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Supplementary Information

Novel Barium titanate based capacitors with high energy density and fast discharge performance

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Experimental Section

The $0.88BaTiO_3$–$0.12Bi(Li_{0.5}Nb_{0.5})O_3$ ceramics were synthesized by the conventional solid state reaction method. Proportionate amounts of reagent-grade $BaCO_3$ (>99.84%), rutile TiO_2(>99.84%), Bi_2O_3(>99%), Li_2CO_3 (>99.5%,), and Nb_2O_5 (>99.5%) as the starting reactants. The mixed powders were milled in absolute ethyl alcohol solution with 2 mm diameter zirconia balls as milling media using planetary mill for 4 h, then calcined in the air at 950°C for 4 h. After being crushed and re-milled for 5 h at 200 rpm to increase reactivity and better homogeneity. Then the dried powders granulated with 5 wt% polyvinyl alcohol (PVA) were uniaxially pressed into cylinders (12 mm in diameter and 1 mm in height) in a steel die under pressure of 150 MPa. PVA was burnt out at 550 °C for 4 h (2 °C/min). Samples were sintered in the temperature ranges from 1200 °C to 1260 °C for 4 h (3 °C/min).

Crystalline structures were investigated by using X-ray diffraction (XRD) with Cu Kα radiation (Rigaku D/MAX-2400 X-ray diffractometer, Tokyo, Japan). Microstructures were observed on fractured surfaces with scanning electron microscopy (SEM) (SEM; Quanta 250 F, FEI). The specimens for high resolution transmission electron microscopy were prepared from the sintered pellets

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and examined using a JEOL 2100 TEM microscope operated at 200 kV (HR-TEM, JEM-2100, JEOL Inc., Japan). The details for TEM experiments are shown in the **TEM experiments**. To determine the dielectric properties, the sintered samples were polished and coated with silver on both surfaces. Temperature dependence of dielectric constant and loss was determined at frequencies between 100 Hz and 1 MHz by means of a LCR meter (HP 4980, Agilent, Palo Alto, CA) interfaced with a computer, where the specimens were heated at a rate of 2 ^{o}C /min from 25 ^{o}C to 300 ^{o}C. Polarization–electric field (P–E) hysteresis loops were measured at room temperature by a TF Analyzer 2000 (aix ACCT) ferroelectric test system. The electric field was applied from 1 to 350 kV cm^{-1} with a triangular wave form under 10 Hz during measurement. The discharge speed and discharged energy were measured using a specially designed, high-speed capacitor discharge circuit similar to that reported in the literature. The discharge current waveforms were obtained by an oscilloscope (Tektronix DPO 4104) connected with a coil (Pearson 6585).

TEM experiments:

Samples (1mm×1mm×20μm cuboids) were prepared by the following procedure:

(1) 10 mm diameter discs were mechanically polished down to 1 mm,

(2) 10 mm diameter discs were cut into 1mm×1mm×1mm cuboid samples using a Gatan diamond wire cutter,

(3) samples were further polished mechanically down to a thickness of 20 μm by using Gatan Disc Grinder System (GATAN 623), (3) Stick to the sample on the one side of copper ring,

(4) final polishing to reach electron transparency was carried out using a Gatan PIPs system (Gatan 691), with Ar-ion beams operated at 1 kV; the beam angles were initially set to 4° and in the final stage to 2°.

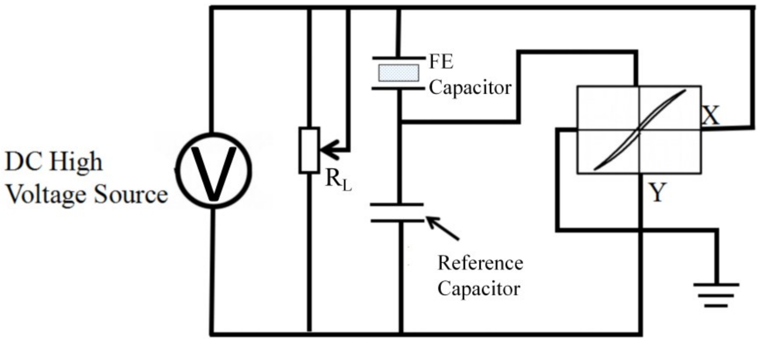

Fig. S1 The schematic diagram for measurement of energy storage properties of ferroelectric capacitor.

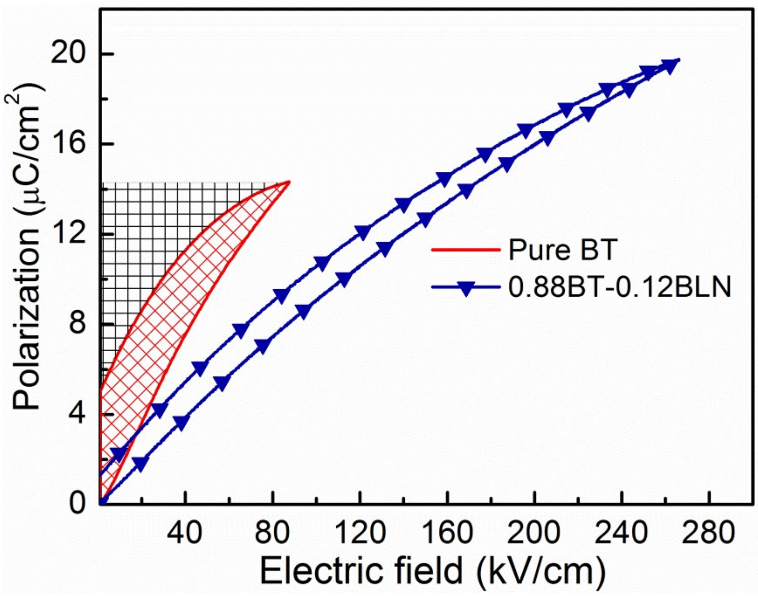

Fig. S2 The unipolar P-E hysteresis of pure BT and 0.88BT-0.12BLN ceramics at room temperatures near breakdown strength

As shown in Fig. S2, the W of a dielectric material is equal to the integral of an area (represented by the black and red areas) enclosed by charge curve and y-axis. The W_{dis} is calculated by integrating the area (represented by the black areas) enclosed by discharge curve and y-axis. The energy loss density is defined as the difference between charged and discharged energy densities, quantitatively equal to the inner space of P-E loop (represented by the red areas).

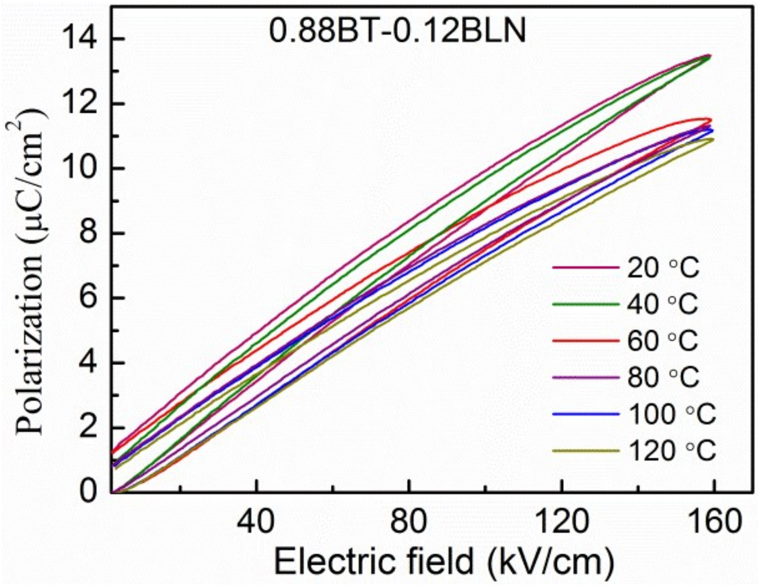

Fig. S3 The unipolar P-E hysteresis of 0.88BT-0.12BLN ceramics at different temperatures.

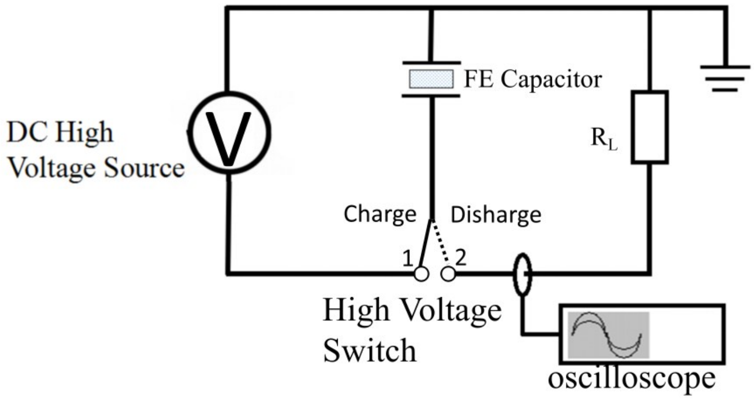

Fig. S4 The schematic diagram for measurement of energy storage properties of ferroelectric ceramics.

Fig. S4 illustrated a charge-discharge platform was established to study the energy release properties of obtained ceramics. Firstly, the high voltage switch is turned "1" to make the $BaTiO_3$-based capacitor charged. After that, the switch is turned "2" and the $BaTiO_3$-based capacitor will discharge. A coil connected to an oscilloscope is used to obtain the discharge current waves.

References:

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