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ЭЛЕКТРИЧЕСКИЕ СВОЙСТВА ГРАФЕНОВ ДЛЯ ПРИМЕНЕНИЯ В ЭЛЕКТРОХИМИЧЕСКИХ УСТРОЙСТВАХ НАКОПЛЕНИЯ ЗАРЯДА

Аннотация: *графены в форме гибких тонких пленок, обработанные различными видами плазмы, были исследованы методом Мотт-Шоттки анализа. Показана возможность варьирования электрических свойств графенов методом плазменной обработки. Полученные материалы являются перспективными для использования в устройствах хранения и накопления электроэнергии.*

***Ключевые слова**: электропроводность, суперконденсаторы, графены, Мотт-Шоттки анализ, ионистеры.*

***Abstract**: graphenes in the form of flexible thin films treated with different types of plasma were investigated by Mott-Schottky analysis. The possibility of variation of electrical conductivity in graphene prepared by plasma treatment was shown. Obtained materials are promising for electric energy storage devices.*

***Keywords**: graphenes, charge storage devices, plasma treatment, Mott-Schottky analysis, electrical conductivity.*

Introduction

During last decades graphenes attracted attention of numerous research groups because of their extraordinary properties: high electron mobility [1], chemical inertness [2], high anisotropy of electron mobility [3], and, therefore, high anisotropy of electrical conductivity (semi-metal in longitudinal, dielectric in cross-sectional direction), ability to change the bandgap width under the influence of external factors [4]. One of the practical applications of graphenes is their use of current collectors [5], in corrosion protection [6] electrochemical charge storage devices including flexible [7;8], light emitting diodes [9], sensors [10].

Materials and methods

Multi-layered grapheme (MLG) samples were synthesized by thermo-mechanical process as described in [11]. Samples of 30 – 50 μm thickness in the form of rounded sheets were applied as electrodes.

Mott-Schottky analysis

Mott-Schottky (MS) analysis is an electrochemical method of studying surfaces, where the impedance response at fixed frequencies, but at different potentials, is scanned. MS analysis can be applied to determine electronic properties of samples, such as bandgap [12].

Results and discussion

MS analysis was used to determine flat-band potential. Flat-band potential was determined from the intersection of C^{-2}/U (inversed squared capacitance / potential) plot with X-axis. The best reproducibility was observed as 5 Hz.

When the electrode is in contact with electrolyte solution, equity of Fermi levels in both materials forces zones boundaries to deform in the place of a contact. Flat-band (FB) potential is the potential necessary to straightening zones at electrolyte/solution interface. Obtained data (

Table 1) shows that FB potential for pure MLG (6.0 V) is close to the gap of carbon with diamond structure (5.49 V) [13; 14], confirming dielectric properties of MLG sample in «normal» (perpendicular to the electrode) direction. Difference of 0.5 V is the evidence of a possible error introduced to measurements relatively to Ag/Ag^+ measurements and variance of diamond bandgap provided by different data sources.

Therefore, applied method allows determining the bandgap of fairly anisotropic samples with relatively high precision.

Surface electrical conductivity (

Table 1) measured by four-probe method [15] shows high values of electrical conductivity in tangential directions that are of the same order of magnitude for treated and non-treated films. Therefore, plasma treatment does not decrease electrical conductivity of surface, while changing bulk properties.

Table 1

Flat band potentials and electrical conductivities for different samples

Sample	MLG pure	MLG treated with oxygen plasma	MLG treated with nitrogen plasma
Flat-band potential, V	6.0	8.3	2.1
Surface electrical conductivity, MSm/m	0,5	0,62	0,7

Conclusions

MLG samples treated with different types of plasma possess different bulk electrical conductivity. Therefore, possibility to alter electrical properties of MLG by plasma treatment is shown, while flexibility of films remains unchanged.

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