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Biodegradable polymer/graphene oxide composite for in vivo use

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Abstract. Recently, there has been a growing need for the installation of implants to monitor particular processes, stimulate cell growth or activity, or to replace tissues. The use of remote monitoring using biodegradable materials would facilitate the work of doctors, simplify the lives of patients, and also have a beneficial effect on the environment. Remote monitoring would allow monitoring of the tissues around the implant and the condition of the implant itself. Reduced graphene oxide (rGO) is one of the promising carbon materials due to its distinctive properties: inexpensive, ease of production, and high conductivity. It is proposed to create an electronic component based on laser-reduced graphene oxide and biodegradable polymers for monitoring the state of the implant. The study of the properties of rGO on biodegradable polymers made it possible to select laser reduction modes and select the PLLA polymer for further study. The mechanical stability test suggests the formation of a composite of rGO and polymers. After chemical exposure, a change in conductivity is observed. The samples turned out to be biocompatible, which means they are suitable for subsequent studies. Further the electrical characterization and approaches to create the electronic components have been investigated. This work paves the way for the development of new implantable electronic components for monitoring important parameters of the human body.
Keywords: biodegradable polymer, graphene, implantable device, electronics.

1. Introduction

There is a wide variety of implantable devices based on biocompatible polymers that allow controlling of certain parameters. However, all of them have a number of limitations and disadvantages, for example, some require extraction or replacement, and others use mainly noble metals or silicon, which, although considered biocompatible, lead to local tissue damage during prolonged use due to their high Young's modulus. This problem has led to active research of conductive composite implants based on polymers used as autonomous implantable electrodes or devices.

Despite considerable efforts in the synthesis of new polymers, the mechanical properties of polymer matrices in most cases are insufficient in terms of mechanical robustness and matching the mechanical properties of human tissue. These limitations compromise implants use in many areas. The isolation of graphene and the evaluation of its outstanding properties, such as high thermal conductivity, excellent mechanical properties, and high electrical conductivity [1], attracted scientific and industrial attention opening up promising prospects for the integration of graphene into polymer matrices for the formation of advanced multifunctional composites [2].

The introduction of graphene into nanocomposites and significant improvements in mechanical strength and electrical conductivity of composites are reported in the literature. These nanocomposites also usually exhibit increased thermal stability and electrochemical activity, as well as gas barrier properties [3]. In addition, various biomedical applications for graphene-based composites have been proposed. The presence of graphene in these composites improves the mechanical and electrical properties of biomaterials and increases the attachment of cells and their growth on the surface of biomaterials. In addition, the main advantage of these nanocomposites is that positive changes occur even with a small amount of graphene-like material and in the presence of various polymer matrices.

We also suggest using laser-reduced graphene oxide as a conductive layer. The main advantages of reduced graphene oxide are its good electrical conductivity, large specific surface area, porous structure, and good biocompatibility, as well as low cost and ease of preparation [4, 5]. The porous graphene structure with a large surface area promotes rapid ion transfer inside the electrode while maintaining good electronic conductivity. The reduced graphene oxide shows very good results in biosensors due to its properties listed above, and the biodegradable polymer allows the use of antennas in vivo. When changing inside the housing at the location of the antenna, there is a shift in the antenna frequency, which can be detected using an external antenna.

2. Experiments

2.1 Sample preparation

Polymers were selected for the experiments: polycaprolactone (PCL), polylactic acid (PLLA), vinylidene fluoride with tetrafluoroethylene (VDF-TeFE) in the form of films and scaffolds. An aqueous dispersion of graphene oxide was applied to the polymer scaffolds. Further, the dried graphene oxide layer was irradiated with a laser with a wavelength of 450 nm, for each polymer, the recovery mode possible for this laser and the recovery conditions was selected, which provided better conductivity and uniformity of the layer by selecting the speed of movement and laser power.

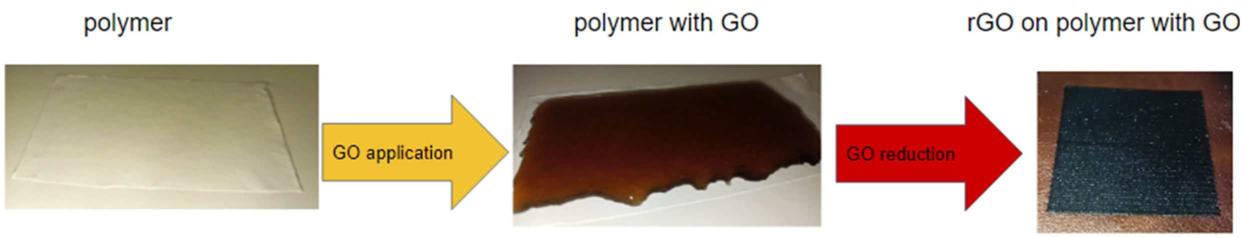

Fig.1 The process of preparing samples to obtain a layer of reduced graphene oxide on a biodegradable polymer.

2.2 Chemical and mechanical stability test

Mechanical stability peeling off test showed the formation of a composite of god and polymer and the removal of the upper layer of rGO. Vinylidene fluoride with tetrafluoroethylene failed this test. The remaining samples showed a decrease in the conductivity of the rGO layer.

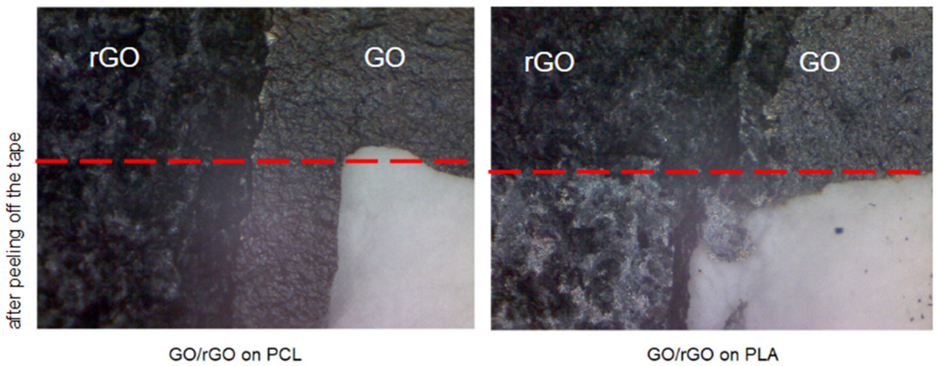

Fig.2. The results of mechanical stability peeling off tests of GO/rGO on polymers.

Tests for mechanical and chemical stability showed an increase and decrease in conductivity after the samples were found in water media and media with different hydrogen indices. As a result of the experiments, due to the best results, the polymer PLLA was selected for further research.

2.3 Biocompatibility test

Samples of polylactic acid and PLLA with rGO on the surface were tested for biocompatibility. They were sterilized and placed in a favorable environment with mouse fibroblast cells for 72 hours. The figure shows images of surfaces with colored cells on the control sample, the cells are located on a coating adapted for cell growth, the surface of the PLLA with cells, and the surface of the rGO on

PLLA with cells. On PLLA, cells grow in the form of islands, compactly. The growth is weak in comparison with the control sample, which is explained by the complex and smooth surface of the polymer. The films coated with rGO are covered with a more even layer of cells, in places the layers were torn and moved away due to the fragility of the rGO scales. There is cell growth on the surface of all samples, the cells are viable, no toxic components are released from the films, and there is no bacterial growth. There was no difference in cell growth during different sample processing. All samples were sterile.

Table 1. Results of experiments on the mechanical and chemical stability of samples of reduced graphene oxide on polymers

Type of polymer and size	Initial sample	After mechanical test	After 24 h in water	After 24 h in pH 1.65	After 24 h in pH 6.86	After 24 h in pH 12.43
rGO on PCL 10·10 mm	5 kOhm	16.6 kOhm	6 kOhm	7 kOhm	7 kOhm	6 kOhm
rGO on PLLA 10·10 mm	6 kOhm	9.4 kOhm	5 kOhm	5.1 kOhm	5.8 kOhm	13 kOhm
rGO on VDF-TeFE 10·10 mm	11.6 kOhm	not conductive	13 kOhm	10 kOhm	15 kOhm	30 kOhm

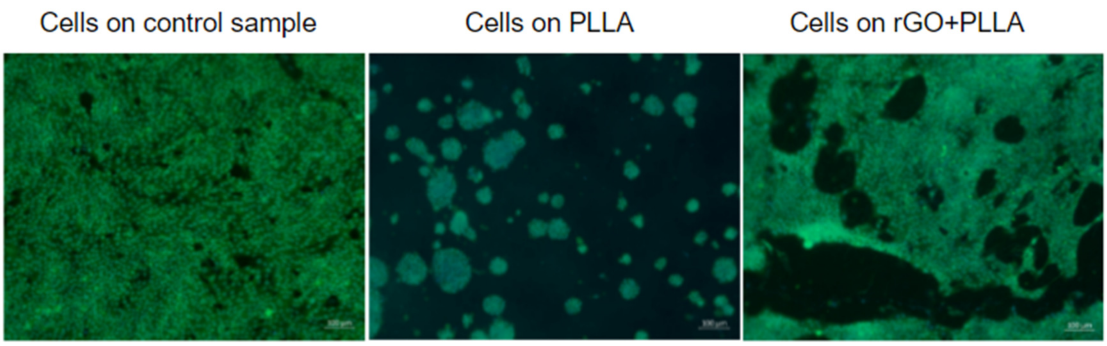

Fig.3. The result of the biocompatibility test of PLLA and rGO with PLLA samples.

3. Conclusion

The recent literature showed that the creation of composites based on graphene-like materials and polymers has great prospects and already has many results. This will improve the mechanical, physical, and chemical properties of polymers, and the graphene-like material, in turn, has high electrical conductivity, but at the same time is biocompatible, which allows them to be used in implantation.

The laser processing parameters were selected for the creation of electronic structures of rGO on polymers. Tests for chemical and mechanical stability showed minor changes in conductivity. The PLLA was chosen as the polymer with the best results in these tests. The biocompatibility test showed the possibility of using these materials in medicine. It is planned to study the biodegradation of the composite and create an antenna to test its properties.

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