Microsc. Microanal. 8 (Suppl. 2), 2002
DOI 10.1017.S1431927602103448

Transmission Electron Microscopy Studies of Epitaxial Superconducting MgB_2 Thin Film

W. Tian,* C. B. Eom**, and X. Q. Pan*

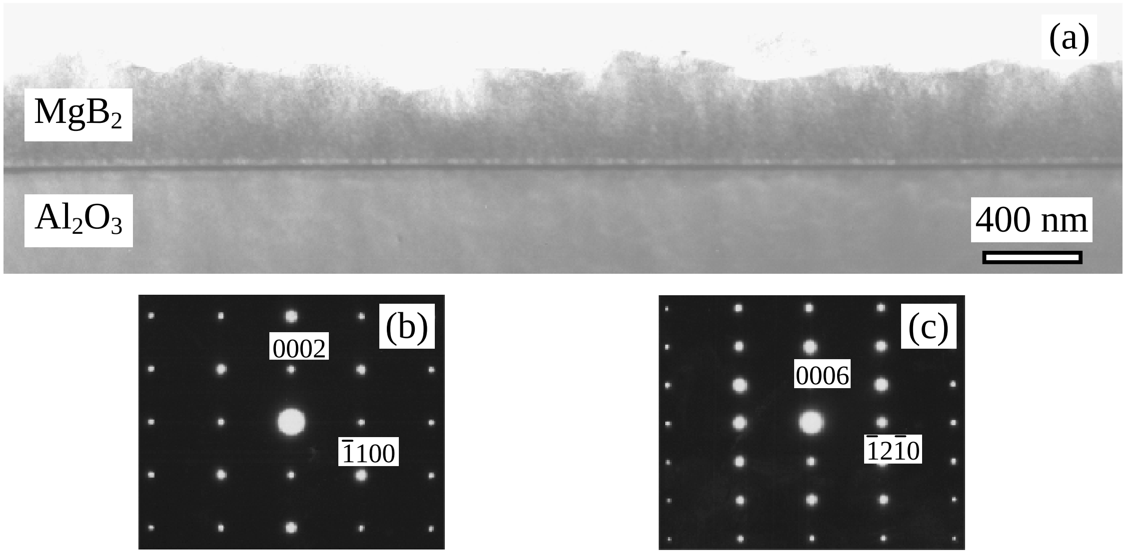
*Dept. of Materials Science and Engineering, The University of Michigan, Ann Arbor, MI-48109
**Dept. of Materials Science and Engineering, The University of Wisconsin, Madison, WI-53706

The recent discovery of superconductivity at 39 K in MgB_2 has resparked worldwide interest in non-oxide superconductors.[1] Among the prominent properties of MgB_2 are the record-breaking critical temperature in metallic superconductors and the ability to carry a strong-linked current flow.[2] Of the special interest to researchers are the fabrications of epitaxial MgB_2 thin films, which is one of the keys to facilitating the exploration of fundamental physics of MgB_2 and the applications in microelectronic devices.

Despite recent intensive efforts, the growth of epitaxial MgB_2 thin films remains challenging due to the high volatility of Mg in a broad temperature window and the tendency to form MgO in the presence of oxygen. Most recently, epitaxial MgB_2 thin films have been successfully fabricated by annealing boron precursor thin film in Mg vapor at high temperature. In this paper we report a transmission electron microscopy (TEM) study of such epitaxial thin films, with a goal to develop structure-property relationships and growth mechanisms.

An epitaxial MgB_2 thin film was fabricated by annealing a boron precursor thin film pre-deposited on the (0001) Al_2O_3 substrate in Mg vapor at 850 °C. Figure 1(a) is a bright-field low magnification cross-section TEM image of a MgB_2 film. Figure 1(b) and (c) are the selected-area electron diffraction pattern taken from the film and the substrate. The patterns were identified to be the $[11\bar{2}0]$ zone axis diffraction pattern of hexagonal MgB_2 and the $[10\bar{1}0]$ zone axis diffraction pattern of Al_2O_3. Detailed studies indicated that a phase-pure MgB_2 thin film grows on the (0001)Al_2O_3 substrate, with an epitaixal orientation relationship of (0001)MgB_2 // (0001)Al_2O_3 and $[11\bar{2}0]MgB_2//[10\bar{1}0]Al_2O_3$, respectively. Interfacial structure between the epitaxial MgB_2 film and the Al_2O_3 substrate was analyzed using high resolution TEM (HRTEM). Figure 2(a) shows an HRTEM image of the interface with the electron beam incident along the $[10\bar{1}0]$ direction of the Al_2O_3 substrate. Between the MgB_2 film and the substrate, two intermediate layers exist. Fourier transformation, computer image simulations, and x-ray energy dispersive spectroscopy analysis revealed that two intermediate phases correspond to MgO (upper) and $MgAl_2O_4$ (lower). Additionally, these intermediate layers were epitaixally grown on the (0001) Al_2O_3. Figure 2(b) is an HRTEM image of the MgB_2/MgO interface taken with the electron beam incident along the$[11\bar{2}0]$ direction of MgB_2. A simulated image that optimally fits the experimental one is inserted in the middle of Fig. 2(b). The atomic structure of the interface determined is schematically shown in Fig. 2(c). The formation of the intermediate layers is ascribed to the presence of oxygen during the cause of annealing. The epitaxial orientation relationships between the Al_2O_3 substrate and the intermediate phases result from the favorable lattice matching between these phases. The existence of MgO layer provides a small lattice-mismatched template to facilitate the epitaxial growth of MgB_2.

[1] J. Nagamatsu *et al.*, Nature (London) **410**, 63 (2001).
[2] D. C. Larbalestier *et al*., Nature (London) **410**, 186 (2001).



(a) Low magnification cross-sectional bright-field TEM image of a MgB_2 film grown on the (0001) Al_2O_3 substrate. (b) and (c) selected-area diffraction patterns taken from the film and the substrate with the electron beam incident along the same direction.

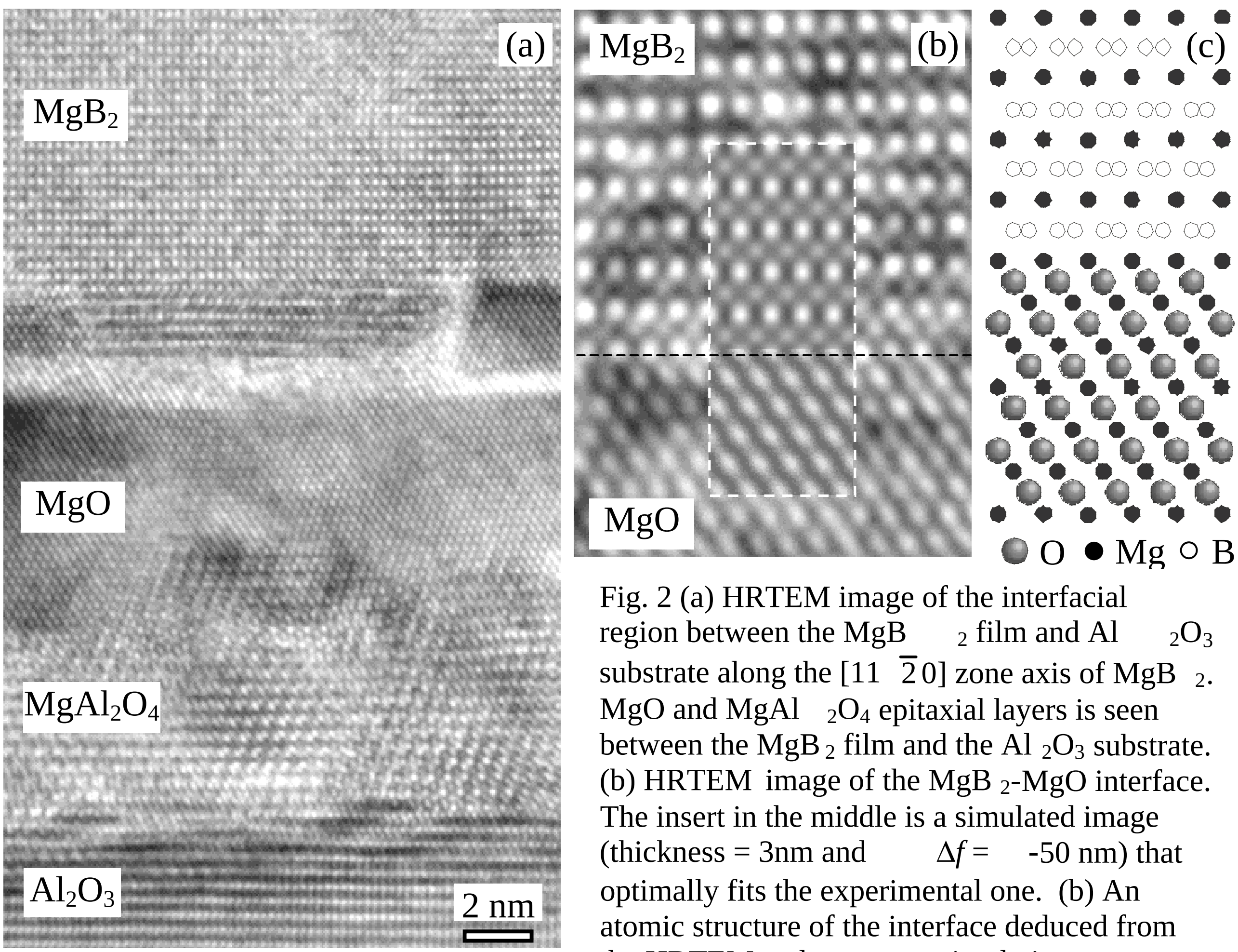


Fig. 2 (a) HRTEM image of the interfacial region between the MgB_2 film and Al_2O_3 substrate along the $[11\bar{2}0]$ zone axis of MgB_2. MgO and $MgAl_2O_4$ epitaxial layers is seen between the MgB_2 film and the Al_2O_3 substrate. (b) HRTEM image of the MgB_2-MgO interface. The insert in the middle is a simulated image (thickness = 3nm and Δf = -50 nm) that optimally fits the experimental one. (b) An atomic structure of the interface deduced from the HRTEM and computer simulations.

https://doi.org/10.1017/S1431927602103448 Published online by Cambridge University Press