HIGH-QUALITY AS-GROWN MgB_2 FILM FABRICATION AT LOW TEMPERATURE USING IN-PLANE-LATTICE NEAR-MATCHED EPITAXIAL-BUFFER LAYER

To date a process for fabricating a superconducting MgB_2 [1] thin film has required a growth and/or annealing temperature higher than 600 ºC [2]. When such a process is applied to the fabrication of an integrated device, interdiffusion occurs at interfaces between the integrated layers, which degrades the quality of the device. This is one problem faced in fabricating a high-quality integrated device. We succeeded in the fabrication of high-quality as-grown MgB_2 films [3] and their structural and superconducting characterization [4]. One of the keys to success was the utilization of low-temperature crystal growth combined with a near-matched epitaxial buffer layer. We clarified the function of the buffer layer from a structural point of view.

A TiZr buffer layer was deposited on a sapphire Al_2O_3 (0001) substrate at 815 ºC by evaporation of a Ti-50 at % Zr alloy source. After the substrate was cooled to room temperature, MgB_2 films were deposited at 270 ºC by coevaporation of Mg and B metals, which were evaporated using an effusion cell and an electron beam gun, respectively. The film and buffer layer were determined to be about 300 and 100 nm in thickness, respectively, by high-resolution SEM observation. For a control experiment, we also prepared a MgB_2 film (without the buffer layer) grown on a sapphire (0 0 0 1) substrate.

Superconducting properties were examined resistively and magnetically. The critical temperature T_c of $MgB_2/TiZr/Al_2O_3$ was about 1 K higher than that of $MgB_2/TiZr/Al_2O_3$ (not shown here). The applied magnetic field dependences of magnetizations were measured under a perpendicular magnetic field to the film surface. The critical current density J_c was estimated from a magnetization hysteresis loop based on the Bean critical state model. The larger hysteresis loop for $MgB_2/TiZr/Al_2O_3$ in comparison with that for MgB_2/Al_2O_3 corresponds to a higher capacity for the flow of current in the former MgB_2 film. J_c at 5 K under 1 T magnetic flux density is 6×10^5 A/cm^2 for $MgB_2/TiZr/Al_2O_3$. J_c obtained from MgB_2/Al_2O_3 is much smaller than this value at 9×10^4 A/cm^2, suggesting that the crystallinity of the MgB_2 film in the $MgB_2/TiZr/Al_2O_3$ could be much improved.

X-ray measurements for film-structural analysis were performed with a six-circle diffractometer at beamline **BL13XU** [5]. An X-ray wavelength of 0.102 nm was used. We located the sample at the 0 1 $\bar{1}$ 1 Bragg position and rotated it around the [0 0 0 1] direction L (almost the surface normal) to record X-ray intensities diffracted from the film (Fig. 1). The MgB_2 film without the buffer layer was a *c*-axis oriented crystal and had no epitaxial relation. Accordingly, we concluded that the crystallinity of the film with the

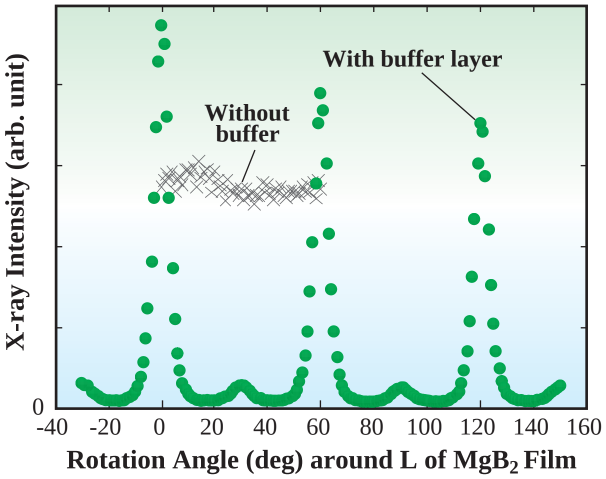

Fig. 1. L *vs.* X-ray intensity scattered from MgB_2 film on the buffer layer (solid circles) and without the buffer layer (crosses). The peaks came from the 0 1 $\bar{1}$1 reflection [4].

buffer layer was improved.

By similar measurements, it was determined that the buffer layer was also crystalline. The epitaxial relationship in a plane perpendicular to L was obtained: MgB_2 (majority domain) $[0\ 1\ \bar{1}\ 0]$ // TiZr $[0\ 1\ \bar{1}\ 0]$ and TiZr $[0\ 1\ \bar{1}\ 0]$ // sapphire $[1\ 1\ \bar{2}\ 0]$.

q_R, q_T and $q_\perp$ scans were carried out in the reciprocal-lattice space to determine in-plane lattice spacings of MgB_2 and the TiZr buffer layer. The q_R and q_T scans were parallel to the radius and tangential direction in the L-constant plane (almost in-plane) passing through a desired Bragg position, respectively. The $q_\perp$ scan was parallel to L around the position. The obtained in-plane lattice spacings, $d_{//}^{MgB_2}$, $d_{//}^{TiZr}$, and $d_{//}^{sapphire}$ are 0.268, 0.258, and 0.239 nm for the MgB_2 $(0\ 1\ \bar{1}\ 0)$, TiZr $(0\ 1\ \bar{1}\ 0)$, and sapphire $(1\ 1\ \bar{2}\ 0)$ planes, respectively. It is noted that $d_{//}^{TiZr}$ was between $d_{//}^{MgB_2}$ and $d_{//}^{sapphire}$. The crystallinity of the film with the buffer layer became higher accordingly.

From FWHMs of Δq_R, Δq_T, and $q_\perp$, we estimated crystal mosaic spreads. The spreads are 6.1° and 0.38° for the MgB_2 film and the TiZr layer, respectively. We plot the spreads with respect to the in-plane lattice spacings (Fig. 2). The spread of the MgB_2 film was around 6°, while the film without the buffer layer was the *c*-axis oriented crystal. This suggests that the buffer layer improves the crystallinity of the MgB_2 film.

In summary, we have found that the in-plane-lattice near-matched TiZr buffer layer aided the fabrication of the as-grown MgB_2 crystalline film. This is because the in-plane lattice spacing of the buffer layer was between those of MgB_2 and the substrate crystal. T_c and J_c of $MgB_2/TiZr/Al_2O_3$ were found to be higher than those of MgB_2/Al_2O_3. The near-matched epitaxial crystallinity of the buffer-layered TiZr was of cardinal importance in the low-temperature growth of the high-quality as-grown MgB_2 film.

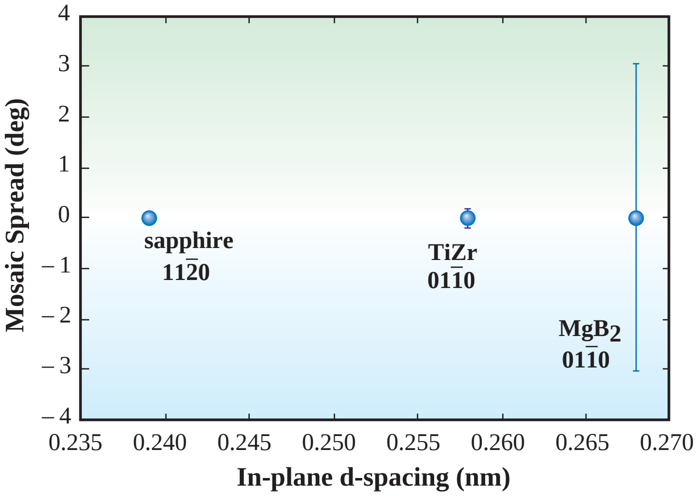

Fig. 2. Measured in-plane lattice spacings and mosaic spreads [4].

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References

[1] J. Nagamatsu *et al*.: Nature **410** (2001) 558.
[2] W.N. Kang *et al*.: Science **292** (2001) 1521.
[3] S. Yata *et al*.: Physica C **388-389** (2003) 155.
[4] *O. Sakata, S. Kimura, M. Takata, S. Yata, T. Kato, K. Yamanaka, Y. Yamada, A. Matsushita and S. Kubo: J. Appl. Phys.* ***96*** *(2004) 3580.*
[5] O. Sakata *et al*.: Surface Rev. Lett. **10** (2003) 543.