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A software-hardware complex for the study of electrophysical parameters of active dielectrics

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Abstract. Since the electrophysical parameters of ferroelectrics and the possibility of their application in functional electronics elements depend significantly on temperature, the work is aimed at solving the actual problem of creating a software-hardware complex that makes it possible to measure the temperature dependences of the capacitance and relative permittivity, taking into account the specifics of the physical effects inherent in these materials. Measurement procedures automation, which makes it possible to reduce the time for performing measurements and processing experimental data, eliminating subjective error and reducing a number of methodological errors is provided, since the electrophysical parameters measurements of ferroelectrics are possible only by indirect methods that require calculations according to the accepted models of the measurement object. As part of the software-hardware complex, it is proposed to use a computer-controlled heat chamber to study the temperature effect in a wide temperature range, which should cover the phase transitions of the studied materials and structures based on them. The principles and methods for measuring various functional dependencies are shown. For example, when studying the frequency characteristics of ferroelectrics, the test signal frequency is changed, the temperature characteristics are changed by the heat chamber temperature, and when studying capacitance-voltage characteristics, the bias voltage on the sample is changed. The article describes the operation of the software-hardware complex and the device of the thermal chamber. The result of the work was a multifunctional measuring device that allows to increase the technical and economic efficiency of the ferroelectrics study, by reducing the measurement time and reducing the measurement errors of material parameters (electric field strengths, sample polarizations and electrical impedance), depending on the influencing factors (range up to 100 °C).

Keywords: ferroelectrics, temperature dependence, software and hardware complex, measurement

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Программно-аппаратный комплекс для исследования электрофизических параметров активных диэлектриков

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Аннотация. В статье рассмотрено применение активных диэлектриков, тонкопленочные наноразмерные структурные устройства прочно вошли в полупроводниковую промышленность, сегнетоэлектрики нашли широкое применение. Из-за влияния температур на характеристики сегнетоэлектриков, важно контролировать температуру при создании сегнетоэлектрических материалов и исследовании уже существующих образцов. Предлагается создание программно-аппаратного комплекса для измерений электрических параметров активных диэлектриков и изделий на их основе, который позволит с большой точностью получать электрические параметры образцов активных диэлектриков с учетом их форм и размеров. Программно-аппаратный комплекс будет автоматизирован для снижения статистических погрешностей, а для решения проблемы исследования влияния температуры на конкретные сегнетоэлектрические образцы, предложена установка термокамеры в программно-аппаратный комплекс. Это позволит расширить возможности исследования сегнетоэлектриков при помощи данного программно-аппаратного комплекса. При снятии частотных характеристик осуществляется изменение частоты тест-сигнала, температурных – изменение температуры в термокамере, вольт-фарадных – изменение смещения на образце. В статье описана работа программно-аппаратного комплекса и устройство термокамеры. Результатом работы стал многофункциональный измерительный прибор, позволяющий повысить технико – экономическую эффективность исследования сегнетоэлектриков, благодаря чему можно получить электрические параметры сегнетоэлектриков (напряженности электрического поля, поляризации образца и электрический импеданс) с учетом влияния температуры (диапазон до 100 °С).

Ключевые слова: сегнетоэлектрики, температурная зависимость, программно-аппаратный комплекс

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Introduction

In recent years, ferroelectrics are of great interest for products of functional nano- and microelectronics due to their nonlinear response to an electric field. Based on these materials, tunable capacitors, delay lines, and phase shifters have been created [1]. Thin-film nanosized structures have firmly entered the semiconductor industry [2]. However, ferroelectrics have a significant feature that limits the possibility of their study and application, due to the temperature dependence of their properties [3–5]. In addition, when changing the size and shape of the active dielectric, not only the electrical parameters of the sample, but also the functional dependences that describe the effect of temperature on the sample change. Therefore, an important task is to measure the electrophysical parameters of specific materials samples in order to systematically study and formalize the established functional dependencies. Functional electronics devices use active dielectrics of various shapes and sizes, which have ferroelectric, piezoelectric and pyroelectric properties, it dictates the need for a systematic study of their parameters depending on heterogeneous influencing factors and substantiates the relevance of this study. Temperature Effect on the Ferroelectrics Characteristics.

The influence of temperature on the characteristics of ferroelectrics

Thin-film ferroelectrics are of great interest in modern nanoelectronics. It is promising to study the temperature effect on the microstructural, structural, and ferroelectric properties of multiferroic ceramics. For example, $HoMnO_3$ ceramics was synthesized in [6] using the mechanochemical reaction of Ho_2O_3 and Mn_2O_3 powders on a high-energy ball milling machine. The powder was sintered at a temperature from 600 to 1250 °C with a step of 50 °C. The results show that the microstructural, structural and ferroelectric hysteresis loops were observed to depend on the sintering temperatures. It has been observed that the polarization and ferroelectric properties improve with increasing grain size due to the sintering temperature.

The tuning properties of thin-film metal-ferroelectric-metal variators and the temperature effect on the ferroelectric properties and the tuning possibility are studied in [7]. As the measurement temperature rises to 200 °C, the maximum adjustability is reduced to 24%. An increased temperature leads to an increase in aniferroelectric-like behavior.

Method for studying the effect of temperature on ferroelectric parameters

However, temperature control is important not only in the creation of ferroelectric materials, but also in the study of already existing samples. Since manufacturers rely on the electrical parameters data of the material used, not taking into account the shape and size of the sample, which leads to a decrease in the reliability of measurements, an increase in methodological errors in measurements performed without taking into account significant factors.

There are various methods for studying the temperature effect on the ferroelectric ceramics parameters. For example, in [8–10] it is proposed to create an automated system for measuring the electrical parameters of active dielectrics and products based on them, which will allow to measure the electrical parameters of active dielectrics samples with guaranteed accuracy, taking into account their shapes and sizes. The increase in technical and economic efficiency will be achieved by increasing the measurements accuracy, reducing the time spent on research through measurements automation; introduction of new techniques [11] that require a smaller number of measurement experiments. The main advantage of this measuring instrument is that it is possible to study the temperature effect on the characteristics of a particular sample. The design of the heat chamber is shown in Fig. 1.

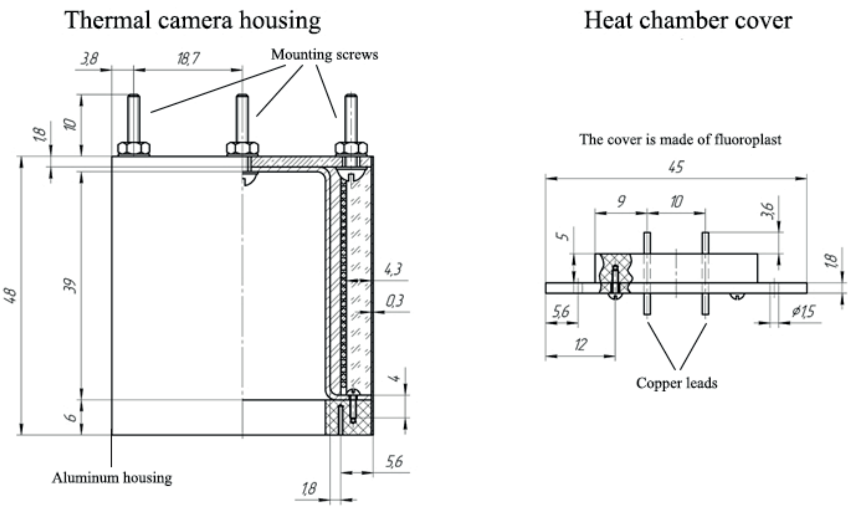

Fig. 1. Heat chamber design

The basis of the heat chamber is a container (in the form of a glass) made of aluminum. Aluminum has good thermal conductivity and is able to withstand heating temperatures up to 600 °C. The capacitance of the heat chamber must be grounded, for which it has a terminal designed to connect the ground on the high-voltage amplifier board. Mica is used to isolate the glass from the heating element. Mica has good thermal conductivity, practically does not interfere with the transfer of heat from the heater to the aluminum cup and has a melting point of 1260 °C. Since the heating element is powered by a 220 V network, it must be reliably isolated from the grounded aluminum base of the heat chamber. Mica winding provides good isolation with high resistivity. In addition, mica has a high electrical strength, which is equal to 1000 kV/cm.

The sample under study is connected to the improved Sawyer-Tower measuring circuit [9, 10]. The Sawyer – Tower circuit is a capacitive voltage divider, in one of the arms – a capacitor and the material under study, in the other – an exemplary capacitor.

The use of this scheme allows, in addition to temperature dependences (Fig. 2), to measure the dependences of electrical parameters (capacitance, relative permittivity) on the electric field strength (Fig. 3).

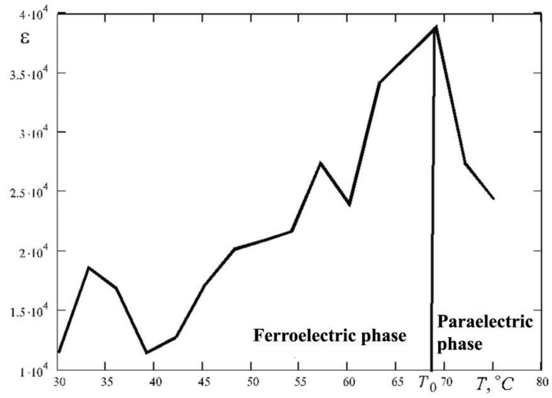

Fig. 2. Temperature dependence of the relative permittivity of varicond ceramics

A combined measuring signal, which provides a constant bias and an alternating voltage with the maximum possible amplitude of 500 V is applied to the test sample, which ensures the creation of the required electric field strength on the test samples. The amplitude value varies depending on the test sample thickness. The relative error of capacitance measurement does not exceed 0.5%.

Measuring signals proportional to the electric field strength and electric displacement in the sample are transferred to a computer after a series of transformations. To determine the electrical parameters of various materials related to active dielectrics, the use of modern mathematical methods of digital signal processing is provided. The proposed software-hardware complex is advisable to use in the study of active dielectrics and structures with ferroelectric properties.

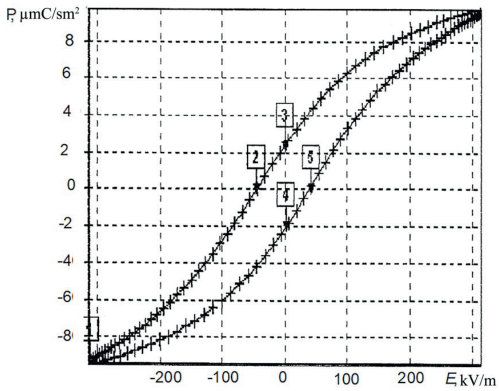

Fig. 3. The result of measuring the dependence of the polarization P of ferroelectric ceramic sample based on barium titanate on electric field *E* tension at a temperature of 80 °C: numbers 2 and 5 indicate the coercive field values, 3 and 4 are the remanent polarization values

Conclusion

A software-hardware complex is proposed for studying the functional dependences of electrophysical parameters (capacitance, relative permittivity, etc.) of active dielectrics on temperature and external electric field strength. The design of a heat chamber made to set the required temperature range covering the temperature of phase transitions of various classes of ferroelectric materials has been developed. An example of the result of the temperature dependence measuring of the relative permittivity of varicond ceramics using the developed software-hardware complex is presented. To measure the dependences of electrophysical parameters on the electric field strength, a measuring channel based on the improved Sawyer-Tower circuit was developed, which uses a combined measuring signal in the form of a DC bias and an AC voltage with a maximum possible amplitude of 500 V, which ensures the creation of the required electric field strength. The proposed software-hardware complex is advisable to use in the study of active dielectrics and structures with ferroelectric properties.

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