Supplementary information

Substantially improved energy density of SrTiO$_3$ thin film by cyclic cooling-heating and interfacial blocking effect

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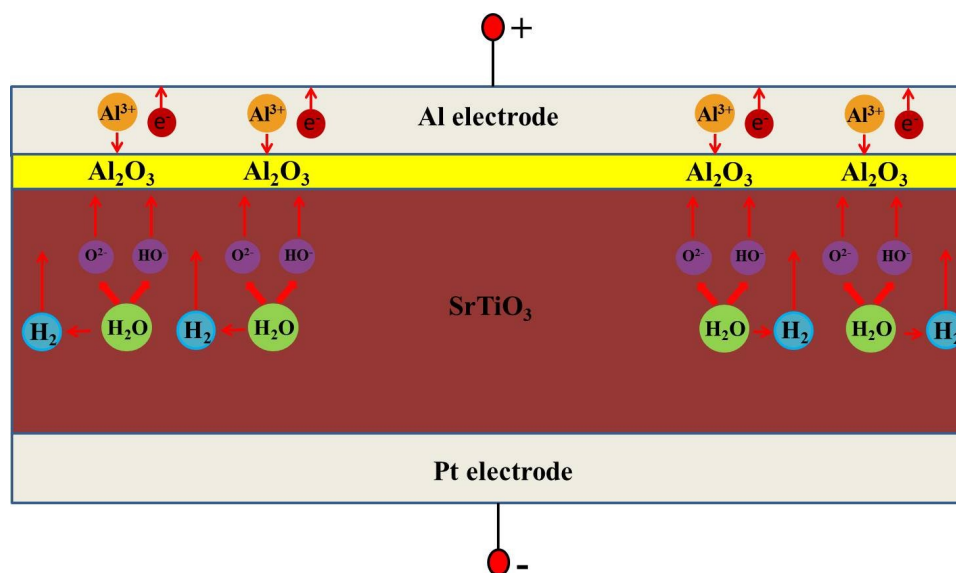
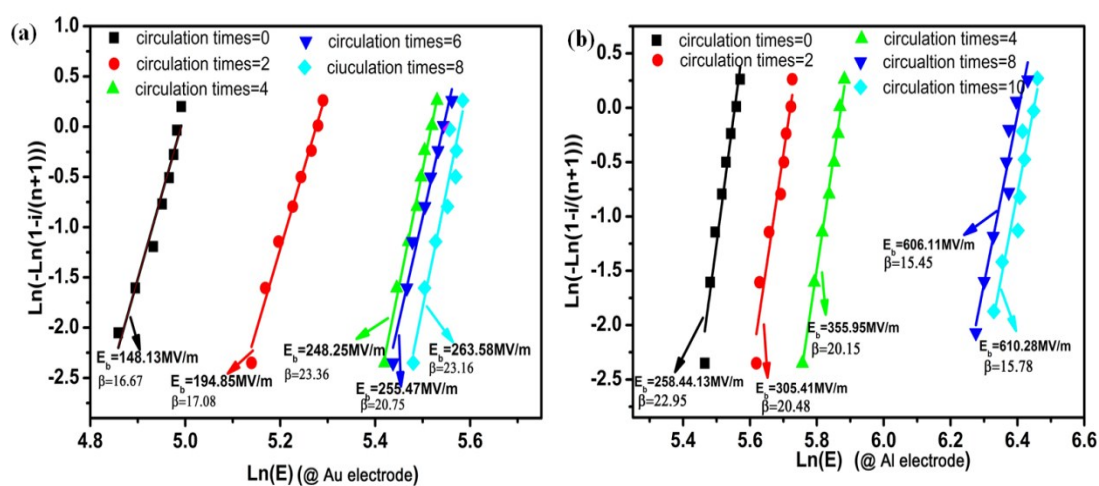**Fig. S1**. The anodic oxidation reaction model of the SrTiO3 film with Al electrode.

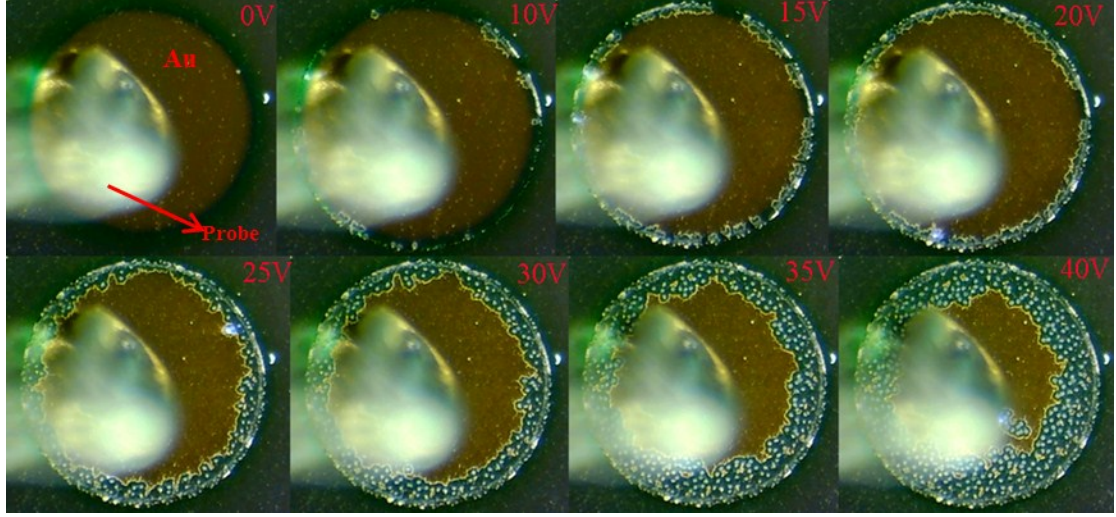**Fig. S2**. Weibull plots for Au and Al electrode.

Fig. S3 Observation of breakdown process for Au electorde with an optical microscopy system.
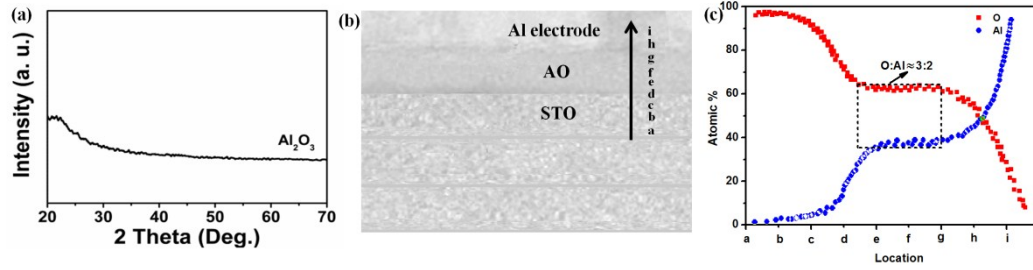

Fig. S4 (a) XRD pattern of generated Al_2O_3 layer. (b)–(c) Selected path of EDS for linear scanning

S5. According to the TSDC theory , dipole polarization can be described with a single relaxation with the classical Debye model and thermally stimulated depolarization process was shown in equation (S1). The corresponding parameters of T is the absolute temperature, p is polarization intensity, β is the heating rate, k is Boltzmann constant, τ_0 is the relaxation time at infinite temperature and H is the activation energy.

$$I\left(TSDC\right)=-\beta\frac{dp\left(T\right)}{dT}=\frac{p_0\left(T_0\right)}{\tau_0}\times\exp\left(-\frac{H}{kT}-\frac{1}{\beta\tau_0}\int_{T_0}^{T}e^{-\frac{H}{kT}}dT\right) \qquad (S1)$$

The characteristics of dipole polarization can be figured out clearly in equation (S3) and (S4) which originated from derivation process in equation (S2). Equation (S3)

displays that peak temperature (T_m) is independent of poling field (E) while equation (S4) exhibits a linear relation of peak current (I_m) with the poling field (E). For the terms in the pre-exponential factor in equation (S4), N is the dipole density, μ is dipole moment, E is poling field, and T_b is poling temperature.

$$\frac{dI(TSDC)}{dT} = \frac{P_0}{\tau_0} \exp(-\frac{H}{kT} - \frac{1}{\beta\tau_0} \int_{T_0}^{T} e^{-\frac{H}{kT}} dT) \times \left(\frac{1}{kT^2} - \frac{1}{\beta\tau_0} e^{-\frac{H}{kT}} \right) = 0 \qquad (S2)$$

$$\frac{H_0}{kT_m^2} = \frac{1}{\beta\tau_0} e^{-\frac{H_0}{kT_m^2}} \qquad (S3)$$

$$I_m = \frac{N\mu^2 E}{3kT_b\tau_0} \times \exp\left(-\frac{H_0}{kT_m} - \frac{1}{\beta\tau_0} \int_{T_0}^{T} e^{-\frac{H_m}{kT_m}} dT \right) \qquad (S4)$$

The total charge of ionic polarization should accord with the form of sinh function, as shown in equation (S5), where q is the ionic charge, N is the density of the moving ions and a is the separation.

$$Q_{TSC} = p(t_b) = \frac{1}{\beta} \int I(T) dT = Q_0 \sinh\left(\frac{qaE_b}{2kT_b} \right) \qquad (S5)$$