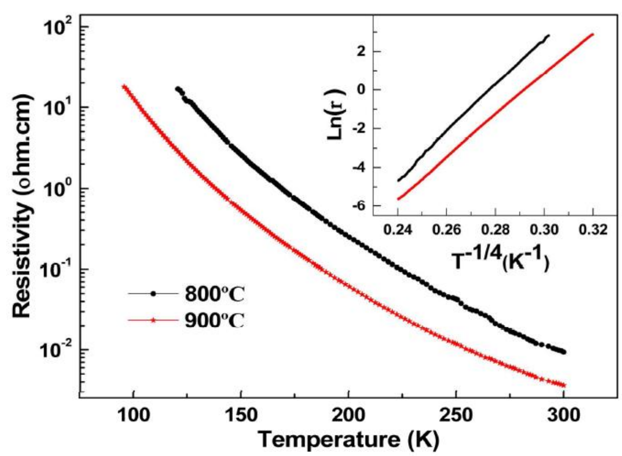


**Figure 2.** Temperature dependence of the electrical resistivity of the films grown at 800 ℃ and 900 ℃. The inset displays a plot of $\ln(\rho)$ versus $T^{-1/4}$.

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