Ferroelectrics go bananas

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VIEWPOINT

Ferroelectrics go bananas

J F Scott

Centre for Ferroics, Earth Sciences Department, University of Cambridge, Cambridge CB2 3EQ, UK

E-mail: jsco99@esc.cam.ac.uk

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Abstract
We show that ordinary bananas exhibit closed loops of switched charge versus applied voltage that are nearly identical to those misinterpreted as ferroelectric hysteresis loops in crystals. The 'ferroelectric' properties of bananas are contrasted with those of the real ferroelectric material $Ba_2NaNb_5O_{15}$, often nicknamed 'bananas'.

Recently there have been a large number of publications in leading physics journals that claim different materials are ferroelectric, based upon the observation of a closed loop in the graph of switched charge Q versus applied electric voltage V. While most researchers are aware of the potential artefacts (outlined in classic texts such as Lines and Glass [1] Jaffe *et al* [2], or Fatuzzo and Merz [3]) associated with the measurement of polarisation-electric field (P–E) loops, there are still far too many articles [4–15] reporting completely meaningless coercive field and remanent polarization values extracted from cigar-shaped loops that are typical of lossy dielectrics and have very little to do with the true ferroelectric properties of the material studied. References [4–15] are an informal list of papers from only a few journals in the past two years; the real total of such artefacts published probably exceeds a hundred. This is particularly problematic in the field of multiferroics where P–E loops for materials such as $BiFeO_3$ are often dominated by leakage currents, an artefact that may not be familiar to scientists whose background is mainly in ferromagnets. The larger leakage currents in magnetoelectrics often result from mixed valence for the magnetic ions (e.g., Fe^{2+} and Fe^{3+}), from oxygen vacancies, or from both. Magnetic hysteresis is measured without contacts, whereas electrical hysteresis requires metal contacts and permits charge injection and real current flow. The inexperience in data interpretation by those new to the field is not helped by 'black-box' measurement approach, as sophisticated ferroelectric testers commercially available automatically label the ordinate intercept as 'remanent polarization' and the abscissa intercept as 'coercive voltage' even for linear lossy dielectrics or shorted circuits. In fact, as shown in figure 1, these intercepts may have nothing to do with polarization or ferroelectricity.

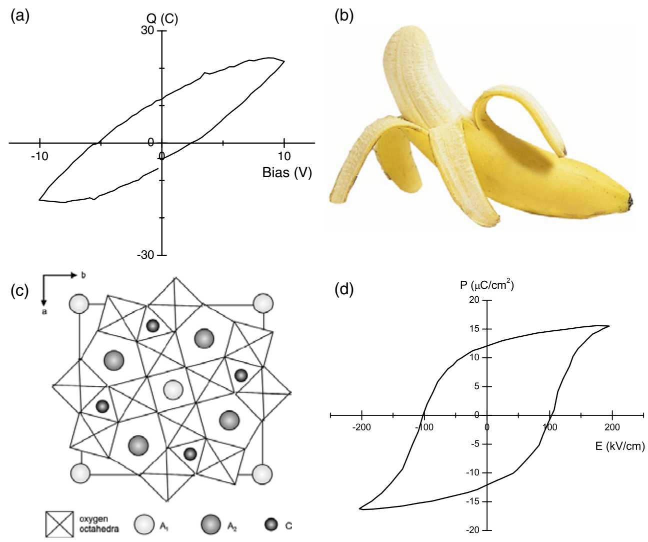

Figure 1. (a) Charge versus voltage loop typical for a lossy dielectric, in this case the skin of a banana (b) electroded using silver paste. The hysteresis loop for a truly ferroelectric material such as $Ba_2NaNb_5O_{15}$ (c) is shown in (d) ferroelectric hysteresis curve for ceramic barium sodium niobate (data from [24]).

(This figure is in colour only in the electronic version)

Several authors have written scholarly articles emphasizing the risk in obtaining spurious artefacts that resemble true hysteresis [16–22]. Pintilie and Alexe showed very clearly [16] that back-to-back diodes give very misleading 'hysteresis' loops. Such back-to-back diodes may result from Schottky-like electrodes on many non-ferroelectric materials, and these may also give misleading dielectric anomalies [23]. However, no one has demonstrated that ordinary household objects or fruits and vegetables will give such data. I hope that 'the ferroelectric banana' will catch more attention; although presented in an intentionally humorous way, the point is quite serious.

Figure 1(a) shows the Q versus V data for an electroded banana, not unlike many of the loops in the literature. To be more precise, a small section of the skin of the fruit was removed and electroded using silver paste. The hysteresis loop was measured using the Radiant Technologies Precision-Pro ferroelectric tester. Figure 1(b) shows the actual sample. This is a real banana. Figure 1(c) shows the structure of ferroelectric $Ba_2NaNb_5O_{15}$, often called 'bananas'. Note that figures 1(b) and (c) are different. Figure 1(d) shows real hysteresis of $Ba_2NaNb_5O_{15}$ [24]. Note that figures 1(a) and (d) are different.

In general, it is possible to measure polarization magnitudes and directions in crystals optically—for example, via second harmonic generation [25]. However, electrical hysteresis measurements determine only switched charge Q, and using the model of a perfectly insulating parallel plate capacitor, experimenters assume

$$Q = 2P_r A \tag{1}$$

where P_r is the remanent polarization, and A is the lateral area of the capacitor. Even neglecting fringing fields, this is not correct for a real dielectric; instead,

$$Q = 2P_r A + \sigma EAt. \tag{2}$$

Here σ is the electrical conductivity; E, the applied field; and t, the measuring time. Note that for a non-ferroelectric linear dielectric Q is not zero but given by

$$Q = \sigma EAt. \tag{3}$$

Since the dielectric loss is proportional to conductivity σ, equation (3) is said to describe a linear lossy dielectric.

Conclusions

If your 'hysteresis loops' look like figure 1(a), please do not publish them. Publish data that are saturated and have a region in Q versus V that is concave. Bananas are not ferroelectric, and it is easy to be misled by closed $Q(V)$ loops.

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