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Formation of a graphene-like conductive film on the surface of SiC by laser destruction of silicon

V.S. Klimin [1] ✉, P.A. Tarasov [1, 2], M.N. Grigoryev [1, 2],
P.E. Gavrish [1, 2], A.A. Tkachyova [1, 2], V.V. Ptashnic [1, 2]

[1] Southern Federal University, Taganrog, Russia;
[2] JSC "TNIIS", Taganrog, Russia
✉ kliminvs@sfedu.ru

Abstract. This study is devoted to the formation of conductive graphene-like layers on the surface of silicon carbide by laser removal of silicon in local zones. The work demonstrates the effect of the laser system pulse frequency on the thickness and electrical conductivity of the resulting conductive graphene-like layer on a silicon carbide plate. In addition, optimal parameters for obtaining a conductive coating and the required surface roughness suitable for designing antenna devices are determined. At a frequency of 100 kHz, conductive graphene films of the coating with a thickness of 6.5 μm were obtained, while the modified zone was 93% of the total impact area. The thickness of the conductive layer in the local zone processed at a frequency of 40 kHz reached 5 μm, and at a frequency of 120 kHz – 7 μm. The results demonstrate the potential for the development and creation of sensor elements, optoelectronics and photonics devices.

Keywords: graphene, laser destruction, silicon carbide, microelectronics

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Формирование графеноподобной проводящей пленки на поверхности карбида кремния методом лазерной деструкции кремния

В.С. Климин [1] ✉, П.А. Тарасов [1, 2], М.Н. Григорьев [1, 2],
П.Е. Гавриш [1, 2], А.А. Ткачева [1, 2], В.В. Пташник [1, 2]

[1] Южный федеральный университет, г. Таганрог, Россия;
[2] АО «Таганрогский научно-исследовательский институт связи», г. Таганрог, Россия
✉ kliminvs@sfedu.ru

Аннотация. Данное исследование посвящено формированию проводящих графеноподобных слоев на поверхности карбида кремния методом лазерного удаления кремния в локальных зонах. В работе продемонстрировано влияние частоты импульсов лазерной системы на толщину и электропроводность образующегося проводящего

графеноподобного слоя на пластине карбида кремния. Кроме того, определены оптимальные параметры для получения проводящего покрытия и требуемой шероховатости поверхности, пригодных для проектирования антенных устройств. В частности, при частоте 100 кГц были получены проводящие пленки графена покрытия толщиной 6,5 мкм, при этом модифицированная зона составила 93% от общей площади воздействия. Толщина проводящего слоя в локальной зоне, обработанной при частоте 40 кГц, достигала 5 мкм, а при частоте 120 кГц – 7 мкм. Полученные результаты демонстрируют потенциал для разработки и создания сенсорных элементов, устройств оптоэлектроники и фотоники.

Ключевые слова: графен, лазерное разрушение, карбид кремния, микроэлектроника

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Introduction

In recent decades, graphene and graphene-like materials have gained significant popularity in the scientific community due to their unique electronic, mechanical and thermodynamic properties. These materials offer prospects for the development of more efficient electronic devices and sensors, as well as energy storage systems. Traditional methods of graphene synthesis, such as chemical vapor deposition or mechanical exfoliation, are associated with certain difficulties, including high cost and complexity of the processes [1–2]. One of the promising approaches to the formation of graphene-like coatings is laser ablation of the silicon component from a silicon carbide (SiC) substrate. This technique allows one to obtain graphene-like films directly on the SiC surface and control the process by optimizing the laser exposure parameters. This method provides a high degree of control over the properties of the final material and helps to reduce the time and cost of synthesis [3].

The relevance of this study is due to the growing demand for graphene and graphene-like materials in microelectronics and sensors, which necessitates the creation of new efficient and cost-effective methods for their production. The SiC substrate on which the conductive layer is formed has properties suitable for creating power electronics devices, which makes it a promising basis for working with graphene-like films [4]. In addition, the SiC laser ablation method opens new opportunities for studying the interaction of laser radiation with materials, which can contribute to the creation of innovative technologies for surface treatment and the formation of structures for microelectronics tasks [5–7]. Thus, the study is significant not only for materials science but also has practical value for the creation of new electronic devices, confirming their relevance in modern scientific and technical conditions.

Materials and Methods

The objects of the study were silicon carbide (SiC) substrates of the 6H-SiC polytype, on the surface of which a conductive graphene layer was formed by laser ablation. In this work, we studied the change in the pulse frequency of the laser system at a constant beam scanning speed of 400 mm/s. For the experiments, we used a PL-DFB-1060 laser system – a source of coherent radiation with a central wavelength of 1060 nm. The size of the processed local area was 700×700 μm. The diameter of the laser spot was 20 μm. The resulting graphene-like film samples were laser-cut to measure the thickness.

Results and Discussion

Based on the results of the conducted experimental studies, the dependences of physical and electrophysical parameters on the pulse frequency of laser processing of the local zone were established. Thus, Figure 1, *a* illustrates a local area with a formed graphene-like film at a pulse frequency of 40 kHz, where the thickness of the conductive layer reached 5 μm. Figure 1, *b* demonstrates the result of laser ablation on a section of silicon carbide at a frequency of 120 kHz with a conductive layer thickness of 7 μm.

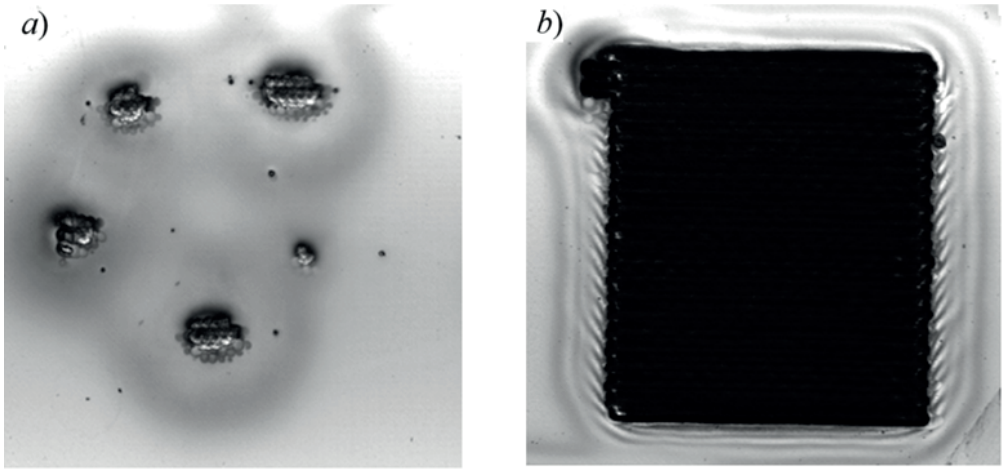

Fig. 1. Images of a local area on the surface of silicon carbide after the formation of a conductive coating using the laser ablation method at a pulse frequency of 40 kHz (*a*) and at a pulse frequency of 120 kHz (*b*)

Despite the color and filling of the area, all local areas starting with a laser pulse frequency of 20 kHz had a conductive surface but had heterogeneity on the surface of the local area, which complicated the calculations of materials or antenna devices for which it was planned to develop this technology. Starting with a pulse frequency of 100 kHz, the surface of the local area changed insignificantly, and the conductivity reached its limit value for the film. The study of samples by Raman spectroscopy showed that it can be stated that graphene was formed on the surface starting with a frequency of 60 kHz. This fact is also indirectly confirmed by the measured specific conductivity of the samples of $5.7 \cdot 10^3$ S/cm.

Conclusion

In the presented work, the effect of the laser system pulse frequency on the thickness and electrical conductivity of the formed conductive graphene-like layer on a silicon carbide plate was established. Additionally, the optimal parameters for the synthesis of the conductive coating and surface roughness suitable for designing antenna devices were determined. At 100 kHz, conductive films of the graphene-like coating with a thickness of 6.5 μm with a proportion of the modified zone of 93% were obtained. The study of the samples by the Raman spectroscopy method directly indicates the formation of graphene on the surface, starting from a frequency of 60 kHz. This fact is indirectly confirmed by the measured specific conductivity of the samples, which was 5.7×10^3 S/cm. The results obtained are applicable in the development of sensor elements, optoelectronics and photonics devices.

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THE AUTHORS

KLIMIN Viktor S.
kliminvs@sfedu.ru
ORCID: 0000-0002-9794-4459

GAVRISH Polina E.
gavrish@sfedu.ru
ORCID: 0009-0007-7197-9104

TARASOV Pavel A.
einjpptc@gmail.com
ORCID: 0009-0000-7843-9839

TKACHYOVA Anastasia A.
anab@sfedu.ru
ORCID: 0009-0007-2496-9317

GRIGORYEV Mikhail N.
gregoryevmikhail@gmail.com
ORCID: 0009-0001-1684-1475

PTASHNIK Vitaliy V.
vptashnik@sfedu.ru
ORCID: 0009-0005-7668-4079

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