Depolarization of multidomain ferroelectric materials

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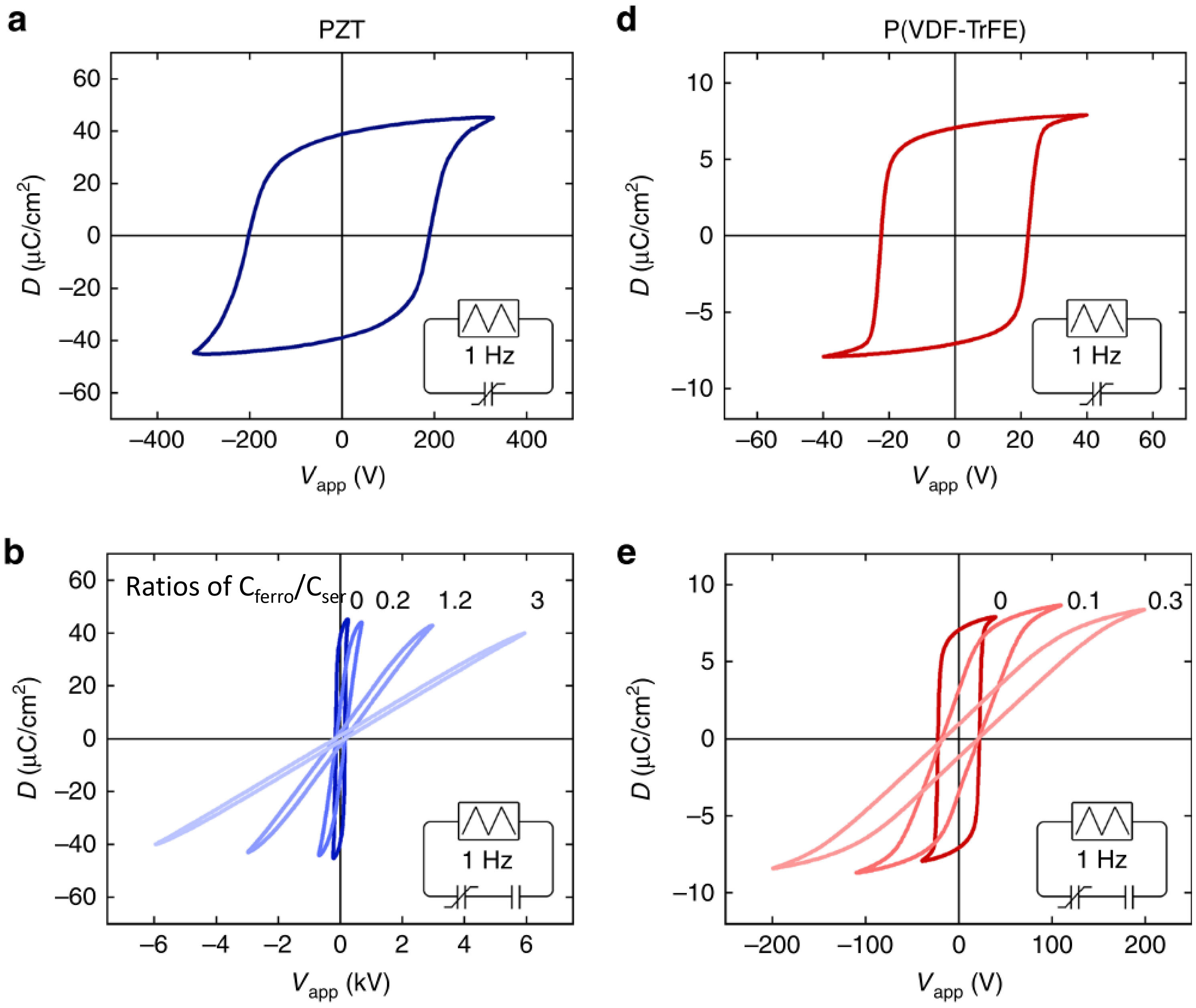
Group meeting

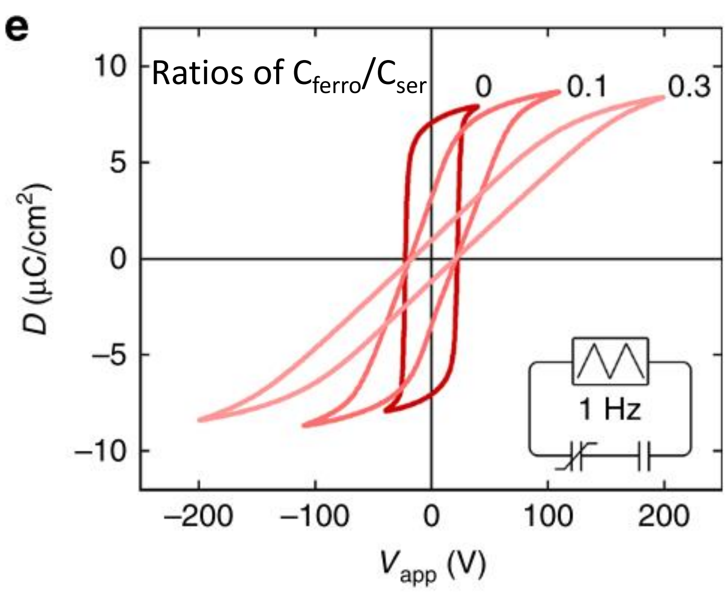
07/10/2020

The effect of the linear capacitors on hysteresis loops



1. The smaller C_{ser} is, the more tilted the loops get
2. For the smaller $C_{ser,}$ a higher applied voltage is needed to fully polarize the ferroelectric capacitor
3. The smaller C_{ser} is, the smaller remnant polarization P_r
4. All loops have an identical apparent coercive voltage

Analysis about the suppression of polarization by linear capacitors



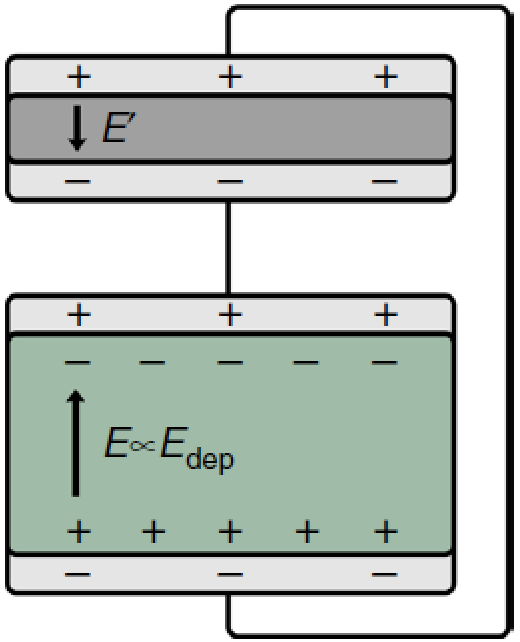
$$V_{app} = V_{ferro} + V_{ser} \qquad (10)$$

$$V_{ferro} = \frac{Q_{ferro} - PA}{C_{ferro}} \text{ and } V_{ferro} = V_{app} - \frac{Q_{ser}}{C_{ser}} \qquad (11)$$

$$Q_{ferro} = Q_{ser} = V_{ferro} C_{ferro} + PA.$$

$$V_{ferro} = \frac{C_{ser}}{C_{ser} + C_{ferro}} V_{app} - \frac{PA}{C_{ser} + C_{ferro}} \qquad (12)$$

$$E_{ferro} = \frac{V_{app}}{d} - \frac{D}{\varepsilon_0 \varepsilon_{ferro}} \cdot \frac{C_{ferro}}{C_{ser}} \qquad (14)$$

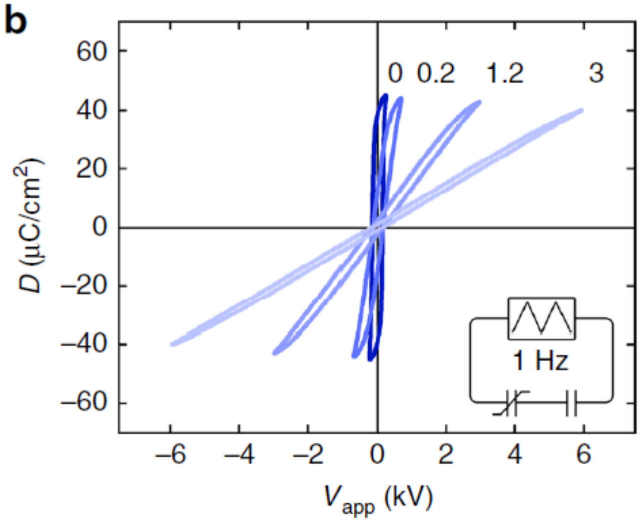


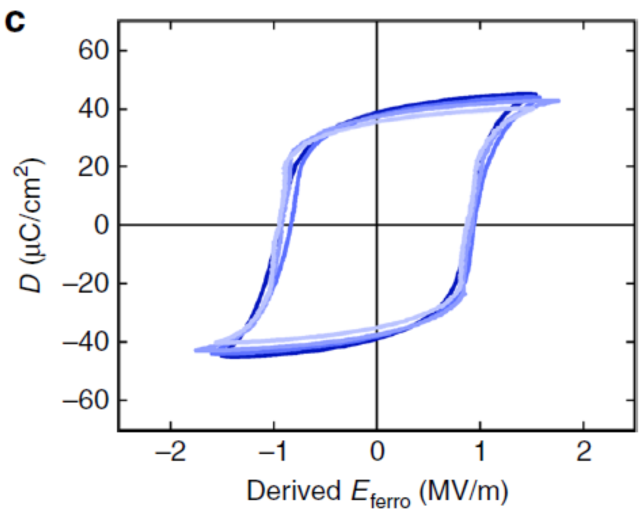
$$E_{dep} = -\frac{P}{\varepsilon_0 \varepsilon_{ferro}} \qquad (1)$$

Analysis about the suppression of polarization by linear capacitors

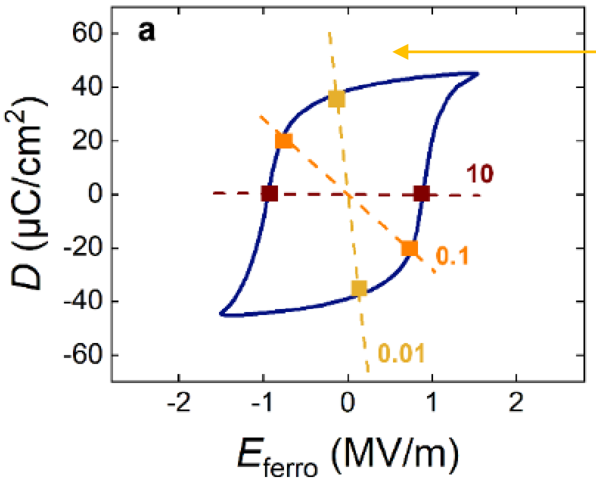
$$E_{\text{ferro}} = \frac{V_{\text{app}}}{d} - \frac{D}{\varepsilon_0 \varepsilon_{\text{ferro}}} \cdot \frac{C_{\text{ferro}}}{C_{\text{ser}}} \quad (14) \qquad V_{app} = V_{app}(D)$$

Quasi-statically measurement





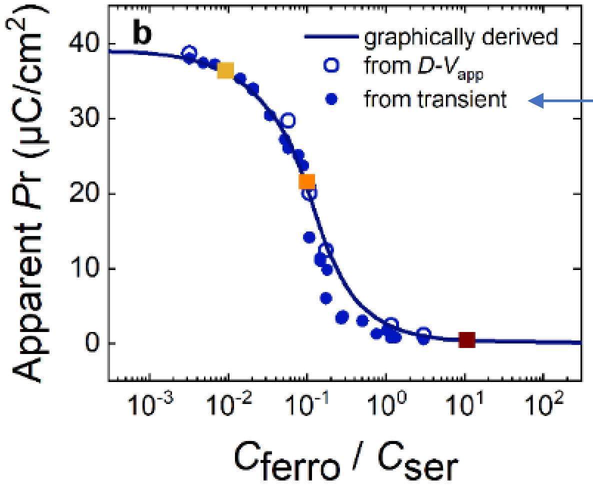
PZT



Graphically derived

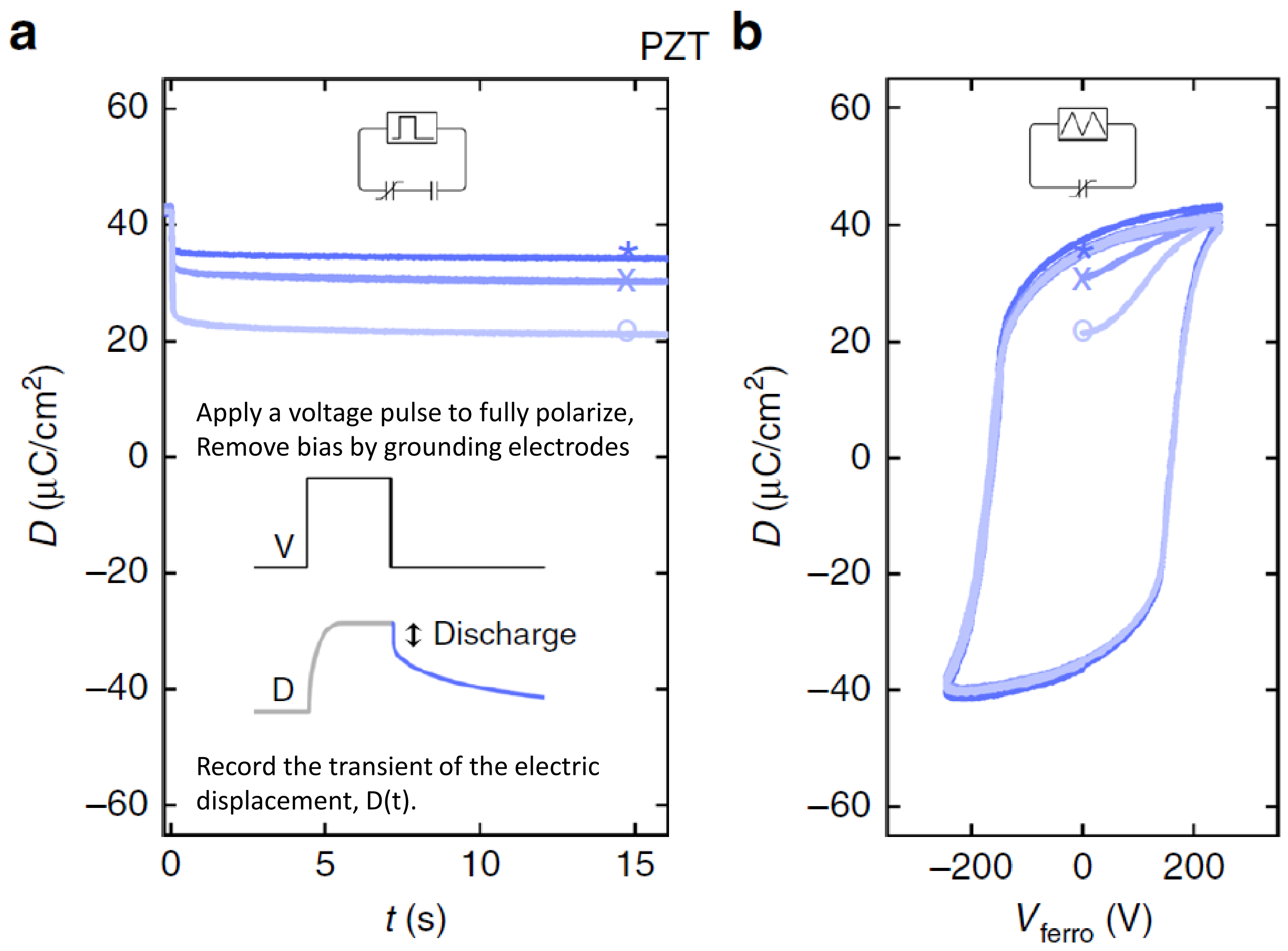
$$E_{ferro} = 0 - \frac{D}{\varepsilon_0 \varepsilon_{ferro}} \cdot \frac{C_{ferro}}{C_{ser}}$$

An excellent agreement is obtained.



Retained polarization

Dynamics of depolarization

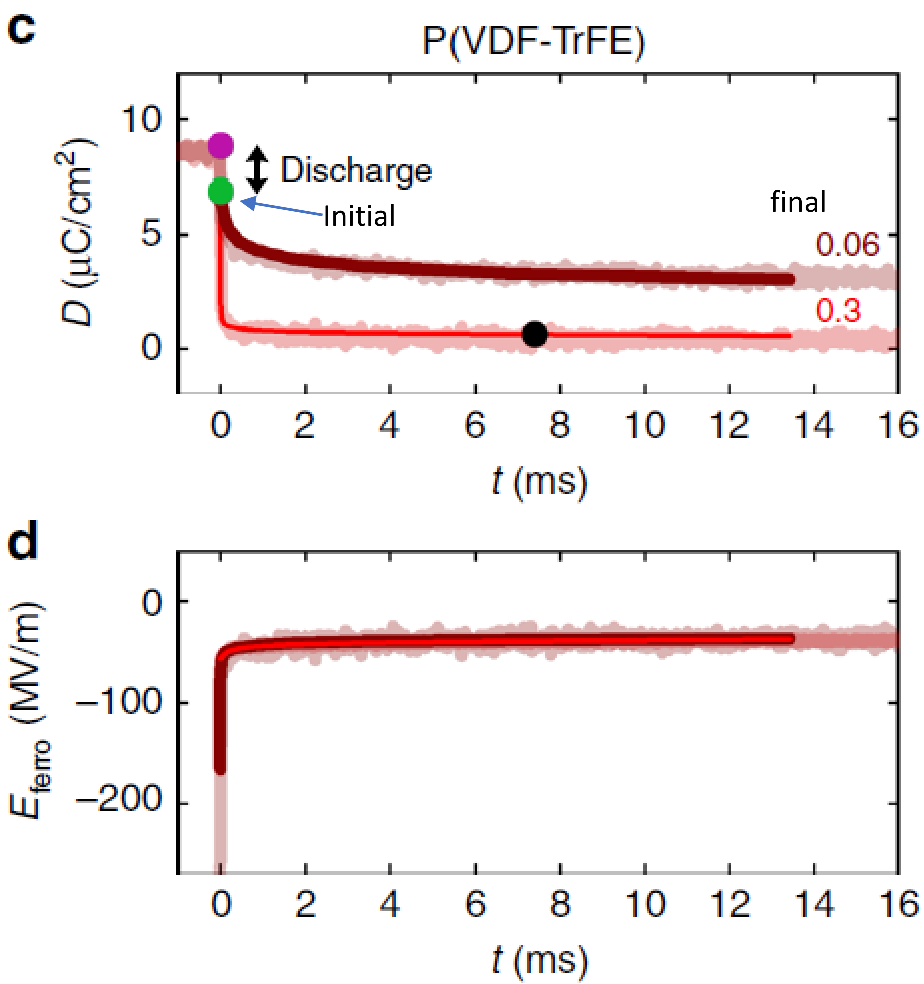


1. Fast discharging
2. Ferroelectric depolarization
3. Get retained polarization

After stabilization of displacement, measure the first two D-V_{ferro} hysteresis loops of the ferroelectric-only capacitor

Conclusion: the final polarization state in the dynamic depolarization measurements is identical to the suppressed polarization state reached quasi-statically.

Dynamics of depolarization



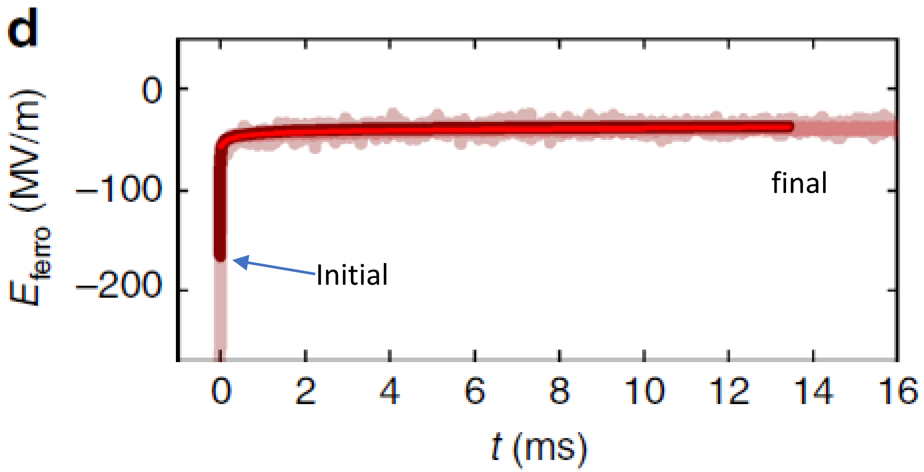
$$E_{ferro} = 0 - \frac{D}{\varepsilon_0 \varepsilon_{ferro}} \cdot \frac{C_{ferro}}{C_{ser}}$$

The final internal field, of about 50 MV/m, is equal to the coercive field.

The initial and final internal fields were calculated from the corresponding displacement *D*

The depolarization transients feature a **negative differential capacitance** (NDC) as their signs are opposite.

Dynamics of depolarization

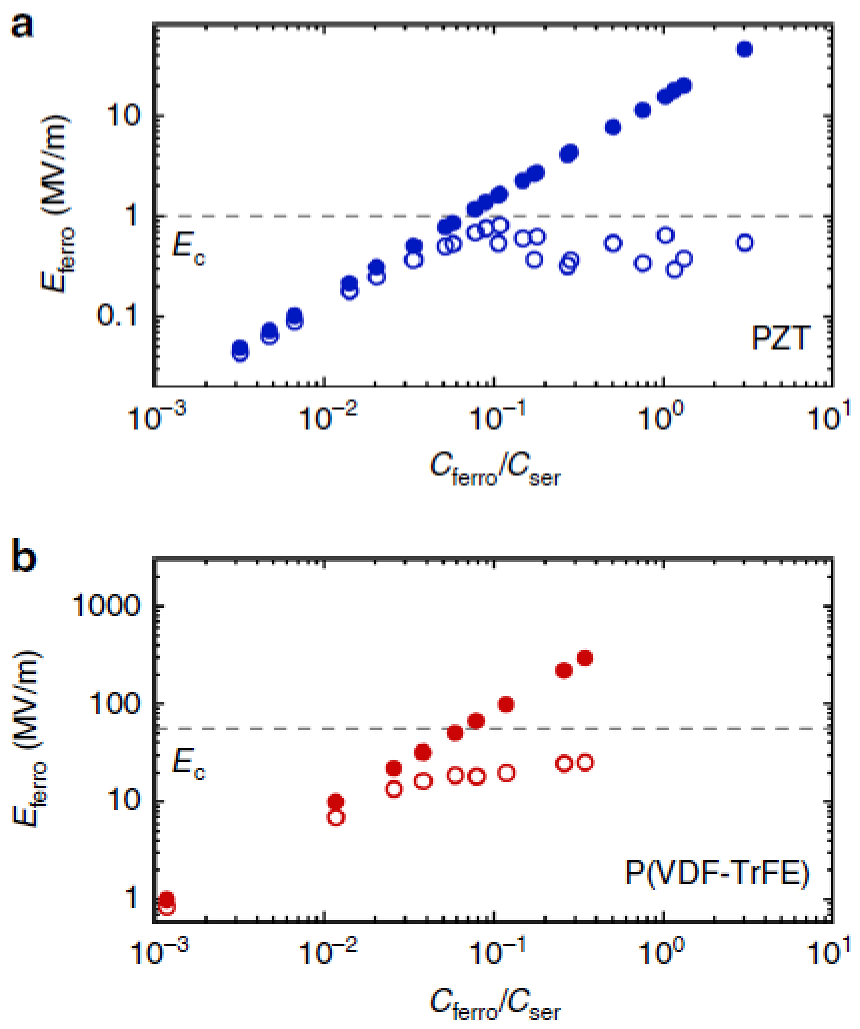


- The initial and final internal fields are identical when the initial internal field is much lower than the coercive field. **No depolarization**

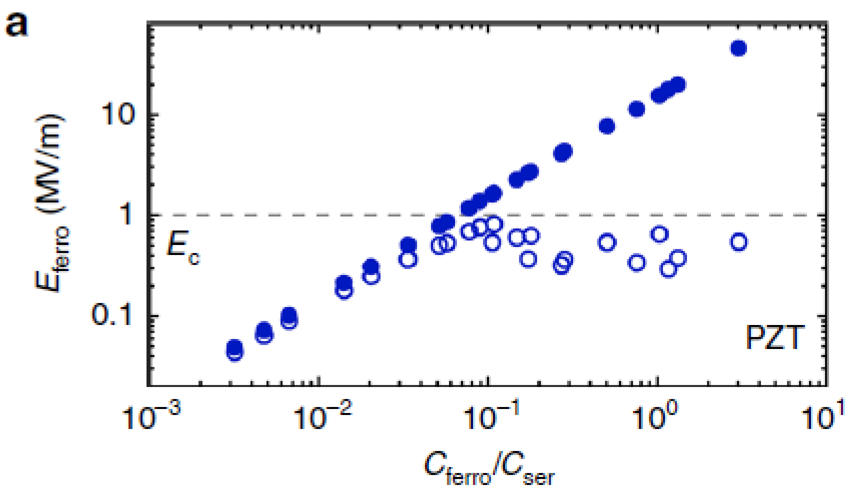
- The final internal field is stabilized at the coercive field, regardless of the ratio C_{ferro}/C_{ser}

The solid circles represent the initial electric field

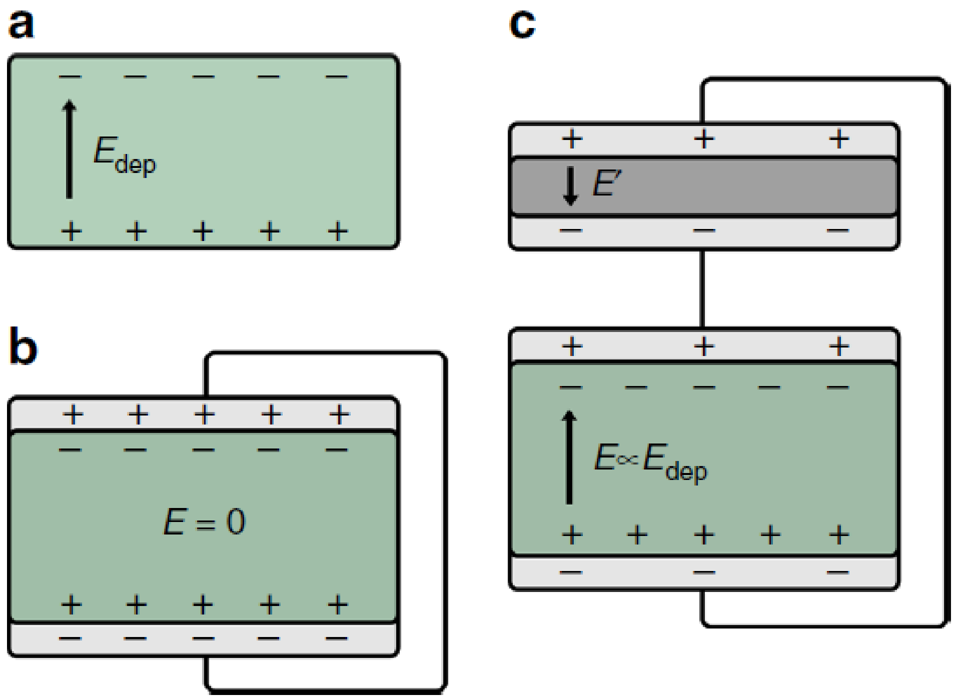
The open circles represent the retained values of the field after depolarization.



Why does the initial internal electric field change with C_{ser}?

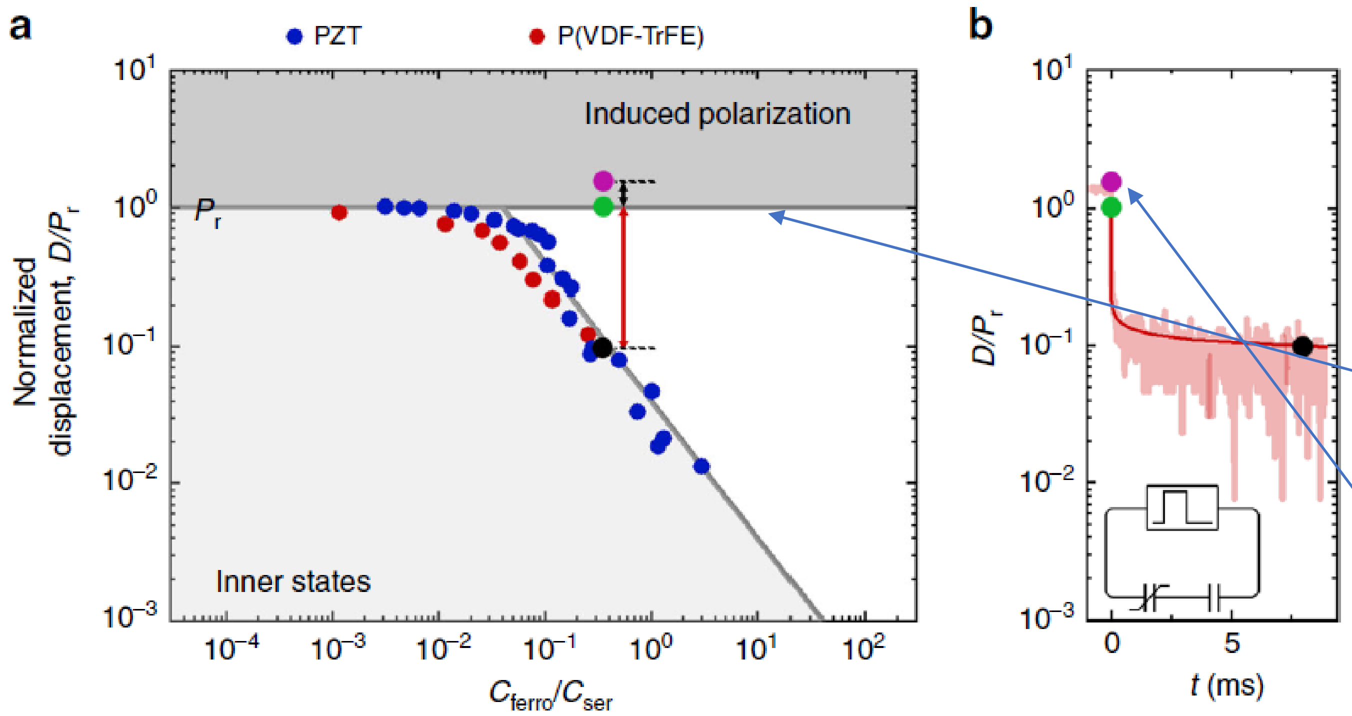


1. For ferroelectric-only capacitors, fully compensated
2. With C_{ser}, incomplete compensation results in a finite internal field



- When this internal field is lower than the coercive field, the system is thermodynamically stable.
- If the initial internal field is larger than the coercive field, then domains will switch, leading to depolarization

Depolarization diagram



the retained displacement as a function of C_{ferro}/C_{ser}

$$D/P_r = \frac{\varepsilon_0 \varepsilon_{ferro} E_c / P_r}{C_{ferro}/C_{ser}} \qquad (4)$$

The overlaps of PZT and PVDF means the proportionality constant, $P_r/\varepsilon_0\varepsilon_{ferro}E_c$, is a **constant**, here of about 15

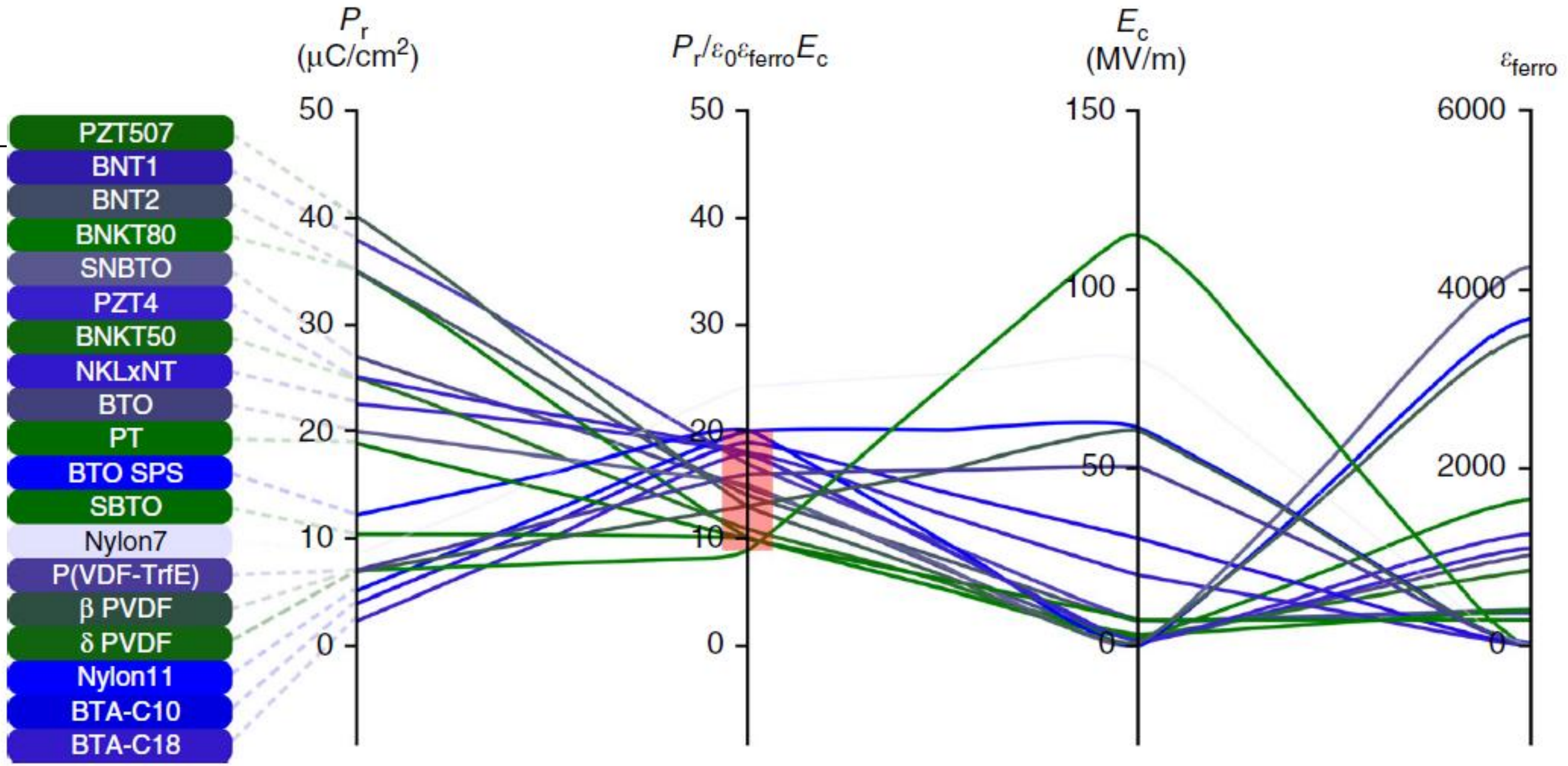
The boundary of thermodynamically stable initial polarization states

The saturated ferroelectric polarization + the linear displacement, termed as **the set displacement**

The inner polarization states formed by incomplete or partial switching of the polarization, when the initial set displacement is smaller than the maximum remanent polarization of the ferroelectric-only capacitor. No depolarization.

Universality of $P_r/\varepsilon_0\varepsilon_{ferro}E_c$

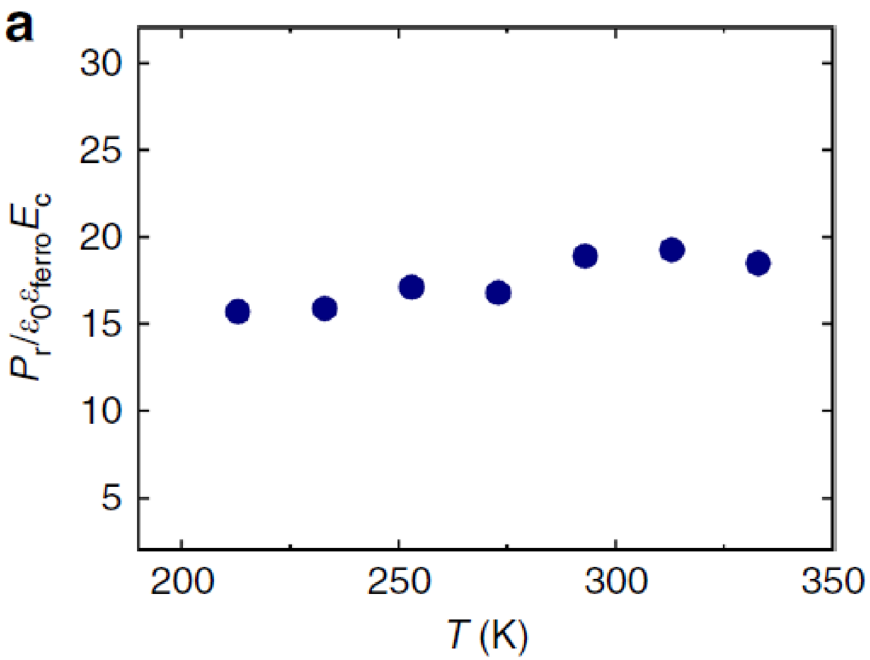
Ferroelectric material	Code
P(VDF-TrFE) 65/35	P(VDF-TrFE)
β PVDF	β PVDF
δ PVDF	δ PVDF
PZT 507 soft	PZT507
PZT 4 hard	PZT4
$PbTiO_3$	PT
$BaTiO_3$	BTO SPS
$BaTiO_3$	BTO
$SrBi_2Ta_2O_9$	SBTO
Nylon-11	Nylon11
Nylon-7	Nylon7
trialkylbenzene-1,3,5-tricarboxamide	BTA-C10
trialkylbenzene-1,3,5-tricarboxamide	BTA-C18
$Bi_{0.5}Na_{0.5}TiO_3$	BNT1
$Bi_{0.5}Na_{0.5}TiO_3$	BNT2
$Bi_{0.5}Na_{0.5}TiO_3$–$Bi_{0.5}K_{0.5}TiO_3$	BNKT50
$Bi_{0.5}Na_{0.5}TiO_3$–$Bi_{0.5}K_{0.5}TiO_3$	BNKT80
$(Na_{0.535}K_{0.485})_{1-x}Li_x(Nb_{0.8}Ta_{0.2})O_3$	NKL_xNT
$Sr_{0.15}(Na_{0.5}Bi_{0.5})_{0.85}TiO_3$	SNBTO



A comparable value for $P_r/\varepsilon_0\varepsilon_{ferro}E_c$ is obtained, of about 15

The standard deviation is only 4.9, which suggests that this constant is universal.

Universality of $P_r/\varepsilon_0\varepsilon_{ferro}E_c$



Extracted value of $P_r/\varepsilon_0\varepsilon_{ferro}E_c$ as a function of temperature for poly (vinylidenefluoride-trifluoroethylene) [P(VDF–TrFE)]

The ideal model system P(VDF–TrFE) the ratio $P_r/\varepsilon_0\varepsilon_{ferro}E_c$ is indeed temperature independent.