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DOMAIN WALLS IN KDP
EXISTENCE OF
CRITICAL ELECTRIC FIELDS

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Abstract. — We report three results obtained in different experimental cases. They prove the existence of critical electric fields necessary to move the domain walls in KDP. We explain these phenomena by the critical shear stresses necessary to move the twinning dislocations which exist at the domain tips. The same conclusion can be applied to the ferroelectric crystals of the Rochelle salt, and gadolinium molybdate family.

Introduction. — We have previously reported studies on the ferroelectric domains in KDP crystals, which prove the systematic existence of dislocations in the domain walls not parallel to the (100) or (010) tetragonal planes: Domains are mechanical twins and the possible dislocations are edge type [1, 2]. Such a result was suggested by Barkla and Finlayson in 1953 [3]. These twinning dislocations determine the domain structure properties below 100 °K (the long range interaction between the domain tips [4] is a typical result). We report here experimental results which prove the existence of critical electric fields necessary to move the domain walls. We explain this phenomenon, obtained in very different experimental cases, by the critical stresses necessary to move the twinning dislocations in their glide plane.

Experimental results. — We give three experimental results related to the existence of critical electric fields necessary to move the domain walls:

The first, described in greater detail in another paper [5], explains the « freezing » of the domains at low temperature (below 100 °K). The stroboscopic observation of the domains (with the light in the direction of the c axis) and simultaneous dielectric measurements allow one to study this phenomenon. For a given temperature, the maximum value of the imaginary part of the dielectric constant, \( \varepsilon ^{\prime \prime} \), corresponds to a critical value \( E_s \) of the measuring electric field; for amplitudes of the electric field greater than \( E_s \), the domain tips of the observed needles move in their longitudinal direction, while for lower values they remain motionless. The most striking result which proves the elastic origin of this phenomenon is given in figure 1: the critical electric field, necessary to move the domain tips depends only on the spontaneous strain \( (x_y) \) of the material and not on the temperature; for different crystals \( (\text{KH}_2\text{PO}_4, \text{KD}_2\text{PO}_4, \text{RbH}_2\text{PO}_4) \) [6] the same value of the critical electric field is found for equal spontaneous strains although at different temperatures. For example \( E_s = 10 \) V/cm corresponds in \( \text{KH}_2\text{PO}_4 \) and \( \text{KD}_2\text{PO}_4 \) to temperatures of 95 °K and 153 °K respectively. The possibility of a normal thermally activated process is then eliminated.

Another point is that, during quasi-static cycles of electric field, the displacement of a domain tip is discontinuous: for a given d. c. applied electric field, a domain tip can stop in the sample in a quasi-equilibrium position (this leads to the classical hysteresis cycles being not perfectly square). For an isolated domain tip, these equilibrium positions change continuously with the applied electric field [4].

Finally, we have previously described a method which allows, the measurement of domain wall velocities, using electric field pulses during quasi-static cycles [7]. Figure 2 shows an interesting observation: for the first pulses applied, the displacement of a domain tip is proportional to the width of the pulse; but after several pulses, this displacement decreases to zero.

Fig. 1. — Correlation between the critical electric field necessary to move the domain walls \( E_s \), and the spontaneous strain of the material (in \( \text{KH}_2\text{PO}_4, \text{KD}_2\text{PO}_4, \text{RbH}_2\text{PO}_4 \)).

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For both the last results, we can suppose that the domain width increases a little during the longitudinal motion of the tip. The critical electric field $E_s$ can only increase (with perhaps a quasi-exponential dependence) due to this variation and the domain tip stops. Beyond this equilibrium position, the domain tip can start again only if the applied electric field is greater than this new $E_s$ value. The figure 3 summarizes this process.

**FIG. 2.** — Decrease of the domain tip velocity versus the tip displacement: we have plotted here the displacement versus the successive electric pulses.

**FIG. 3.** — Explanation of the increase of $E_s$ during the longitudinal motion of a domain tip by increasing of the domain width.

**Discussion.** — The first experimental result can be easily understood: we have demonstrated the existence of twinning dislocations at the domain tips, in KDP [2]. The edge dislocations move in their glide plane only if a sufficient external shear stress $\sigma_{xy}$ is applied in the plane. The critical shear stress $\sigma_c$ of a dislocation, in the simple model of Peierls [1], changes exponentially with the Burgers vector of the dislocation, which is proportional to the spontaneous strain ($\chi_s$) of the material. The critical electric field $E_s$ can be deduced from $\sigma_c$ by the piezoelectric effect and the quasi-exponential variation of the figure 1 is explained [5]. The problem is not simple: a domain tip is, in fact, an assembly of twinning dislocations, but all the results are consistent with this explanation.

It is important to note that our elastic analysis on the KDP domain structure [2] can be applied to the crystals of the Gd$_2$(MoO$_4$)$_3$ family and a similar analysis for the Rochelle salt family: the twinning dislocations exist also in these ferroelectric crystals. The critical electric field necessary to move the domain walls (not a general phenomenon in the ferroelectrics) has been observed in these crystals (see the domain velocity measurements of Mitsui et Furuichi in Rochelle salt [8] and A. Kumada et al. in GMO [9]). The importance of the twinning dislocations on the domain structure properties is evident in these ferroelectric families.

**References**