Supplementary Information

Ferroelectric Field Manipulated Nonvolatile Resistance Switching in Al:ZnO/Pb($Mg_{1/3}Nb_{2/3}$)$_{0.7}$$Ti_{0.3}O_3$ Heterostructures at Room Temperature

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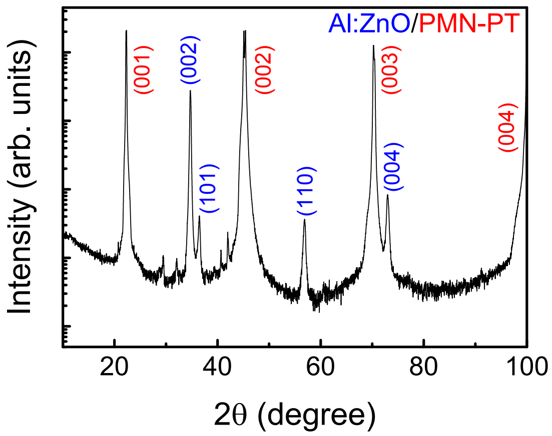

Fig. S1 XRD θ–2θ scan of the Al:ZnO (125 nm)/PMN-PT (001) heterostructures.

The XRD θ–2θ scan of Al:ZnO (125 nm)/PMN-PT heterostructures is shown in Fig. S1. The (001), (002), (003) and (004) diffraction peaks of the PMN-PT substrate can be observed. Except the (002) and (004) diffraction peaks of Al:ZnO films, (101) and (110) peaks are also visible, indicating the polycrystalline properties of the films. Based on the Bragg equation, the out-of-plane lattice parameter of Al:ZnO film is ~5.201 Å. Compared to the ZnO film (5.206 Å),[1] decreases of the lattice parameter of the Al:ZnO film are observed, which can be understand by the smaller ionic radii Al^{3+} (0.535 Å) compare to Zn^{2+} (0.740 Å).[2] According to Debye Scherrer's formula $D_{\rm hkl} = 0.9\lambda / \beta_{\rm hkl} \cos\theta$, the average crystalline size ($D_{\rm hkl}$) of the Al:ZnO films was calculated, where λ is the wavelength of X-ray (1.5406 Å), $\beta_{\rm hkl}$ the full width at half maximum of the (002) peak in radians and θ is the Bragg's diffraction angle.[3–7] The D_{002} of the Al:ZnO thin film is ~35 nm. The micro strain (ε) of the Al:ZnO thin film was determined to be ~0.98×10^{-3} based on the equation $\varepsilon = \beta_{\rm hkl}\cos\theta / 4$.[3–5,8]

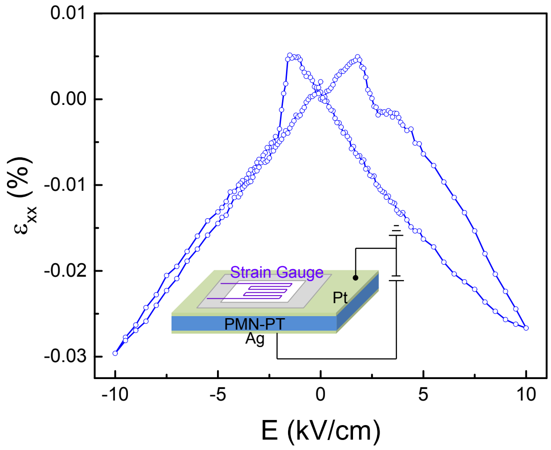

Fig. S2 Strain *vs.* electric field of PMN-PT substrate. The inset shows the measurement structure diagram. The electric field was applied from zero to positive, then to negative and finally back to zero during the measurement of *S*−*E* curve.

The in-plane strain *vs.* electric field of the PMN-PT substrate was measured by using a strain gauge that attached to the PMN-PT surface with glue. A typical butterfly curve is obtained. The strain returns to zero after the electric field removed, which is almost volatile.

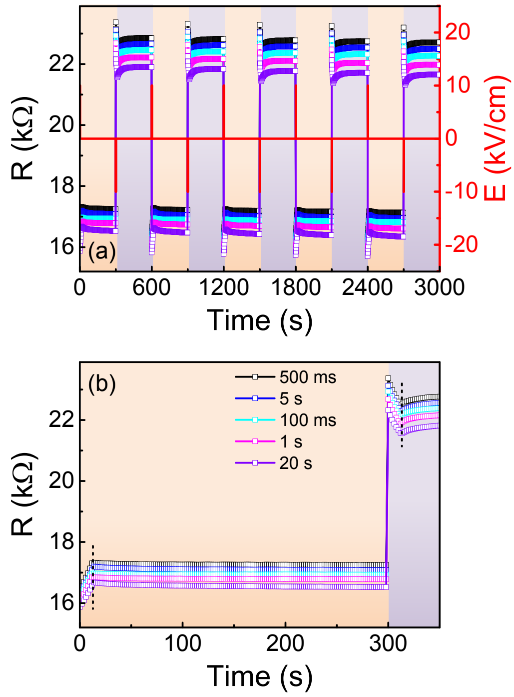

Fig. S3 (a) Resistance *vs.* time with different pulse width measured at room temperature after poling by +10 kV/cm and −10 kV/cm. The electric field was applied along out-of-plane (001) directions. (b) Enlarged view in 0−350 s.

Except the pulse width of 20 s, the resistance switching properties of 100 ms, 500 ms, 1 s and 5 s were also measured. In the all impulse width, the resistance *vs.* time is similar, as shown in Fig. S3. The resistance switching properties of the all impulse width are same.

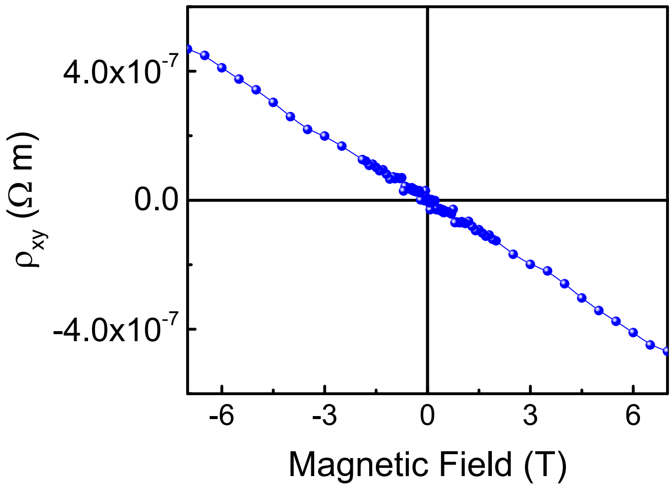

Fig. S4 Hall resistivity ρ_{xy} *vs*. magnetic field H of the Al:ZnO (125 nm)/PMN-PT heterostructure at 300 K.

To obtained the carrier density of the Al:ZnO film, the Hall effect of the Al:ZnO (125 nm)/PMN-PT heterostructure was measured at 300 K. As shown in Fig. S4, the slope of the Hall resistivity ρ_{xy} *vs*. magnetic field H is negative, indicating the *n*-type nature of the Al:ZnO film. The slope of $\rho_{xy}-H$ is obtained by linear fitting, i.e., the Hall coefficient R_H. The carrier density of ~9.3×10^{19} cm^{-3} can be obtained by $R_H = -1/ne$, where n and e are the volume carrier density of the Al:ZnO film and the elementary charge, respectively.

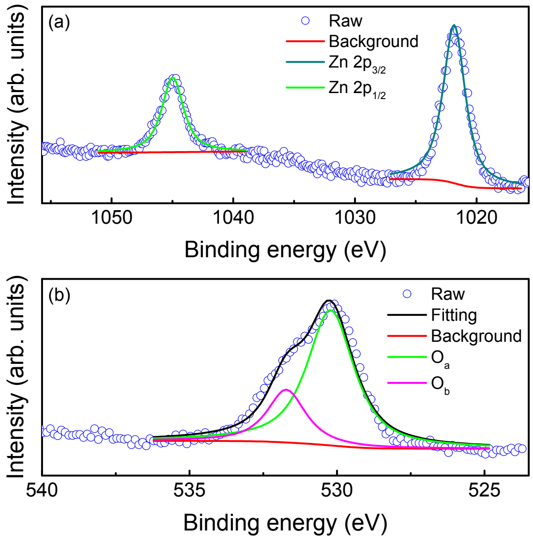

Fig. S5 XPS spectra of the Al:ZnO film in the region of (a) Zn 2$p_{1/3}$, 2$p_{2/3}$ and (b) O 1s peaks.

To confirm the presence oxygen vacancies in the Al:ZnO films, the XPS was measured. The XPS spectra of the Zn 2$p_{1/3}$, 2$p_{2/3}$ and O 1s are given in Fig. S5. The peaks of Zn 2p are located at 1021.9 eV (Zn 2$p_{1/3}$) and 1044.9 eV (Zn 2$p_{2/3}$), respectively.[9] The O 1s XPS spectrum can be fitted into two components. One peak is around 530.2 eV (O_a), which can be attributed to the O^{2-} ions in Al:ZnO. The other peak is around 531.6 eV (O_b), it is related to the O^{2-} ions in the oxygen deficient regions of the Al:ZnO.[10]

References

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