МІНІСТЕРСТВО ОСВІТИ І НАУКИ УКРАЇНИ

ОДЕСЬКА НАЦІОНАЛЬНА АКАДЕМІЯ ХАРЧОВИХ ТЕХНОЛОГІЙ

ЗБІРНИК ТЕЗ ДОПОВІДЕЙ

80 НАУКОВОЇ КОНФЕРЕНЦІЇ ВИКЛАДАЧІВ АКАДЕМІЇ

Одеса 2020

Наукове видання

Збірник тез доповідей 80 наукової конференції викладачів академії
7 – 8 травня 2020 р.

Матеріали, занесені до збірника, друкуються за авторськими оригіналами.
За достовірність інформації відповідає автор публікації.

Рекомендовано до друку та розповсюдження в мережі Internet Вченою радою
Одеської національної академії харчових технологій,
протокол № 15 від 05.05.2020 р.

Під загальною редакцією Заслуженого діяча науки і техніки України,
Лауреата Державної премії України в галузі науки і техніки,
д-ра техн. наук, професора Б.В. Єгорова

Укладач Т.Л. Дьяченко

$$P_{st} = \begin{cases} P_o & E_{cr} \le E_c \\ P_o + 2P_r(E_{cr} - E_c)/(E_s - E_c) & E_{cr} \ge E_c \end{cases}. \quad (8)$$

Eqs. (1) to (8) were solved numerically in relation to the ferroelectric polarization P. The best fitting was obtained for the case 2 with the following values of parameters: $\mu=10^{-11}$ m^2/V s, $\tau_o=2\cdot10^{-8}$ s, $E_A=1.1\cdot10^9$ V/m, and $\alpha=0.5\cdot10^{-20}$ m^3/s. The same parameters were used in calculations of the case 1. In the case 3, $n=n_o=3.92\cdot10^{26}$ m^{-3} causing $g=g_{max}=6.32\cdot10^{-4}$ S/m, while $n=0$ and $g=g_o=3\cdot10^{-11}$ S/m corresponded to the case 4.

The best agreement between experimental and theoretical dynamics of the polarization switching was observed in the case 2 corresponding to an instantaneous release of the screening charges upon application of the switching voltage. With all other models, a fit of the theoretical prediction to the experimental data was unsuccessful.

The physical reason why all other models fail can be seen in the dynamics of the released charges. In the model with the constant low conductivity (case 4) the charges are released according to the Maxwell relaxation time constant $\tau_M=\varepsilon_o\varepsilon/g_o$, which is $\tau_M=4.5$ s for the present case. The consequence is that only a small fraction of the polarization can switch freely, whereas the rest is hindered by the electric field of the still persisting screening charges. This situation changes around the Maxwell relaxation time when the screening charges are released.

The model of instantaneous release (case 2) seems to offer the right mix of released charge, recombining charge and conducting charge. The initially very high number of released charges forms a high conductivity that allows polarization to switch unimpeded.

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HOW ELECTRIC CONDUCTIVITY AFFECTS POLARIZATION IN FERROELECTRIC POLYMERS

Prof. S. N. Fedosov[1], Prof. A. E. Sergeeva[1], Prof. H. von Seggern[2]
[1]Odessa National Academy of Food Technologies,
[2]Darmstadt University of Technology, Germany

Ferroelectric polymers like polyvinylidene fluoride (PVDF) and its copolymers have attracted attention during the last years due to a promising for sensors combination of high residual polarization and good mechanical properties. Initially, conductivity and space charge were considered as secondary and even interfering side effects in such materials. It is shown in this paper that the residual intrinsic conductivity plays an important role in formation of the polarized state and its dynamics during operation of the devices.

There is one feature of the ferroelectric polymers that was not given enough consideration so far. All these materials are two-phase systems with different dielectric constants and polarization-field dependences of the individual phases. In this paper four important processes in ferroelectric polymers are analyzed comprising initial poling, short circuiting, partial polarization back-switching, and polarization switching by application of the reversed polarity voltage by using experimental data and a two-layer model.

Experiments were carried out on 12 μm-thick samples of PVDF, as well as P(VDF-TFE) and P(VDF-TrFE) 20 μm-thick films with metal electrodes of 0.2 cm^2 area deposited by cathode

sputtering. IR spectra indicated different proportion of the ferroelectric β-phase in relation to the non-polar α-phase. Poling and switching experiments were performed utilizing an electronic high voltage / high current push-pull switch capable of supplying voltage pulses from 100 ns to 1000 s duration controlled by a low-voltage pulse generator. The measuring branch consisted of the sample, a current limiting resistor and a series measuring capacitor.

Polarization – field dependence in most studies was considered as a quasi stationary one assuming that independently on the field value, polarization instantly follows the field. For the first time we introduced time in the polarization – field relation considering not only the value of the applied field, but also the polarization dynamics at a definite field.

By solving numerically a set of differential equations, such as the current equation, the intrinsic polarization dynamics, hysteresis of the ferroelectric polarization, accumulation and release of the screening charges at the interphase boundaries and by comparing experimental data with results of appropriate modeling we were able to explain a two stage behavior of the polarization build-up during poling and switching. Moreover, the reason of a huge discrepancy between expected and observed poling and switching times in the ferroelectric polymers has been also explained.

It is shown that conductivity during initial poling is responsible for the second slow stage of the polarization build-up. In the case of short circuiting, the conductivity prevents undesired back-switching of the already formed ferroelectric polarization. During the switching of polarization, the critical dependence of the polarization phenomena on conductivity was also revealed. The results stress the importance of an instantaneous release of the screening charges in the fast phase of switching and its reconstruction to screen the reversed polarization in the slow part of the switching process.

The authors strongly believe that the discovered features related to the effect of conductivity, in general, are characteristic not only for ferroelectric polymers, but also for other two-component ferroelectric systems, such as the ferroelectric ceramics and polymer-ferroelectric composites.

FEP/ePTFE/FEP FERROELECTRET SANDWICHES

S.N. Fedosov[1], A.E. Sergeeva[1], H. von Seggern[2]
[1]Odessa National Academy of Food Technologies,
[2]Darmstadt University of Technology, Germany

A new option for constructing piezoelectric sensors are three layer structures called ferroelectrets consisting of two solid blocking layers of fluorinated ethylene propylene (FEP Teflon) films and fibrous polytetrafluoroethylene (ePTFE) in between them. The piezoelectricity of such FEP/ePTFE/FEP sandwich results from charge layers of opposite polarity formed due to charges generated by Paschen's breakdown and trapped at the interfaces between FEP and ePTFE films. A unique combination of the charge storage ability with a low elasticity modulus makes the sandwiched structures very promising objects for applications in electromechanical sensors.

We investigated limits of the piezoelectric d_{33} coefficient and possibilities of optimizing interrelation between solid and porous layers thicknesses, the Young modulus of the porous layer and dependence of the breakdown field on thickness of the porous layer. The following expression was obtained for the maximum value of d_{33} coefficient

$$d_{33}^{\max} = \frac{\varepsilon_o \varepsilon_F \varepsilon_P E_B}{Y_P\left(\varepsilon_F + \alpha\varepsilon_P\right)} \tag{1}$$

where Y_P is the Young modulus of the porous layer, E_B the breakdown field, ε_o permittivity of a vacuum, ε_F and ε_P dielectric constants of blocking and porous layers, respectively; $\alpha=2d_F/d_P$ the geometric factor characterizing interrelation between layer thicknesses d_F and d_P.

СЕКЦІЯ «АВТОМАТИЗАЦІЯ ТЕХНОЛОГІЧНИХ ПРОЦЕСІВ, РОБОТОТЕХНІЧНІ СИСТЕМИ»

СЕКЦІЯ «ТЕХНОЛОГІЧНЕ ОБЛАДНАННЯ ЗЕРНОВИХ ВИРОБНИЦТВ»

СЕКЦІЯ «ФІЗИКА І МАТЕРІАЛОЗНАВСТВО»