Proceedings of the 6th International Conference on Theoretical and Applied Nanoscience and Nanotechnology (TANN'22)
Niagara Falls, Canada – June 02-04, 2022
Paper No. 120
DOI: 10.11159/tann22.120

Effects of Biocompatible Substrates on the Electrical Properties of Graphene

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***Abstract* -** Graphene is a single-atomic two-dimensional crystal of carbon atoms that has considerable properties due to its unique structure and physics with applications in different fields. Graphene has sensitive electrical properties due to its atomic-thin structure. Along with the substrate materials and their influence on the transport properties in graphene, design and fabrication of graphene-based devices for biomedical and biosensor applications are challenging. In this work, large-area high-quality graphene nanosheets were prepared by low pressure chemical vapor deposition using methane gas as carbon source on copper foil and transferred on the biocompatible substrates. Through deposition of titanium and gold contacts, current-voltage response of the transferred graphene on four biocompatible substrates including PDMS, SU-8, Nitrocellulose, and Kapton (Fig. 2) were experimentally determined. The considerable effect of the substrate type on the electrical properties of graphene is shown. The sheet resistance of graphene is changed from 0.34 to 14.5 kΩ/sq depending on the substrate.

***Keywords*:** Graphene; Sheet resistance; Biocompatible substrates

1. Introduction

In recent years, nanotechnology has had a profound impact on the development of new methods to diagnose and treat diseases [1]. Particularly, carbon nanomaterials have found of great interest due to their unique properties [2]. Various studies have shown that graphene, which is a single-atomic layer of graphite, has great potential to be used for biological applications. The novel and special properties of graphene are due to the unique structure and physics of this two-dimensional material [3-4]. Due to exceptional properties of graphene including high electron mobility, huge mechanical strength, flexibility, biocompatibility, etc., potential applications of graphene in biomedical engineering have already been foreseen in biosensors, drug delivery, bioimaging and tissue engineering [1, 6].

Different methods have been developed for the growth and synthesis few-layer graphene [4-5]. Although mechanical exfoliation can yield high-quality graphene, however, it is non-reproducible and the size is limited to few microns [7]. Liquid-phase exfoliation has relatively low cost, but the inferior quality of the product limits its application for electronic applications and device fabrication [7]. Chemical vapour deposition (CVD) on transition metals is the most common technique, which enables to grow large-area high-quality graphene nanosheets in a reproducible manner [8-9]. Therefore, the CVD process is considered as a potential candidate for graphene-based device technology.

For many applications, the CVD-grown graphene nanosheets on transition metals have to be transferred on desirable substrates for practical applications [5]. In recent years, transferring of graphene on biocompatible substrate has attracted interest in order to be used in bio-related applications. It should be noted that the electrical properties of graphene is influenced by the substrate [10]; so that, many studies have been carried out to determine the effect of environmental conditions on the electrical properties of graphene [3, 11-13].

In this study, the effect of biocompatible substrates on the electrical properties of graphene was studied in order to gain a deeper knowledge on the properties and the behavior of graphene-based Biosystems, and to take more efficient steps to improve their functionalities and performance.

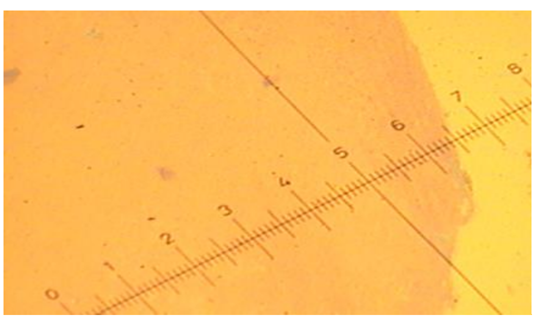
2. Experimental procedure

High purity copper foil (99.8%, 50µm thick), 99.9% CH_4 and 99.9999% Ar-10%H_2 were used for Low Pressure CVD (LPCVD) graphene growth. One molar $FeCl_3$ (SAMCHUN Chemicals) solution in 10% HCl (Merck co.), PMMA (Sigma-Aldrich) and Anisole (SAMCHUN Chemicals) were used for the graphene transfer process. PDMS (DOW-corning), Nitrocellulose (Sigma-Aldrich), SU-8 (Micro Chem) and Kapton were used as biocompatible substrates for Graphene and S-1813 photoresist (DOW Chemicals) was used for photo-lithography patterning.

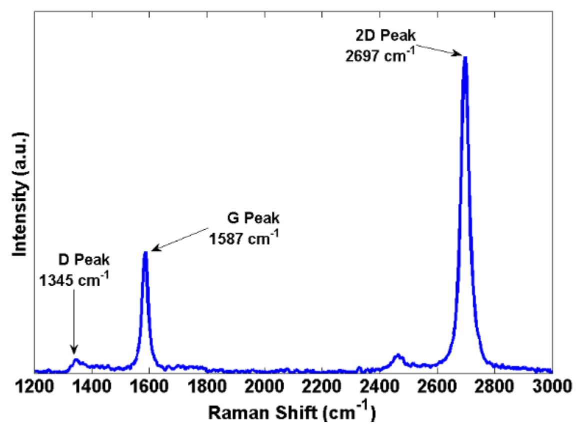
The LPCVD grown monolayer Graphene was grown on copper foil substrates similar to the process reported before [14]. The grown nanosheets were transferred on the biocompatible substrates using the well-known wet transfer method [11]. Graphene patterns were fabricated using standard photo-lithography process and oxygen plasma etching [15]. The metallic contacts were fabricated using standard lift-off process. Herein, 150nm Ti and 50nm Au were DC sputtered for this purpose. Finally, the current-voltage characterization of the samples was determined by employing a Keithly high precision characterization system coupled with 4-probe station.

3. Results and Discussion

Fig. 1a shows an optical image of prepared graphene nanosheets been transferred on 500µm Si wafer with 300 nm thermally grown SiO_2 to ease visualization. As seen, the graphene layer has large area with high quality (without defects and wrinkles). The Raman spectra of the nanosheets is shown in Fig. 1b. The position of 2D and G peaks, 2D/G peaks ratio (~2.6) and the symmetric shape of 2D peak shows that the graphene is single atomic thick [10].



(a)



(b)

Fig. 1. a) Optical microscope image of graphene transferred on Si/SiO_2 substrate (Each unit represents 25µm), b) Raman spectra of graphene on Si/SiO_2 substrate.

Fig.2. Graphene monolayers on (from left to right) PDMS, Kapton and SU-8 substrates with metallic contacts.

The graphene nanosheets were transferred on biocompatible substrates including PDMS, SU-8, Nitrocellulose and Kapton. Ti/Au contacts are fabricated using standard lift-off process, as shown in Fig. 2. Afterward, the I-V curve of graphene on different substrates was measured. Typical I-V curve of CVD-grown graphene nanosheets on Nitrocellulose substrate is shown in Fig. 3. The linear I-V curve indicates the ohmic contact between graphene and the metal layers. The averaged sheet resistance of graphene on different biocompatible substrates is reported in Table 1. It is deducible that the type of biocompatible substrate influences the sheet resistance of graphene. The lowest resistant was attained for Nitrocellulose and the highest value for Kapton.

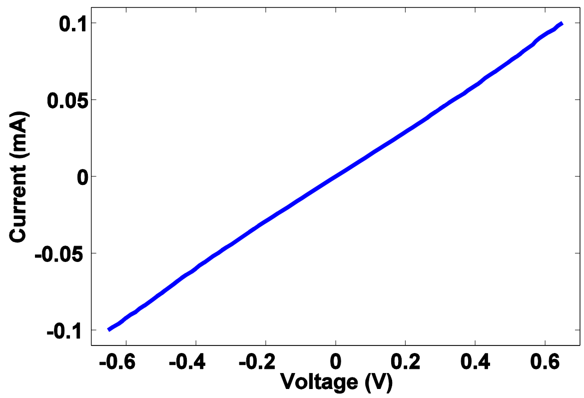


Fig.3. I-V curve of Graphene on Nitrocellulose substrate.

4. Conclusions

Large-area monolayer graphene films were grown on a copper foil using LPCVD method and transferred on different biocompatible substrates including PDMS, SU-8, Nitrocellulose, and Kapton. Microscopic and spectroscopic techniques showed that the graphene monolayers have large area with high quality. By depositing metal contacts on the transferred graphene, its current-voltage characteristics were determined. It was shown that the graphene/Ti/Au is an ohmic contact with linear I-V curve. The type of the biocompatible substrate had a profound influence on the sheet resistance of graphene monolayers. The lowest sheet resistance was attained when Nitrocellulose substrate was utilized.

Table 1. Sheet resistance of graphene monolayers on different biocompatible substrates.

Substrate	Sheet Resistance (kΩ/sq)
Nitrocellulose	0.345
SU-8	1.680
PDMS	8.965
Kapton	14.467

Acknowledgments

A. Simchi would like to thank Sharif University of Technology (Grant Program No.G930305) and Iran National Science Foundation (INSF, Grant No. 95-S-48740) for supporting CVD synthesis of 2D materials including graphene.

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