Asian Journal of Chemistry; Vol. 36, No. 4 (2024), 885-888

ASIAN JOURNAL OF CHEMISTRY

https://doi.org/10.14233/ajchem.2024.30616

Sol-Gel Spin Coated Transparent Single-TiO_2 and SiO_2 Thin Film on Glass for Opto-electronic Applications

Saravanan Sigamani[1,*], M.V. Someswararao[2] and V. Swaminatham[1]

[1]Department of Physics (S&H), Swarnandhra College of Engineering & Technology (A), Seetharampuram, Narsapur-534280, India
[2]Department of Engineering Physics, S.R.K.R. Engineering College, Bhimavaram-534204, India

*Corresponding author: E-mail: shasa86@gmail.com

Received: 29 September 2023; *Accepted*: 26 February 2024; *Published online*: 30 March 2024; AJC-21586

Great attention has been given on the sol-gel synthesis and spin-coating deposition techniques for the fabrication of various thin films. Because of its simple technique to fabricate dielectric (metal oxide) films using tetraethyl orthosilicate and titanium isopropoxide precursors. In this work, transparent single layer of SiO_2 and TiO_2 thin film was deposited on a glass substrate and characterized by FTIR, UV-visible spectroscopy, fluorescence and scanning electron microscopy techniques. The single layer thin film was mechanically stable and strong by adhering to glass substrates. The FTIR transmittance spectrum evidenced the existence of Si-O-Si and Ti-O-Ti at ~1100 and 1400 cm^{-1}. The UV-visible absorbance spectra of single layer of SiO_2 and TiO_2 thin films showed strong absorption at below 300 nm. The excitation wavelength at 380 nm, the fluorescence spectra of both thin films showed the highest emission spectrum in between 733-798 nm. The SEM studies confirmed the smooth surface in both SiO_2 and TiO_2 layers. Further, it could be useful for various applications such as back reflector in solar cells, anti-reflection coatings, hydrophobic and anti-fogging materials.

Keywords: Sol-gel, Thin film, Anatase, Fluorescence, SiO_2, TiO_2.

INTRODUCTION

Thin film nanotechnology is just a wing in nanoworld in which involves fabricating a layered thin coating on the desired substrate at nanoscale level. Mostly, the current research has been focused on by developing metal oxide nanostructures. It has enormous applications; a single thin film grown on the desired substrate can act as a multiplier in photonic applications [1]. The glass plays significant architectural material and used in various opto-electronic applications such as displays, automobiles, anti-reflection coating, self-cleaning, windshield, solar photovoltaic panels *etc*. The individual fabrication of thin films with a layer-by-layer arrangement creates a multilayer structure that can support interference properties in achieving the reflector configuration [2]. These inspired researchers in the field of photonics to create a biomimetic structure known as a photonic crystal, also known as a dielectric single or multilayers. The creation of a biomimic structure inspired by the above mentioned nature living creatures that can reform as a dielectric reflector begins with the formation of individual thin films of the desired materials [3-5].

Thin film layer has been promising as reported by several researchers using different physical (radio frequency magnetron sputtering, e-beam evaporation, *etc.*) and chemical methods (sol-gel, co-precipitation, green synthesis, *etc.*) [6]. Among various materials, titanium dioxide (TiO_2) is one of the significant materials to enhance the light harvesting mechanism (solar cells) with respect to the high specific area, non-toxicity, excellent chemical stability and economical price [7]. Here, TiO_2 nanoparticles have great importance in various applications [8-10]. The TiO_2 material has a wider band gap of 3.2 eV and active in the UV-visible region of the solar spectrum. On account of this, numerous attempts had been made to alter the band gap size of TiO_2 in order to improve its applicability and the results reported an increase in efficiency [8]. The doping element with the metallic ions could be straight in the band gap for that the reduced charge recombination mechanism and received wider light absorption in TiO_2. Fardo *et al.* [11] reported the double thin film layers of TiO_2 and SiO_2 using the sol-gel and dip-coating method. With the optical investigations, decreased light scattering and observed the water contact angle of 10º. The prepared samples were used for various applications such as self-cleaning (super hydrophilicity), anti-fogging and anti-reflection coating. Shukla & Subramanian [12] presented the structural colours by growing TiO_2 nanorods on the substrate and polyethylene terephthalate substrates. The obtained experimental results were compared with the theoretical calculations. This color based thin film transformed at superhydrophilicity state by a self-cleaning process.

Kumar *et al.* [13] synthesized 2D-TiO_2 heterostructure and capped MoS_2@TiO_2 nanomaterials by using the hydrothermal method. They demonstrated that MoS_2@TiO_2 heterostructure layer was shown dye-sensitized solar cell performance and significantly improved conversion cell efficiency of 3.3%. The SiO_2 and TiO_2 thin films are useful for various applications for example thin film solar cell backside reflector also known as distributed Bragg reflector (DBR), anti-reflection coating (ARC) and photoanode materials in dye sensitized solar cell devices (DSSCs), photocatalytic, light emitting device (LED) *etc*. [14-21].

In this work, the synthesis and characterization of TiO_2/SiO_2 thin film coating on the glass (substrate) *via* the sol-gel spin-coating process is carried out.

EXPERIMENTAL

All reagents and solvents were of analytical reagent grade and used without further purifications. Titanium isopropoxide (TTIP, $C_{12}H_{28}O_4Ti$), tetraethyl orthosilicate (TEOS, $SiC_8H_{20}O_4$), distilled water, ethanol, acetic acid and HCl were procured.

Preparation of SiO_2 solution: SiO_2 solution was prepared by sol-gel method by adding dropwise TEOS to a solution of acetic acid (1.7 mL) and ethanol (10 mL) with constant stirring for 5 min using a magnetic stirrer. Here, tetraethyl orthosilicate was taken as a source for silicon and acetic acid was used as a chelating agent. By allowing the above solution to vigorous stirring for 2 h, the solution was taken out from magnetic stirrer and kept for aging at room temperature for 24 h.

Preparation of TiO_2 solution: TiO_2 precursor solution was prepared by using titanium tetraisopropoxide (1.2 mL, Sigma-Aldrich), acetic acid (1.7 mL), ethanol (10 mL) and HCl (few drops). Ethanol and acetic acid were taken into a beaker and stirred for 10 min under constant stirring (500 rpm/min) by using magnetic stirrer (KEMI). Then, dropwise titanium isopropoxide (as source of Ti) was added into the above solution (for 20 min) under constant stirring. The transparent gel was formed with little viscosity and without precipitation; the solution beaker was taken out from the magnetic stirrer (roughly from 15 to 20 min). The prepared solution was kept for 1 h aging at room temperature to get the further viscosity to the solution and used for producing thin films.

Spin coating technique for thin film coatings: Spin coating is a technique and used to prepare a smooth film layer by spreading a prepared suspension with the specific range of substrates by under a constant speed (rpm) and pressure. This glass substrate was fixed at particular pressure, which helped to control. The solution or suspension was dropping by dropwise on the substrate. It was rotated under different conditions (parameters) by depositing with the uniform (or smooth) thin film surface. These spin-coated substrates could be shown in a homogeneous (or hetero) rough surface coating. Both TiO_2 and SiO_2 thin films were coated on the glass substrate area (2.5 cm × 2.5 cm) by using spin coater equipment. Initially, the glass substrates were cleaned by ultrasonication process using ethanol, distilled water and acetone. The spin coating settings used to deposit the TiO_2 and SiO_2 thin films were 3000 rpm for 30 s. Individually, the single-SiO_2 and single-TiO_2 layer coating on glass substrates were deposited. Simultaneously, both low refractive material and high refractive material were deposited on separate ultrasonically cleaned glass substrates. The sintering temperature applied to SiO_2 was 300 ºC and for TiO_2 it requires 500 ºC to get an anatase crystal structure as it reported [14,22]. In order to maintain a uniform deposition of the film, each layer deposition film was kept for sintering (targeted temperature depends upon type of material) up to their targeted temperature for 30 min in a muffle furnace.

Characterization: The single SiO_2 and TiO_2 layer on glass substrates were characterized by various techniques such as UV-visible (UV-Vis), fluorescence (FL), Fourier transform infrared (FTIR) and scanning electron microscopy (SEM). Thin film nanostructures were examined for their absorbance by using UV-vis spectroscopy (Perkin-Elmer, Lambda 35, USA). The fluorescence light emission spectrum investigation carried out with Perkin-Elmer-LS 45, USA. The functional groups of the prepared samples were analyzed by FTIR (Perkin-Elmer, Spectrum Two, USA) in the range of 4000-400 cm^{-1}. The SEM technique (Carl Zeiss-EVO 18, Germany) displays the surface morphological images of the material at micro or nano structure, revealing its nature.

RESULTS AND DISCUSSION

UV-Visible spectral studies: The prepared thin film samples (SiO_2 and TiO_2) absorbance was calculated at room temperature from the wavelength of 300 to 1100 nm. Initially, Fig. 1 gives the absorbance spectra of single layer of SiO_2 and TiO_2 thin films, which are prepared using sol-gel and spin coating techniques. These thin films have decreasing the absorption in the ultraviolet region (at 340 nm-SiO_2 and 356 nm-TiO_2). Slightly, the TiO_2 deposition depicted increased absorbance as compared to SiO_2 thin film. These findings show that the created thin film can function when exposed to both UV and visible light, which is agreement with the reported literature [23-26].

Florescence spectral studies: The excitation wavelength at 380 nm, the fluorescence spectra of both thin films showed the highest emission spectrum in between 733-798 nm indicates the substrate, which was used during the testing the samples (Fig. 2). However, the prepared single layer of SiO_2 and TiO_2 thin film showed emission peak at 476 and 475 nm [27,28].

FTIR spectral studies: The Fourier transmission infrared (FTIR) spectra of single layer SiO_2 and TiO_2 coating on glass substrate is depicted in Fig. 3. The prepared sample chemical compositions confirmed the presence of anatase phase (O-Ti-O) at 940 cm^{-1} and asymmetric stretching Si-O-Si vibration modes at 1186 cm^{-1} [27,29]. Also, the peaks at 1379 and 1630 cm^{-1} in TiO_2/SiO_2 thin films are attributed due to the presence of O-H bonds [30], further, the hydroxyl groups appeared around 3400 cm^{-1} because of the surface water molecules [31].

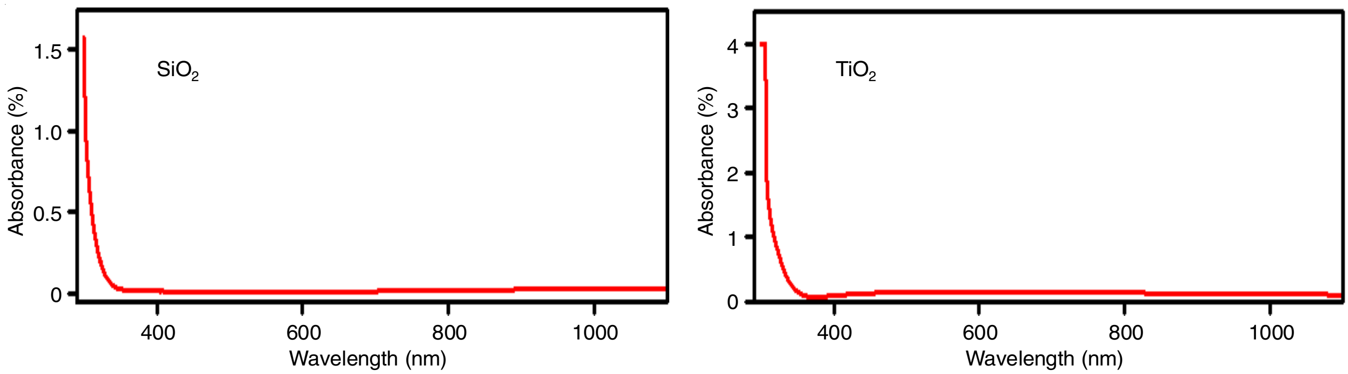

Fig. 1. UV-Visible absorbance spectra of single layer-SiO_2 and TiO_2 thin film

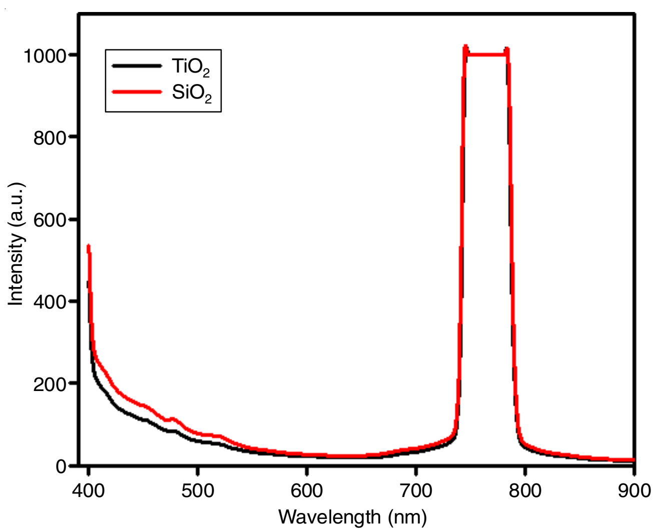

Fig. 2. Fluorescence spectra of single layer-SiO_2 and TiO_2 thin film

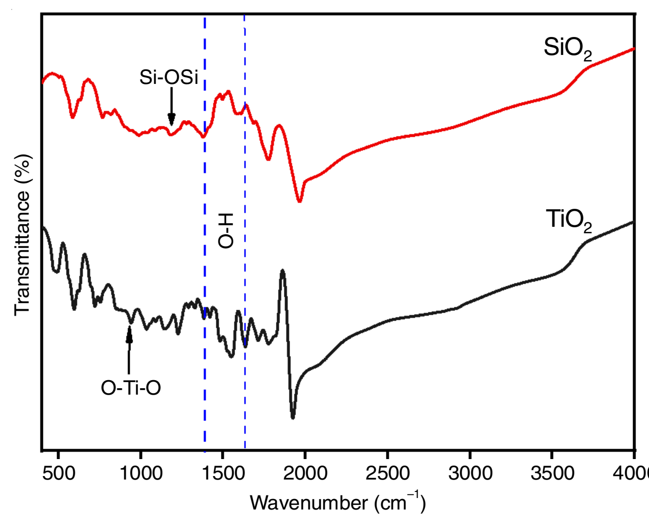

Fig. 3. FTIR transmittance spectra of SiO_2 and TiO_2 thin film

Morphology: Fig. 4a-b shows the morphology of thin films deposited on glass substrates at high magnification of 200 nm and 2 µm. The smooth surface morphological images depict a single layer of SiO_2 and TiO_2 thin film. A single layer of SiO_2 and TiO_2 thin film composes the surface morphological images appear to be smooth, however, some of the amorphous nature particles appeared on the sample surfaces were due to the calcinations process [32-38].

Conclusion

This study describes the sol-gel and spin-coated processes used to produce clear thin films of single-TiO_2 and SiO_2 on glass substrates that have been cleansed using ultrasonically. Thin films were characterized by their optical, functional and morphological properties using UV-vis, fluorescence, FTIR and SEM techniques. The UV-visible absorbance spectra showed the strong absorption in the lower spectral region and TiO_2

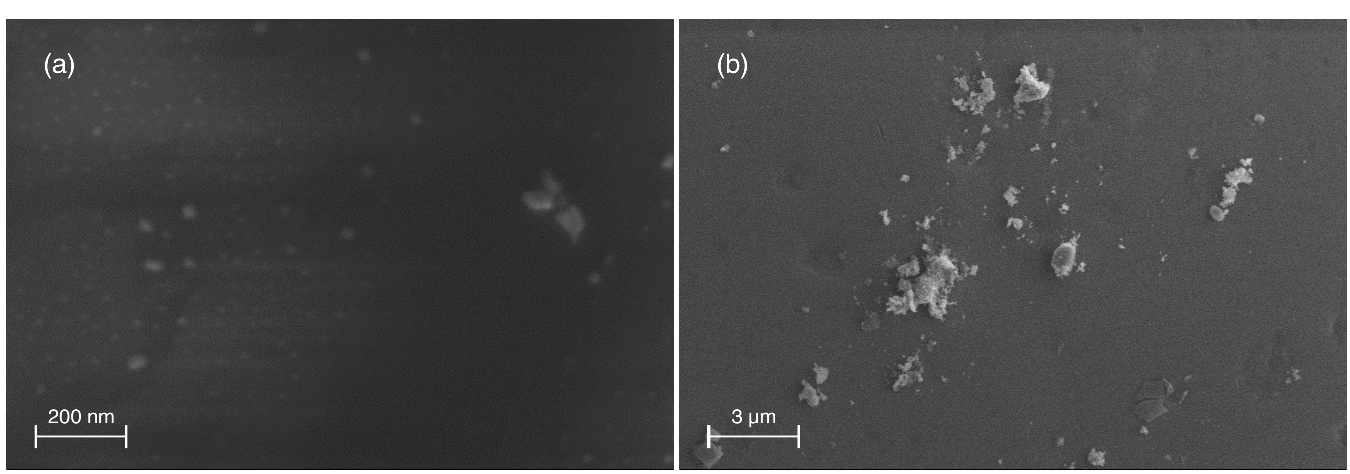

Fig. 4. Surface morphological images of single layer of SiO_2 and TiO_2 thin film

depicted an enhanced absorbance as compared to SiO_2 thin film. The fluorescence spectra of both thin films showed the surface defects and observed the highest emission spectrum in between 733-798 nm. The smooth surface morphological structure was confirmed by SEM analysis. These result demonstrated the successful preparation of the thin films, enhancing their quality and making them suitable for transparent device applications.

ACKNOWLEDGEMENTS

The authors thank Mr. Vincent Sagayaraj, Department of Physics, St. Joseph College (A), Trichy, India for helping in characterizating the materials.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this article.

REFERENCES

1. P.J.D. Whiteside, J.A. Chininis and H.K. Hunt, *Coatings*, **6**, 35 (2016); https://doi.org/10.3390/coatings6030035
2. Z. Hu, F. Huang and Y. Cao, *Small Methods*, **1**, 1700264 (2017); https://doi.org/10.1002/smtd.201700264
3. M.H. Himel, B. Sikder, T. Ahmed and S.M. Choudhury, *Nanoscale Adv.*, **5**, 596 (2023); https://doi.org/10.1039/D2NA00571A
4. G.M. Luz and J.F. Mano, *Philosoph. Trans. A*, **367(1893)**, 1587 (2009); https://doi.org/10.1098/rsta.2009.0007
5. D. Wang, Z. Liu, H. Wang, M. Li, L.J. Guo and C. Zhang, *Nanophotonics*, **12**, 1019 (2023); https://doi.org/10.1515/nanoph-2022-0063
6. O.O. Abegunde, E.T. Akinlabi, O.P. Oladijo, S. Akinlabi and A.U. Ude, *AIMS Mater. Sci.*, **6**, 174 (2019); https://doi.org/10.3934/matersci.2019.2.174
7. A.J. Haider, Z.N. Jameel and I.H.M. Al-Hussaini, *Energy Proc.*, **157**, 17 (2019); https://doi.org/10.1016/j.egypro.2018.11.159
8. R. Li, T. Li and Q. Zhou, *Catalysts*, **10**, 804 (2020); https://doi.org/10.3390/catal10070804
9. X. Kang, S. Liu, Z. Dai, Y. He, X. Song and Z. Tan, *Catalysts*, **9**, 191 (2019); https://doi.org/10.3390/catal9020191
10. I. Ali, M. Suhail, Z.A. Alothman and A. Alwarthan, *RSC Adv.*, **8**, 30125 (2018); https://doi.org/10.1039/C8RA06517A
11. F.M. Fardo, R.S. Ribeiro, J.A. Strauss, J. Nardi, L.C. Ferreira, G. Schmökel, T.M.H. Costa, M.B. Pereira and F. Horowitz, *Appl. Optics*, **59**, 7720 (2020); https://doi.org/10.1364/AO.397484
12. G. Shukla and A. Subramanian, *Appl. Optics*, **59**, 10483 (2020); https://doi.org/10.1364/AO.404553
13. B. Arjun Kumar V. Vetrivelan, G. Ramalingam, A. Manikandan, S. Viswanathan, P. Boomi and G. Ravi, *Physica B: Cond. Matter*, **633**, 413770 (2022). https://doi.org/10.1016/j.physb.2022.413770
14. D.J. Kim, S.H. Hahn, S.H. Oh and E.J. Kim, *Mater. Lett.*, **57**, 355 (2002); https://doi.org/10.1016/S0167-577X(02)00790-5
15. S. Saravanan, R.S. Dubey and Y. Venkatesh, *Mater. Today: Proc.*, **64**, 1666 (2022); https://doi.org/10.1016/j.matpr.2022.04.993
16. R.S. Dubey and S. Saravanan, *Nanosystems: Phys., Chem., Math.*, **13**, 223 (2022); https://doi.org/10.17586/2220-8054-2022-13-2-220-226
17. Y. de Jesús Acosta-Silva, M. Toledano-Ayala, S. Gallardo-Hernández, L.A. Godínez and A. Méndez-López, *Nanomaterials*, **13**, 1403 (2023); https://doi.org/10.3390/nano13081403
18. H.M. Yadav and J.-S. Kim, *J. Mater. Sci.: Mater. Electron.*, **27**, 10082 (2016); https://doi.org/10.1007/s10854-016-5082-4
19. J.B. Chemin, S. Bulou, K. Baba, C. Fontaine, T. Sindzingre, N.D. Boscher and P. Choquet, *Sci. Rep.*, **8**, 9603 (2018); https://doi.org/10.1038/s41598-018-27526-7
20. L. Ye, Y. Zhang, X. Zhang, T. Hu, R. Ji, B. Ding and B. Jiang, *Solar Energy Mater. Solar Cells*, **111**, 160 (2013); https://doi.org/10.1016/j.solmat.2012.12.037
21. A. Fattah-Alhosseini, A.H. Jawad, M. Maaza and K. Babaei, *Surf. Interface*, **16**, 194 (2019); https://doi.org/10.1016/j.surfin.2018.10.005
22. K. Ramakrishnan, V. Gayathri, K. Aravinthkumar, K. Ramachandran, B. Ajitha, M. Rameshbabu, S. Sasiflorence, S. Karazhanov, K. Praba and C.R. Mohan, *Inorg. Chem. Commun.*, **144**, 109842 (2022); https://doi.org/10.1016/j.inoche.2022.109842
23. R.-C. Suciu, M.-C. Rosu, T.-D. Silipas, A.R. Biris, I. Bratu and E. Indrea, *Rev. Roum. Chim.*, **56**, 607 (2011).
24. H. Adullah, D.-H. Kuo, J.-Y. Lee, C.-M. Wu, *Appl. Phys. A*, **122**, 750 (2016); https://doi.org/10.1007/s00339-016-0276-4
25. S. Saravanan and R.S. Dubey, *Roman. J. Inform. Sci. Technol.*, **23**, 105 (2020).
26. J. Wang, R. Qianwen, X. Xu, B. Zhu and W. Zhang, *IOP Conf. Series: Earth Environ. Sci.*, **310**, 042029 (2019); https://doi.org/10.1088/1755-1315/310/4/042029
27. J. Wang, Q. Ran, X. Xu, B. Zhu and W. Zhang, *IOP Conf. Series: Earth Environ. Sci.*, **310**, 042029 (2019); https://doi.org/10.1088/1755-1315/310/4/042029
28. G.A. Nowsherwan, A. Zaib, A.A. Shah, M. Khan, A. Shakoor, S.N.S. Bukhari, M. Riaz, S.S. Hussain, M.A. Shar and A. Alhazaa, *Energies*, **16**, 900 (2023); https://doi.org/10.3390/en16020900
29. R.A. Aziz and I. Sopyan, *Indian J. Chem.*, **48A**, 951 (2009).
30. F. Farzaneh and L. J. Fourozune, *Bull. Mater. Sci.*, **37**, 1 (2014); https://doi.org/10.1007/s12034-014-0622-0
31. A. Nilchi, S.R. Garmarodi and S.J. Darzi, *Sep. Sci. Technol.*, **45**, 801 (2010); https://doi.org/10.1080/01496390903562332
32. S. Saravanan, R.S. Dubey and P.S. Subbarao, *Nanomater. Energy*, **12**, 44 (2023); https://doi.org/10.1680/jnaen.22.00039
33. R. Ayouchi, L.S. de Melo, S.R. Bhattacharyya, N. Bundaleski, O. Teodoro, L. Santos and R. Schwarz, *Proc. Technol.*, **17**, 303 (2014); https://doi.org/10.1016/j.protcy.2014.10.241
34. M. Ciprian, E. Alexandru, and D. Anca, *Bull. Mater. Sci.*, **40**, 473 (2017); https://doi.org/10.1007/s12034-017-1398-9
35. D.C. Halin, M.M.A.B. Abdullah, N. Mahmed, S.N.A. Abdul Malek, P. Vizureanu and A.W. Azhari, *IOP Conf. Series: Mater. Sci. Eng.*, **209**, 012002-1-8 (2017); https://doi.org/10.1088/1757-899X/209/1/012002
36. A.K.N. Fadzeelah, M.Z. Ramli, N. Amri and H.I. Maarof, IEEE Symposium on Humanities, Science and Engineering Research, pp. 52-57 (2012); https://doi.org/10.1109/SHUSER.2012.6268887
37. T. Touam, L. Znaidi, D. Vrel, I. N. Kuzntsova, O. Brinza, A. Fischer and A. Boudrioua, *Coatings*, **3**, 49 (2013); https://doi.org/10.3390/coatings3010049
38. B.R. Bricchi, M. Sygletou, L. Ornago, G. Terraneo, C. Mancarella, F. Bisio, L. Stasi, F. Rusconi, E. Mogni, M. Ghidelli, P. Biagioni and A.L. Bassi, *Mater. Adv.*, **2**, 7064 (2021); https://doi.org/10.1039/D1MA00584G