

Mini Review

Review on Recent Developments in Coating Procedure by Using Direct Current (DC) Sputtering for Optical Medical Applications

Akram Jassim Jawad^{a,b,*}

^aUniversity of Babylon, College of Materials Engineering, Department of Polymer and Petrochemicals Industrials Engineering, Hilla, Iraq

^bQueen Mary University of London, School of Engineering and Materials Science, London, UK

(received October 21, 2020; revised February 16, 2021; accepted August 12, 2021)

Abstract. Nano thin films and nano coating have been applied in different fields in health care system because of their higher antiviral properties. Additionally, as the world have suffered since December 2019 from Covid-19 situation, different scientists and industrials people have tried to apply nano antiviral films and coatings in our daily life. In this mini review, nano thin film coating procedure by DC sputtering technique has been reviewed, investigated and evaluated by using different materials and device parameters in recent years. This report focuses on device factors that affect the thickness of nano-thin films for optical and optic electric applications. These parameters including time, temperature, power, pressure and flow rate of gases. The review provides more understanding meaning of the coating procedure by DC sputtering process.

Keywords: direct current (DC) sputtering, coating, nano thickness, films, antiviral properties, optic electric applications

Introduction

Nano film thickness of metals coating on polymer substrate plays an important issue in direct current (DC) sputtering techniques for many technical advance applications, such as optical coatings, biomedical, surface and electronic applications (Dornhof *et al.*, 2018; Kylián *et al.*, 2014; Beyene *et al.*, 2011). For instance, nano thin film and coatings based on Cu can be an important barrier against spreading Covid-19 (Jawad, 2021). However, the antibacterial ability of nano thickness Cu film manufactured by DC sputtering was investigated to be higher more than three times (Ehiasarian *et al.*, 2012). Thickness can affect coating properties such as shielding against electromagnetic, ultraviolet (UV) resistance, electrical conductivity, antibacterial ability reported by (Liu *et al.*, 2017; Jia *et al.*, 2014), while Kylián *et al.* (2014) illustrates an example of the deposition of nano thickness of Cu thin film coatings on polymer substrate. The relationship between the Argon plasma and surface bonding of treating the Ajinomoto build-up film (ABF) and surface studies by (Oh *et al.*, 2016). Zakharova *et al.* (2012) investigated the effect of Cu coating nano-thickness on

transparency ability for the visible light, it shows that there are transparency and reflection enhancement of about 60% and 84%, respectively (Zakharov *et al.*, 2012).

There are many factors in the nano-film coating procedure in DC sputtering that can affect the thickness and coating related properties which including optical and optic-electric properties (Oh *et al.*, 2016; Kylián *et al.*, 2014; Jia *et al.*, 2014). These parameters may belong into materials characteristics that used in the coating process, such as type and compositions of target and substrate materials and present in progressing and has many different disciplines sector studies. Alternatively, the another factors may belong to device ability and designs, for instance the distance and angle between substrate and target, voltage and current capacity, cooling and gas systems efficiency and chamber pressure permeability. This group has been more opportunity to achieve development in the coating procedure by DC sputtering, especially for optical properties. These characteristics including transmittance, reflectance and absorption spectra of ultra volte and visible light (UV-VIS) in wavelength about (200-800) nm that have been investigated in recent works (Liu *et al.*, 2017; Beyene *et al.*, 2011).

*Author for correspondence;

E-mail:akrammaterials4@gmail.com

The objective is to evaluate and analyze the recent developments in parameters that affect the nano-film coating procedure by DC sputtering technique. However, it will be more focused on time, temperature, pressure, power and flow rate factors than others because they have more attention in recent years and they have more significant role in that procedure. Moreover, the attention will be more on the effect of these factors in the sense of optical and electrical properties, especially the optic electric characteristics for electrical applications. To achieve by this report to organized into different parts namely methods, procedures, results and discussions and conclusion. Firstly, a simple explanation of standard DC sputtering device components will be introduced in the methods section. Then, clarifying in detail the coating procedure by DC sputtering will be explained in the procedure section. After that, the more recent development and results of time, temperature, pressure, power and flow rate factors on the optical and related electrical properties with evaluation and analysis will be selected and discussed in the results and discussion section.

Materials and Methods

The main components of DC sputtering technique including the main device, pump and gas system (Wang and Chung, 2013). The main device contains all the electrical parts such as the voltage system to generate high voltage current, water system for cooling DC sputtering parts during the coating process. Also, the heating system control of substrate temperature, the chamber that including target and substrate and pipe line nets to vacuum and inject an inert gas from the outer bottle, usually argon or nitrogen gas, into the chamber under controlling pressure by the pump. There are different collections of target and substrate configuration inside the chamber sputtering. Some designs have that in a vertical, horizontal, or angular level, as shown in Fig. 1 and 2 (Wang and Chung, 2013). In addition to that, in some, there is more than one target material to produce different composites materials.

There are different coating procedures by DC sputtering that depend on the device type, organization and automatic operation level that have been written in the last few years (Liu *et al.*, 2017; Oh *et al.*, 2016; Wang and Chung, 2013). Gobbl *et al.* (2013) presented a simple procedure of nano-film coating by horizontal and vertical organization DC sputtering with comprehensive details of parameters, as shown in Fig. 3 (Wang

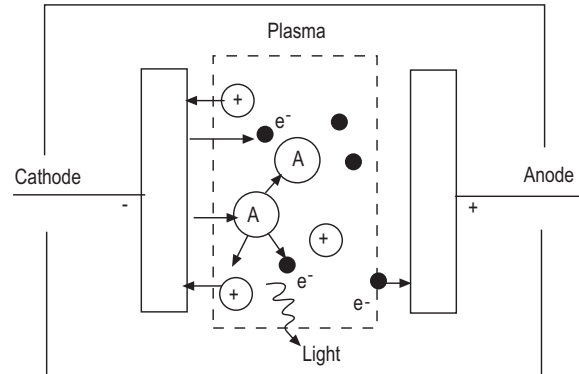


Fig. 1. A simple schematic of the plasma formation principle between cathode and anode (Wang and Chung, 2013).

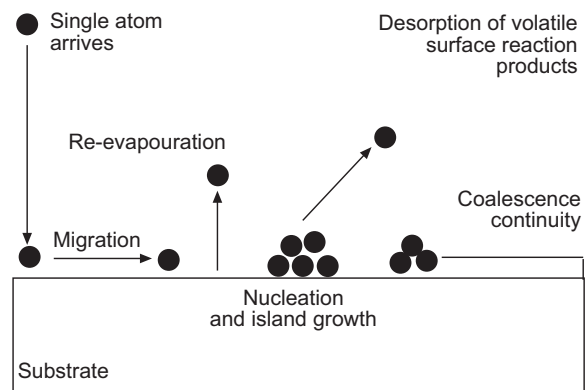


Fig. 2. A schematic of the main stages to format nano-films by DC sputtering (Wang and Chung, 2013).

and Chung, 2013). This procedure contains many steps and these steps make the main differences between different procedures. However, these differences could be eliminated by making a general development in those parameters, such as generalization of substrate temperature which may produce similar procedures for the heating process for different coating materials.

There is a wide range of parameters that control the coating process in DC sputtering which lead to make this technique quiet complex. These parameters including materials properties, which maybe have more ability for developing process and device factors, which has limited improvement ability. It seems that the enhancement in DC procedure could achieve in the materials characterizes because it has more flexibility to design and selection materials for any possible and appropriate

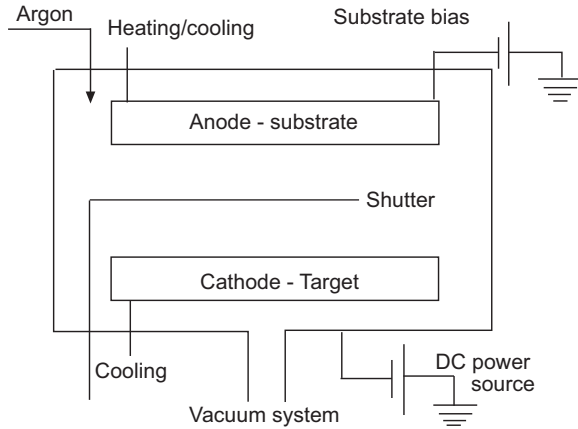


Fig. 3. A schematic of DC sputtering chamber with the main and important factors that effect on the process (Wang and Chung, 2013).

application. On the other hand, if device factors need to be in a line of developing process of coating procedure, it might need more time and more advanced technology, as well as changes in design and configuration of devices, which in fact depend on materials choosing. Therefore, it is supposed that target, substrate temperature, compositions and type of substrate, and target materials may have more attention in the next few years. However, the current research focus on voltage, current, gas pressure, the distance between target and substrate, gas flow rate and gas content.

Results and Discussion

Sputtering time is a challenging part of the developing process in DC sputtering procedure. There are a number of studies that focused on this factor to make the technique more economical and applicable in industrial fields. For example, Zhanga *et al.* (2016) focus on the effect of sputtering time parameter on nano shell optical properties of TiO₂/ZnO that used in solar cell applications (Zhang *et al.*, 2016). Figure 4 shows the relationship between UV-VIS absorption of nanoshell MS ZnO on Rutile substrate and DC sputtering times for wavelength range between (200-700) nm (Zhang *et al.*, 2016). The results prove that there is an enhancement in the optical properties with short sputtering times, about 3-15 min. That is mean there is high ability to develop DC sputtering procedure with shorter sputtering times in the next few years to be applicable in industrials sectors. In addition to that, Aragóna *et al.* (2017) characterize

films of SnO₂ by DC sputtering at different sputtering times in terms of electrical and morphological properties (Aragón *et al.*, 2017). This gives a wide view of how sputtering times effect not just on optical characterization but also on different properties.

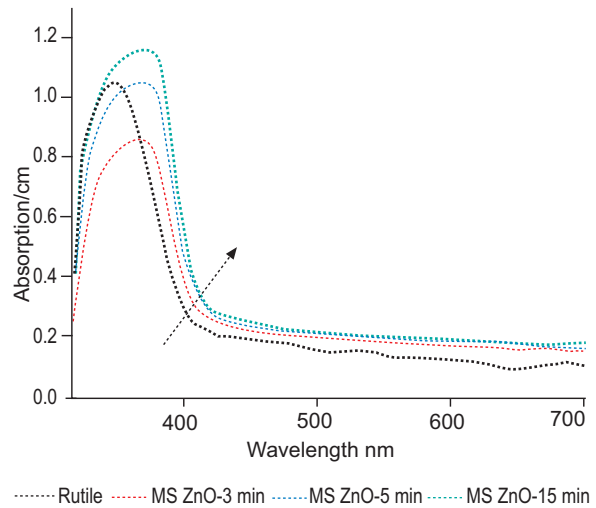


Fig. 4. The relationship between UV-VIS absorption and sputtering times (3-15) min, for wavelength range between (200-700) nm (Zhang *et al.*, 2016).

The operating temperature factor has a significant role in the approximated proposed age of devices, especially in the highly advanced techniques that are operated in a high environment of temperature such as DC sputtering. As a result of that, many authors investigate the enhancement in the temperature factor to minimize it as much as possible which leads to the high quality of nanofilms coating and shorter time of device maintenance. Park *et al.* (2012) studied the impact of temperature of substrate on the DC sputtering procedure of Ga-doped ZnO nano-films coating for electrical uses (Park *et al.*, 2012). Figure 5 shows the relationship between transmittance spectra of UV-VIS between (200-800) nm of Ga-doped ZnO nano-films with different substrate temperatures (25, 75, 150 and 230) °C (Park *et al.*, 2012). The results provide high conservation of the consumption energy approach by minimizing substrate temperature which was 75 °C as an optimal operation temperature, as well as decreasing maintenance time of high temperature problems. Moreover, the electrical efficiency of these coating in electrical applications like in sollar cells will increase compared with

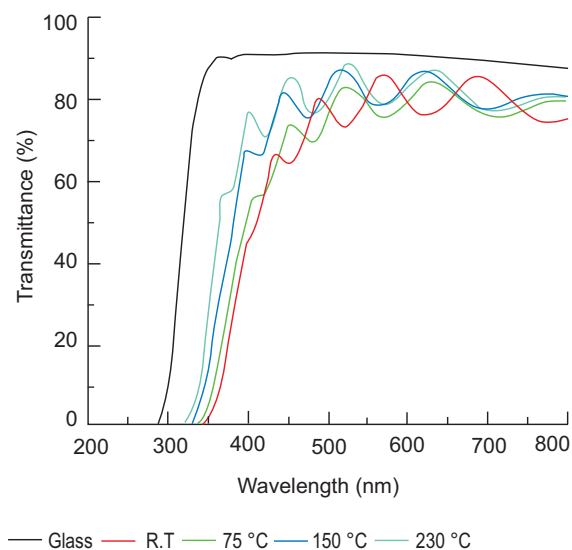


Fig. 5. The relationship between transmittance spectra of UV-VIS between (200-800) nm of Ga-doped ZnO nano-films with different substrate temperature (25, 75, 150, 230) °C (Park *et al.*, 2012).

traditional coating as a results of high transmittance ability.

The pressure factor considers an important factor in any procedure of advanced technology such as in DC sputtering because of a critical its effect on the price, quality and safety of the devices. Since, DC sputtering technique was discovered, there have been many redesigning, re-planning and studies of coating procedures by DC sputtering technique to minimize and manage the high pressure uses, especially in the last few years. For example, Hsua *et al.* (2013) studied the effect the pressure in DC procedure on the optical characteristics of Nano thin films for electrical applications (Hsu *et al.*, 2013). Figure 6 illustrates the transmittance spectra of UV-VIS radiation in the range of wavelength (200-900) nm of Al-Y Co doped ZnO nano-films at different ranges of DC sputtering pressure (5, 7, 11, 13) mTorr (Hsu *et al.*, 2013). This figure provides a significant decrease in the pressure range in DC sputtering procedure that might be applicable in a wide range of industries fields, especially electric and optic-electric applications and products. Moreover, it seems that in the next few years there are high opportunities to manufacture small devices of DC sputtering at lower prices compared with the current one.

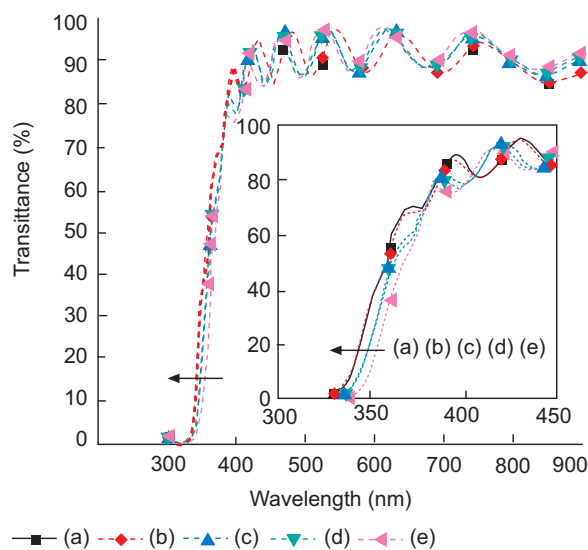


Fig. 6. Transmittance spectra of UV-VIS radiation for wavelength (200-900) nm of Al-Y Co doped ZnO nano thin films at different range of DC sputtering pressure (5, 7, 11, 13) mTorr (Hsu *et al.*, 2013).

One of the most important factors is the mixture and content of gases in sputtering chamber, especially oxygen percentage. Consequently, studying ratios of oxygen in sputtering chamber has been achieved in a number of experimental studies under different conditions due to the effect of oxygen ratio on the safety and quality of Nano thin films. For instance, ABE *et al.* (2005) investigated the effect of oxygen content in Argon based gas to fabricate Nano-thin films of Amorphous indium tungsten oxide and studied its optical related properties (Abe *et al.*, 2005). Figure 7 represents the spectra of transmittance and reflectance of UV-VIS radiation for wavelength between 200 nm and 2600 nm of Amorphous indium tungsten oxide nano-film at a different range of oxygen ratios inflow of sputtering gas (0.5, 1, 1.5, 2) % (Abe *et al.*, 2005). This figure shows there is an enhancement in the transmittance and reflectance of prepared nano thin films as the oxygen ratios in sputtering gas decreasing.

Power consumption plays a crucial factor in success opportunities in any technical process, especially with high consumption advanced technology like DC sputtering. Therefore, there are many attempts in the last few years that have been tried about effect power factor on different properties of nano-films, in particular

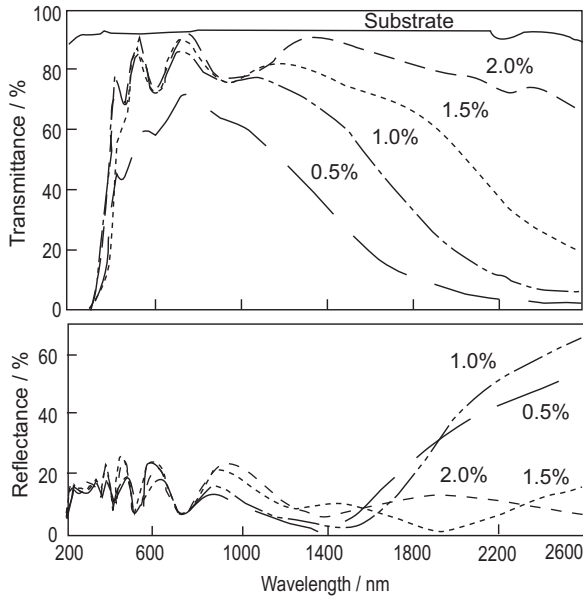


Fig. 7. Spectra of transmittance and reflectance of UV-VIS radiation for wavelength between 200 nm and 2600 nm of Amorphous IWO nano films at different range of oxygen ratios in flow of sputtering gas (0.5, 1, 1.5, 2) % (Abe *et al.*, 2005).

optical properties. For example, Rashida *et al.* (2019) study the effect of power factor on optical characteristics of molybdenum nano-films for electrical applications (Rashid *et al.*, 2019). Figure 8 illustrates the relationship between the reflectance spectra of UV-VIS radiation and DC sputtering power in the range of 100, 150 and 200 watts, for wavelength between (200-150) nm (Rashid *et al.*, 2019). The obtained results provide a significant improvement in energy consumption of coating by DC procedure because there are more acceptable optical properties in lower DC sputtering power compared with higher values, especially for optic-electric properties such as anti-reflectance coating (ARC) in solar cells applications. Other findings were obtained of the effect DC sputtering power on the transmittance property (Jin-Hua *et al.*, 2015). Figure 9 represents the transmittance UV-VIS spectra of Indium-tin oxide nano-films with different range of DC power (50, 65, 80, 95 and 110) watts for wavelength between (300-800) nm (Jin-Hua *et al.*, 2015). These results give an opportunity to make DC sputtering more economic in the next few years to be used in a wide range of daily and high use products.

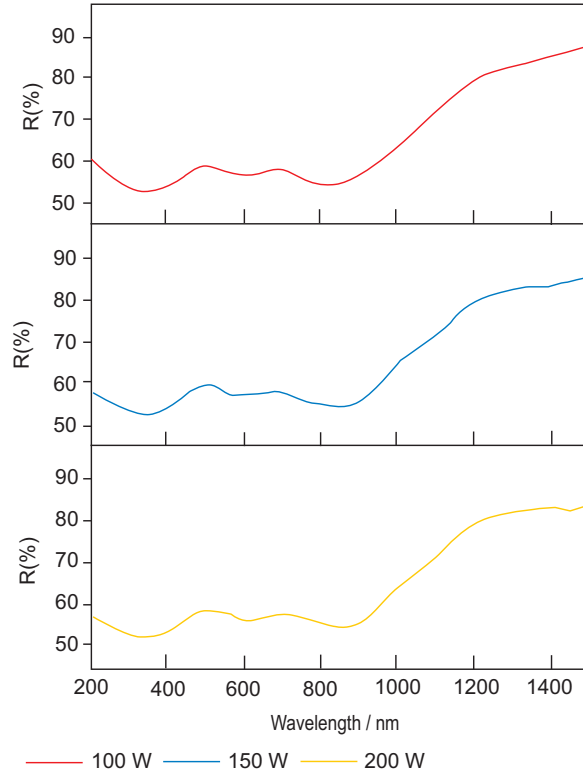


Fig. 8. Reflectance of UV-VIS spectra of molybdenum nano-film at different values of DC sputtering power (100, 150, 200) watts (Rashid *et al.*, 2019).

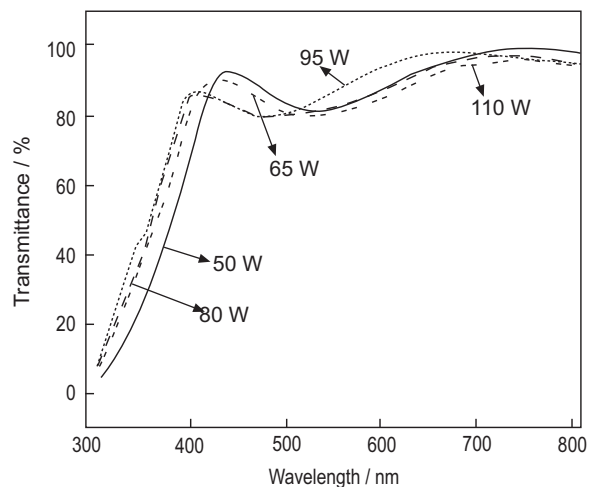


Fig. 9. Transmittance spectra of UV-VIS radiation for (300-800) nm of IWO nano-film at different values of DC sputtering power (50, 65, 80, 95, 110) watts (Jin-Hua *et al.*, 2015).

Conclusion

In summary, the recent developments of parameters in the last few years that effect on coating procedure by DC sputtering has been presented, evaluated and discussed. It has found that there is a significant enhancement in the sputtering time to be shorter which enables the coating process to be more effective and efficient. The consumption of energy in terms of power and substrate temperature has been developed to be at a lower level in recent years compared with the old DC sputtering procedure when it is started to use. Also, investigation of the effect of gases content in the sputtering chamber has been reported especially for oxygen ratios, which gives a high indicator for optimum quality of nano-thin films in low percentage of oxygen in Argon based gases. Finally, the relationship between pressure factor and optical properties has been reviewed in the sense the recent developments and its effect on optic-electric properties. These improvements in that parameters might give a chance to produce high quantity and quality in small size space with lower prices. Therefore, these findings may encourage to make DC sputtering in a simple procedure to be more familiar in all educational, researcher and industrial sectors.

References

- Abe, Y., Ishiyama, N., Kuno, H., Adachi, K. 2005. Amorphous indium tungsten oxide films prepared by DC magnetron sputtering. *Journal of Materials Science*, **40**: 1611-1614.
- Aragón, F.H., Aquino, J.C.R., Gomes, N.C.S., Ardisson, J.D., Da Silva, S.W., Pacheco-Salazar, D.G., Coaquira, J.A.H. 2017. Characterization of polycrystalline SnO₂ films deposited by DC sputtering technique with potential for technological applications. *Journal of the European Ceramic Society*, **37**: 3375-3380.
- Beyene, H.T., Tichelaar, F.D., Verheijen, M.A., Van de Sanden, M.C.M., Creatore, M. 2011. Plasma-assisted deposition of Au/SiO₂ multi layers as surface plasmon resonance based red-coloured coatings. *Plasmonics*, **6**: 255-260.
- Dornhof, J., Urban, G.A., Kieninger, J. 2018. Deposition of copper nano films by surface-limited redox replacement of under potentially deposited lead on polycrystalline gold. *Journal of the Electrochemical Society*, **166**: D3001.
- Ehiasarian, A., Pulgarin, C., Kiwi, J. 2012. Inactivation of bacteria under visible light and in the dark by Cu films. Advantages of Cu-HIPIMS-sputtered films. *Environmental Science and Pollution Research*, **19**: 3791-3797.
- Hsu, F.H., Wang, N.F., Tsai, Y.Z., Chuang, M.C., Cheng, Y.S., Houg, M.P. 2013. Study of working pressure on the opto electrical properties of Al-Y Co doped ZnO thin film deposited using DC magnetron sputtering for solar cell applications. *Applied Surface Science*, **280**: 104-108.
- Jawad, A. 2021. A review of antiviral polymer nano composites (PNC) in biomedical applications; corona virus pandemic situation. *Epidemiology International Journal*, **5**: 1-8.
- Jia, Z.N., Hao, C.Z., Yang, Y.L. 2014. Tribological performance of hybrid PTFE/serpentine composites reinforced with nano particles. *Tribology-Materials, Surfaces and Interfaces*, **8**: 139-145.
- Jin-Hua, G., Jia-Le, S., Jiu-Xiu, W., Ya-Yang, F., Xiao-Yong, G., Jing-Xiao, L. 2015. Indium-tin oxide films obtained by DC magnetron sputtering for improved Si hetero junction solar cell applications. *Chinese Physics B*, **24**: 117703.
- Kylián, O., Kratochvíl, J., Hanuš, J., Polonskyi, O., Solař, P., Biederman, H. 2014. Fabrication of Cu nanoclusters and their use for production of Cu plasma polymer nano composite thin-films. *Thin Solid Films*, **550**: 46-52.
- Liu, Y., Leng, J., Wu, Q., Zhang, S., Teng, X. 2017. Investigation on the properties of nano copper matrix composite via vacuum arc melting method. *Materials Research Express*, **4**: 106512.
- Oh, Y., Kim, E.J., Kim, Y., Choi, K., Han, W.B., Kim, H.S., Yoon, C.S. 2016. Adhesion of sputter deposited Cu/Ti film on plasma-treated polymer substrate. *Thin Solid Films*, **600**: 90-97.
- Park, J.H., Shin, B.K., Moon, H.M., Lee, M.J., Park, K.I., Ahn, K.J., Lee, W., Myoung, J.M. 2012. Effect of the substrate temperature on the properties of Ga-doped ZnO films for photo voltaic cell applications deposited by a pulsed DC magnetron sputtering with a rotating cylindrical target. *Vacuum*, **86**: 1423-1427.
- Rashid, H., Rahman, K.S., Hossain, M.I., Nasser, A.A., Alharbi, F.H., Akhtaruzzaman, M., Amin, N. 2019. Physical and electrical properties of molybdenum thin films grown by DC magnetron sputtering for photovoltaic application. *Results in Physics*, **14**: 102515.
- Wang, Q.J., Chung, Y.W. 2013. *Encyclopedia of Tribology* (eds. 1), PPLI, 4139, Springer US, USA.
- Zakharov, A.N., Kovsharov, N.F., Oskomov, K.V., Rabotkin, S.V., Solovyev, A.A., Sochugov, N.S. 2012. Properties of low emission coatings based on Ag and Cu deposited on polymer film by magnetron sputtering. *Inorganic Materials: Applied Research*, **3**: 433-439.
- Zhang, Z., Hu, Y., Qin, F., Ding, Y. 2016. DC sputtering assisted nano branched core-shell TiO₂/ZnO electrodes for application in dye-sensitized solar cells. *Applied Surface Science*, **376**: 10-15.