The effect of passive layer on the hysteresis loop of ferroelectric thin films

Yifan Yuan

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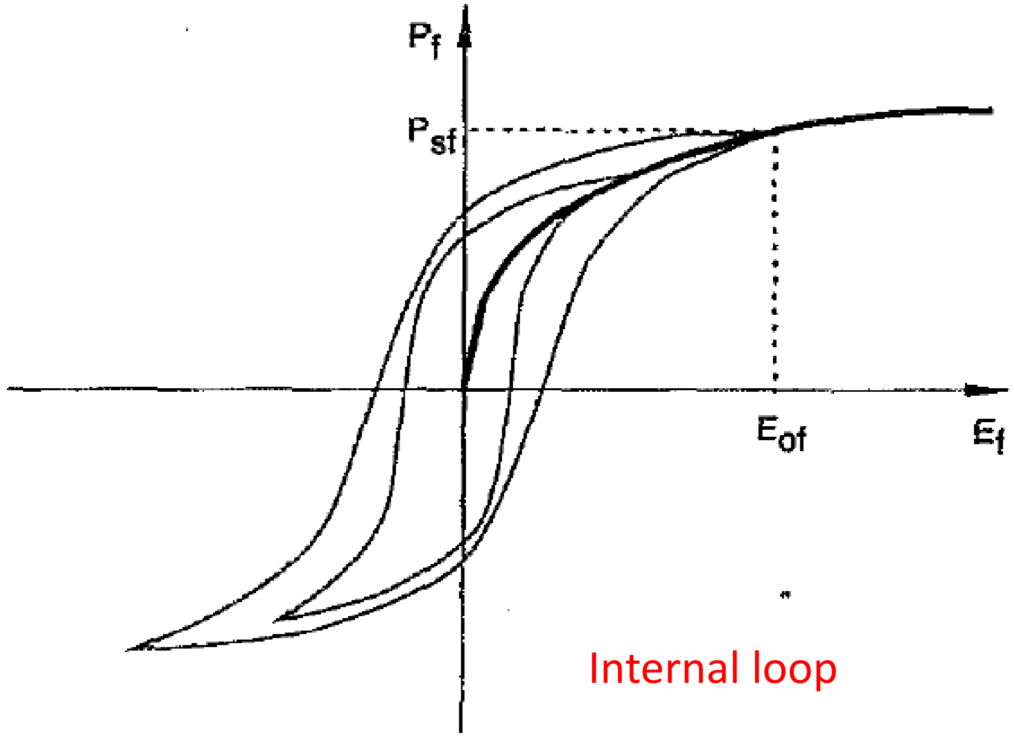
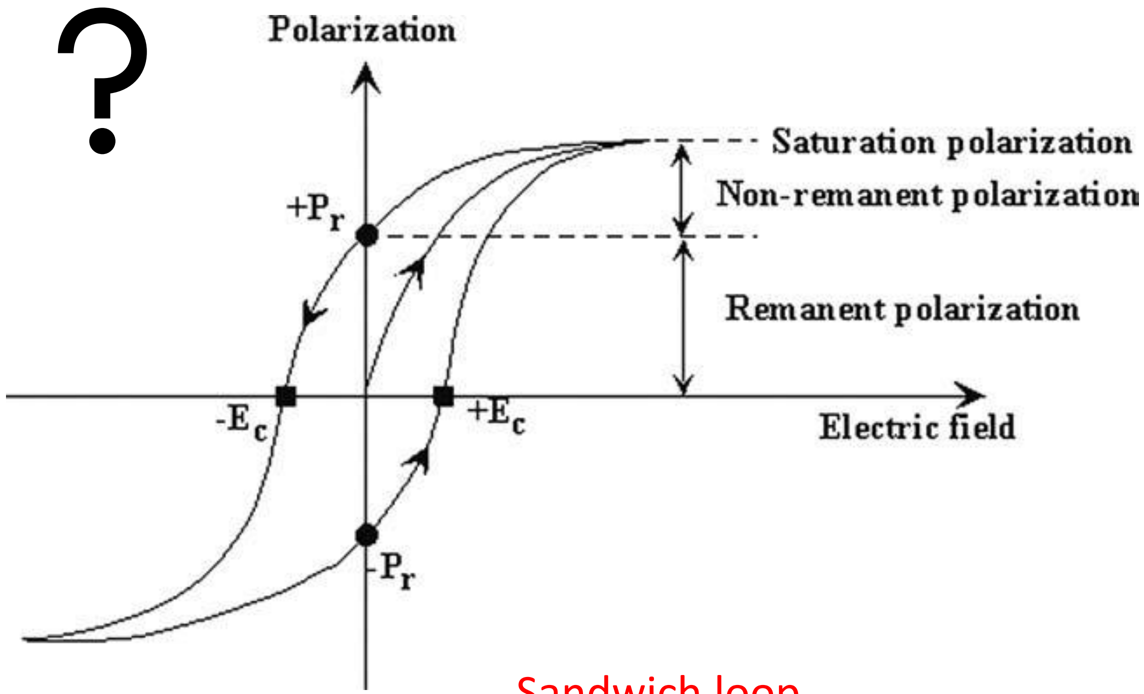
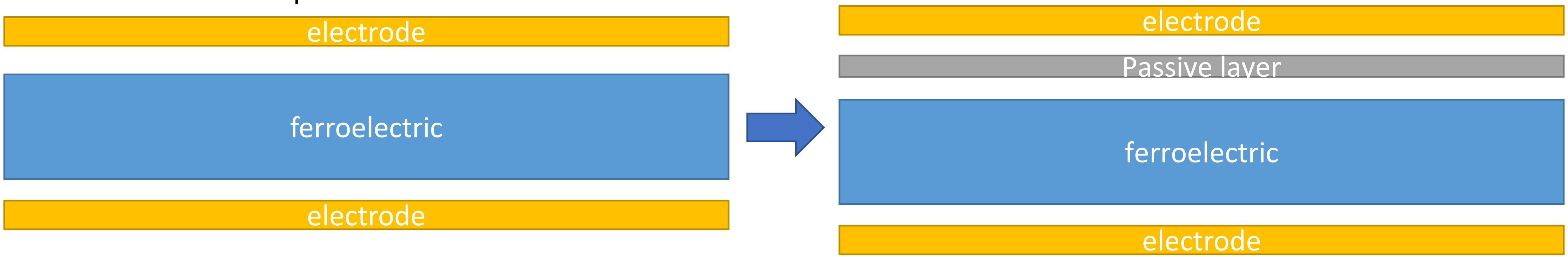
Tagantsev, A. K., et al. "Identification of passive layer in ferroelectric thin films from their switching parameters." *Journal of applied physics* 78.4 (1995): 2623-2630.

The question

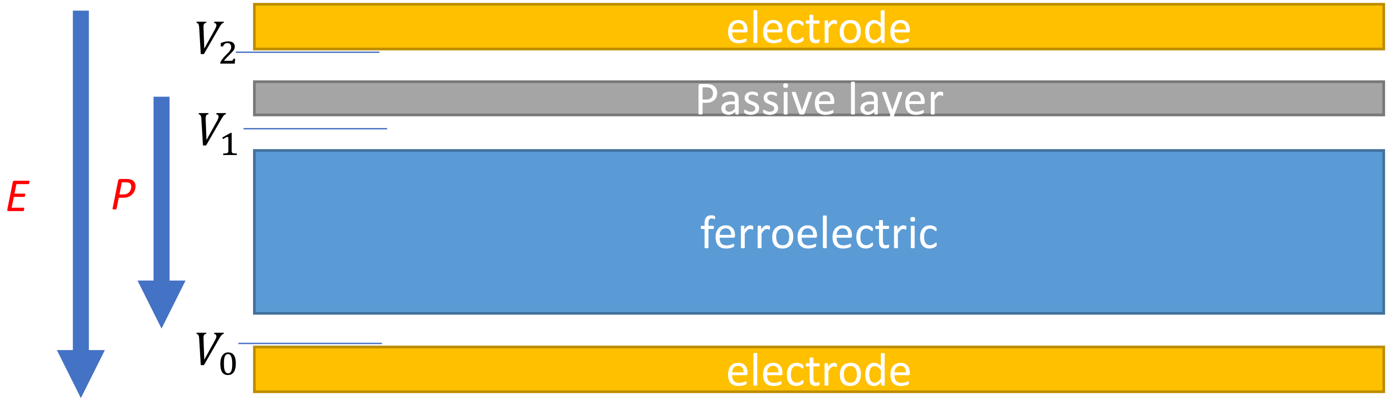






Fundamental equations

The system of equations for the sandwich structure (a ferroelectric of thickness ***L*** in series with a passive layer of thickness ***d*** and the relative ϵ_d)



σ the surface charge density on the electrodes

thickness *d*, dielectric constant ϵ_d

thickness *L* , the polarization P_f and the field E_f in the ferroelectric

$$\epsilon_0 E_f = \sigma - P_f, \quad (2)$$

$$E(d+L) = \sigma d / \epsilon_0 \epsilon_d + L E_f, \quad (3)$$

← $V_2 - V_0 = (V_2 - V_1) + (V_1 - V_0)$

$$P = \sigma - \epsilon_0 E, \quad (4)$$

The coercive field E_c

The condition: $P = 0$

Using $P = \sigma - \epsilon_0 E,$ (4)

$\sigma = \epsilon_0 E_c$

Substitute into $E(d+L) = \sigma d / \epsilon_0 \epsilon_d + L E_f,$ (3)

$$E_i = E_c\left(1 + \frac{d}{L} - \frac{d}{\epsilon_d L}\right). \quad (15)$$

E_i is the value of electric field E_f seen by the ferroelectric when P=0

So, the field seen by ferroelectric is a little bit higher than the applied to the sandwich (average) electric field.

However, If $\frac{d}{L} \ll 1,$ $E_c = E_i.$

The coercive field E_c

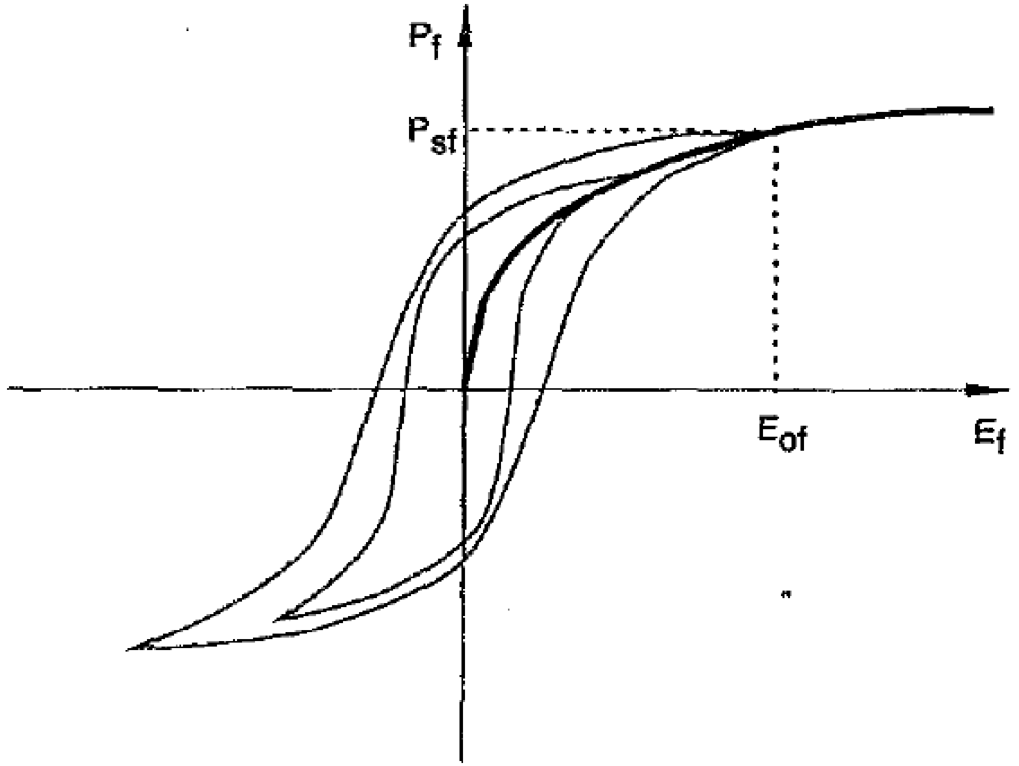


FIG. 1. Sketch of the dielectric portrait of the ferroelectric. The hysteresis loops seen by the ferroelectric ("internal" loops) are shown by thin lines for two values of the amplitude of the electric field, E_{0f}, seen by it. The set of these loops for different E_{0f} is described by Eq. (5). The thick line shows the dependence of the maximal polarization on the loop, P_{sf}, on E_{0f}, which is given by Eq. (6).

E_{cf} is an increasing function of E_{0f}
(the coercive field is an increasing function of the maximum applied field)

For a given amplitude E_0, the greater the relative thickness of the dielectric layer d/L, the smaller the amplitude of the field seen by the ferroelectric, E_{0f}

Therefore, E_{cf} is a decreasing function of d/L. All in all, E_c decreases with increasing d/L.

The remanent polarization P_r

$$\epsilon_0 E_f = \sigma - P_f, \quad (2)$$

$$E(d+L) = \sigma d / \epsilon_0 \epsilon_d + L E_f, \quad (3)$$

$$P = \sigma - \epsilon_0 E, \quad (4)$$

$$E(d+L) = \left(\frac{d}{\epsilon_d} + L\right) E_f + \frac{d}{\epsilon_0 \epsilon_d} P_f, \quad (7)$$

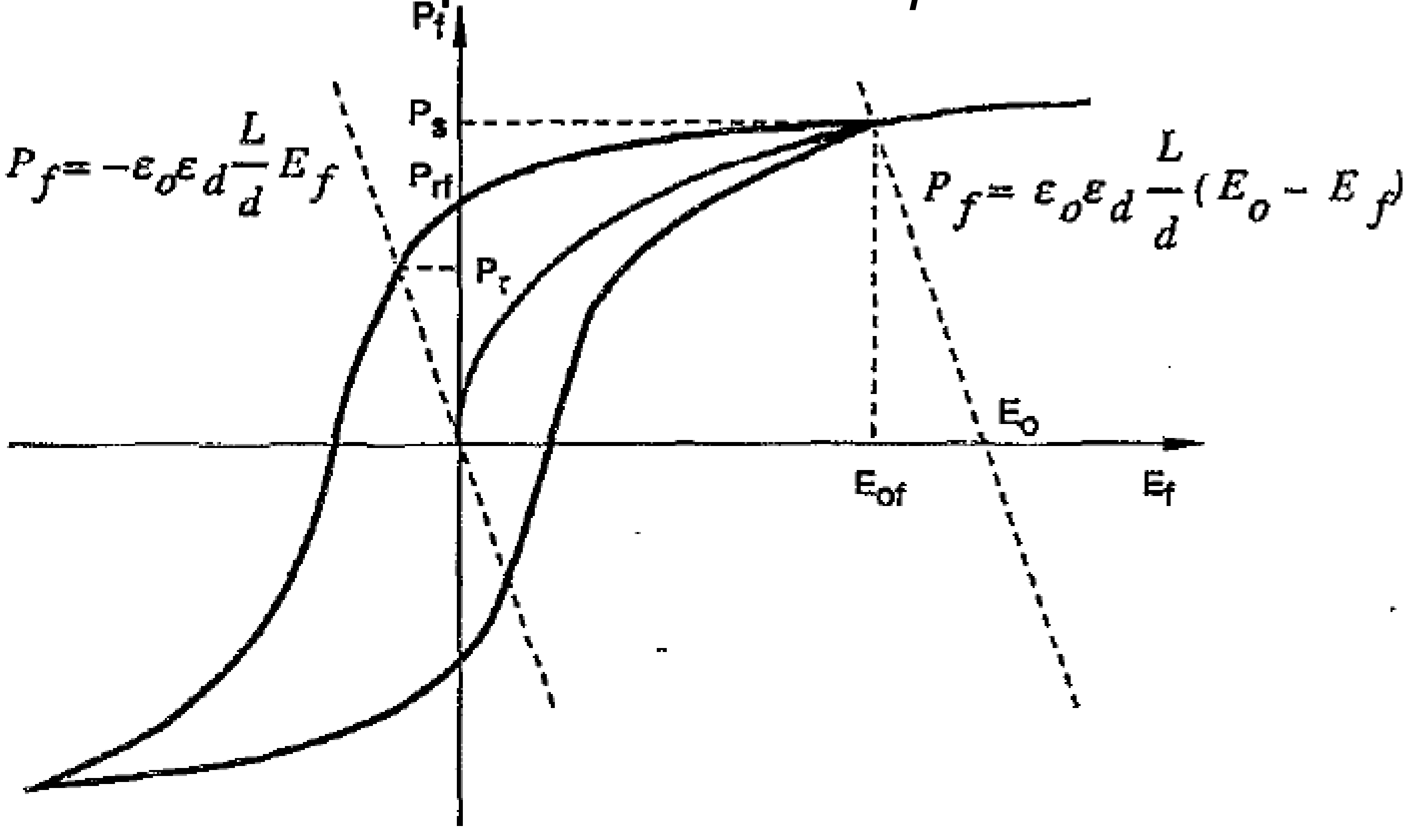
$$P = P_f + \epsilon_0 (E_f - E). \quad (8)$$

$d/L \ll 1,$

$$\epsilon_0 \epsilon_d \frac{L}{d} (E - E_f) = P_f, \quad (9)$$

$$P = P_f. \quad (10)$$

The remanent polarization P_r



$$\epsilon_0 \epsilon_d \frac{L}{d} (E - E_f) = P_f, \qquad (9)$$

$$P = P_f. \qquad (10)$$

The remanent polarization of the sandwich P_r, (taken from the external loop at E=0) can be substantially smaller than that seen by the ferroelectric P_{rf}.

FIG. 5. The graphical solution of the system equations (6), (11), (12), (5), (9), and (10). The shown loop is the internal loop. Here E_0 and E_{0f} are the amplitude of the external field and that of the field seen by the ferroelectric. The remanent polarization and the amplitude of the polarization for the sandwich are indicated as P_r and P_s. The remanent polarization on the hysteresis loop seen by the ferroelectric is denoted as P_{rf}.

Slope of the loop at E_C

$$\epsilon_0 \epsilon_d \frac{L}{d} (E - E_f) = P_f , \qquad (9)$$

$$P = P_f . \qquad (10)$$

$$\left(\frac{dE}{dP}\right)_{E_c} - \left(\frac{dE_f}{dP_f}\right)_{E_c} = \epsilon_0^{-1} \frac{d}{L\epsilon_d} .$$

The passive layer could result in a strong tilt of the loops.

Slope of the loop at E_C (COMPUTER SIMULATION OF THE LOOPS OF SANDWICH STRUCTURE)

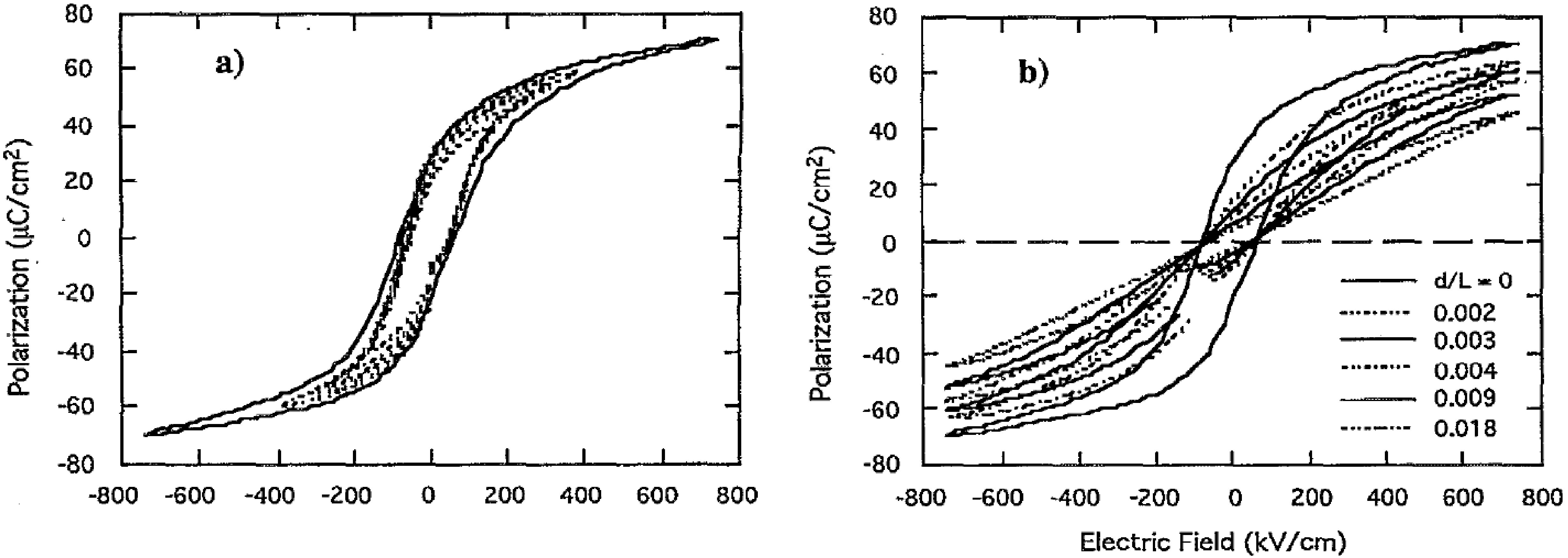


FIG. 6. Set of experimental hysteresis loops for a $PbZr_{0.53}Ti_{0.47}O_3$, thin film taken for different maximal fields (a). Calculated loops for a fixed maximal field for various passive layer thicknesses in the sandwich structure “ferroelectric/passive layer” calculated using this set as a dielectric portrait of the ferroelectric (b). Here d and L are the thickness of the passive layer and the film. The dielectric constant of the layer is unity.

In summary

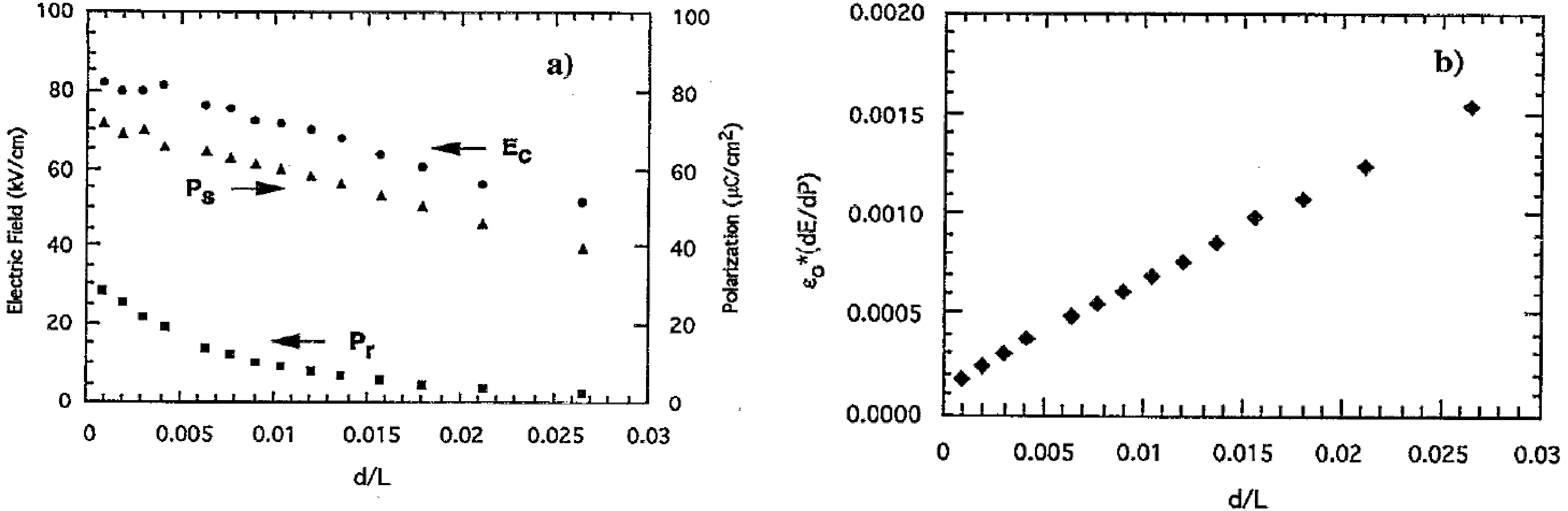


FIG. 7. Parameters of the calculated hysteresis loops of the sandwich structure “ferroelectric/passive layer” for different relative thickness d/L of the passive layer: (a) remanent polarization P_r , maximal polarization on the loop P_S , and coercive field E_C; (b) the reciprocal of the slope of the hysteresis loop taken at E_C, (multiplied by the dielectric constant of the vacuum ϵ_0). The set of experimental loops used for the calculations is shown in Fig.6(a). The dielectric constant of the passive layer is unity.

THANK YOU