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MODELING OF VOLTAGE-AMPERE CHARACTERISTIC STRUCTURES ON THE BASIS OF GRAPHENE OXIDE/SULFUR COMPOUNDS

R.G. Abaszade [1] A.G. Mammadov [1] V.O. Kotsyubynsky [2] E.Y. Gur [3] I.Y. Bayramov [1] E.A. Khanmamadova [1] O.A. Kapush [4]

1. Azerbaijan State Oil and Industry University, Baku, Azerbaijan, abaszada@gmail.com, mamedov_az50@mail.ru, imranb1963@mail.ru, khanman.ea@gmail.com
2. Vasyl Stefanyk Precarpathian National University, Ivano-Frankivsk, Kyiv, Ukraine, kotsuybynsky@gmail.com
3. Ataturk University, Erzurum, Turkey, emregur@atauni.edu.tr
4. V.E. Lashkarev Institute of Semiconductor Physics, National Academy of Science of Ukraine, Kyiv, Ukraine, cccsavchuk-olja@ukr.net

Abstract- Last years, the direction actively associated with the structures on the basis of graphene oxide. We have synthesized large scale, thin, transparent graphene oxide flakes by Hummer's method and investigated their suitability for making of transparent nanocomposites. The results of modeling of experimental points as separate sections, as well as all volt-ampere characteristics for two samples of the structure based on the combination of graphene oxide/sulfur. Particular attention is paid to the modeling of sites with negative differential conduction. It is shown that areas with negative differential conductivity for the first type of samples are well approximated by polynomials of the 3rd and 4th orders, and for the second type of samples - by a polynomial of the 5th order. Modeling is performed using Matlab R2021a software. The resulting models have high reliability.

Keywords: Graphene Oxide, Sulfur, Negative Differential Conduction, Volt-Ampere Characteristics, Modeling, Structure, Connection.

1. INTRODUCTION

The rapid development of science and technology in recent years necessitates the application of nanoelectronics. Last years, the direction actively associated with the structures on the basis of graphene oxide [1-4]. We have synthesized large scale, thin, transparent graphene oxide (GO) flakes by Hummer's method and investigated their suitability for making of transparent nanocomposites. The GO flakes were comprehensively investigated by X-ray diffraction, Scanning Electron Microscopy (SEM), Energy Dispersive X-ray analysis (EDX), Raman spectroscopy and Differential Scanning Calorimeter (DSC).

X-ray diffraction displayed the peak of graphene degree, which is characteristic peak of GO in respectively with the literature results. Scanning Electron oxide at 9 Microscopy images revealed that thin, transparent, flake form GO with 14.8 µm lateral size and 0.31 µm thickness were synthesized. In literature have shown that, the average lateral sizes of GO flake change between 0.4-12.4 µm. The comparison with literature results shows that for the first time, our group could synthesize large scale, thin and more transparent GO flakes by simple Hummer's method using simple dispersed graphite.

EDX measurements indicate the formation of layered structure with oxygen containing functional groups. The intensity ratio between D and G peaks in the Raman spectra proves that less defective GO flakes have been synthesized. The solution ability of the synthesized material indicate that high quality GO flakes were synthesized, which make them effective soluble material due to oxygen containing groups formed on the graphene plane during synthesis process. DSC results shows that these flakes are thermally stable till 200 °C. Due to high solubility properties, large scale and transparency they can be very useful in fabrication of high optical transparent nanocomposites for replacement indium tin oxide transparent conductors in solar panels, biomedical applications and microwave absorbers for electromagnetic interference (EMI) environmental protection [5].

In the work [6] for the combination of graphene oxide/sulfur (GO/sulfur) on the volt-ampere characteristic (VAC) are found sections with negative differential conductivity (NDC). This has led to even greater interest in such structures, as from the point of view of the study of mechanisms of similar effects, as well as from the position of the implementation of new functional possibilities of these structures in electronics. For the identification of physical mechanisms and purposeful implementation of the properties of the structure on the basis of the GO/sulfur combination is the sufficiently effective approach to the modeling of sites VAC, as well as all the characteristics in general. The particular interest is the plot with NDC.

Various physical properties of graphene-based samples were analyzed. The study of the graphene-based samples was performed using scanned electron microscopy (SEM), energy dispersion analysis (EDA), X-ray diffraction analysis, Raman scattering and IR luminescence, and noted the strong effect of the additive on the physical properties [7]. The results of an analysis of some properties of carbon nanotubes using X-ray diffraction analysis, Raman scattering, and IR luminescence are given. After doping with gadolinium the peak intensities in X-ray and Raman spectra drastically increase.

It was found that 15% doping with gadolinium strongly affects the physical properties of carbon nanotubes functionalized by a carboxyl group [8]. The effect of phonon scattering on electrical conductivity (EC) of 2D electron gas in quantum well (QW) systems with a complicated potential profile is described. Dependence of QW electrical conductivity on QW parameters (such as QW width, Fermi level positions etc.) when phonon scattering is employed has been calculated. NDC in EC when it varies with width of the QW has been found [9].

The aim of this paper is the comparison of structural, morphological and electrical properties of thermally extended graphite synthesized by chemical oxidation of graphite with sulfur of nitric acids at all other same conditions. Thermal treatments of graphite intercalation compounds were performed at a temperature of 600 °C on the air for 10 min but additional annealing in temperature range of 100-600 °C for 1 hour was done.

The obtained materials were studied by XRD, Raman spectroscopy and impedance spectroscopy. The evolution of structural ordering of thermally extended graphite samples at increasing of annealing temperature was traced. It was determined that the additional annealing allows to control the electrical conductivity and structural disordering degree of extended graphite samples that is useful for preparation of efficient current collectors for electrochemical capacitors [10].

2. EXPERIMENT AND DISCUSSION

At present, there are practically no scientific publications devoted to modeling questions of volt-ampere characteristics (VAC) of structure on the basis of graphene oxide/sulfur compounds. The purpose of this work is the implementation of simulation of individual sites, and in particular, the site with negative differential conductivity (NDC), as well as of the volt-ampere characteristics (VAC) of all structures based on the combination of graphene oxide/sulfur.

Volt-ampere characteristics are modeled on the basis of graphene oxide/sulfur matter measurements at room temperature. The samples were cut out in the form of rectangles and placed on a substrate of Teflon. The contacts of the silver paste were applied to the substrate for attaching the wires so that it was possible to measure the resistance with the help of the usual two-prong method.

On the curve volt-ampere characteristics with the ratio of oxygen to carbon 3.54 and the ratio to gray 42.54 observed a negative differential resistance. Samples had content and 76.59, 21.61 and 1.8 mass. %, respectively (Table 1).

Table 1. Elemental composition, mass. %, and the ratio of synthesized GO/sulfur [6]

C	O	S	O/C	O/S
76.569	21.62	1.8	3.54	42.54

On the curve of volt-ampere characteristics (VAC) of graphene oxide/sulfur on Figure 1 shows two sharp peaks (about 0.24 V - section 1 and 0.495 V - section 2), which indicates local minimums in the resistance, characterized by a change in the ratio of current-voltage) - the appearance of negative differential resistance.

Figure 2 presents experimental points and the polynomial interpolation curve, describing section 1 volt-ampere characteristics with negative differential conduction correlation

$$I = 0.56V^3 - 0.418V^2 + 0.104V - 0.861 \quad (1)$$

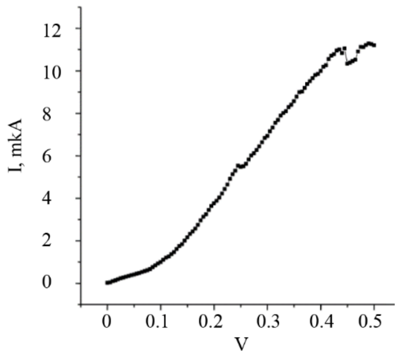

Figure 1. Experimental points of voltage characteristics of structures based on graphene oxide/sulfur compounds [6].

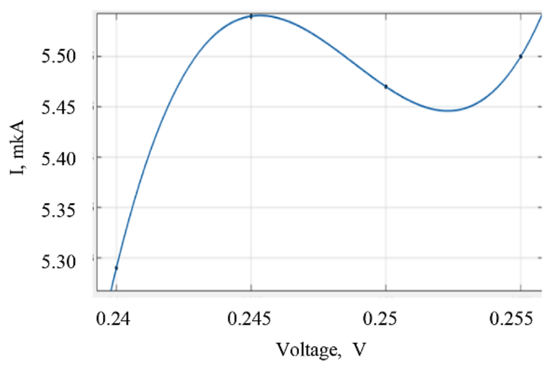

Figure 2. Experimental points and polynomial interpolation curve, describing the section 1 of volt-ampere characteristics with negative differential conduction

Figure 3 shows experimental points and the polynomial approximation curve, with high reliability (R^2 = 0.999) describing section 2 VAC with negative differential conductivity in relation to

$$I = -0.5867V^2 + 43.95V - 566.4 \quad (2)$$

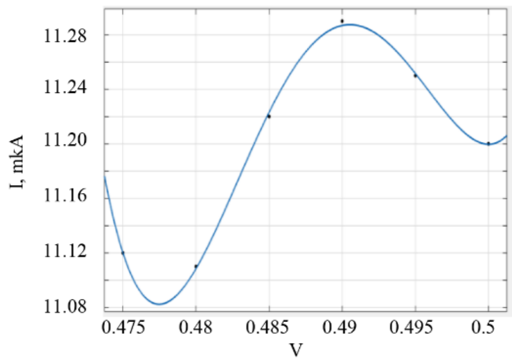

Figure 3. Experimental points and the polynomial approximation curve, describing section 2 volt-ampere characteristics with negative differential conductivity

Table 2. Presents the parameters of sections 1 and 2 VAC with negative differential conductivity

Parameter name	Plot 1	Plot 2
The minimum value of the current of the site VAC with negative differential conductivity, µA	5.44	11.2
The maximum value of the current of the site VAC with negative differential conductivity, µA	5.54	11.28
Range of current changes in the VAC section with negative differential conductivity, µA	0.1	0.08
The initial value of the voltage of the site VAC with negative differential conductivity, V	0.245	0.49
The final value of the voltage of the site VAC with negative differential conductivity, V	0.252	0.5
Range of voltage changes in the VAC section with negative differential conductivity, V	0.007	0.01
Significance of differential resistance of the site VAC with negative differential conductivity, mOhm	0.05	0.125

Figures 4-7 presents the different types of structures of volt-ampere characteristics (VAC) on the basis of graphene oxide/sulfur compounds, in which metallic electrodes are located on opposite surfaces graphene oxide/sulfur. At the same time, the similar structure of VAC has essential differences from the previously represented, and also has the effect of negative differential conduction.

Figure 4 presents a polynomial model (R^2=0.9961) of the VAC section with negative differential conductivity, structures graphene oxide/sulfur:

$$I = -8.581V^5 + 750.53V^4 - 26235V^3 + 4581724V^2 - -4\times10^6 V + 10^7 \quad (3)$$

The volt-ampere characteristics (VAC) site in the range 6-17 V, as can be seen from Figure 5, with high reliability (R^2=0.9856) is described by the linear model of the species

$$I = 7.874V - 46.39 \quad (4)$$

Volt-ampere characteristics for the same structure on the plot in the range 21-32 V, as can be seen from Figure 6, is sufficiently accurate (R^2=0.9895) is described by the parabolic dependence of the species

$$I = -0.5867V^2 + 43.95V - 566.4 \quad (5)$$

At this maximum failure of the approximation curve is reached at (U=26 V).

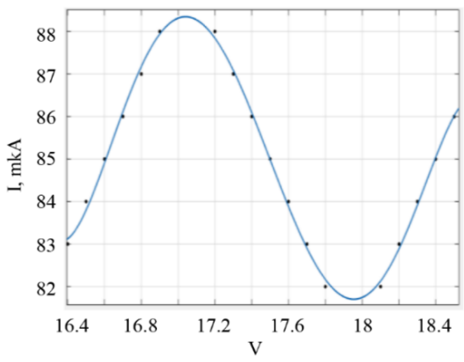

Figure 4. Polynomial model section volt-ampere (R^2=0.9961) characteristics with negative differential conductivity structures graphene oxide/sulfur

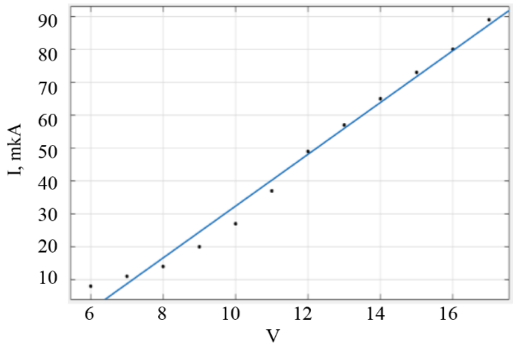

Figure 5. Line model of the site volt-ampere characteristics (VAC) of structure graphene oxide/sulfur in the range 6-17 V

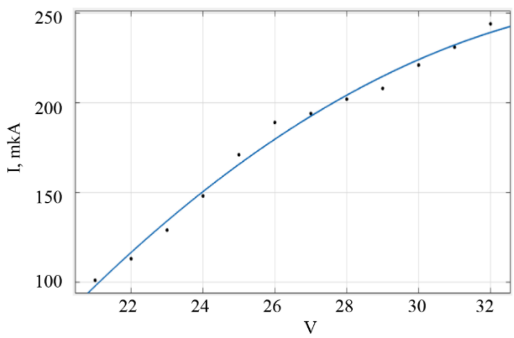

Figure 6. Parabolic model of the site volt-ampere characteristics of structures graphene oxide/sulfur in the range 21-32 V

Ignoring the fact that volt-ampere characteristics -like structure has a section with negative differential resistance, it makes sense to carry out an approximation for the entire range of voltage changes. The results of such an approximation are presented in Figures 7-8. Apparently, the approximation by a power function of the species

$$I = 0.4659V^{1.813}$$

and second order polynomial

$$I = 0.2023V^2 + 1.49V - 4.495$$

gives a single good result and therefore can be used effectively. Naturally, when the greatest failure of approximation occurs at the site of volt-ampere characteristics (VAC), corresponding to the site with negative differential conductivity.

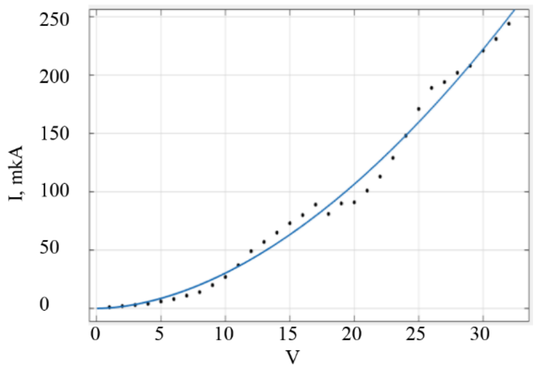

Figure 7. Approximation of experimental points of volt-ampere characteristics (VAC) of structures on the basis of graphene oxide/sulfur by a power function

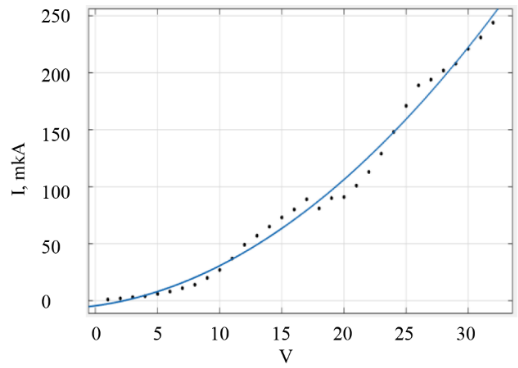

Figure 8. Approximation of experimental points of volt-ampere characteristics (VAC) of structures on the basis of graphene oxide/sulfur polynomial function

3. CONCLUSION

On the curve volt-ampere characteristics with the ratio of oxygen to carbon 3.54 and the ratio to gray 42.54 observed a negative differential resistance. Modeling of sections of current-voltage characteristics, including sections with negative differential conductivity, as well as the entire volt-ampere characteristics curve for two samples of structures based on the graphene oxide/sulfur compound, was carried out. It is shown that areas with negative differential conductivity for the first type of samples are well approximated by polynomials of the 3rd and 4th orders, and for the second type of samples - by a polynomial of the 5th order. For the second type of samples, it was found that the volt-ampere characteristics section in the range of 6-17 V is described by a linear model; and the volt-ampere characteristics section in the range of 21-32 V is described by a 2nd order polynomial model. At this maximum failure of the approximation curve is reached at U=26 V. It is found that the volt-ampere characteristics of such structures in the entire voltage range are equally well described by a power function and a 2nd order polynomial. Modeling is performed using Matlab R2021a software. The resulting models have high reliability.

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BIOGRAPHIES

Rashad G. Abaszade was born in Baku, Azerbaijan, in March 1982. He received the B.Sc. degree from Baku State University, Baku, Azerbaijan in 2003 and the M.Sc. degree in 2006. He received his Ph.D. degree from Institute of Physics, Azerbaijan National Academy of Sciences, Baku, Azerbaijan in 2018. Currently, he is an Associate Professor at Azerbaijan State Oil and Industry University, Baku, Azerbaijan and Head of Innovation Research Department of International

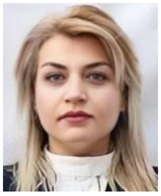
Ecoenergy Academy, Baku, Azerbaijan. His research interests are synthesis of carbon nanomaterial's, their application in Nano composites, nanotechnology and Nano electronics, theoretical and Experimental investigation of Nanomaterials. He is the author of 76 scientific papers, 6 textbooks and 3 patents.

Azer G. Mammadov was born in Baku, Azerbaijan, in February 1950. He is graduated in the field of Radio Engineering from Moscow Energy Institute, Russia in 1973. Since September 1977, he has worked at Department of Industrial Electronics, Azerbaijan Technical University, Baku, Azerbaijan as a senior engineer, graduate student, junior researcher, senior researcher, assistant, senior teacher, Associate Professor, and since 2008 as a Professor. In 2004, he defended his doctoral dissertation and was awarded the title of Doctor of Technical Sciences. Currently, he is a Professor at Azerbaijan State Oil and Industry University, Baku,Azerbaijan. He is the author of 110 scientific papers and 10 patents.

Volodymir O. Kotsyubynsky was born in Kiev, Ukraine, in November 1976. He graduated from Department of Materials Science and New Technologies, Faculty of Physics with a degree in physics. In 2002, he became a candidate of physical and mathematical sciences. Since 2013, he has been a Professor at Department of Materials Science and New Technology, National University of Precarpathian, Ukraine. His research focuses on testing materials with XRD, Mossbauer spectroscopy, low temperature gas absorption, XRF, thermal analysis and impedance spectroscopy. He has published 30 papers in WOS and Scopus databases.

Emre Y. Gur was born in Cihanbeyli, Konya, Turkey in August 1976. He received his Bachelor degree in 1999 from Department of Physics, Middle East Technical University, Ankara, Turkey. He received his Master degree in 2003 from Department of Solid State Physics, Ataturk University, Erzurum, Turkey. Since 2007, he has been defending his Ph.D. at Department of Solid State Physics, Ataturk University. He is currently a Professor at Ataturk University. He is the author of 86 scientific papers.

Imran Y. Bayramov was born in Dmanisi, Georgia, in February 1963. He received the B.Sc. degree from Baku State University, Baku, Azerbaijan in 1985. He received his Ph.D. degree in 2013. Currently, he is an Associate Professor at Azerbaijan State Oil and Industry University, Baku, Azerbaijan. His research interests are modeling, fizzy systems, automation simulation, programming, optimization, applied mathematics. He is the author of 60 scientific papers and 4 textbooks.



Elmira A. Khanmamadova was born in Tyumen, Russian, in September 1982. She graduated the Department of Physical Electronics. Currently, she is working at Azerbaijan State Oil and Industry University, Baku, Azerbaijan. Her research interests are electrical and photoelectric characteristics of heterojunctions, production of thin films by photoelectric conversion of hetero-junctions, photosensitive semiconductor materials and devices, nanotechnology and nanoelectronics, theoretical and experimental investigation of Nanomaterials. She is the author of 52 scientific papers, 5 textbooks and 1 patent.

Olga A. Kapush was born in Svirshkivtsi, Ukraine, in March 1986. She is the senior researcher at Department of Optics and Spectroscopy of Semiconductor and Dielectric Materials, V.E. Lashkaryov Institute of Semiconductor Physics, National Academy of Sciences of Ukraine, and Ph.D in Solid State Chemistry. He received B.Sc. degree from Y.F. Cernivtsi National University, Ukraine in 2007 and the M.Sc. degree in 2008. His research interests are work with development of methods for the formationand study of physical properties of nanosized structures based on semiconductors. She published 150 publications, including 2 chapters in monographs, 23 patents for inventions and utility models.