



# POLARIZATION REVERSAL IN T. G. S. SINGLE CRYSTALS

M. Chabin, F. Gilletta

## ► To cite this version:

M. Chabin, F. Gilletta. POLARIZATION REVERSAL IN T. G. S. SINGLE CRYSTALS. Journal de Physique Colloques, 1972, 33 (C2), pp.C2-211-C2-213. 10.1051/jphyscol:1972273 . jpa-00215009

**HAL Id: jpa-00215009**

**<https://hal.science/jpa-00215009>**

Submitted on 4 Feb 2008

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coalescence,  $K$  est constant et noté  $k_2$ . Les relations (5) et (6) donnent alors  $J \propto \exp k_2 t$ , ce qui représente la variation expérimentale de  $J$  en fonction du temps.

2) Les domaines croissent ensuite latéralement et la coalescence intervient. Le recouvrement des germes croît avec  $\theta$  tandis que  $K$  décroît.  $K$  peut être exprimé sous la forme :

$$K = k_2 - k_3(\theta). \quad (7)$$

L'hypothèse la plus simple sur  $k_3$  est d'écrire :

$$k_3 = \theta \times \text{Cte}. \quad (8)$$

Compte tenu du fait que  $(dJ/dt) = 0$  pour  $t = t_{\max}$ , c'est-à-dire pour  $\theta = \theta_{t_{\max}}$ , la relation (7) devient :

$$K = k_2 \left( 1 - \frac{\theta}{\theta_{t_{\max}}} \right). \quad (9)$$

Les relations (5) et (6) donnent :

$$J \propto \left( \theta - \frac{\theta^2}{2\theta_{t_{\max}}} \right). \quad (10)$$

Cette relation (10) n'est autre que la loi expérimentale vérifiée par  $J$  quand  $0,10 < \theta < 0,50$ .

A la fin de cette phase, lorsque  $\theta$  est voisin de 0,50,  $K$  est négatif.

3) Lorsque la coalescence des domaines est terminée on peut penser qu'il reste des régions isolées dans lesquelles la polarisation n'est pas encore renversée. La fin du processus concerne le renversement de la polarisation dans ces régions isolées.

Comme dans la première phase on peut supposer que  $K$  est une constante qui est ici négative et notée  $k_4$ . Les relations (5) et (6) donnent alors

$$J(t) \propto \exp - |k_4| t.$$

On en déduit que  $k_4$  est le coefficient expérimental B.

**Conclusion.** — Les courbes de densité de courant  $J(t)$  peuvent être décomposées en trois parties, chacune d'elle présentant une forme analytique différente. Par ailleurs, il peut être rendu compte de la forme des courbes  $J(t)$  si nous supposons que le mécanisme prépondérant qui régit le renversement de la polarisation est une nucléation adjacente aux parois de domaines ; la probabilité de nucléation apparente par unité de temps dépendant de la valeur de l'aire renversée  $\theta(t)$ .

## POLARIZATION REVERSAL IN T. G. S. SINGLE CRYSTALS

**Abstract.** — The investigation of polarization reversal in T. G. S., performed on carefully prepared samples, has allowed us to find new laws for the variations of characteristic quantities  $J_{\max}$ ,  $t_{\max}$ ,  $t_s$ . A mechanism which accounts for the shape of switching current density  $J(t)$  is discussed.

**Introduction.** — The polarization reversal in T. G. S. has been extensively investigated by several authors [1] to [8]. In particular Taylor [7] has pointed out the role played by the crystal surfaces. From this point of view we have improved the preparation of samples : chosen in the best part of single crystals, they are cleaved under vacuum and electroded by vapor-deposited gold immediately after cleaving.

**Experimental results.** — New results are obtained in the characteristic quantities  $J_{\max}$ ,  $t_{\max}$ ,  $t_s$ , in the ranges of field amplitude :  $E \leq 6 \text{ kV.cm}^{-1}$ , pulse frequency :  $0.015 \text{ Hz} \leq \nu \leq 100 \text{ Hz}$ , temperature :  $-62^\circ\text{C} \leq T \leq 29^\circ\text{C}$  and sample thickness :  $0.47 \text{ mm} \leq e \leq 4.45 \text{ mm}$ . They have been already published [9] : for instance  $J_{\max}$  follows the law :

$$J_{\max} = E^\beta (a_1 + a \log \nu) \exp \frac{-W_0}{kT} \quad (1)$$

$a_1 = 6.58 \times 10^{-2}$  ;  $a = 1.58 \times 10^{-2}$  (with  $J$  in  $\text{A.cm}^{-2}$  and  $E$  in  $\text{V.cm}^{-1}$ ) ;  $\beta \approx 5/3$  ;  $W_0 = 0.29 \pm 0.01 \text{ eV}$  ;  $a_1/a = 4.1 \pm 0.3$ .

Figure 1 shows that  $J_{\max}$  is proportional to  $E^\beta$  and independent of sample thickness.

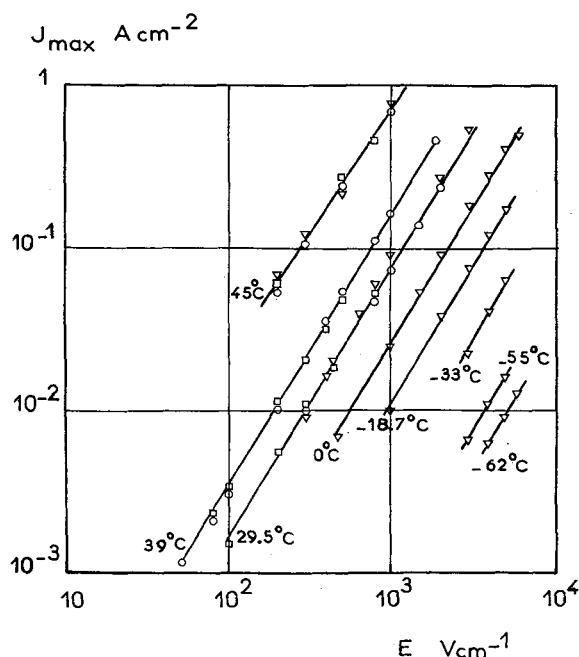


FIG. 1. —  $\log_{10} J_{\max}$  versus  $\log_{10} E$  for different temperatures. Pulse frequency  $\nu$  : 0.5 Hz ; Sample thickness :  $\nabla$  0.68 mm ;  $\circ$  1.45 mm ;  $\square$  4.45 mm.

$t_{\max}$  and  $t_s$  obey similar laws and verify

$$\frac{J_{\max} t_{\max}}{2 P_s} = f(e),$$

(Fig. 2), and

$$\frac{J_{\max} t_s}{2 P_s} = 2.25 \pm 0.25 = \text{Cte},$$

in the previous defined ranges of parameters.

Here we are concerned with the shape of the curves of switching transients. It can be investigated by studying the switching current density  $J(t)$  and the switched area  $\theta(t)$  per unit surface of sample, which is obtained by integrating  $J(t)$ .

The following results hold in the whole range of variation of parameters  $E$ ,  $\nu$ ,  $T$ ,  $e$ .

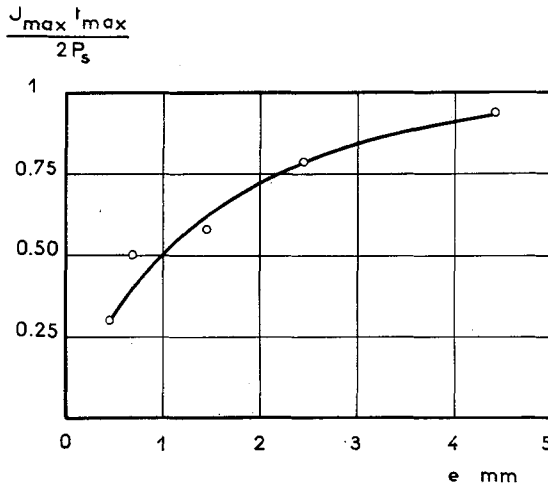


FIG. 2. — Experimental value of  $J_{\max} t_{\max}/2 P_s$  versus sample thickness.

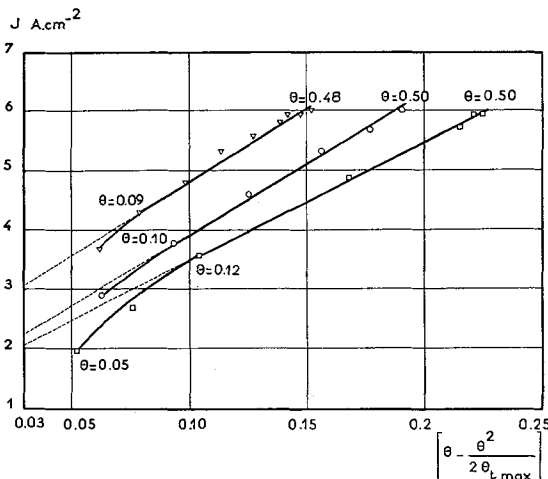


FIG. 3. —  $J$  is plotted as a function of  $[\theta - (\theta^2/2 \theta_{t \max})]$  for three samples.  $E = 800 \text{ V.cm}^{-1}$ ;  $\nu = 0.5 \text{ Hz}$ ;  $T = 29^\circ \text{C}$ .

$\nabla e = 0.68 \text{ mm}$   $t_{\max} = 36 \mu\text{s}$   $\theta_{t \max} = 0.304$   
 $\circ e = 2.45 \text{ mm}$   $t_{\max} = 65 \mu\text{s}$   $\theta_{t \max} = 0.384$   
 $\square e = 4.45 \text{ mm}$   $t_{\max} = 80 \mu\text{s}$   $\theta_{t \max} = 0.448$ .

1) When  $\theta < 0.50$ ,  $J$  depends on  $\theta$  according to the law (Fig. 3) :

$$J = A \left( \theta - \frac{\theta^2}{2 \theta_{t \max}} \right) + C \quad (2)$$

$\theta_{t \max}$  is the numerical value of  $\theta$  for  $t_{\max}$ .

2) When  $\theta < 0.08$  to  $0.12$ , this law no longer holds. Within the experimental inaccuracy it seems that  $J$  increases like an exponential function of time.

3) For  $\theta > 0.50$ , figure 4 shows that  $J(t)$  decreases exponentially with time :

$$J(t)_{\text{decr}} \propto \exp - Bt, \quad (3)$$

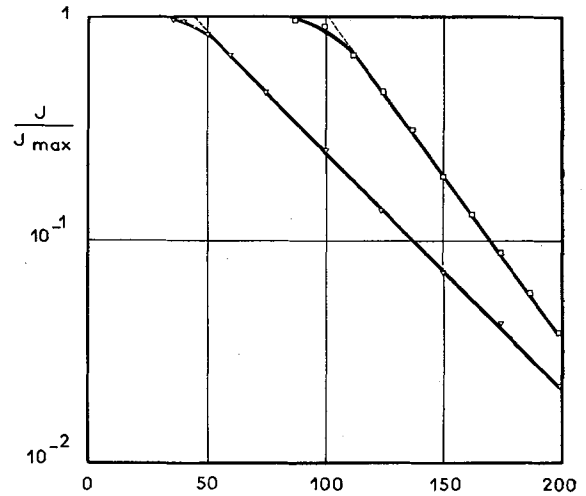


FIG. 4. —  $\log_{10} J_{\text{decr}}/J_{\max}$  versus time  $t$ .  $J_{\text{decr}}$  is obtained when  $t > t_{\max}$ , i. e.  $\theta > 0.50$ . In this range of time  $J$  is proportional to  $\exp - Bt$ .  $E = 800 \text{ V.cm}^{-1}$ ;  $\nu = 0.5 \text{ Hz}$ ;  $T = 29^\circ \text{C}$ .

$\nabla e = 0.68 \text{ mm}$   $\square e = 4.45 \text{ mm}$ .

The coefficient  $B$  is given by :

$$B = F(e) E^{\beta} (d_1 + d \log \nu) \exp \frac{-W_0}{kT} \quad (4)$$

$\beta \simeq 5/3$ ;  $W_0 = 0.29 \pm 0.02 \text{ eV}$ ;  $d_1/d = 4.7 \pm 0.5$ .  $F(e)$  depends on sample thickness.

**Discussion.** — We want to discuss now a mechanism which can account for the experimental laws connected with the shape of switching transients  $J(t)$ .

Let us assume that the reversal is only due to the lateral expansion of a certain number of microdomains which all appear at the beginning of the process.

This lateral expansion can be described by the nucleation of nuclei along the domains walls. They grow rapidly through crystal thickness and become steps. At a given time  $t$  a step-like structure is realized, as suggested by Nettleton [10]. In the following we shall neglect the transit time.

Let be  $N(t) dt$  the number of steps created between  $t$

and  $t + dt$ . The switching current density  $J(t)$  is proportional to  $N(t)$  :

$$J(t) = k' N(t). \quad (5)$$

During a later  $dt$  it is assumed that  $dN dt$  new steps appear on the  $N(t) dt$  steps and that their number is proportional to  $N(t) dt$ . We can write :

$$\frac{dN}{N} = K dt. \quad (6)$$

The apparent value of the nucleation probability per unit time  $K$  cannot be expected as constant during the whole reversal. Due to the coalescence of domains a certain number of nuclei cannot be formed :  $K$  is lower than expected if it were no coalescence. It follows that  $K$  depends on switched area  $\theta(t)$ .

Our purpose is now to show that simple assumptions on  $K$  can account for the experimental laws.

1) At the beginning of the reversal, the size of domains is small, no coalescence occurs, then  $K$  is constant and denoted  $k_2$ . Relations (5) and (6) give  $J \propto \exp k_2 t$ , which is the experimental behaviour of  $J$ .

2) Then, domains expand sideways and coalesce. The coalescence increases with  $\theta$  and  $K$  decreases.  $K$  can be written as :

$$K = k_2 - k_3(\theta). \quad (7)$$

The simplest assumption on  $k_3$  is to write :

$$k_3 = \theta \times \text{Cte}. \quad (8)$$

Connected with the fact that  $(dJ/dt) = 0$  for  $t = t_{\max}$  (i. e. for  $\theta = \theta_{t_{\max}}$ ), relation (7) gives :

$$K = k_2 \left( 1 - \frac{\theta}{\theta_{t_{\max}}} \right). \quad (9)$$

It follows from (5) and (6) that :

$$J \propto \left( \theta - \frac{\theta^2}{2\theta_{t_{\max}}} \right). \quad (10)$$

This eq. (10) is nothing else than the experimental law obeyed by  $J$  when  $0.10 < \theta < 0.50$ . At the end of this phase ( $\theta \simeq 0.50$ ),  $K$  is negative.

3) When domains have coalesced it can be thought that it remains isolated regions which are not yet switched.

The end of the switching concerns the individual reversal of these « not yet switched domains ».

As in the first part, we can assume that  $K$  is a constant, which is, here negative and denoted  $k_4$ .

Then it can be shown that the law  $J \propto \exp - |k_4| t$  is obtained.  $k_4$  appears as the experimental coefficient  $B$ .

**Conclusion.** — The switching transients  $J(t)$  can be decomposed in three parts, each of them showing a different analytical form.

It can be accounted for the shape of  $J(t)$  if we assume that the most important mechanism is a step by step nucleation along domain walls, the apparent value of the nucleation probability per unit time depending on the value of switched area  $\theta(t)$ .

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