Supporting Information

Significant enhancement of energy storage density and polarization in self-assembled $PbZrO_3$:NiO nano-columnar composite film

Mingjing Chen[1,2], Xingkun Ning[1,*], Shufang Wang[1] and Guangsheng Fu[1]

Mingjing Chen, Prof. Xingkun Ning, Prof. Shufang Wang, Prof. Guangsheng Fu,

Hebei Key Lab of Optic-electronic Information and Materials, The College of Physics Science and Technology, Hebei University, Baoding 071002, People's Republic of China

Mingjing Chen

College of Quality and Technical Supervision, Hebei University, Baoding 071002, People's Republic of China

XPS characterization of $PbZrO_3$:NiO nanocomposites

XPS method has been used to confirm the exact compositon ratios. The Ni 2*p* have been used to calculate the ratio of the NiO. The results show that the deposition time has to be conformity with the volume ratio of NiO.

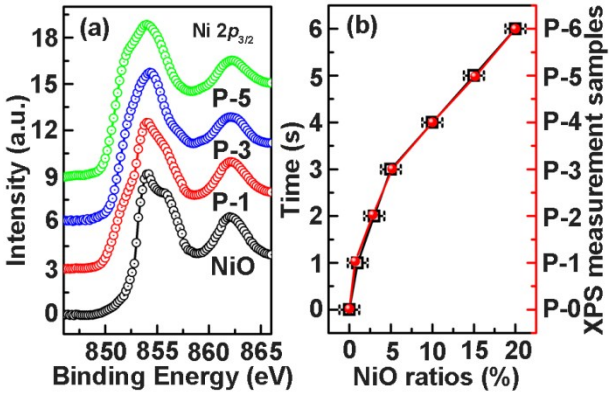

Figure S1. (a) Ni $2p_{3/2}$ spectra for the pure NiO films, P-1, P-3, P-5 nanocolunar composites. (b) NiO composite ratio versus the deposition time and the XPS data.

HAADF images of $PbZrO_3$:NiO nanocomposite films

From the interfacial region, we achieve the average diameter of NiO nanocolumnar is around 2~7 nm within the PZO matrix for the nanocomposite film. From the Figure S3, it is clear that the average diameter of NiO and the number of the NiO nanocolunnars increases with the addition of NiO.

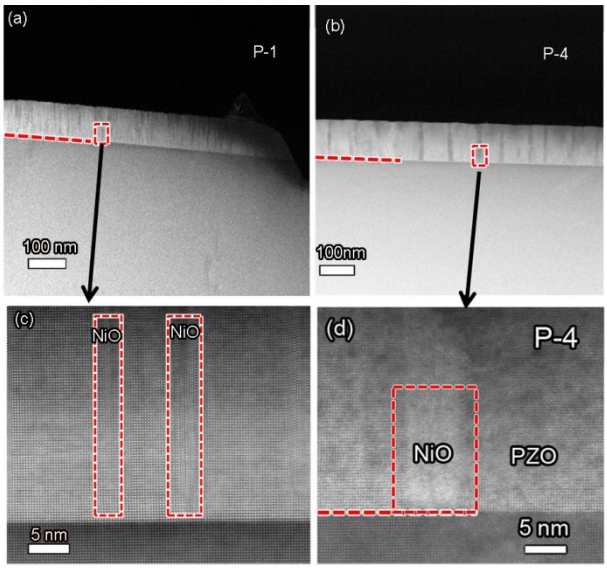

Figure S2. (a)-(c) The Low-magnification HAADF images of the P-1 and P-4 nanocolumns, respectively. (d) High-resolution image of a single NiO nanocolumnar within the PZO matrix for the corresponding nanocolumn composites.

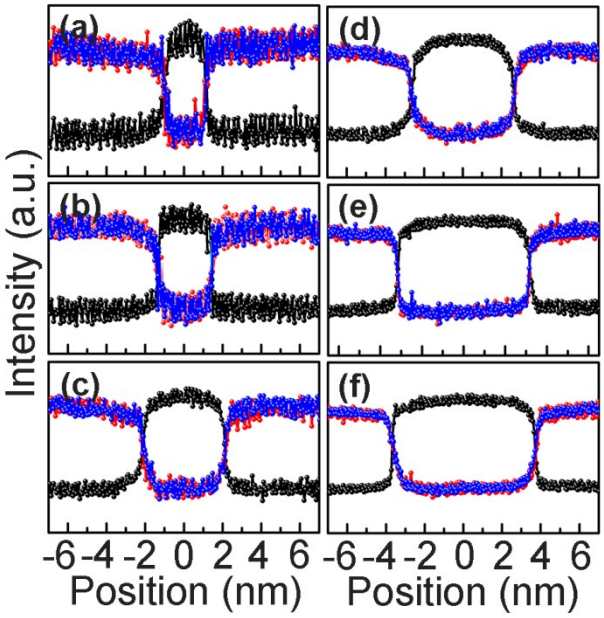

Figure S3. (a)-(f) STEM-EDS line scans for Pb, Zr and Ni atom in the interfacial region around the NiO nanocolomnar (the black, red and blue dot reprents Ni atom, Pb atom and Zr atom, respectively.) for the P-1, P-2, P-3, P-4, P-5 and P-6 PZO:NiO nanocolumn composites, respectively.

Leakage current density for $PbZrO_3$:NiO nanocomposites

The leakage current conduction for these samples have been shown in Figure S4. Figure S4 shows leakage current density of the PZO:NiO nanocomposites as a function of increasing NiO ratio. The lowest leakage current density capacitor of the pure PZO thin film is about 9.5×10^{-3} A/cm^2 and breakdown occurred at ~550 kV/cm. The addition of NiO can decrease the leakage current density. However, when NiO ratio increases beyond 5%, PZO:NiO nanocomposits capacitor can lead to higher leakage current density.

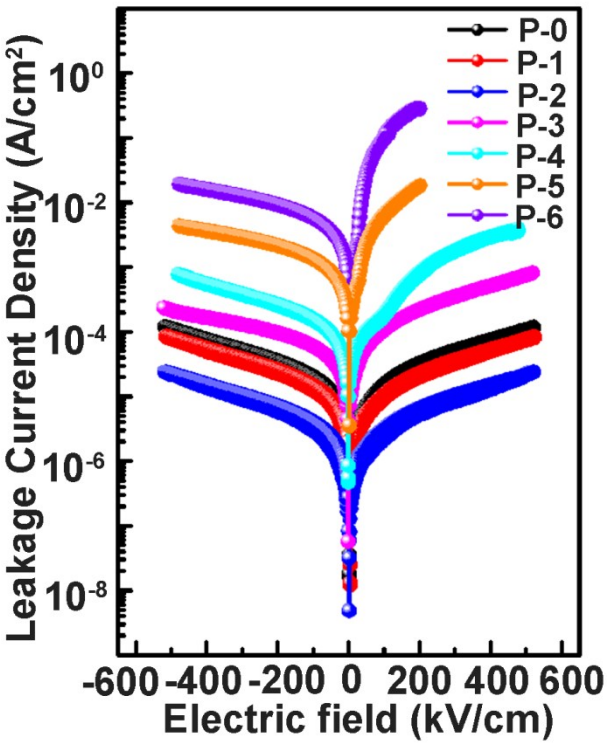

Figure S4. (a) The leakage current density of the PZO:NiO nanocomposites with verious NiO ratios.

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[2] Koo CY, Eum YJ, Hwang S-O, Jung H-S, Yeum J-H, Lee J-Y, Lee HY, Development of High Energy Capacitors Using La-Doped $PbZrO_3$ Anti-Ferroelectric Thin Films. Ferroelectrics 2014;465:89-95.

[3] Liu YJ, Hao XH, Zhou J, Xu JZ, An SL, Effects of raw materials on microstructure and dielectric properties of $PbZrO_3$ antiferroelectric thin films prepared via sol–gel process. Journal of Alloys and Compounds 2011;509:8779–8782.