

Growth of rare-earth niobate-based pyrochlores on textured Ni–W substrates with ionic radii dependency

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Epitaxial films of rare-earth (RE) niobates, RE_3NbO_7 with pyrochlore structures, were grown on biaxially textured nickel–3 at.% tungsten (Ni–W) substrates using a chemical solution deposition process. A precursor solution of 0.3–0.50 M concentration of total cations was spin coated on to short samples of Ni–W substrates, and the films were crystallized at 1050–1100 °C in a gas mixture of Ar–4% H_2 for 15 min. Detailed studies revealed that RE-niobates with ionic radius ratio $R_{\text{RE}}/R_{\text{Nb}}$ (R = ionic radius) from 1.23 to 1.40 (i.e., Sm, Eu, Gd, Ho, Y, and Yb) grow epitaxially with the pyrochlore structure. X-ray studies showed that the films of pyrochlore RE niobate films were highly textured with cube-on-cube epitaxy. Scanning electron and atomic force microscopy investigations of RE_3NbO_7 films revealed a fairly dense and smooth microstructure without cracks and porosity. The rare-earth niobate layers may be potentially used as buffer layers for $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ coated conductors.

I. INTRODUCTION

Thin films with pyrochlore structures have been used as potential buffer layers for $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ (YBCO)-coated conductors due to their thermal stability and their chemical and structural compatibility with the substrates and superconducting layers.¹ Basic pyrochlores are ternary compounds² with an $\text{A}_2\text{B}_2\text{O}_7$ stoichiometry, where A is a larger and trivalent cation and B is a smaller and tetravalent cation. The ideal pyrochlore structure possesses cubic symmetry with space group $Fd\bar{3}m$, and there are eight molecules per unit cell. The pyrochlore structure, as shown in Fig. 1, is related to fluorite structure. Pyrochlore structure ($Fd\bar{3}m$) can be derived from the fluorite structure ($Fm\bar{3}m$) by ordering the cation sublattice and creating ordered oxygen vacancies in such a way that coordination of A atoms remains cubic, as in fluorite, but coordination of B cations decreases to octahedral.

Ordering causes the pyrochlore unit cell to double with respect to the fluorite unit cell. Due to the extensive compositional range of the compounds that exhibit the pyrochlore structure, there are a variety of actual and potential applications for these materials. Examples include: dielectric materials,^{3,4} catalysts,^{5,6} solid electrolytes,^{7–9} thermal-barrier coatings,^{10,11} as well as actinide host phases for nuclear waste encapsulation.^{12–15} However, the phase stability for any $\text{A}_2\text{B}_2\text{O}_7$ pyrochlore compound (where A is a 3+ rare-earth cation ranging in size from Lu^{3+} to La^{3+} and B is a 4+ cation ranging in size from Ti^{4+} to Pb^{4+}) is not well characterized. It was demonstrated¹⁶ that rare earth (RE) containing titanates, $\text{A}_2\text{B}_2\text{O}_7$ pyrochlore, trend to decrease in stability with decreasing R_A/R_B (R = ionic radius) due to increasing propensity to disorder and a more energetically favorable fluorite structure. Bulk superconductivity with $T_c = 9.6$ K was reported in a pyrochlore-related oxide KOs_2O_6 .¹⁷

The pyrochlore structure under study has the chemical formula A_3BO_7 , where A (Lu to La) is a larger trivalent and B (Nb) is a smaller pentavalent cation. If we consider $1/8$ of a pyrochlore unit cell, A cations occupy the face-centered position, and B cations occupy the corner position. Of the pyrochlores, there exists a selected phase diagram¹⁸ of the compound Y_3NbO_7 from the series of A_3BO_7 . A pyrochlore solid solution region having a

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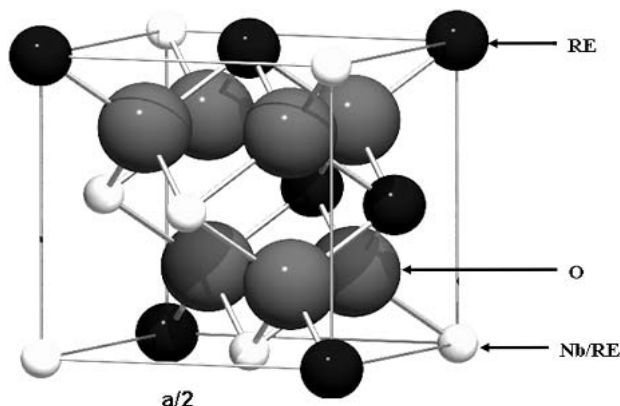


FIG. 1. Schematic illustration of a pyrochlore structure ($1/8$ of unit cell). The medium-sized sphere represents RE^{3+} cation; the small sphere, the Nb^{5+}/RE^{3+} cation; and the large sphere, O^{2-} .

nominal composition of $3Y_2O_3 \cdot Nb_2O_5$ was found between 20% and 31.5% Nb_2O_5 , and no solid solubility of Y_2O_3 in Nb_2O_5 was found. It is to be noted that no studies of pyrochlore phases regarding ionic radii dependency in the form of thin film have been reported so far.

Here, we report the successful growth of textured film of rare-earth niobates, RE_3NbO_7 , on Ni–W substrates and its ionic radius dependency on the formation of pyrochlore structure. Various rare-earth oxides^{19–22} and rare-earth pyrochlore^{23–25} films have been grown epitaxially on biaxially textured Ni and Ni–3 at.% W (Ni–W) substrates by solution-based methods as buffer layers for YBCO-coated conductors. Since chemical solution-based deposition of buffer layers is a potentially lower cost and higher performance approach for YBCO-coated conductors, we believe that the solution-deposited RE_3NbO_7 films with good epitaxy and lattice matching are potential candidates.

II. EXPERIMENTAL

The precursor solutions for the rare-earth niobates were prepared using two different routes, namely sol-gel and metalorganic decomposition (MOD), depending on the solution chemistry. Solution chemistry can play an

important part on film orientation, morphology, and oxygen diffusivity.²⁶ Using the sol-gel precursor route, La, Y, Eu, and Gd niobates were prepared, and using the MOD precursor route, Ce, Nd, Sm, Ho and Yb niobates were prepared. All solution manipulations for sol-gel precursor were carried out under an atmosphere of argon using standard Schlenk techniques, and the starting reagents were weighed in an argon-filled, inert-atmosphere glove box. The chemical reagents La isopropoxide (Alfa, 40%), Y isopropoxide (Alfa, 92–95%), niobium ethoxide (99.999%, Ward Hill, MA) and 2-methoxyethanol (Alfa, spectrophotometric grade) were used as received from Alfa Aesar whereas; Eu acetate and Gd acetate were purified beforehand. For the purification of Eu acetate first, Eu acetate was prepared by the reaction of europium oxide (Alfa, 99.99%) with a 5-fold excess of 25% acetic acid at 80 °C for 1 h.²⁷ The resulting clear solution was filtered, and the solvent was removed. The precipitate was dried at 120 °C under dynamic vacuum for 16 h. Finally, a small amount of sample was allowed to react with excess water and then dried to constant weight at 35 °C to form the hydrated sample. The weight gain of this sample allowed us to estimate that the degree of hydration of the europium acetate after vacuum drying is about 1.5 ± 0.2 . A similar procedure was followed for the purification of Gd acetate.

Europium methoxyethoxide solution in 2-methoxyethanol was prepared by charging a flask with 0.987 g europium acetate and 10 ml 2-methoxyethanol. The flask was refluxed for 1 h at 130 °C, and 0.318 g niobium ethoxide was added. The contents were rediluted with additional 2-methoxyethanol, and the distillation/redilution cycle was repeated twice more to ensure complete formation of europium methoxyethoxide. The final concentration was adjusted to produce 10 ml of a 0.50 M stock solution.

All the MOD precursor solution was prepared in ambient atmosphere. The reagents Ce acetylacetonate (Alfa, hygroscopic), Nd acetylacetonate (Alfa, 99.9%), Sm acetate (Alfa, 99.9%), Ho acetate (Alfa, 99.9%), Yb acetylacetonate (Alfa, 99.9%), niobium ethoxide (Alfa, 99.999%), acetic acid (Alfa, 99.9985%), and methanol

TABLE I. Starting chemicals, solvents, and molarities for the RE_3NbO_7 precursors.

| Rare-earth niobates, RE_3NbO_7 (RE) | Chemical reagents | Stoichiometric quantity (g) | Solvent and reactant | Final molarity (M) |
|---------------------------------------|--------------------------------|-----------------------------|--------------------------|--------------------|
| La | La-isopropoxide/Nb-ethoxide | 1.1857/0.398 | 2 methoxyethanol | 0.5 |
| Ce | Ce-acetylacetonate/Nb-ethoxide | 0.656/0.16 | Acetic acid and Methanol | 0.4 |
| Nd | Nd-acetylacetonate/Nb-ethoxide | 0.662/0.16 | Acetic acid and Methanol | 0.4 |
| Sm | Sm-acetate/Nb-ethoxide | 0.5783/0.16 | Acetic acid and Methanol | 0.4 |
| Eu | Eu-acetate/Nb-ethoxide | 0.9873/0.318 | 2 methoxyethanol | 0.4 |
| Gd | Gd-acetate/Nb-ethoxide | 1.003/0.318 | 2 methoxyethanol | 0.4 |
| Ho | Ho-acetate/Nb-ethoxide | 0.415/0.12 | Acetic acid and Methanol | 0.3 |
| Y | Y-isopropoxide/Nb-ethoxide | 0.998/0.398 | 2 methoxyethanol | 0.5 |
| Yb | Yb-acetylacetonate/Nb-ethoxide | 0.9587/0.199 | Acetic acid and Methanol | 0.5 |

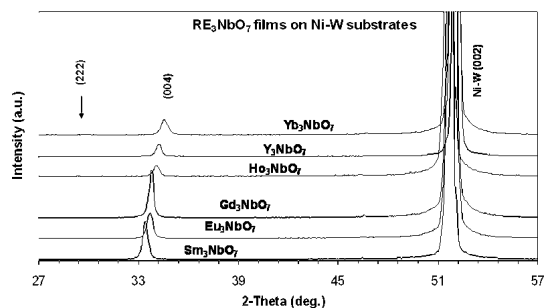


FIG. 2. A typical θ - 2θ scan for 20-nm-thick RE_3NbO_7 ($\text{RE} = \text{Sm}, \text{Eu}, \text{Gd}, \text{Ho}, \text{Y}, \text{and Yb}$) films grown on biaxially textured Ni–W substrates using chemical solution deposition. RE_3NbO_7 films have preferred c -axis orientation.

(Alfa, 99.9%) were used as received from Alfa Aesar. The precursor solution for Ce niobate was prepared by dissolving 0.656 g Ce acetylacetonate in acetic acid and methanol with continuous stirring for 10 min in a hot plate at 60 °C. Then, 0.16 g Nb ethoxide was added, and the final volume of the solution was adjusted to obtain 0.4 M precursor solution. The chemical reagents, solvents, and molarities for all the precursors are listed in Table I.

These solutions were spin coated onto short cube textured Ni–W substrates 2×1 cm in size at 4000 rpm for 30 s, followed by heat treatment in a reducing atmosphere of Ar–4% H_2 . After a 5 min purge with Ar–4% H_2 gas mixture at room temperature, the samples were introduced into a preheated furnace. Then, at the end of heat treatment, cycles the samples were quenched to room temperature in the same atmosphere. The heating and cooling rates were in the range of 350–400 °C/min, annealing time 15–30 min and annealing temperatures were 1050–1100 °C. Except for Eu niobate, which was

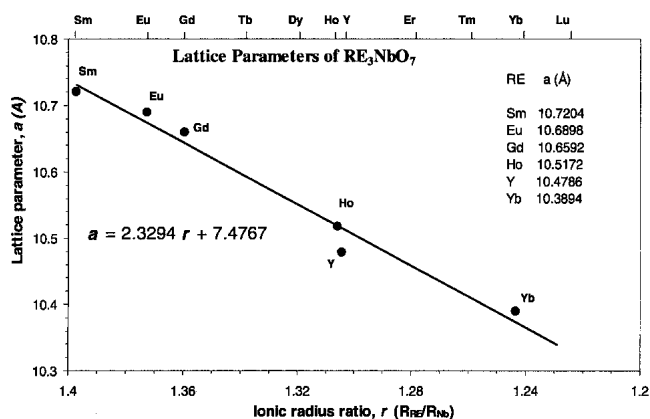


FIG. 3. Lattice parameters of the solution grown RE_3NbO_7 films on Ni–W substrates. All data points represent experimental value calculated by MDI-JADE6 software.

heat treated at 1050 °C for 15 min due to the phase instability at higher temperature, all the other niobates were heat treated at 1100 °C for 15–30 min.

The RE_3NbO_7 films were characterized using x-ray diffraction (XRD) for phase purity and texture, scanning electron microscopy (SEM) for homogeneity and microstructure, and atomic force microscopy (AFM) for surface roughness analysis. A Philips model XRG3100, USA diffractometer with Cu K_α radiation was used to record the θ - 2θ XRD patterns. The texture analysis was performed using a Picker 4-circle diffractometer, USA. Phase analysis was done using XRD patterns and the lattice parameters were determined using the MDI-JADE 6 program (Livermore, CA). The microstructure analyses of these samples were performed using a Hitachi S-4100, Japan, field emission SEM and Digital Instruments, USA, nanoscope AFM in contact mode.

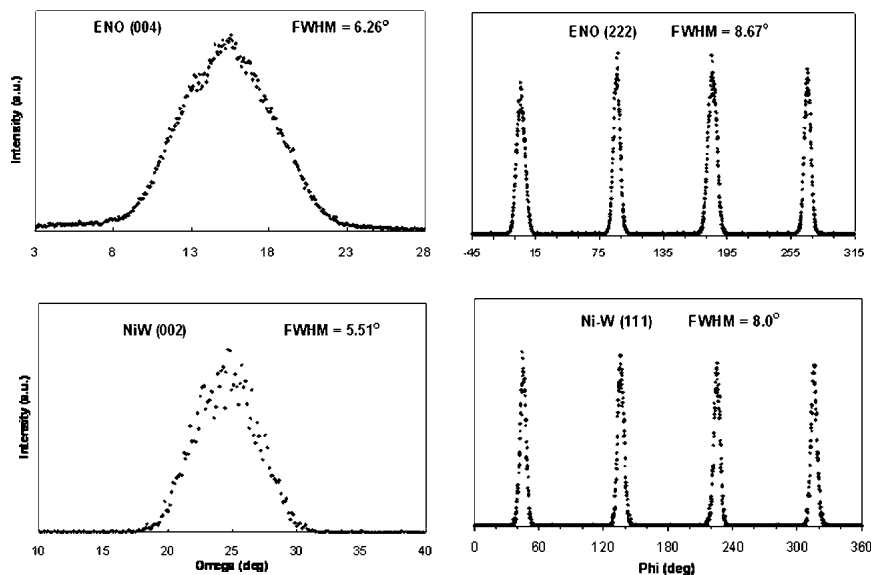


FIG. 4. The ω and ϕ scans obtained for 80-nm-thick Eu_3NbO_7 film grown on textured Ni–W substrate. The FWHM values for each scan are shown inside the patterns.

TABLE II. Texture data of RE niobate films on Ni–W substrates.

| Rare-earth niobates | FWHM of RE ₃ NbO ₇ | | FWHM of Ni–W substrates | |
|----------------------------------|--|---------------------------|-----------------------------|---------------------------|
| | ω scans (°) (004) | ϕ scans (°) (222) | ω scans (°) (002) | ϕ scans (°) (111) |
| Sm ₃ NbO ₇ | 7.47 | 9.35 | 5.4 | 7.61 |
| Eu ₃ NbO ₇ | 6.26 | 8.67 | 5.77 | 8.0 |
| Gd ₃ NbO ₇ | 7.15 | 8.0 | 5.47 | 6.7 |
| Ho ₃ NbO ₇ | 8.0 | 8.92 | 5.4 | 7.62 |
| Y ₃ NbO ₇ | 7.72 | 8.23 | 5.47 | 6.7 |
| Yb ₃ NbO ₇ | 7.21 | 8.58 | 5.66 | 7.91 |

III. RESULTS AND DISCUSSION

X-ray diffraction patterns for the solution-deposited RE₃NbO₇ films grown on Ni–W substrates were collected at room temperature. From the XRD patterns, it was found that the niobates of Sm, Eu, Gd, Ho, Y, and Yb grow epitaxially with pyrochlore structure whereas the niobates of Ce and Nd crystallize without any preferred orientation and the La niobate decomposes to mixed phases of LaNbO₄ and La₂O₃ under the experimental conditions used. Although these phases are stable between the temperatures 800 and 1100 °C, Eu₃NbO₇ partially decomposes to Eu₂O₃ and Nb₂O₅ at temperature above 1050 °C. Room-temperature XRD patterns for the pyrochlore phase RE₃NbO₇ thin films deposited on Ni–W substrates are shown in Fig. 2. Because of highly *c*-axis (004) oriented films, no (222) peaks are present in the patterns. There is a clear indication of (004) peak shifting to the right as a result of decreasing ionic radii of the rare earth elements. Therefore, the lattice parameters of the pyrochlore phase increases with increase in ionic radii.

Figure 3 shows the cell parameters of the RE₃NbO₇ pyrochlore as a function of the ionic radius ratio, and as expected, the cell parameters increase linearly with ionic radius. The data in Fig. 3 is the actual experimental value calculated from the XRD patterns using MDI-JADE 6 program. From the linear equation shown inside the graph, cell parameters for other RE₃NbO₇ pyrochlores can be easily calculated. From Sm to Yb niobates, the cell parameter decreases from 10.7204 to 10.3894 Å, which is about 3% decrease.

To grow a textured film by a chemical solution deposition, a highly textured substrate is very important. Cube-textured Ni–W substrates serve the purpose with an excellent in-plane (ϕ scan) and out-of-plane (ω scan) texture of full width at half-maximum (FWHM) about 8.0° and 5.77°, respectively. All the RE₃NbO₇ films grown by solution deposition on Ni–W substrates have the out-of-plane texture with FWHM value in the range of 6.25–8° and the in-plane texture in the range of 8.0–9.35°. The ω (out-of-plane) and ϕ (in-plane) scans of Eu₃NbO₇ films on the Ni–W substrates are shown in Fig. 4. The Eu₃NbO₇ film has a good out-of-plane and in-plane texture with FWHM of 6.26° and 8.67°, respectively. These values are well comparable to those of Ni–W substrates ($\Delta\omega = 5.77^\circ$, $\Delta\phi = 8.0^\circ$). A list of FWHM values for the RE₃NbO₇ films is given in Table II.

The typical (222) pole figures for all 6 RE₃NbO₇ films grown on the Ni–W substrate are shown in Fig. 5, indicating single cube-on-cube epitaxy. Microstructure studies of the RE₃NbO₇ films exhibit a uniform, smooth, and crack-free surface morphology. As an example, a SEM micrograph for Eu₃NbO₇ film on rolled Ni–W substrate using spin coating is shown in Fig. 6(a). Most of the Ni–W grain boundary grooves on the Ni–W surface were

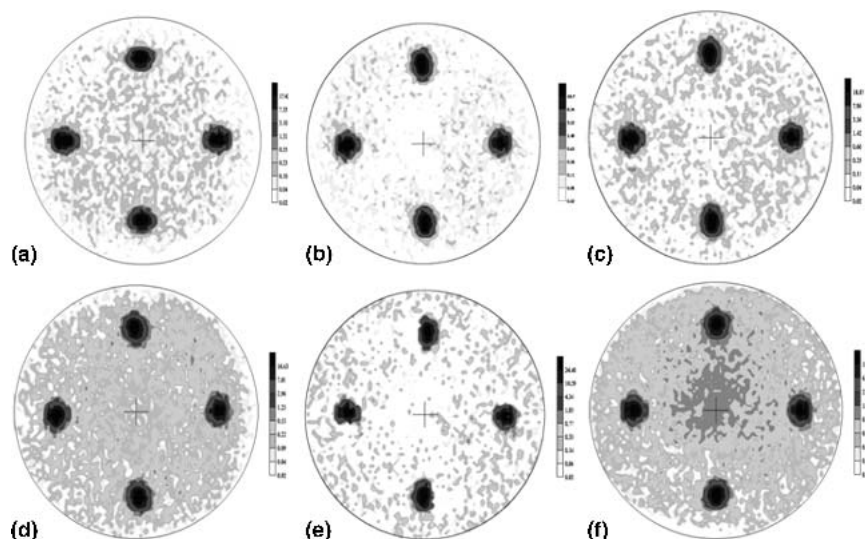


FIG. 5. The typical (222) log scale pole figures of 20-nm-thick (a) Sm₃NbO₇, (b) Eu₃NbO₇, (c) Gd₃NbO₇, (d) Ho₃NbO₇, (e) Y₃NbO₇, and (f) Yb₃NbO₇ films grown on textured Ni–W substrate.

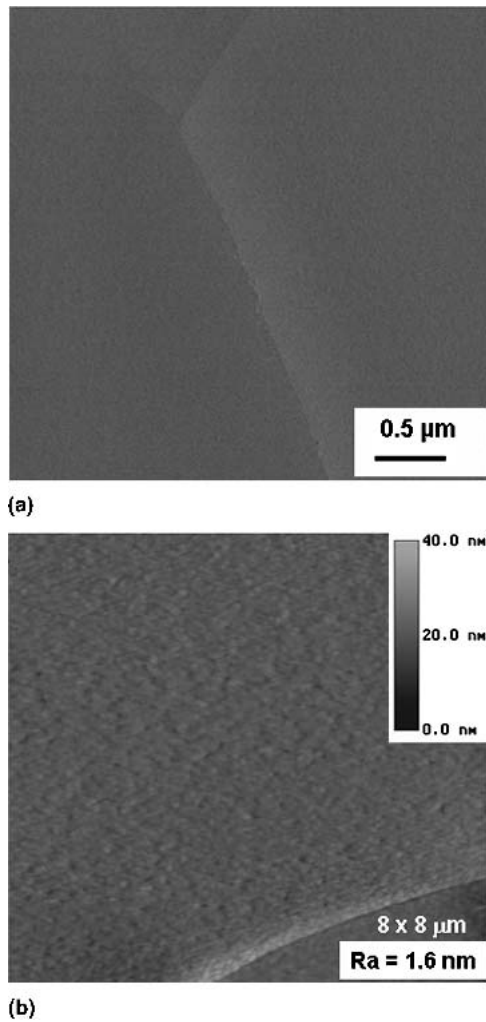


FIG. 6. (a) SEM micrograph and (b) AFM image obtained from a 80-nm-thick Eu_3NbO_7 film surface.

found to be well covered. Figure 6(a) also shows that the film surface is continuous as well as crack free. AFM image of the same sample is shown in Fig. 6(b). It reveals an average surface roughness (Ra) of 1.6 nm for the Eu_3NbO_7 film.

Lattice matching between the substrates and the films play a key role in the epitaxial growth. The pseudo-cubic cell parameters for the RE_3NbO_7 films closely follow that of the Ni–W substrates, as shown in Table III. Since the films were grown epitaxially with a 45° rotation with respect to the substrates, the pseudo-cubic cell parameters were calculated by dividing cubic cell parameter with $\sqrt{2}$. The percentage lattice mismatch between these films and the substrates is 4–8%. The lattice mismatch between the niobate buffers and YBCO is much smaller and in the range of -0.5% to -4% , which unfolds the possibility for RE_3NbO_7 films as a potential buffer layers for coated conductors. Efforts are underway to deposit YBCO by the pulsed laser deposition/MOD technique

TABLE III. List of lattice parameters for RE_3NbO_7 (Ni; $a = 3.524 \text{ \AA}$; YBCO: $a = 3.823 \text{ \AA}$, $b = 3.887 \text{ \AA}$, $c = 11.68 \text{ \AA}$).

| Rare-earth niobates | Lattice parameter a (\AA) | Pseudo-lattice parameter $a/2\sqrt{2}$ (\AA) | Percent lattice mismatch versus Ni (%) | Percent lattice mismatch versus YBCO (%) |
|---------------------------|--|---|--|--|
| Sm_3NbO_7 | 10.720 | 3.790 | 7.56 | -0.85 |
| Eu_3NbO_7 | 10.690 | 3.779 | 7.25 | -1.14 |
| Gd_3NbO_7 | 10.659 | 3.769 | 6.95 | -1.42 |
| Ho_3NbO_7 | 10.517 | 3.718 | 5.52 | -2.74 |
| Y_3NbO_7 | 10.479 | 3.705 | 5.13 | -3.1 |
| Yb_3NbO_7 | 10.389 | 3.673 | 4.23 | -3.92 |

on these films. As an initial demonstration, a YBCO film with a critical current density of $1.1 \times 10^6 \text{ A/cm}^2$ in self-field at 77 K has been grown on single Gd_3NbO_7 -buffered Ni–W substrate using pulsed laser deposition.²⁴

IV. CONCLUSION

We have grown textured RE_3NbO_7 (RE = Sm, Eu, Gd, Ho, Y and Yb) films on cube-textured Ni–W substrates using chemical solution deposition and demonstrated the strong dependency of epitaxy on the ionic radii of the rare earth elements. Niobates of the rare-earth elements with an ionic radius ratio $r < 1.40$ grow as epitaxial pyrochlore phases on Ni–W substrates. Microstructure studies of the RE_3NbO_7 films deposited on rolled Ni–W substrates using solution process reveal a smooth, dense, and crack-free surface. Such epitaxial, dense, and crack-free RE_3NbO_7 buffer layers may be suitable buffer candidates for YBCO-coated conductors.

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REFERENCES

1. S. Sathyamurthy, M. Paranthaman, H.Y. Zhai, S. Kang, T. Aytug, C. Cantoni, K.J. Leonard, E.A. Payzant, H.M. Christen, A. Goyal, X. Li, U. Schoop, T. Kodankandath, and M.W. Rupich: Chemical solution deposition of lanthanum zirconate barrier layers applied

- to low-cost coated-conductor fabrication. *J. Mater. Res.* **19**, 2117 (2004).
- M.A. Subramanian, G. Aravamudan, and G.V. Subba Rao: Oxide pyrochlores—A review. *Prog. Solid State Chem.* **15**, 55 (1983).
 - D.P. Cann, C.A. Randall, and T.R. Shrout: Investigation of the dielectric properties of bismuth pyrochlores. *Solid State Commun.* **100**, 529 (1996).
 - M. Valant and P.K. Davies: Crystal chemistry and dielectric properties of chemically substituted $(\text{Bi}_{1.5}\text{Zn}_{1.0}\text{Nb}_{1.5})\text{O}_7$ and $\text{Bi}_2(\text{Zn}_{2/3}\text{Nb}_{4/3})\text{O}_7$ pyrochlores. *J. Am. Ceram. Soc.* **83**, 147 (2000).
 - J.B. Goodenough and R.N. Castellano: Defect pyrochlores as catalyst supports. *J. Solid State Chem.* **44**, 108 (1982).
 - S.J. Korf, H.J.A. Koopmans, B.C. Lippens, A.J. Burggraaf, and P.J. Gellings: Electrical and catalytic properties of some oxides with the fluorite or pyrochlore structure. CO oxidation on some compounds derived from $\text{Gd}_2\text{Zr}_2\text{O}_7$. *J. Chem. Soc., Faraday Trans. 1* **83**, 1485 (1987).
 - H.L. Tuller: Mixed ionic-electronic conduction in a number of fluorite and pyrochlore compounds. *Solid State Ionics* **52**, 135 (1992).
 - S. Kramer, M. Spears, and H.L. Tuller: Conduction in titanate pyrochlores: Role of dopants. *Solid State Ionics* **72**, 59 (1994).
 - C. Heremans, B.J. Wuensch, J.K. Stalick, and E. Prince: Fast-ion conducting $\text{Y}_2(\text{Zr}_y\text{Ti}_{1-y})_2\text{O}_7$ pyrochlores: Neutron Rietveld analysis of disorder induced by Zr substitution. *J. Solid State Chem.* **117**, 108 (1995).
 - M.J. Maloney: Thermal Barrier Coating Systems and Materials. U.S. Patent No. 6 117 560 (2000).
 - M.J. Maloney: Thermal Barrier Coating Systems and Materials. U.S. Patent No. 6, 177 200 B1 (2001).
 - W.J. Weber, R.C. Ewing, C.R.A. Catlow, T. Diaz de la Rubia, L.W. Hobbs, C. Kinoshita, H. Matzke, A.T. Motta, M. Nastasi, E.K.H. Salje, E.R. Vance, and S.J. Zinkle: Radiation effects in crystalline ceramics for the immobilization of high-level nuclear waste and plutonium. *J. Mater. Res.* **13**, 1434 (1998).
 - R.C. Ewing, W. Lutze, and W.J. Weber: Zircon: A host-phase for the disposal of weapons plutonium. *J. Mater. Res.* **10**, 243 (1995).
 - R.C. Ewing, W.J. Weber, and F.W. Clinard, Jr.: Radiation effects in nuclear waste forms for high-level radioactive waste. *Prog. Nucl. Energy* **29**, 63 (1995).
 - K.E. Sickafus, L. Minervini, R.W. Grimes, J.A. Valdez, M. Ishimaru, F. Li, K.J. McClellan, and T. Hartmann: Radiation tolerance of complex oxides. *Science* **289**, 748 (2000).
 - K.B. Helean, S.V. Ushakov, C.E. Brown, A. Navrotsky, J. Lian, R.C. Ewing, J.M. Farmer, and L.A. Boatner: Formation enthalpies of rare earth titanate pyrochlores. *J. Solid State Chem.* **177**, 1858 (2004).
 - S. Yonezawa, Y. Muraoka, Y. Matsushita, and Z. Hiroi: Superconductivity in a pyrochlore-related oxide KOs_2O_6 . *J. Phys. Condens. Matter* **16**, L9 (2004).
 - A.E. McHale and R.S. Roth: *Phase Equilibria Diagrams, Volume XII, Oxides* (American Ceramic Society, Westerville, OH, 1996), p. 113.
 - M. Paranthaman, T.G. Chirayil, F. List, X. Cui, A. Goyal, D.F. Lee, E.D. Specht, P.M. Martin, R.K. Williams, D.M. Kroeger, J.S. Morrel, D.B. Beach, R. Feenstra, and D.K. Christen: Fabrication of long lengths of epitaxial buffer layers on biaxially textured nickel substrates using a continuous reel-to-reel dip-coating unit. *J. Am. Ceram. Soc.* **84**, 273 (2001).
 - T. Aytug, M. Paranthaman, B.W. Kang, D.B. Beach, S. Sathyamurthy, E.D. Specht, D.F. Lee, R. Feenstra, A. Goyal, D.M. Kroeger, K.J. Leonard, P.M. Martin, and D.K. Christen: Reel-to-reel continuous chemical solution deposition of epitaxial Gd_2O_3 buffer layers on biaxially textured metal tapes for the fabrication of $\text{YBa}_2\text{Cu}_3\text{O}_7$ -coated conductors. *J. Am. Ceram. Soc.* **86**, 257 (2003).
 - M.S. Bhuiyan, M. Paranthaman, S. Sathyamurthy, T. Aytug, S. Kang, D.F. Lee, A. Goyal, E.A. Payzant, and K. Salama: MOD approach for the growth of epitaxial CeO_2 buffer layers on biaxially textured Ni–W substrates for YBCO coated conductors. *Supercond. Sci. Technol.* **16**, 1305 (2003).
 - M.S. Bhuiyan, M. Paranthaman, S. Sathyamurthy, T. Aytug, S. Kang, D.F. Lee, A. Goyal, E.A. Payzant, and K. Salama: Growth of epitaxial Y_2O_3 film on biaxially textured Ni–W substrates, in *Frontiers in Superconducting Materials—New Materials and Applications*, edited by V. Matias, J. Talvacchio, X. Xi, Z. Han, and H-W Neumuller, (Mater. Res. Soc. Symp. Proc. **EXS-3**, Warrendale, PA, 2004), p. 57.
 - S. Sathyamurthy, M. Paranthaman, T. Aytug, B.W. Kang, P.M. Martin, A. Goyal, D.M. Kroeger, and D.K. Christen: Chemical solution deposition of lanthanum zirconate buffer layers on biaxially textured Ni–1.7% Fe–3% W alloy substrates for coated-conductor fabrication. *J. Mater. Res.* **17**, 1543 (2002).
 - M. Paranthaman, M.S. Bhuiyan, S. Sathyamurthy, H.Y. Zhai, A. Goyal, and K. Salama: Epitaxial growth of solution based rare earth niobate, RE_3NbO_7 films on biaxially textured Ni–W substrates. *J. Mater. Res.* **20**, 6 (2005).
 - M.S. Bhuiyan, M. Paranthaman, D. Beach, L. Heatherly, A. Goyal, E.A. Payzant, and K. Salama: Epitaxial growth of Eu_3NbO_7 buffer layers on biaxially textured Ni–W substrates. *Ceramic Trans.* **160**, 35 (2004).
 - J.T. Dawley, R.J. Ong, and P.G. Clem: Chemical solution deposition of (100)-oriented SrTiO_3 buffer layers on Ni substrates. *J. Mater. Res.* **17**, 1678 (2002).
 - L. Gmelin: *Gmelin Handbook of Inorganic Chemistry*, 8th ed. (Springer-Verlag, Berlin, Germany, 1984), p. 34.