Electronic supplementary information (ESI)

Wide-frequency-range dielectric tuning of $BaTiO_3$ by embedding metal nanocrystals

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Electronic Supplementary Information (ESI) available: Electron energy loss spectroscopy of Fe-$L_{3,2}$ in the composite films.

We further provided the EELS of Fe-$L_{3,2}$ in the composite films (Fig. S1, Supplementary information). It can be seen that the position of the L_3 and L_2 edge from the area of Fe is 707.2 and 721.3 eV, respectively. It proves that the Fe element presents a metallic state in the composite films instead of iron oxides [1, 2].

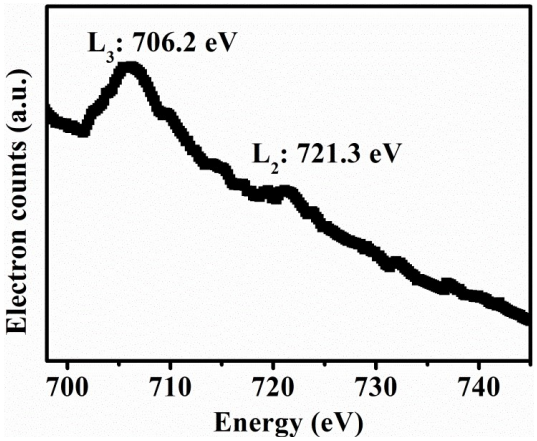

Fig. S1 Electron energy loss spectroscopy of Fe-$L_{3,2}$ in the composite films.

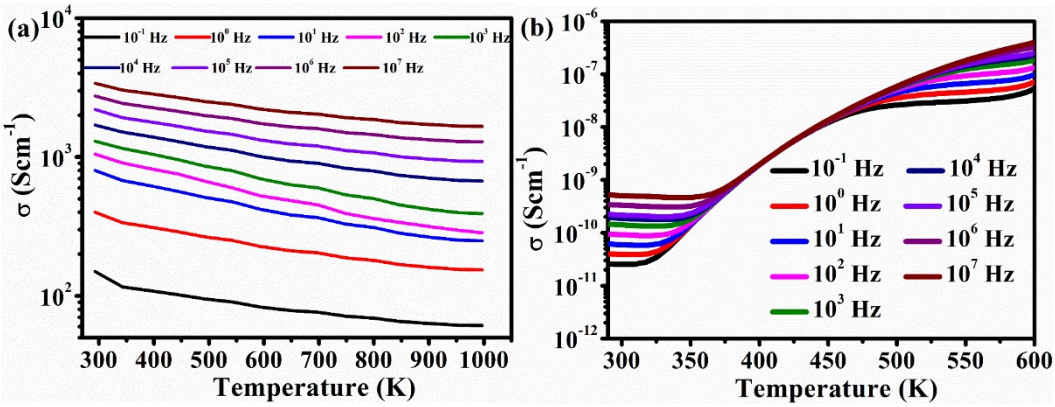

Fig. S2(a) Temperature dependence conductivity (σ) of 0.5 wt% Nb:$SrTiO_3$ substrates and (b) pure epitaxial BTO films at varied frequencies.

Fig. S2 shows the temperature dependence conductivity (σ) of 0.5 wt% Nb:$SrTiO_3$ substrates and epitaxial BTO films. With the increase of temperatures, the σ of

$Nb:SrTiO_3$ substrate is almost linearly decreased (Fig. S2a), ascribing that the $Nb:SrTiO_3$ behaves as a doped semiconductor with electrons being thermally activated. On the contrary, the σ-T curves of BTO films present the insulating properties. So we can exclude the influence of 0.5 wt% $Nb:SrTiO_3$ substrates to the films. By comparison, the conductivities of Fe NCs-BTO composites (Figs. 6c, d) are higher than that of BTO films (Fig. S2b), proving that the embedded Fe NCs could really increase the σ of BTO matrix. The increased leakage conductance further brings the increase of tanδ (Fig. 4b). To sum up, it can be concluded that the embedded Fe NCs could indeed change the dielectric properties of epitaxial BTO films.

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[2] K. F. Chen, S. C. Lo, L. Chang, *et al*., Valence state map of iron oxide thin film obtained from electron spectroscopy imaging series, Micron, 2007, **38**, 354-361.