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COLE-COLE DIAGRAM OF THE NON LINEARISED RELAXATION EQUATION

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Résumé. — On dérive une équation générale décrivant le phénomène de relaxation dans les diélectriques. On a tenu compte de l'abaissement du potentiel par l'effet Schottky. Au contraire de ce que l'on fait généralement, l'équation obtenue n'est pas linéarisée ; l'influence de ce fait est clairement indiquée sur le diagramme de Cole-Cole.

Abstract. — In this paper a general equation for the relaxation mechanism in dielectrics is derived. The lowering of the potential barrier due to the Schottky mechanism has been taken into account. The equation is not linearised as is usually done and the influence of this fact is clearly demonstrated by the Cole-Cole diagram.

In many dielectrics a relaxation mechanism determines the dielectric properties [1]. Similar properties have also been observed on evaporated SiO dielectrics containing mobile ions [2] and measurements with different electrode materials indicate the existence of surface traps for these mobile ions [3]. In order to describe the dielectric properties, a theoretical model has been proposed in which the ions can relax between the traps located at the two electrodes [4]. Let $n_A(n_B)$ be the average number of ions in a trap A(B), we may write (Fig. 1) :

$$\dot{n}_A = -\dot{n}_B = -p_{AB} n_A + p_{BA} n_B \quad (1)$$

where $p_{AB}(p_{BA})$ denotes the transition probability of a jump from A to B (B to A) per unit time. These transition probabilities depend upon the potential barrier which the charged particles must overcome. Using Boltzmann statistics, we have (Fig. 1) :

$$p_{AB} = C e^{-W_A/kT} \quad (2)$$

$$p_{BA} = C e^{-W_B/kT} \quad (3)$$

C is assumed to be a constant. This implies that once a charge has passed over the potential barrier there is zero probability that the ion falls back into the same state [4]. An extension of this can be found in the literature [5]. The energy diagram under influence of an electric field $E = V/a$ is shown on figure 1. The potential barriers are lowered by an amount $\Delta\phi$ due to the Schottky mechanism :

$$\Delta\phi = \left(\frac{q^3}{4\pi\epsilon_0\epsilon} \right)^{1/2} \sqrt{|E|} = kT\beta \sqrt{|V|} \quad (4)$$

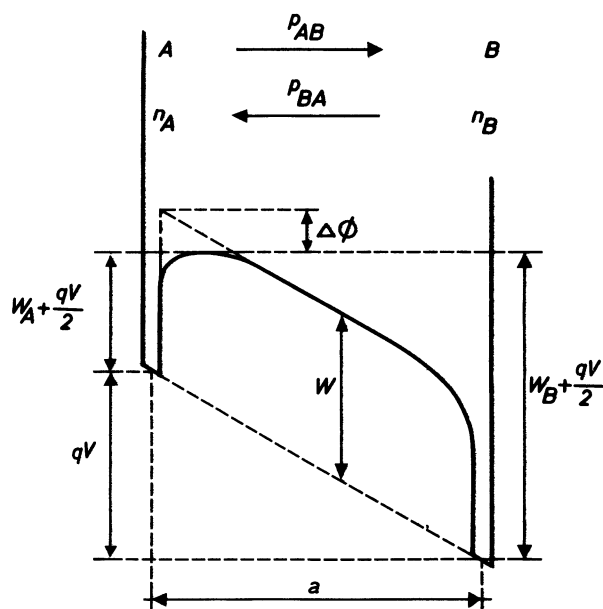


FIG. 1. — Energy diagram for mobile ions illustrating relaxation between two states A and B.

The zero level for W_A and W_B has been chosen to obtain the symmetrical expressions :

$$W_A = W - \Delta\phi - qV/2 \quad (5)$$

$$W_B = W - \Delta\phi + qV/2 \quad (6)$$

Using (4), (5) and (6), p_{AB} and p_{BA} read :

$$p_{AB} = \frac{1}{2\tau} \exp(\beta \sqrt{|V|}) \exp\left(\frac{qV}{2kT}\right) \quad (7)$$

$$p_{BA} = \frac{1}{2\tau} \exp(\beta \sqrt{|V|}) \exp\left(-\frac{qV}{2kT}\right) \quad (8)$$

The charge measured on the capacitor will be proportional to $Q = n_A - n_B$. The total numbers of ions $N = n_A + n_B$ being a constant, we obtain :

$$\dot{Q} + \frac{1}{\tau} \exp(\beta \sqrt{|V|}) \operatorname{ch}\left(\frac{qV}{2kT}\right) Q = \frac{N}{\tau} \exp(\beta \sqrt{|V|}) \operatorname{sh}\left(\frac{qV}{2kT}\right). \quad (9)$$

For a sinusoidally varying voltage $V \cos \omega t$, (9) has been solved numerically. The dielectric constants ϵ' and ϵ'' were calculated from the first harmonic components of the solution $Q(t)$ and results for some values of β and V are shown in figure 2. The top of the Cole-Cole diagram lies higher when β increases. Experimental results obtained using evaporated SiO capacitors indicate the contrary [6]. This can be explained by introducing a suitable probability distribution function for the relaxation time τ , since the top of the Cole-Cole diagram is then lowered [7], [8], [9]. In our experiments the influence of the Schottky mechanism on the Cole-Cole diagram is entirely masked by the distribution of the relaxation times.

However, time constant measurements, made on the same SiO capacitor, clearly indicate the existence of a Schottky mechanism [10].

In order to detect a Schottky mechanism one should not use a Cole-Cole diagram because other mechanisms mask the effect. A time constant measurement of the response to a voltage step is then recommended.

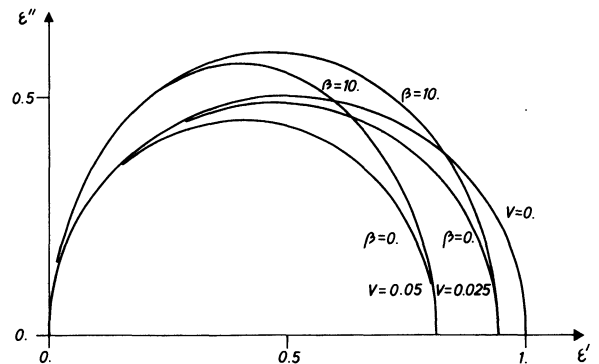


FIG. 2. — Cole-Cole diagram for a relaxation mechanism involving the Schottky effect for various values of β and voltage amplitudes (in volt). ϵ' and ϵ'' are normalised to $\epsilon' = 1$ for $\omega = 0$ and $V = 0$.

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