Conference materials
UDC 666.665
DOI: https://doi.org/10.18721/JPM.163.136

Determination of the electrophysical parameters of piezoelectrics using complex conductivity

A.E. Zhurina ✉, E.A. Pecherskaya, N.S. Emelyanov
J.V. Shepeleva, G.V. Kozlov

Penza State University, Penza, Russia
✉ gelya.zhurina@mail.ru

Abstract. The use of piezomaterials as a substrate for a graphene structure is considered. Since the surface acoustic waves generated in piezoelectric materials, are on the surface of a solid body, piezoelectrics can act as a substrate for graphene. Methods for determining the electrical parameters of piezoelectric materials are studied and selected, the ways to improve these methods are considered. In order for piezoelectrics to be used as a substrate for graphene, the properties of piezoelectrics must be carefully studied. Therefore, the frequency characteristics of a sample in the form of a tablet based on solid solutions of zirconate – lead titanate were measured. As an improvement in the methods for determining the electrophysical parameters of piezoelectric elements, it is proposed to process the measurement results automatically using a multifunctional mathematical program, such data processing helps to reduce the error of indirect measurement results of the electrophysical parameters of piezoelectric materials. A graph of the amplitude-frequency characteristics of the sample was built. Thanks to computer processing, it was possible to reveal the relationship between the piezoelectric constant of the sample and its geometric dimensions. It turned out that the piezoelectric element dimensions strongly affect the frequency response and other piezoelectric constants.

Keywords: graphene, piezoelectrics, electrophysical parameters of piezoelectrics

Citation: Zhurina A.E., Pecherskaya E.A., Emelyanov N.S., Shepeleva J.V., Kozlov G.V., Determination of the electrophysical parameters of piezoelectrics using complex conductivity, St. Petersburg State Polytechnical University Journal. Physics and Mathematics. 16 (3.1) (2023) 204–208. DOI: https://doi.org/10.18721/JPM.163.136

Материалы конференции
УДК 666.665
DOI: https://doi.org/10.18721/JPM.163.136

Определение электрофизических параметров пьезоэлектриков через систему уравнений комплексной проводимости

А.Е. Журина ✉, Е.А. Печерская, Н.С. Емельянов
Ю.В. Шепелева, Г.В. Козлов

Пензенский государственный университет, г. Пенза, Россия
✉ gelya.zhurina@mail.ru

Аннотация. Рассмотрено применение пьезоматериалов в качестве подложки для графеновой структуры. Поскольку поверхностные акустические волны, создаваемые в пьезоэлектрических материалах, находятся на поверхности твердого тела, пьезоэлектрики могут выступать в качестве подложки для графена. Изучены и выбраны методы определения электрофизических параметров пьезоэлектрических материалов и рассмотрены пути улучшения этих методов. Предлагается автоматизировать обработку данных, что существенно упростит определение параметров и позволит снизить статистическую погрешность.

Ключевые слова: графен, пьезоэлектрики, электрофизические параметры пьезоэлектриков

Ссылка при цитировании: Журина А.Е., Печерская Е.А., Емельянов Н.С., Шепелева Ю.В., Козлов Г.В. Определение электрофизических параметров пьезоэлектриков через систему уравнений комплексной проводимости // Научно-технические ведомости СПбГПУ. Физико-математические науки. 2023. Т. 16. № 3.1. С. 204–208. DOI: https://doi.org/10.18721/JPM.163.136

Introduction

Piezoelectric materials are used in many fields of technology; with the development of science, piezoelectric materials have found a new application as a substrate for graphene. Graphene is a two-dimensional material; it is formed by a cellular lattice of carbon atoms [1]. Due to its unique properties, graphene is of great fundamental and applied interest. Since carbon graphene is an atomically thin material, charge carriers in graphene are very sensitive to ambient electromagnetic fields, and the ability to change the concentration of graphene carriers by applying an external gate voltage is an important feature of many graphene-based devices. The high mobility of carriers is a consequence of the high frequencies of optical phonons in a rigid cellular lattice, due to which the effect of electron-phonon scattering on charge transfer is insignificant compared to ordinary metals [2]. However, in most cases, graphene is deposited on a substrate, and the substrate material that creates the electric field will affect the charge carrier in the graphene wafer, making the choice of substrate material critical to device performance. Because the surface acoustic waves generated in piezoelectric materials are at the surface of a solid or at an interface between two solids, piezoelectrics can act as a substrate for graphene. They are used to control the properties of semiconductor materials and structures [3].

Piezomaterial research

The use of a piezomaterial as a substrate for graphene puts forward certain requirements for the piezoelectrics parameters. To indirectly determine the piezoelectrics parameters, a system equations that takes into account the measured values of the frequency parameters of the product (resonance and antiresonance frequencies, quality factor), as well as the maximum voltage at the output of the measuring circuit at the resonant frequency is solved [4]. The mathematical model is the exact solution of the electromechanical problem of one-dimensional vibrations of a piezo sample, taking into account all types of energy losses. In the case of piezo-soft modes, the solution for complex conductivity is used, in the case of piezo-hard modes, for complex resistance. To implement this method, the real and imaginary parts of the complex conductivity of a piezoelectric are measured at several frequencies of the resonant region. The measurement results are used to solve the system of complex conductivity equations. The system is constructed in such a way that its equations relate the measured value of the complex conductivity to its theoretical expression in terms of the corresponding complex constants of the piezoceramics.

$$Y = j\omega\left[1+\frac{k^2}{1-k^2}I_D(\varphi)\right], \tag{1}$$

where $I_D(\varphi)$ is a function defining the dynamic side of the piezomaterial.

To obtain the amplitude-frequency characteristics, a piezoelectric sample was taken in the form of a tablet based on solid solutions of lead zirconate – titanate with a piezomodule equal to d_{33} = 567 pKl/N (Fig. 1).

Figure 1 shows a smooth rise from 30 kHz to 90 kHz and a sharp fall from 90 kHz to 110 kHz. There is one large peak and two peaks several times smaller than the first one.

To calculate the piezoelectric constants of a sample in the form of a disk, the complex conductivity for high-frequency piezo-soft modes corresponding to formula (1) is taken as a basis.

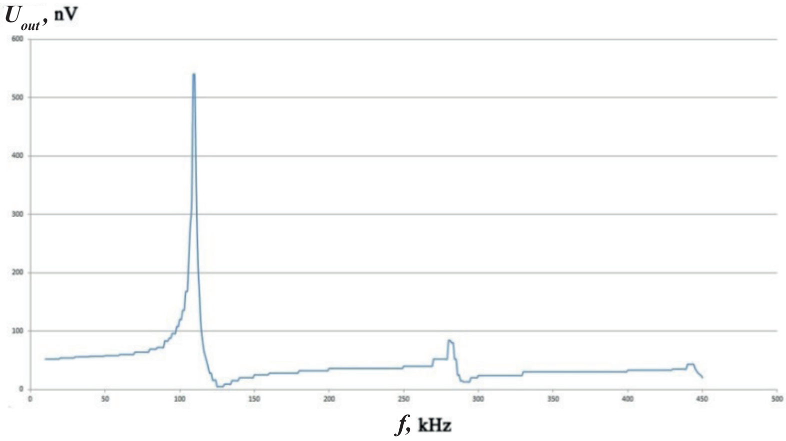

Fig. 1. Amplitude-frequency response of a piezoelectric sample in the form of a tablet based on solid solutions of lead zirconate – titanate

The dimensions and shapes of a piezoelectric strongly affect the electrophysical parameters of the sample [5], and it should be taken into account when choosing a method for determining a piezoelectric characteristics. Thanks to computer processing of the results of electrical measuring the parameters of the sample under study, it can be seen that the effect of the sample dimensions on the parameters is an important criterion that must be taken into account. Figure 2 shows the dependence of the piezoelectric modulus of the sample on its area.

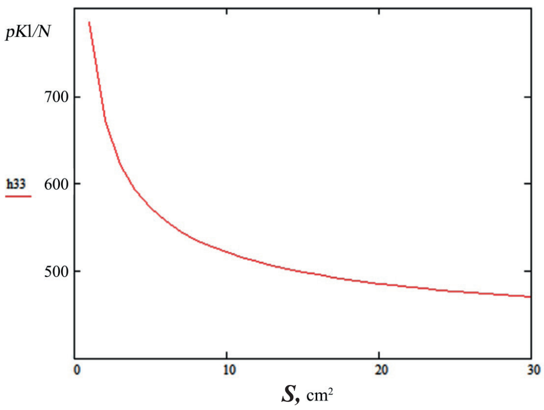

Fig. 2. Dependence of the piezoelectric modulus on the area of a sample in the form of a tablet based on solid solutions of zirconate – lead titanate

The piezoelectric constant was derived from the complex conductivity (1):

$$h_{33} = 2f_p\sqrt{\frac{m}{C^S}\left(\frac{\pi}{2}\frac{f_s}{f_p}\right)tg\left(\frac{\pi}{2}\frac{\Delta f}{f_p}\right)}, \quad (2)$$

where m is the mass of the sample, C^S is the electrical capacitance of the sample; $C^S = \frac{\varepsilon_{33}^S \pi r^2}{t}$,

where r is the radius, t is the thickness of the sample, f_S is the frequency of the dynamic (series) resonance, f_p is parallel resonance frequency (antiresonant frequency), $\Delta f = f_p - f_S$.

Then the piezoelectric constant will look like:

$$h_{33} = 2f_p\sqrt{\frac{m}{\frac{\varepsilon_{33}^S \pi r^2}{t}}\left(\frac{\pi}{2}\frac{f_s}{f_p}\right)\mathrm{tg}\left(\frac{\pi}{2}\frac{\Delta f}{f_p}\right)} \quad (3)$$

where ε_{33}^S is the dielectric constant, t is the thickness of the sample.

As it can be seen from Figure 2, the piezoelectric constant of the sample strongly depends on its dimensions. It is because the fluctuation of properties during the transition from a piezoelectric element of one geometry to a piezoelectric element with another one is significant due to the different level of their polarization, the spread in the degree of their structural inhomogeneity.

To consider the influence of dimensions on the sample parameters, the parameters of the existing sample were taken and its model was built. A piezoelectric system was calculated and designed using software products that allow simulating physical phenomena in a sample based on calculation methods. Thanks to the calculation methods [6], it is possible to evaluate how the computer model of the piezoelectric element behaves under various conditions, as well as the influence of temperature and electric field. Many scientists resort to mathematical and computer modeling of the piezoelectrics processes in their scientific research [7, 8, 9].

A solid-state model was created in the form of a cylinder made of a piezoelectric material with dimensions h = 1 mm (thickness), r = 20 mm (radius) based on solid solutions of zirconate – lead titanate.

After the piezomaterial was described and the model was built, the direction of polarization was indicated (the sample is polarized in height). After that, the frequency of the applied voltage was set. The resonant frequencies of the sample and the frequency distribution in the sample were measured (Fig. 3). The sample dimensions were then changed to reveal the effect of the dimensions on the frequency characteristics.

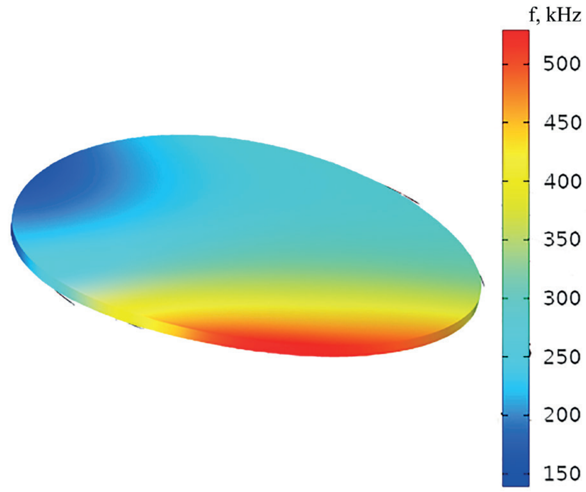

Fig. 3. Frequency distribution in a piezoelectric sample in the form of a tablet with dimensions h = 1 mm (thickness), r = 20 mm (radius) based on solid solutions of zirconate – lead titanate

It can be seen from the constructed model that the frequency distribution differs for samples of different sizes. In a sample with a greater thickness, resonance also appears at higher frequencies, however, the main peak (at 120 kHz) was preserved in both samples. Due to the fact that the frequency characteristics in the samples vary, the full set of constants obtained for a sample of one shape will differ from a sample from the same material of a different shape.

Conclusion

The method described above makes it possible to determine the piezoelectric constants of the sample, the complex constants are measured at a single frequency. However, the method has a complex mathematical apparatus [10], so it is important to simplify the process of solving the system of equations, taking into account the formulated assumptions. The processing of the measurement results was carried out automatically using a multifunctional mathematical program, such data processing helps to reduce the error of indirect measurements results of the electrophysical parameters of piezoelectric materials. In addition, thanks to computer processing, it was possible to reveal the relationship between the piezoelectric constant of the sample and its geometric dimensions.

REFERENCES

1. **Junxiao F.,** Preparation and Application of Graphene. Academic Journal of Science and Technology 4 (2022) 59–62.

2. **González D., Guinea Lypez F., Sols Lucia F.,** Electronic properties of graphene on a piezoelectric substrate Propiedades electrynicas del grafeno sobre un sustrato piezoelйctrico / Madrid, (2019) 170.

3. **Burkov S.I., Zolotova O.P., Sorokin B.P.,** The influence of uniform pressure on propagation of acoustic waves in piezoelectric layered structures. Journal of Siberian Federal University - Mathematics and Physicsthis link is disabled, 7 (1) (2014) 10—21.

4. **Svetlov A.V., Nguyen N.M.,** Determination of the parameters of products from piezomaterials represented by resonant four-element equivalent circuits. Measurements. Monitoring. Control. Control, 3 (2022) 69—75.

5. **Poorna M., Mossi K., Ali R., Bryant R., Castro N.,** Piezoelectric Actuators as Synthetic Jets: Cavity Dimension Effects. Journal of Intelligent Material Systems and Structures - J INTEL MAT SYST STRUCT, 18 (2007) 1175–1190.

6. **Sefer A., Janez S., Naim S.,** Modeling of the piezoelectric effect using the finite-element method (FEM). All content following this page was uploaded by Sefer Avdiaj on 21 November, (2014) 283–291.

7. **Basilo S., Hu Z., Petukhov S., On M.,** Modeling bimorph piezoelectric elements for biomedical devices Advances in artificial systems for medicine and education III. AIMEE (2019). Advances in Intelligent Systems and Computing, Volume 1126.

8. **Imperiale S., Joly P.,** Mathematical and numerical modelling of piezoelectric sensors. ESAIM: Mathematical Modelling and Numerical Analysis. EDP Sciences, SMAI, (2012) 875–909.

9. **Vinh-Tan N., Pankaj K., J. Yu., Leong C.,** Finite Element Modellingand Simulations of Piezoelectric Actuators Responses with Uncertainty Quantification Computation 6 (60) (2018) 1–20.

10. **Barkhatov V.A.,** Electromechanical model of a piezoelectric transducer. Defectoscopy, 8 (2018) 3—15.

THE AUTHORS

ZHURINA Angelina E.
gelya.zhurina@mail.ru
ORCID: 0000-0002-5076-3191

SHEPELEVA Juliya V.
eduard.shepelev.67@mail.ru
ORCID: 0000-0001-5075-2727

PECHERSKAYA Ekaterina A.
pea1@list.ru
ORCID: 0000-0001-5657-9128

KOZLOV Gennady V.
politeh@pnzgu.ru
ORCID: 0000-0002-5113-1305

EMELYANOV Nikita S.
emelianoff.nikita@gmail.com
ORCID: 0009-0000-9721-9401

Received 30.06.2023. Approved after reviewing 02.08.2023. Accepted 02.08.2023.