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Microstructure and Strain Relaxation of Single-crystal Gadolinium-doped Ceria Thin Films on $LaAlO_3$ Substrates

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Gadolinium-doped ceria (GDC) is very attractive as an electrolyte for solid oxide fuel cell (SOFC) applications at low operating temperature (~500 °C) due to its high ionic conductivity. The ohmic loss across the electrolyte can be further minimized by using a thin film of the electrolyte. Lower operating temperatures can lead to SOFC devices with reduced cost and higher long-term stability. For practical SOFC applications, therefore, fabricating high-performance GDC in thin film form is highly desirable.

In this study, single-crystal $LaAlO_3$ (LAO) substrates with excellent high-temperature insulating properties were selected for the convenience in the measurement of film electric properties. Gadolinium-doped ceria ($Ce_{0.8}Gd_{0.2}O_{2-\delta}$) thin films were grown using pulsed laser ablation. Transmission electron microscopy (TEM) has been used to investigate the film microstructure.

As shown in Fig. 1, the films are single crystallized and have a sharp interface with an epitaxial relationship of $(001)_{film}||(001)_{substrate}$ and $[100]_{film}||[110]_{substrate}$. Accompanying the high film crystallinity, a unique directionally aligned, precipitated nanoparticle structure has been observed. The precipitated particles have an average size of ~4 nm, a Ga-rich composition of $Ce_{0.7}Gd_{0.3}O_{2-\delta}$, a rhombic shape with mainly {111} facets, and are uniformly distributed over the entire film area. The nanoparticles contribute a uniform tensile strain to the film that effectively compensates the compressive film strain induced by the substrate, and also leads to a uniform relaxation of the residual film strain by generating misfit dislocations at the film/particle interfaces [1]. The high film crystallinity is believed to result from this uniform film strain relaxation mechanism.

Fig. 2 shows the shape interface and a unique type of periodic film distortion can be seen clearly along the film/substrate interface. Each distorted film area is associated with a few substrate surface steps and the spacing is about 50 µm. The distorted area has an average size of about 15 nm, being composed of a {111} planar defect network. The local film distortion induced by the step is found to propagate always along one of the {111} planes in the step-forward direction to form a {111} planar defect. The adjacent step-induced {111} planar defects interact each other and create new {111} planar defects and then finally form a network. The detailed distortion structure model has been developed [2].

References

[1]D.X. Huang et al., Appl. Phys. Lett. 84 (2004) 708.
[2]D.X. Huang et al., J. Appl. Phys. 97 (2005) 043506.

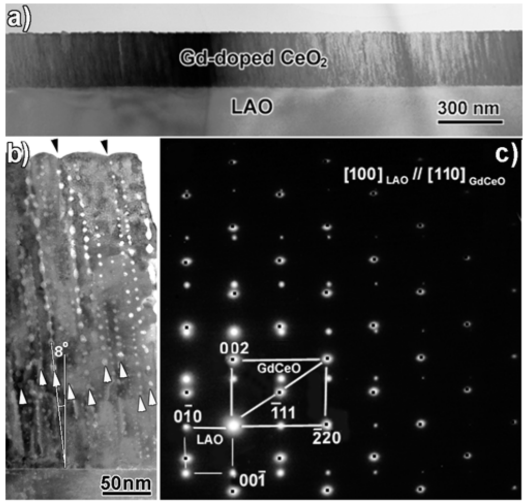

Fig. 1. Electron microscope images show the uniform 270 nm thick Gd-doped ceria thin film grown on (100) LAO substrates (a), directionally-aligned Gd-rich precipitate nanoparticle system in the film (b), and the film/substrate orientation relationships (c).

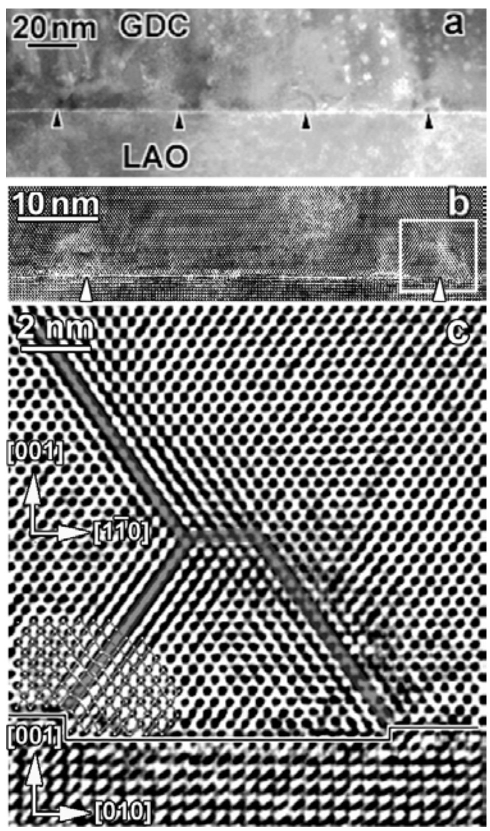

Fig. 2. Cross-sectional TEM images showing the microstructure of a periodic distortion induced by substrate surface steps in GDC films grown on (001) LAO: (a) low magnification bright field image; (b) enlarged image of the interface area for the right part of (a); (c) high resolution image to show the relationship of the substrate surface steps and the film distortions in a typical film distorted area which is framed in (b).

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