PREDICTION OF SiO₂ NANO COATING PROPERTIES USING FUZZY LOGIC

Antons Stekleins, Eriks Gerins & Artis Kromanis

This Publication has to be referred as: Stekleins, A[ntons]; Gerins, E[riks] & Kromanis, A[rtis] (2017). Prediction of SiO₂ Nano Coating Properties Using Fuzzy Logic, Proceedings of the 28th DAAAM International Symposium, pp.0654-0660, B. Katalinic (Ed.), Published by DAAAM International, ISBN 978-3-902734-11-2, ISSN 1726-9679, Vienna, Austria

DOI: 10.2507/28th.daaam.proceedings.092

Abstract

The paper analyses SiO₂ vacuum nano coating technological process and its influence on coating quality and properties. Use of fuzzy logic is proposed to develop a process prediction models for vacuum coating. Several experiments were designed and conducted using UV80 laboratory vacuum system, wherein SiO₂ coating light transmission coefficient and thickness were measured. SiO₂ nano coating light transmission and thickness predictions models were designed using fuzzy logic techniques. After preliminary analysis it was concluded that models developed by fuzzy logic have high accuracy and can be used to predict SiO₂ vacuum nano coating properties if a leak in vacuum system appears during technological process, thus enabling continuation of the technological process as long as coating properties will match selected criteria.

Keywords: SiO₂; vacuum coating; fuzzy logic; prediction model; coating deposition

1. Introduction

Nowadays nano coatings are one of the most commonly used and desired product in vacuum field, which can be applied onto webs, films and foils. For example, in SiO₂ vacuum nano coating technology a magnetron sputtering is used and SiO₂ coating itself is unique and demanded coating due to its properties. Thin layers having high insulation resistance are required for many applications in electronics and in sensor and photovoltaic technology [2]. SiO₂ is one of these materials. These applications include gate oxide layers in microelectronics (which are only a few nanometers thick), insulating layers in sensor applications (for which higher dielectric strengths can be required) and insulating layers in photovoltaic technology (for which the requirements on dielectric strength are lower) [2]. Therefore, it is essential to maintain required coating technological process parameters to provide good product quality. System leakage is one of the main problems we encountered with during SiO₂ coating process. Pressure deviations, process parameter changes and leakage can damage the coating, its quality and properties. Therefore, it is necessary to establish models, which can be used to predict vacuum nano coating properties when there is a leakage in vacuum system. Such models would help to evaluate SiO₂ coating sputtering process condition and predict its output parameters (light transmission coefficient and

thickness). In this study models were developed using fuzzy logic method. Fuzzy set theory which formed the basis of fuzzy logic, as an alternative to classical set theory, was presented by L.A. Zadeh [1]. In the fuzzy set theory, the transition between membership to non-membership is done progressively [1].

Unlike Boolean Logic fuzzy logic was designed to reproduce human thinking technique using mathematical approach [1, 5]. This particular approach helps to visualize and predict possible output data variables depending on the input data changes [3, 7, 6]. Several SiO₂ experiments were designed and conducted, a light transmission coefficient and thickness were measured for each coating sample. Using fuzzy logic method thickness and light transmission coefficient models were developed and compared with measured values.

2. Design of SiO₂ coating experiment

Experiments to develop prediction models were carried out at a laboratory vacuum machine UV80 for coating webs and films [8]. Silicon reactive sputtering was selected for the experiments, where SiO₂ coating was applied onto polyethylene terephthalate (PET) film. For the process power supply (8kW), argon flow 75 sccm, variable oxygen and airflows were used. Main idea of the experiment was to change airflow quantity thus simulating leak condition, to verify coating quality, i.e. measure its thickness and a light transmission coefficient. After conducting SiO₂ vacuum coating experiments samples were verified and measured. Measured results are given in table 1.

No.	O ₂ , sccm	Air, sccm	d (thickness, nm)	T (transmission coefficient, %)
1	0	70	142.1	86.64
2	0	65	133	86.49
3	0	55	128.5	87.54
4	0	50	121.3	88.36
5	7	45	115.2	89.35
6	17	40	110.7	89.45
7	20	35	109.8	89.19
8	25	30	112.8	87.66
9	30	25	11.6	87.55
10	41	15	119.9	86.81
11	50	5	126	85.33
12	52	0	130.5	83.98

Table 1. Technological parameters and the results of SiO₂ coating samples

Coating sample measurement was performed on spectrophotometer MC 122 for light transmission coefficient calculation and FILMETRICS F20-UV machine to determine coating thickness. SiO₂ coating light transmission should not be less than 88% to match the requirements. Results showed that in leak situation under certain circumstances coating light transmission property does not match 88% boundary. After coating visual verification it was concluded that SiO₂ coated samples No. 4, 5, 6, and 7 are pure, clean and doesn't have any browning signs, thus visual coating quality matches the desired requirements.

3. Design of prediction models using Fuzzy Logic

One of the main reasons of the research is to develop prediction models to control SiO₂ coating light transmission coefficient and thickness under leak circumstances. Developed prediction models can be implemented in vacuum coating sputtering laboratories or factories. In the beginning input values were defined, then the fuzzification was performed or in other words fuzzy logic was used [4]. The next step included generation of output values according to the defined fuzzy rules previously defined in the database [4]. After fuzzy model was developed, a defuzzification we performed in order to obtain 3D output parameter plot.

Fuzzy modelling was performed using fuzzyTECH 8.30b Professional Demo software. To develop fuzzy logic model two input variables were used: O₂ flow rate and air flow rate, while output variables were coating light transmission coefficient (T) and thickness (d). The following model shows relationship between input data, output data and rule block (see figures 1 and 2).

Fig. 1. Light transmission coefficient fuzzy model

Fig. 2. SiO2 nano coating thickness fuzzy model

After fuzzy logic model development it was necessary to define membership functions to all input and output parameters and create rule block definitions between technological and output parameters. Logic variables have truth-values that lies in range between 0 and 1. Membership functions for input and output parameters were developed based on the results from experiment conducted and described, thus these results are considered as preliminary result database which is shown in table 1.

For the airflow five membership functions were selected that are as follows (shown at figure 3): very small (12 sccm); small (24 sccm); medium (36 sccm); big (48 sccm); very big (60 sccm).

Fig. 3. Five membership functions for air flow rate

Fig. 4. Five membership functions for O2 flow rate

For oxygen flow rate (O2) five membership functions were selected that are as follows (shown at figure 4): very small (10 sccm); small (20 sccm); medium (30 sccm); big (40 sccm); very big (52 sccm).

Similar fuzzification procedure was made for thickness and light transmission coefficient (shown at figure 5). For light transmission coefficient five membership functions were selected that are as follows: very small (84, 5%); small (86%); medium (87%); big (88.5%); very big (90%).

Fig. 5. Five light transmission membership functions

For thickness were selected five membership functions, as follows (shown at figure 6): very small (113 nm); small (119 nm); medium (126 nm); big (133 nm); very big (142 nm).

Fig. 6. Five thickness membership functions

The division created by membership function is sufficient to set up a full-fledged light transmission coefficient and thickness fuzzy logic model. Therefore, it is necessary to set a correlation between input and output data using fuzzy rule block, where a database of rules were formed. Since fuzzy logic is based on humanlike operating principles, thus the rule block operates by means of “IF”, “THEN”. In table 2 a rule block of light transmittance is shown. Rule block database is design based on the obtained and measured SiO₂ coating sputtering experiment results, which are shown in table 1.

Nr.	IF		THEN
	Air flow	O ₂ flow	Light transmission coefficient
1	Very small	Big	Small
2	Very small	Big	Very small
3	Very small	Very big	Very small
4	Very small	Small	big
5	Very small	Medium	medium
6	Small	Small	Very big
7	Small	Medium	Big
8	Small	Very big	Big
9	Small	Very big	medium
10	Medium	Very small	Big
11	Medium	Very small	Very big
12	Medium	Very small	Medium
13	Medium	Small	Big
14	Medium	Small	Very big
15	Medium	Medium	Medium
16	Big	Very small	Big
17	Big	Very small	Medium
18	Big	Small	Very big
19	Big	Small	Big
20	Very big	Very small	Small
21	Very big	Very small	Medium
22	Very big	Very small	Big

Table 2. Fuzzy logic rule block of light transmission

4. Data defuzzification

Next step after development of the rule block was data defuzzification, where linguistic values are transferred into numerical values and prediction models are graphically displayed in 3D and 2D plots. Light transmission coefficient 3D prediction fuzzy model is shown in figure 7. Thickness 3D prediction fuzzy model is shown in figure 8. In additional window “Watch: Interactive debug mode” input values can be changed to obtain output values, thus oxygen and air flows can be changed and after data defuzzification thickness and light transmission coefficient values can be obtained.

Fig. 7. Light transmission (T) prediction model 3D plot

Fig. 8. Coating thickness (d) prediction model 3D plot

One particular example is showed in Fig. 8, where in the interactive debug mode the airflow is to 35 sccm and O2 flow is 20 sccm, thus data defuzzification calculates light transmission coefficient 88.71%. Same principle applies to nano coating thickness prediction model at figure 9, where airflow is 23 sccm and oxygen flow is 30 sccm and thickness prediction model result is 113 nm. Developed fuzzy logic models must be compared with experimental measured results. Therefore, several samples were selected from table 1 and combined with fuzzy logic generated predicted values changing gas flows (see figure 9, 10).

Fig. 9. Measured and predicted nano coating thickness (d)

Fig. 10. Measured and predicted light transmission coefficient (T)

Vacuum SiO₂ nano coating light transmission was evaluated as the main criteria, which it must meet. Therefore, if the leak appears it is necessary to follow light transmission prediction model in order to secure determined coating quality. Measured and fuzzy logic calculated light transmission and thickness results are shown in figures 9 and 10. Calculated light transmission results show high accuracy of 93.9% at fourth sample and highest value of 99.8% at eight sample. Calculated nano coating thickness results show high accuracy of 90% at fourth sample and highest value of 99.5% at eight sample. Light transmission model has high accuracy and can be used for vacuum nano coating properties prediction. Thickness model showed accuracy deviation is from 90% up to 99.5%. Thus, thickness model accuracy can be considered as decently high. Both models can be used to predict nano coating properties if a leak in vacuum system appears during technological process. As for the priority, the light transmission model remains as main.

5. Conclusion

This paper, investigate leak influence on coating quality and its properties during vacuum coating sputtering technological process. Experiment results and developed fuzzy logic models show that it is possible to predict vacuum nano coating light transmission coefficient and thickness under leak conditions with decently high accuracy. Experiments showed that light transmission accuracy diapason is from 93.9% up to 99.8% and thickness accuracy diapason is from 90% up to 99.5%. Fuzzy logic developed models present reliable accuracy, thus can be used in laboratory or vacuum coating sputtering facilities to predict coating properties and quality in leak conditions. Prediction models can save time, material and allow coating process to continue. Fuzzy model development is a complicated task, where precise definition of membership functions and rules are important.

6. References

- [1] Ata, S. & Dincer, K. (2017). Fuzzy logic modeling of performance proton exchange membrane fuel cell with spin method coated with carbon nanotube”, *International Journal of Hydrogen Energy*, Vol. 42, 2017, pp. 2626-2635., <https://doi.org/10.1016/j.ijhydene.2016.04.134>
- [2] Frach, P., Bartzsch, H., Glöß, D., Fahland, M. & Händel, F. (2008). Electrically insulating Al₂O₃ and SiO₂ films for sensor and photovoltaic applications deposited by reactive pulse magnetron sputtering, hollow cathode arc activated deposition and magnetron-PECVD”, *Surface and Coating Technology*, Vol. 202, 2008, pp. 5680–5683., <https://doi.org/10.1016/j.surfcoat.2008.06.043>
- [3] Harun, T., Cemalettin, K., Özer, U. & Seher, A. (2006). FUZZYFCC: Fuzzy logic control of a fluid catalytic cracking unit (FCCU) to improve dynamic performance, *Computers & Chemical Engineering*, Vol. 30/5, 2006, pp. 850-863., <https://doi.org/10.1016/j.compchemeng.2005.12.016>
- [4] Kromanis, A. & Krizbergs, J (2013). Prediction of 3D Surface Roughness Using Regression Analysis and Fuzzy Logic, and their Comparative Analysis, *Proceedings of the 20th International DAAAM Symposium 2009, Vienna, Austria, 25-28 November 2009*, ISSN: 17269679, ISBN: 978-390150970-4, Danube Adria Association for Automation and Manufacturing, DAAAMTop of Form, pp. 803-804.
- [5] Mohammad Hossein Nadian., Mohammad Hossein Abbaspour-Fard., Alex Martynenko., Mahmood Reza Golzarian (2017). An intelligent integrated control of hybrid hot air-infrared dryer based on fuzzy logic and computer vision system, *Computers and Electronics in Agriculture*, Vol. 137, 2017, pp. 138-149., DOI: <https://doi.org/10.1016/j.compag.2017.04.001>
- [6] Ooi, E., Sayuti, M. & Ahmed A.D.S (2015). Fuzzy logic-based approach to investigate the novel uses of nano suspended lubrication in precise machining of aerospace AL tempered grade 6061, *Journal of Cleaner Production*, Vol. 89, 2015, pp. 286-295., DOI: <https://doi.org/10.1016/j.jclepro.2014.11.006>.
- [7] Zalnezhad, E. & Ahmed, A.D.S. (2014). A Fuzzy logic predictive model for better surface roughness of Ti-TiN coating on AL7075-T6 alloy for longer fretting fatigue life”, *Measurement*. Vol. 49, 2014, pp. 256-265., <https://doi.org/10.1016/j.measurement.2013.11.042>
- [8] http://www.sidrabe.com/assets/files/Processes%20Control%20for%20Oxide%20Layer%20Deposition%20in%20Roll%20Vacuum%20Machines_2013.pdf, (2013). Sidrabe, Publications, Accessed on: 08.06.2017

Roll-to-