Supporting information for:

Interface-induced Transition from Cluster Glass State to Spin Glass State in $LaMnO_3/BiFeO_3$ Heterostructures

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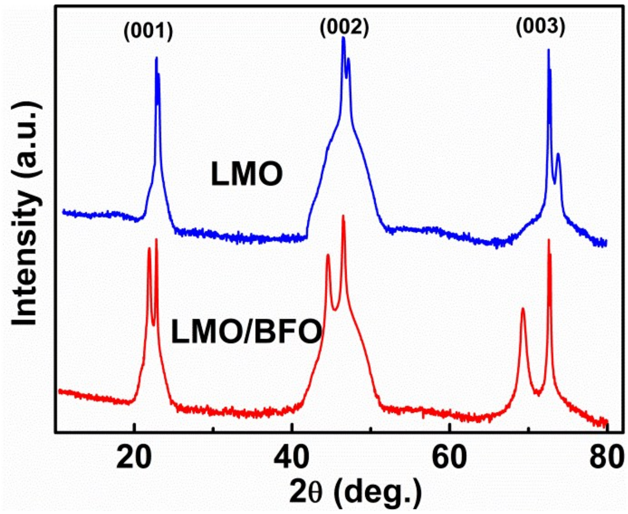

Fig. S1 Full XRD patterns with the range of 20-80 degrees for the LMO/BFO heterostructure and the pure LMO film.

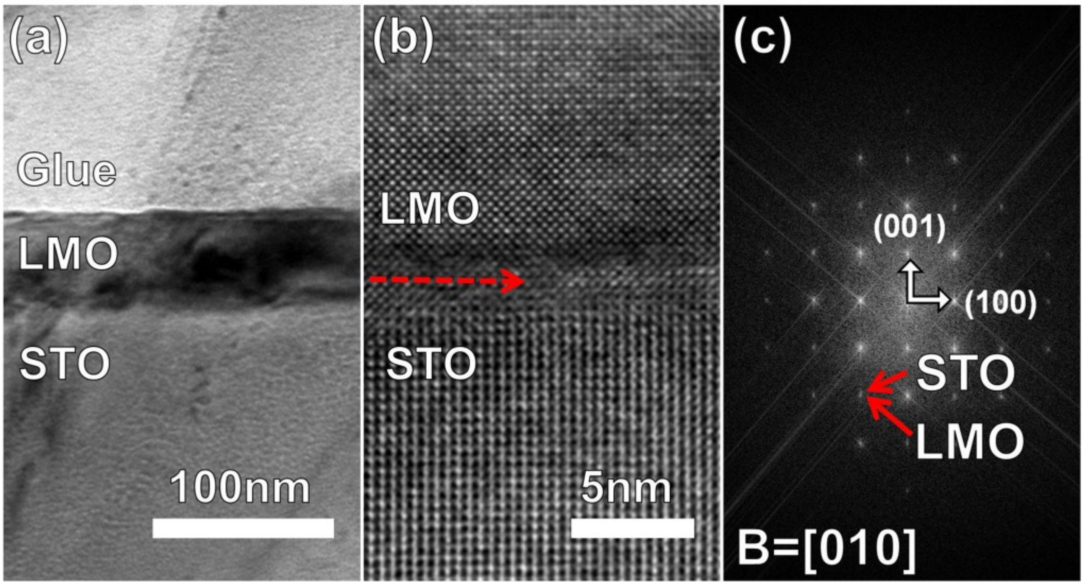

Fig. S2 (a) A cross-sectional TEM image of the LMO film. (b) A HRTEM image of the LMO/STO interface of the LMO film. (c) Fast Fourier Transform (FFT) patterns of the LMO/STO interface transformed from the corresponding HRTEM image.

Fig. S2a shows a cross-sectional TEM image of the LMO film, in which the thickness of LMO film is approximately 55 nm. The high-resolution TEM image (Fig. S2b) demonstrates the sharp LMO/STO interface and the epitaxial growth of the LMO film on the STO substrate. As shown in Fig. S2c, the Fast Fourier Transform (FFT) patterns of the LMO/STO interface indicate that the epitaxial relationship of the LMO/STO interface is $(100)_{LMO}//(100)_{STO}$ and $(001)_{LMO}//(001)_{STO}$.

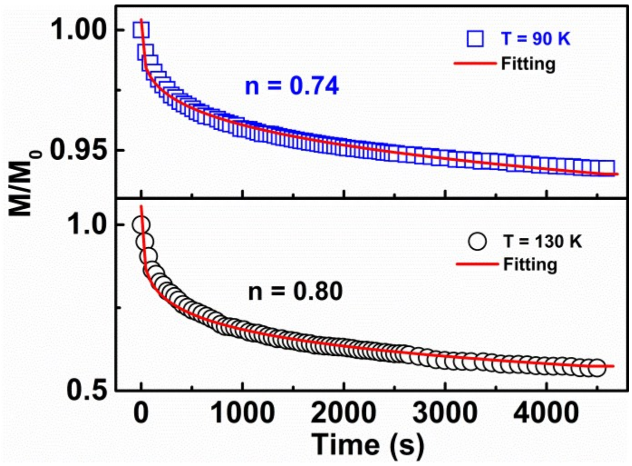

Fig. S3 Time dependence of the thermal remnant magnetization of the LMO/BFO heterostructure measured under an in-plane magnetic field of 100 Oe in the zero field cooling (ZFC) mode from 300 K to 90 K and 130 K, respectively.

To deeply demonstrate the spin glass state in the LMO/BFO heterostructure, we studied the relaxation of the thermal remnant magnetization at two typical temperatures: 90 K and 130 K, which are bellow and around the spin-glass freezing temperature (T_F). The time dependent thermal remnant magnetization was measured after the in-plane magnetic cooling field of 100 Oe from 300 K to the specific temperature, and the results are illustrated in Fig. S3. The stretched-exponential function is used to fit the decay curves:

$$M(t) = M_0 \exp[-C(\omega t)^{1-n}/1-n] \quad (2)$$

where C is the exponential factor, n is the fitting parameter and ω represents the relaxation frequency.[1, 2] The fitted values of n, which were respectively calculated to be 0.74 at 90 K and 0.80 at 130 K, are approximate to the values reported for other systems with spin glass state,[2, 3] further indicating that the formation of the spin glass state in the LMO/BFO heterostructure.

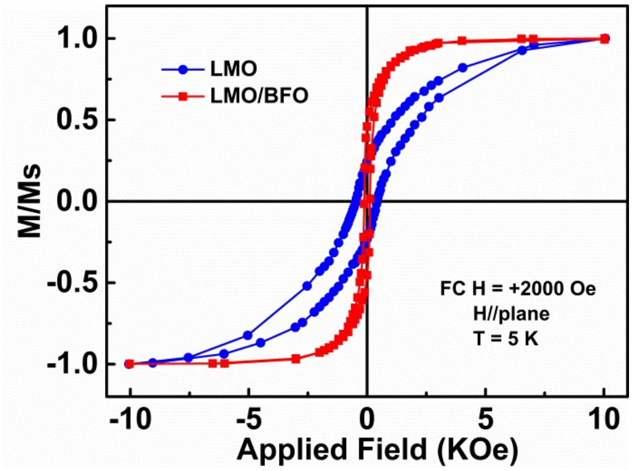

Fig. S4 Magnetic hysteresis loops of the LMO/BFO heterostructure and the LMO film measured at 5 K after cooling field of +2 kOe.

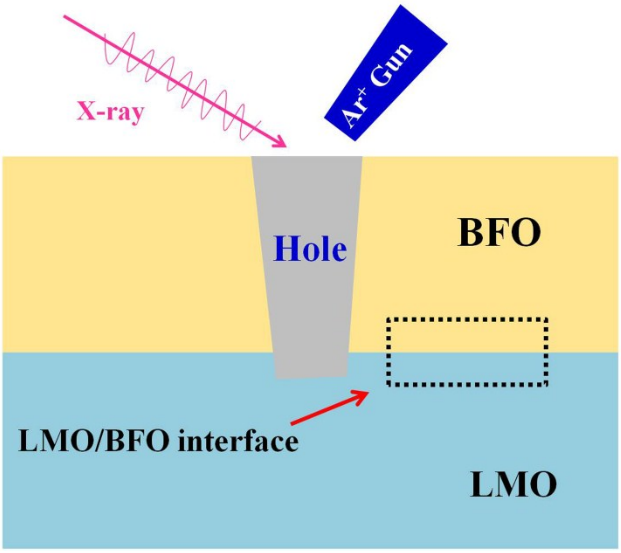

Fig. S5 Schematic illustration of the procedure for XPS measurement.

Firstly, we investigated the Fe 2p spectra of Fe ions of the BFO layer using X-Ray. Secondly, we dug a“hole” to the LMO/BFO interface using an Ar ion sputtering beam, then the Fe 2p spectra of Fe ions and the Mn 3s spectra of Mn ions at the interface region were investigated by X-Ray. Thirdly, we continued to dig the “hole” to the LMO layer, and the the Mn 3s spectra of Mn ions of the LMO layer were investigated.

References

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