VASE of Graphene-Based Films

Subjects: Materials Science, Coatings & Films
Contributor: Grazia Giuseppina Politano

The interaction of graphene oxide (GO) with magnetron-sputtered metals is a promising research area. VASE optical models of GO thin films deposited on magnetron-sputtered titanium (Ti), silver (Ag) and gold (Au) are discussed. Moreover, the optical properties of graphene nanoplatelet (GNPS) films and reduced graphene oxide (RGO) stabilized with Poly(Sodium 4-Styrenesulfonate) (PSS) films, which are less studied graphene-related materials, are shown. Finally, different optical behaviors of chemical vapor deposition (CVD)-grown monolayer, bilayer, and trilayer graphene films on silicon and polyethylene terephthalate (PET) substrates are recapitulated.

Keywords: ellipsometry ; graphene oxide ; reduced graphene oxide ; graphene ; CVD ; optical properties ; magnetron sputtering ; thin films

1. Introduction

A transparent conductor is a relevant constituent in several photoelectronic appliances. Indium tin oxide (ITO) is principally used for fabricating transparent conductors due to its properties [1]. Nevertheless, ITO has many disadvantages; for instance, it is expensive and it does not find application in flexible devices because of its brittle nature [2]. Consequently, consideration in the semiconductor field has been drawn to graphene [3], which shows broadband light absorption, linear dispersion band structure and an ultrahigh charge-carrier mobility. Graphene-based materials are thus advantageous materials that can be produced in ultrathin sheet form and may be used in several applications [4][5][6][7][8][9][10][11].

Chemical vapor deposition (CVD) is a technique used for high-quality graphene production [12]. The employment of CVD technology in ultradense photonic, optoelectronic, and electronic instruments has been reported [13][14][15].

Graphene oxide (GO) is a graphene-based material that has more oxygen-containing groups and defects in comparison with mechanically exfoliated or CVD-grown graphene. These defects are advantageous to enhance the performance of photodetectors [16]. Additionally, GO thin films show high optical transmittance in the visible region that allows their use as protective coatings and optically transparent electrodes, crucial in solar cells and for optical applications [17].

GO reduction is a method for large scale graphene manufacturing [18]. Reduced graphene oxide (RGO) is achieved using chemical methods [19], which eliminate or diminish the oxygen-containing groups. Additional reduction methods are thermal annealing that should be carried out above 200 °C [20] and “green reducers” (for instance vitamin C) [21].

RGO can be functionalized with Poly(Sodium 4-Styrenesulfonate) (PSS), which is a polyelectrolyte that avoids RGO aggregation. PSS interacts with graphene by means of π-π interactions, is soluble in water and safe to use [22].

Presently graphene nanoplatelets (GNPs) have arisen as a new graphene-based material. GNPs show some of the beneficial properties of single layer graphene [23]. GNPs are composed of mono- to few-layer sheets of sp^2 bonded carbon atoms that overlap creating nanometers thick 2D particles [24]. They can be obtained by means of exfoliation of cheap graphite flakes and then through chemical oxidation and graphite oxide nanoplatelets reduction [24].

Graphene-based materials show notable optical properties such as highly transparency in visible spectrum, photo-response up to Terahertz frequency range and tunable infrared optical absorbance [25].

2. Optical Properties

Spectroscopic Ellipsometry (SE) [26] is an highly precise optical method designed for studying the optical properties of materials.

SE has been extensively used to study graphene-based films. The complex refractive index of monolayer graphene has been investigated using SE [25][27][28]. In Ref. [29] the optical constants of graphene were studied by means of a phenomenological Fano model. The optical properties of thick as well as few-layer GO and RGO were studied using SE

[30][31].

We present a review of the authors' research works on Variable-Angle Spectroscopy (VASE) of graphene-based films [32][33][34][35][36][37][38][39].

Despite the availability of literature on SE of graphene-based materials [40], there are not reviews about the optical interaction of GO with magnetron-sputtered metals studied using VASE, which is a promising research area. Moreover, we report about VASE optical model of less studied graphene-based materials such as GNPs and RGO stabilized with PSS films; particular attention to CVD-grown graphene on flexible substrates is given.

3. Conclusions and Outlook

It is no doubt that VASE is among the most valuable tools for studying graphene-based films and it is well-suited for many industrial applications.

As in other fields, research on graphene-based applications using VASE has seen dramatic development and it is expanding fast. The advances made in this area are stimulating and hopeful; nevertheless, the challenges are also enormous and should be overcome.

Future investigation on VASE of GO films should mainly focus on a much deeper understanding of the reduction mechanism. In fact, further studies on the controllable oxidation and reduction of GO could improve its use as semiconductor for transistor and photoelectronic devices.

Moreover, there are several ways that graphene-based films can be functionalized for use in different applications. For instance, VASE could be used to study the optical properties of compounds made by combining graphene-based material with other 2D materials. For instance, multilayers made alternating GO and Molybdenum disulfide (MoS_2) could be used for metamaterials with application in energy storage.

Another possible application of VASE may be the research on mixing graphene-based materials with matrix polymers, such as polyvinyl alcohol (PVA), to provide an original synthesis route to make graphene-polymers nanocomposites. It would be also interesting studying functional hybrid material composed of CVD-grown graphene on PET substrates and magnetron-sputtered Au and/or Ag for flexible high-performance graphene photodetectors.

References

1. Zheng, Q.; Li, Z.; Yang, J.; Kim, J.-K. Graphene oxide-based transparent conductive films. Prog. Mater. Sci. 2014, 64, 200–247.
2. Bouten, P.C.P.; Slikkerveer, P.J.; Leterrier, Y. Mechanics of ITO on plastic substrates for flexible displays. Flex. Flat Panel Displays 2005, 99–120.
3. Geim, A.K.N.; Novoselov, K.S. The Rise of Graphene. Nat. Mater. 2007, 6, 183–191.
4. Manasoglu, G.; Celen, R.; Kanik, M.; Ulcay, Y. An investigation on the thermal and solar properties of graphene-coated polyester fabrics. Coatings 2021, 11, 125.
5. Abakah, R.R.; Huang, F.; Hu, Q.; Wang, Y.; Jing, L. Comparative study of corrosion properties of different graphene nanoplate/epoxy composite coatings for enhanced surface barrier protection. Coatings 2021, 11, 285.
6. Dou, B.; Xiao, H.; Lin, X.; Zhang, Y.; Zhao, S.; Duan, S.; Gao, X.; Fang, Z. Investigation of the anti-corrosion properties of fluorinated graphene-modified waterborne epoxy coatings for carbon steel. Coatings 2021, 11, 254.
7. Baibarac, M.; Daescu, M.; Fejer, S.N. Optical evidence for the assembly of sensors based on reduced graphene oxide and polydiphenylamine for the detection of epidermal growth factor receptor. Coatings 2021, 11, 258.
8. Imae, I. Reduction of graphene oxide using an environmentally friendly method and its application to energy-related materials. Coatings 2021, 11, 297.
9. Zhou, Z.-M.; Wang, K.; Wang, Y.-H. High Performance of thermoplastic polyurethane-graphene oxide self-healing composite film. coatings 2021, 11, 128.
10. Chen, X.; Zhang, Y.; Li, S.; Geng, Y.; Hou, D. Influence of a new type of graphene oxide/silane composite emulsion on the permeability resistance of damaged concrete. Coatings 2021, 11, 208.
11. Yung, T.-Y.; Lu, Y.-C.; Chen, J.-S.; Cheng, Y.-W.; Liu, T.-Y.; Chen, P.-T. Reinforcement of epoxy resin by additives of amine-functionalized graphene nanosheets. Coatings 2021, 11, 35.

12. Zhang, Y.; Zhang, L.; Zhou, C. Review of chemical vapor deposition of graphene and related applications. Acc. Chem. Res. 2013, 46, 2329–2339.
13. Ahmadivand, A.; Gerislioglu, B.; Ramezani, Z. Gated graphene island-enabled tunable charge transfer plasmon teraher tz metamodulator. Nanoscale 2019, 11, 8091–8095.
14. Wang, Z.; Uzlu, B.; Shaygan, M.; Otto, M.; Ribeiro, M.; Marín, E.G.; Iannaccone, G.; Fiori, G.; Elsayed, M.S.; Negra, R.; et al. Flexible one-dimensional metal–insulator–graphene diode. ACS Appl. Electron. Mater. 2019, 1, 945–950.
15. Kim, H.; Ahn, J.-H. Graphene for flexible and wearable device applications. Carbon N. Y. 2017, 120, 244–257.
16. Zhu, M.; Li, X.; Guo, Y.; Li, X.; Sun, P.; Zang, X.; Wang, K.; Zhong, M.; Wu, D.; Zhu, H. Vertical junction photodetectors based on reduced graphene oxide/silicon Schottky diodes. Nanoscale 2014, 6, 4909–4914.
17. Naumov, A.V. Optical properties of graphene oxide. In Graphene Oxide: Fundamentals and Applications; Dimiev, A.M., Eigler, S., Eds.; John Wiley & Sons, Ltd.: Hoboken, NJ, USA, 2016; pp. 147–174.
18. Pei, S.; Cheng, H.-M. The reduction of graphene oxide. Carbon N. Y. 2012, 50, 3210–3228.
19. Chua, C.K.; Pumera, M. Chemical reduction of graphene oxide: A synthetic chemistry viewpoint. Chem. Soc. Rev. 201 4, 43, 291–312.
20. Jung, I.; Dikin, D.A.; Piner, R.D.; Ruoff, R.S. Tunable electrical conductivity of individual graphene oxide sheets reduce d at “low” temperatures. Nano Lett. 2008, 8, 4283–4287.
21. MAunkor, T.H.; Mahbubul, I.M.; Saidur, R.; Metselaar, H.S.C. The green reduction of graphene oxide. RSC Adv. 2016, 6, 27807–27828.
22. Yan, W.; Yu, W.-J.; Wang, L.; Zhang, D.; Ge, X.-Q.; Hang, J.-Z.; Deng, W.; Shi, L.-Y. Preparation of partially reduced gr aphene oxide nanosheets/poly(sodium 4-styrenesulfonate) composite with high capacitance. Electrochim. Acta 2014, 1 47, 257–264.
23. Moosa, A.A.; Sa, A.R.; Ibrahim, M. Mechanical and electrical properties of graphene nanoplates and carbon-nanotubes hybrid epoxy. Nanocomposites 2016, 6, 157–165.
24. Laurenzi, S.; Santonicola, M.G. 7—Impact Response of Advanced Composite Structures Reinforced by Carbon Nanop articles; Lopresto, V., Langella, A., Abrate, S., Eds.; Woodhead Publishing: Sawston, UK, 2017; pp. 217–235.
25. Li, W.; Cheng, G.; Liang, Y.; Tian, B.; Liang, X.; Peng, L.; Walker, A.R.H.; Gundlach, D.J.; Nguyen, N.V. Broadband opti cal properties of graphene by spectroscopic ellipsometry. Carbon N. Y. 2016, 99, 348–353.
26. Tompkins, H.; Irene, E.A. Handbook of Ellipsometry; William Andrew: Norwich, NY, USA, 2005.
27. Weber, J.W.; Calado, V.E.; van de Sanden, M.C.M. Optical constants of graphene measured by spectroscopic ellipsom etry. Appl. Phys. Lett. 2010, 97, 91904.
28. Nelson, F.J.; Kamineni, V.K.; Zhang, T.; Comfort, E.S.; Lee, J.U.; Diebold, A.C. Optical properties of large-area polycrys talline chemical vapor deposited graphene by spectroscopic ellipsometry. Appl. Phys. Lett. 2010, 97, 253110.
29. Matković, A.; Beltaos, A.; Milićević, M.; Ralević, U.; Vasić, B.; Jovanović, D.; Gajić, R. Spectroscopic imaging ellipsomet ry and Fano resonance modeling of graphene. J. Appl. Phys. 2012, 112, 123523.
30. Schöche, S.; Hong, N.; Khorasaninejad, M.; Ambrosio, A.; Orabona, E.; Maddalena, P.; Capasso, F. Optical properties of graphene oxide and reduced graphene oxide determined by spectroscopic ellipsometry. Appl. Surf. Sci. 2017, 421, 7 78–782.
31. Shen, Y.; Zhou, P.; Sun, Q.Q.; Wan, L.; Li, J.; Chen, L.Y.; Zhang, D.W.; Wang, X.B. Optical investigation of reduced gra phene oxide by spectroscopic ellipsometry and the band-gap tuning. Appl. Phys. Lett. 2011, 99, 141911.
32. Politano, G.; Vena, C.; Desiderio, G.; Versace, C. Variable angle spectroscopic ellipsometry characterization of reduced graphene oxide stabilized with poly(sodium 4-styrenesulfonate). Coatings 2020, 743.
33. Politano, G.G.; Vena, C.; Desiderio, G.; Versace, C. Variable angle spectroscopic ellipsometry characterization of turbo stratic CVD-grown bilayer and trilayer graphene. Opt. Mater. 2020, 107, 110165.
34. Politano, G.G.; Nucera, A.; Castriota, M.; Desiderio, G.; Vena, C.; Versace, C. Spectroscopic and morphological study o f graphene nanoplatelets thin films on Si/SiO2 substrates. Mater. Res. Express. 2019, 6, 106432.
35. Politano, G.G.; Cazzanelli, E.; Versace, C.; Castriota, M.; Desiderio, G.; Davoli, M.; Vena, C.; Bartolino, R. Micro-Rama n investigation of Ag/graphene oxide/Au sandwich structure. Mater. Res. Express. 2019, 6, 075605.
36. Castriota, M.; Politano, G.G.; Vena, C.; de Santo, M.P.; Desiderio, G.; Davoli, M.; Cazzanelli, E.; Versace, C. Variable A ngle Spectroscopic Ellipsometry investigation of CVD-grown monolayer graphene. Appl. Surf. Sci. 2019, 467–468.

37. Politano, G.G.; Cazzanelli, E.; Versace, C.; Vena, C.; de Santo, M.P.; Castriota, M.; Ciuchi, F.; Bartolino, R. Graphene oxide on magnetron sputtered silver thin films for SERS and metamaterial applications. Appl. Surf. Sci. 2018, 427, 927–933.
38. Politano, G.G.; Vena, C.; Desiderio, G.; Versace, C. Spectroscopic ellipsometry investigation of the optical properties of graphene oxide dip-coated on magnetron sputtered gold thin films. J. Appl. Phys. 2018, 123, 055303.
39. Politano, G.G.; Versace, C.; Vena, C.; Castriota, M.; Ciuchi, F.; Fasanella, A.; Desiderio, G.; Cazzanelli, E. Physical investigation of electrophoretically deposited graphene oxide and reduced graphene oxide thin films. J. Appl. Phys. 2016, 120, 195307.
40. Losurdo, M.; Giangregorio, M.M.; Bianco, G.V.; Capezzuto, P.; Bruno, G. How spectroscopic ellipsometry can aid graphene technology? Thin Solid Films 2014, 571, 389–394.