Scopus

Documents

Guzali, H.[a] , Ayob, N.I.[a] , Mohamad, M.N.H.[a] , Zamzuri, A.S.[a] , Che Hak, C.R.[b] , Ahmad, Z.[a] , Md Ralib, A.'.[c]

High energy electron radiation inducing non-homogeneous structural changes on single layer graphene/SiO2/Si substrate

(2025) *Radiation Physics and Chemistry*, 235, art. no. 112848, .

DOI: 10.1016/j.radphyschem.2025.112848

[a] Department of Materials and Manufacturing Engineering, Kulliyyah of Engineering, International Islamic University Malaysia (IIUM), Gombak, Kuala Lumpur, 53100, Malaysia
[b] Material Technology Group, Malaysian Nuclear Agency, Bangi, Selangor, Kajang, 43000, Malaysia
[c] Department of Electrical and Computer Engineering, Kulliyyah of Engineering, International Islamic University Malaysia (IIUM), Gombak, Kuala Lumpur, 53100, Malaysia

Abstract
Graphene's performance under radiation is crucial for its potential applications in radiation-hardened electronics. In this study, we investigate the physical topology and lattice modification of single layer graphene (SLG) grown on a SiO2/Si substrate when exposed to high energy (MeV) electron radiation. SLG samples, synthesized via chemical vapor deposition (CVD), were irradiated with a 3 MeV electron beam at doses of 50 kGy, 100 kGy, and 200 kGy. Raman microscopy and Field Effect Scanning Electron Microscopy (FESEM) were employed before and after radiation to analyze the microstructural and lattice changes. Our findings reveal that at 200 kGy, certain regions of the sample exhibit G band splitting in the Raman spectra, correlating with FESEM images showing wrinkles, ripples, and folded-like structures. This suggests interactions between surface charges and graphene phonons due to high-energy electron radiation, along with strain-induced lattice distortions in disordered graphene. Interestingly, other regions maintain the sharp shape of G and 2D bands, with a smaller D band peak, indicating minimal structural disorder. The weak defect peak suggests the early stages of amorphization caused by radiation-induced defects. These results highlight the non-homogeneous structural changes in SLG under high energy electron radiation, emphasizing the complex effects of radiation on graphene. © 2025 Elsevier Ltd

Author Keywords
Electron radiation; Graphene; Non-homogenous structure; Radiation effect; Structural disorder

Index Keywords
Amorphization, Photons; Electron radiation, Graphenes, High-energy electron, Homogenous structure, Non-homogeneous, Non-homogenous structure, Si substrates, Single layer, SiO 2, Structural disorders; Crystal lattices

References

- Algara-Siller, G., Santana, A., Onions, S., Suyetin, M., Biskupek, J., Bichoutskaia, E., Kaiser, U.
  Electron-beam engineering of single-walled carbon nanotubes from bilayer graphene
  (2013) *Carbon*, 65, pp. 80-86.
- Antonova, I.V., Nebogatikova, N.A., Erohin, S.V., Prenas, V.A., Smovzh, D.V., Suprun, E.A., Volodin, V.A., Sorokin, P.B.
  Nanostructuring of CVD graphene by high-energy heavy ions
  (2022) *Diam. Relat. Mater.*, 123.
- Chan, S.H., Chen, S.H., Lin, W.T., Li, M.C., Lin, Y.C., Kuo, C.C.
  Low-temperature synthesis of graphene on Cu using plasma-assisted thermal chemical vapor deposition
  (2013) *Nanoscale Res. Lett.*, 8, p. 285.
- Childres, I., Jauregui, L.A., Park, W., Cao, H., Chen, Y.P.
  Raman spectroscopy of graphene related materials
  (2013) *New Dev. Phot. Mater. Res.*, 1, pp. 1-20.
- Cho, J.H., Na, S.R., Park, S., Akinwande, D., Liechti, K.M., Cullinan, M.A.
  Controlling the number of layers in graphene using the growth pressure

(2019) *Nanotechnology*, 30.

- Deng, C.
  The Influence of Irradiation on Structural and Transport Properties of Graphene PhD thesis Paris Sud-Univ
  (2015),
  Paris, France

- Dresselhaus, M.S., Dresselhaus, G., Saito, R., Jorio, A.
  Raman spectroscopy of carbon nanotubes
  (2005) *Phys. Rep.*, 409, pp. 47-99.

- Ferrari, A.C.
  Raman spectroscopy of graphene and graphite: disorder, electron–phonon coupling, doping and nonadiabatic effects
  (2007) *Solid State Commun.*, 143, p. 47.

- Ferrari, A.C., Meyer, J.C., Scardaci, V., Casiraghi, C., Lazzeri, M., Mauri, F., Piscanec, S., Geim, A.K.
  Raman spectrum of graphene and graphene layers
  (2006) *Phys. Rev. Lett.*, 97.

- Ferrari, A.C., Robertson, J.
  Interpretation of Raman Spectra of disordered and amorphous carbon
  (2000) *Phys. Rev. B*, 61.

- Ferrari, A.C., Robertson, J.
  Resonant Raman spectroscopy of disordered, amorphous, and diamond like carbon
  (2001) *Phys. Rev. B*, 64.

- Fischbein, M.D., Drndić, M.
  Electron beam nanosculpting of suspended graphene sheets
  (2008) *Applied Phys. Letters*, 93.

- Geim, A.K., Novoselov, K.S.
  The rise of graphene
  (2007) *Nat. Mater.*, 6, pp. 183-191.

- Homma, Y., Kato, H.
  SEM observation of carbon nanotube and graphene
  (2015) *Hyomen Kagaku*, 36, pp. 178-183.

- Iveković, D., Kumar, S., Gajović, A., Čižmar, T., Karlušić, M.
  Response of bilayer and trilayer graphene to high-energy heavy ion irradiation
  (2023) *Materials*, 16, p. 1332.

- Jain, S., Gajarushi, A.S., Gupta, A.K., Rao, V.R.A.
  Passive gamma radiation dosimeter using graphene field effect transistor
  (2020) *IEEE Sens. J.*, 20, pp. 2938-2944.

- Kashid, R.V., Dhole, S.D., More, M.A., Panchakarla, L.F.
  Effect of 6 MeV electron beam irradiation on the field emission current noise behavior of graphene
  (2013) *26th Int. Conf. On Vacuum Nanoelec. (IVNC)*, 1, pp. 29-30.

- Kim, J., Choi, J., Lee, H., Lee, H.-K., Kang, T.-H., Han, Y.-H., Lee, B.-C., Kim, B.
  Effects of 1 MeV electron beam irradiation on multilayer graphene grown on 6H-SiC(0001)
  (2008) *The Journal of Phy. Chem.*, 34, pp. 13062-13064.

- Krsihna, B.V., Ravi, S., Prakash, M.D.
  Recent developments in graphene-based field effect transistors

(2021) *Mater. Today Proc.*, 45, pp. 1524-1528.

- Li, Z., Deng, L., Kinloch, I.A., Young, R.J.
  Raman spectroscopy of carbon materials and their composites: graphene, nanotubes and fibres
  (2023) *Prog. Mater. Sci.*, 135.

- Malard, L.M., Pimenta, M.A., Dresselhaus, G., Dresselhaus, M.S.
  Raman spectroscopy in graphene
  (2009) *Phys. Rep.*, 473, pp. 51-87.

- Mohiuddin, T.M.G., Lombardo, A., Nair, R.R., Bonetti, A., Savini, G., Jalil, R., Bonini, N., Ferrari, A.C.
  Uniaxial strain in graphene by Raman spectroscopy: gpeak splitting, Grüneisen parameters, and sample orientation
  (2009) *Phys. Rev. B*, 79.

- Ni, Z.H., Yu, T., Luo, Z.Q., Wang, Y.Y., Liu, L., Wong, C.P., Miao, J., Shen, Z.X.
  Probing charged impurities in suspended graphene using Raman spectroscopy
  (2009) *ACS Nano*, 3, pp. 569-574.

- Ono, T., Okuda, S., Ushiba, S., Kanai, Y., Matsumoto, K.
  Challenges for field-effect-transistor-based graphene biosensors
  (2024) *Materials*, 17, p. 333.

- Patil, A., Childress, I., Foxe, M., Lopes, G., Roecker, C., Boguski, J., Gu, J.J., Chen, Y.P.
  Graphene field effect transistor as radiation sensor
  (2011) *IEEE Nuclear Sci. Sympo. Med. Imaging Conf.*, 2, pp. 455-459.

- Saeed, M., Alshammari, Y., Majeed, S.A., Al-Nasrallah, E.
  Chemical vapour deposition of graphene - synthesis, characterisation, and applications; a review
  (2020) *Molecules*, 25, p. 3856.

- Song, W., Lee, S.I., Kim, Y., Jung, D.S., Jung, M.W., An, K.-S., Park, C.-Y.
  Effect of MeV electron beam irradiation on graphene grown by thermal chemical vapor deposition
  (2013) *Jpn. J. Appl. Phys.*, 52.

- Stubrov, Y., Nikolenko, A., Strelchuk, V., Nedilko, S., Chornii, V.
  Structural modification of single-layer graphene under laser irradiation featured by micro-Raman spectroscopy
  (2017) *Nanoscale Res. Lett.*, 12, p. 297.

- Tawfik, M., Sharaf, A., Serry, M.
  Monolayer graphene radiation sensor with backend RF ring oscillator transducer
  (2022) *Nanomaterials*, 12, p. 305.

- Teweldebrhan, D., Balandin, A.A.
  Modification of graphene properties due to electron-beam irradiation
  (2009) *Appl. Phys. Lett.*, 94.

- Tomić Luketić, K., Hanžek, J., Mihalcea, C.G., Dubček, P., Gajović, A., Siketić, Z., Jakšić, M., Karlušić, M.
  Charge state effects in swift-heavy-ion-irradiated nanomaterials
  (2022) *Crystals*, 12, p. 865.

- Wang, J., Chen, D., Chen, T., Shao, L.
  Displacement of carbon atoms in few-layer graphene
  (2020) *J. Appl. Phys.*, 128, p. 8.

- Yung, K.C., Wu, M.W., Pierpoint, M.P., Kusmartsey, F.V.
Introduction to graphene electronics – a new era of digital transistors and devices
(2013) *Contemp. Phys.*, 54, pp. 233-251.

- Zamzuri, A.K., Ayob, N.I., Abdullah, Y., Saidin, N.U., Hak, C.R.C.
Electrical behavior of graphene/SiO₂/silicon material irradiated by electron for field effect transistor (FET) applications
(2020) *Mater. Sci. Forum*, 6, pp. 339-345.

- Zamzuri, A.S., Ayob, N.I., Abdullah, Y., Hasbullah, N.F.
Effect of irradiation upon single layer graphene on SiO₂/Si substrate using electron beam irradiation (EBI)
(2020) *Mater. Today Proc.*, 29, pp. 115-118.

- Zhou, C., Senegor, R., Baron, Z., Chen, Y., Raju, S., Vyas, A.A., Chan, M., Yang, C.Y.
Synthesis and interface characterization of CNTs on graphene
(2017) *Nanotechnology*, 28.

- Zhou, Y., O'Connell, R., Maguire, P., Zhang, H.
High throughput secondary electron imaging of organic residues on a graphene surface
(2014) *Sci. Rep.*, 4, p. 7032.

Correspondence Address
Ayob N.I.; Department of Materials and Manufacturing Engineering, Gombak, Malaysia; email: idayuayob@iium.edu.my

Publisher: Elsevier Ltd

ISSN: 0969806X
CODEN: RPCHD
Language of Original Document: English
Abbreviated Source Title: Radiat. Phys. Chem.
2-s2.0-105003239524
Document Type: Article
Publication Stage: Final
Source: Scopus