Journal of Nano- and Electronic Physics
Vol. **17** No 5, 05001(6pp) (2025)

Журнал нано- та електронної фізики
Том **17** № 5, 05001(6cc) (2025)

OPEN ACCESS

REGULAR ARTICLE

Influence of NaCl Concentration on the Size of CdS Nanoparticles in the Presence of PVA

O.V. Smitiukh[1,*], O.M. Yanchuk[1], O.V. Marchuk[1], O.A. Vyshnevskyi[2]

[1] *Lesya Ukrainka Volyn National University, 43025 Lutsk, Ukraine*
[2] *2M.P. Semenenko Institute of Geochemistry, Mineralogy and Ore Formation NAS of Ukraine, Kyiv, 03142, Ukraine*

(Received 15 August 2025; revised manuscript received 20 October 2025; published online 30 October 2025)

The present study is devoted to the synthesis of cadmium sulfide (CdS) powders through electrolysis is, revealing their structural and morphological characteristics. By electrochemical method, we obtained the mix nanoparticles with two modifications – sphalerite and wurtzite, whereas the wurtzite is predominant. X-ray phase analysis confirmed that all synthesized powders are pure cadmium sulfide in both sphalerite (space group CdS_$F\bar{4}3m$) and wurtzite (space group $P6_3mc$) modifications. Utilizing peak parameters from diffractograms and the Scherrer method, we calculated average thickness of the particles. The particles of sphalerite is bigger than wurtzite ones: the average size of the sphalerite particles is 19.5 nm, wurtzite – 13.5 nm, and general thickness – 14.4 nm. The effect of the NaCl concentration is not significant in the presence of PVA. Scanning Electron Microscopy (SEM) analysis revealed a flaky morphology with significant size variation among particles, ranging from 20 to 200 nm, and an average diameter increase from 100 to 120 nm at higher NaCl concentrations. The largest particles emerged at NaCl concentrations of 1.8-2.0 mol/L. Additionally, the incorporation of polyvinyl alcohol (PVA) into the electrolyte resulted in a notable increase in average particle diameters. Since particles with a large size range are synthesized, it can be assumed that PVA has the minor influence as the stabilizer. These findings contribute to the understanding of the synthesis and properties of CdS nanoparticles, with implications for their potential applications in various fields.

Keywords: Electrochemical Synthesis, Nanoparticles, Cadmium Sulfide, Structure.

DOI: 10.21272/jnep.17(5).05001 PACS numbers: 61.46.Df, 78.67.Bf

1. INTRODUCTION

The study of synthesis of nanoparticles in modern world is booming due to their practical applications and unique physical and chemical properties [1]. Their optical properties and reactivity depend on the size. Certainly, binary compounds are basic material to provide the synthesis of nanoparticles. For instance, ZnO and ZnS may be obtained with different methods [2-5].

Cadmium Sulphide (CdS) is well-used direct bandgap semiconductor (bulk band gap 2.42 eV at 300 K) in assorted areas like photodetector [6], solar cell [7], photocatalysts [8], nonlinear optical material [9] etc.

The chemical method is clean and inexpensive to obtain CdS nanoparticles [10]. In many syntheses, the precursors are used. They often are unstable causing environmental hazards. Hence, using NaCl is the simple way to make the synthesis eco-friendly. Obviously, the size of CdS nanoparticles has a crucial role on its properties [11].

In order to stabilize the size of nanoparticles, scientists apply different stabilizers [12-13]. Polyvinyl alcohol (PVA) is a versatile polymer widely used as a stabilizer for nanoparticles, particularly in aqueous solutions. Its effectiveness stems from its ability to adsorb onto the nanoparticle surface, creating a steric barrier that prevents aggregation and ensures stable colloidal dispersion [14]. PVA, with its polar hydroxyl groups, can form strong hydrogen bonds with the nanoparticle surface. This adsorption creates a protective layer that hinders close approach and aggregation of nanoparticles [15].

In the present work, the synthesis of cadmium sulfide is carried out by electrolysis of an aqueous solution of sodium chloride and thiourea with a soluble cadmium anode. Among the advantages of electrochemical synthesis are high yields of solid-phase product, short electrolysis time, current-time control over the amount of product, etc.

2. EXPERIMENTAL DETAILS

Nanoparticles of cadmium sulfide deposits are obtained through the electrolysis of an aqueous solution containing sodium chloride and thiourea in a galvanostatic mode with corresponding identical cylindrical rod electrodes made of cadmium at a constant temperature. The power source used was the B5-46 device. A constant current was passed through the electrolyte solution for a certain period.

Pre-calculated amounts of electrolyte and thiourea were weighed, poured into a 0.5 L volumetric flask, and

* Correspondence e-mail: bvv260170@ukr.net

Cite this article as: O.V. Smitiukh et al., *J. Nano- Electron. Phys.* 17 No 5, 05001 (2025) https://doi.org/10.21272/jnep.17(5).05001

brought to the mark with distilled water (at the temperature of the experiment). To determine the theoretical yield of the electrolysis products, the electrodes were weighed before and after the electrolysis process. The resulting solution was poured into a 400 mL beaker. The electrodes were immersed in the beaker, which were connected with copper wires to the B5-46 direct current source. The electrolyzer (the beaker with the electrolyte solution, a magnetic stirrer, and electrodes submerged in the solution along with contact and standard thermometers) was placed in a thermostat that maintained a constant temperature. Within 20-40 minutes, the desired constant temperature was established in the electrolyzer. The thermostat was installed on a magnetic stirrer, allowing for mixing of the electrolyte and electrolysis products. After this, the magnetic stirrer, rectifier, and stopwatch were activated, setting the required current strength. Time readings from the stopwatch, temperature, and voltage were recorded in the working journal. The current strength was maintained constant throughout the entire duration of electrolysis.

Electrolysis began with hydrogen evolution at the cathode and dissolution of the anode. Approximately 30 seconds after the reaction started, solid particles began to form and settle at the bottom of the electrolyzer. Hydrogen was released at the cathode in all cases according to the scheme:

$$2H_2O + 2\,e^- = 2OH^- + H_2,$$

while the anode mostly dissolved ($M - 2\,e^- = M^{2+}$), and particles started to form around it, settling at the bottom of the beaker or on the surface of the cathode.

The processes occurring in the system are as follows:

$$\text{Anode (+): } Cd - 2\,e^- = Cd^{2+}$$

$$\text{Cathode (-): } 2H_2O + 2\,e^- = 2\,OH^- + H_2$$

In this equation, thiourea is converted into urea and S^{2-} ions:

$$H_2N - C(S) - NH_2 + 2OH^- \rightarrow H_2N - C(O) - NH_2 + S^{2-} + H_2O.$$

The overall equation for electrolysis is:

$$Cd^{2+} + S^{2-} \rightarrow CdS.$$

In most cases, the anode dissolved, and particles immediately began to form around it, settling at the bottom of the beaker or on the surface of the cathode. A powdery sediment of brick color was predominantly obtained in the volume of electrolyte, while only a negligible amount of powdery substance precipitated on the cathode.

After turning off the current, the electrodes were disconnected, thermometers removed, and the beaker taken out of the thermostat. The beaker was left to cool down. A sediment remained at the bottom of the beaker. The electrodes were dried in air. After cooling, the solution was decanted from the beaker and refilled with distilled water. After a few hours, the solution was decanted again and filled with distilled water once more.

After another decantation, distilled water was added again, and after a few hours, the water was decanted again, and the contents of the beaker were poured into a Petri dish and left to dry for a day at a temperature of 50°C. The dried electrodes were weighed. The amount and mass of dissolved metal or formed sulfide are theoretically calculated based on the amount of electricity passed ($m = MI\tau/zF$). The practical yield of electrolysis products was determined by measuring changes in mass of the anode. The product was weighed. After identifying the product (establishing its chemical formula), its practical yield was also evaluated. Similar methods have been used to obtain nanoparticles under other conditions in work [16-17] where their non-linear optical properties were described.

In total, 10 samples of the product were synthesized, differing in sodium chloride content. The concentration of thiourea (0.2 mol/L) and PVA (5 g/L) remained unchanged. The concentration of NaCl varied from 0.2 to 2.0 g/L.

The X-ray diffractograms have been obtained with DRON 4-13 (range 10-70, step 0.05° time 3 s).

Table 1 – The details of experiment: conditions of electrochemical synthesis in the presence of PVA with changing NaCl concentration [TC] = 0.2 mol/l; [PVA] = 5 g/l; S = 5 cm²; I = 0.96 A; T = 90°C

No	[NaCl], M	Current, V
1	0.2	9.6
2	0.4	5.8
3	0.6	4.7
4	0.8	3.7
5	1.0	3.5
6	1.2	3.0
7	1.4	2.9
8	1.6	2.5
9	1.8	2.1
10	2.0	2.0

The surface area of the cathode was 5 cm². The current strength in all experiments was 0.96 A. Thus, the current density was maintained constant at 0.192 A/cm² in all experiments. All experiments lasted for 20 minutes at a constant temperature of 90°C.

3. DISCUSSION

In Scherrer' first work [18] on particle size determination, Paul Scherrer proposed the following formula in 1918:

$$D = K\lambda/(\beta\cos\theta),$$

where D is the average particle size in nm; K is a constant whose value depends on the shape of the particle, in our case it is 0.941; β is determined as half the width of the maximum peak measured in radians; λ is the wavelength of the X-ray radiation, which is 0.15418 nm; θ is the diffraction angle for the maximum.

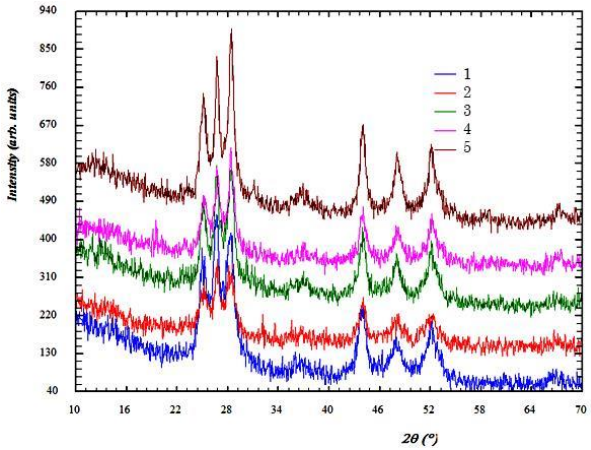

Fig. 1 – Diffraction patterns of powder samples 1-5 obtained with NaCl concentrations ranging from 0.2 to 1.0 M

The X-ray phase analysis has been conducted with the program PowderCell. According to the results of the analysis, all diffractograms contain two modification of CdS: sphalerite (space group $F\bar{4}3m$) and wurtzite modification (space group $P6_3mc$).

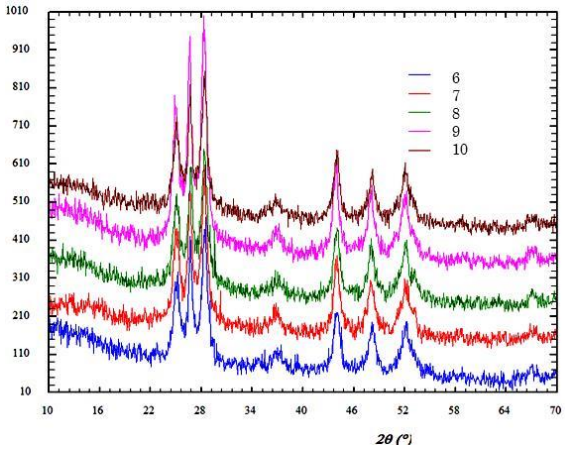

Fig. 2 – Diffraction patterns of powder samples 6-10 obtained with NaCl concentrations ranging from 1.2 to 2.0 M

Table 2 – The content of sphalerite (CdS_$F\bar{4}3m$) and wurtzite (CdS_$P6_3m$) depending on the NaCl concentration in the presence of PVA

No	[NaCl], M	Content of CdS_*F43m*	Content of CdS_*P6₃m*
1	0.2	27	73
2	0.4	25	75
3	0.6	21	79
4	0.8	21	79
5	1.0	11	88
6	1.2	10	90
7	1.4	11	89
8	1.6	11	89
9	1.8	14	86
10	2.0	18	82

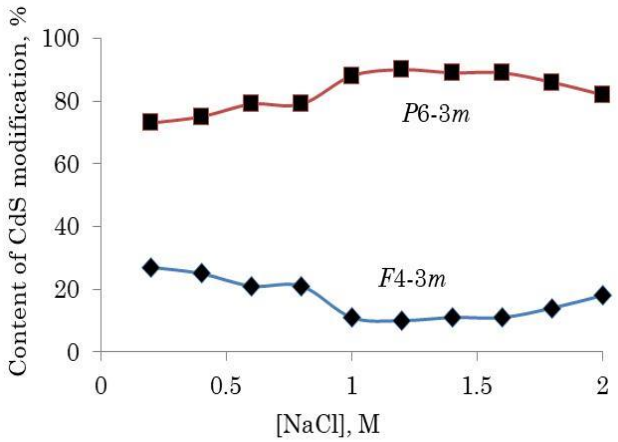

Fig. 3 – Dependence of the content of sphalerite (CdS_$F\bar{4}3m$) and wurtzite (CdS_$P6_3m$) on the concentration of NaCl in the presence of PVA

As can be seen in fig.3, the proportion of sphalerite in cadmium sulfide varies from 10 to 27%, and of wurtzite from 73 to 90%.

The crystal structure is similar if we consider the second atomic coordination. ½ of tetrahedral voids are occupied with Cd atoms. All octahedral voids are not fulfilled. Such tetrahedral environment is perfect for application the materials in solar panels.

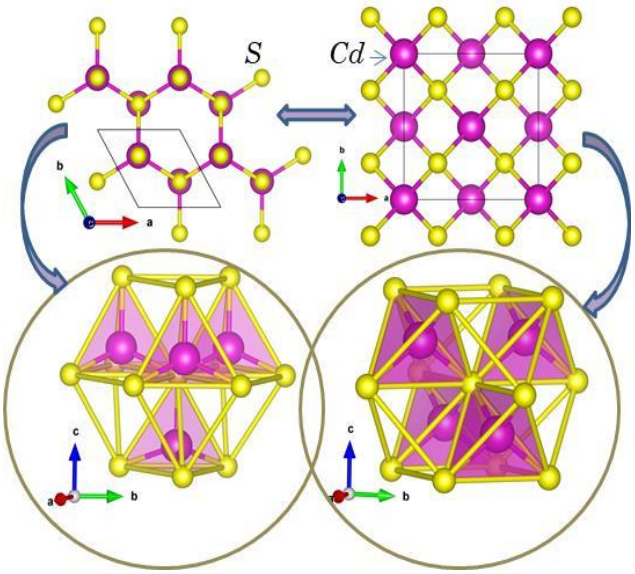

Fig. 4 – Structural transformations in the synthesized samples

From diffractograms derived on DRON 3-14, for the maximum of the peaks we can identify the thickness of the nanoparticles of sphalerite and wurtzite modification. The results of calculation of the peaks are presented in Table 3.

The thickness of the nanoparticles of sphalerite is in the range from 14.5 to 23.1 nm, i.e. the spread in thickness can be considered insignificant. The average particle thickness is 19.5±2.4 nm, the standart deviation is 2.9 nm.

Table 3 – Results of determination of the thickness of cadmium sulfide particles by the Scherrer method in the presence of PVA synthesized with different concentrations of NaCl at a peak of 26.5º $K = 0.941$; $\lambda = 0.154178$ nm

No	$2\theta_1$-$2\theta_2$	β	2θ	cos θ	[NaCl], M	D, nm
1	0.59	0.0103	26.7	0.97298	0.2	14.5
2	0.5	0.00873	26.8	0.97278	0.4	17.1
3	0.49	0.00855	26.7	0.97278	0.6	17.4
4	0.44	0.00768	26.7	0.97278	0.8	19.4
5	0.43	0.0075	26.7	0.97278	1.0	19.9
6	0.38	0.00663	26.700	0.97278	1.2	22.5
7	0.41	0.00716	26.700	0.97278	1.4	20.8
8	0.49	0.00855	26.860	0.97278	1.6	17.4
9	0.37	0.00646	26.650	0.97278	1.8	23.1
10	0.37	0.00646	26.700	0.97278	2.0	23.1

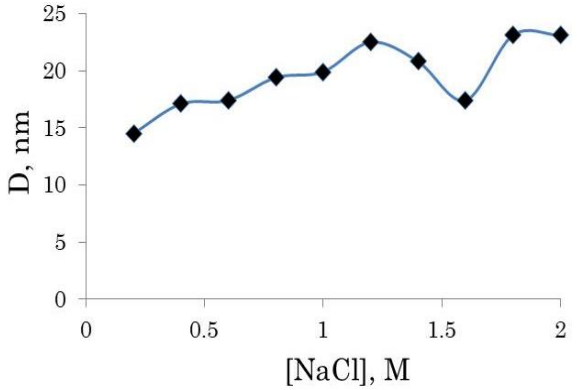

Fig. 5 – Dependence of the thickness of electrolytically synthesized cadmium sulfide (sphalerite) particles (nm) on the concentration of NaCl (M) in the presence of PVA at peak

As can be seen from Fig.5, the thickness of particles of sphalerite modification is changing monotonuously for except 1.6 M.

The results of calculation of the peaks of wurtizite modification are presented in Table4 and Fig. 6. In the range of sodium chloride concentration from 0.6 to 0.8 M, a monotonic increase in particle size is observed. The maximum particle size of cadmium sulfide is obtained at a sodium chloride concentration of 0.8 M (17.5 nm).

Table 4 – Results of determination of the thickness of cadmium sulfide particles by the Scherrer method in the presence of PVA synthesized with different concentrations of NaCl at a peak of 28.3º $K = 0.941$; $\lambda = 0.154178$ nm

No	$2\theta_1$-$2\theta_2$	β	2θ	cos θ	[NaCl], M	D, nm
1	0.94	0.016406	28.35	0.969552	0.2	9.1
2	0.57	0.009948	28.5	0.969231	0.4	15.0
3	0.81	0.014137	28.35	0.969552	0.6	10.6
4	0.49	0.008552	28.35	0.969552	0.8	17.6
5	0.58	0.010123	28.4	0.969445	1.0	14.8
6	0.54	0.009425	28.5	0.969231	1.2	15.9
7	0.60	0.010472	28.4	0.969445	1.4	14.3
8	0.72	0.012566	28.31	0.969638	1.6	11.9
9	0.64	0.01117	28.25	0.969765	1.8	13.4
10	0.69	0.012043	28.4	0.969445	2.0	12.4

The thickness of the nanoparticles of wurtzite is in the range from 9.1 to 17.5 nm, i.e. the spread in thick-ness can be considered insignificant. The average particle thickness is 13.5±2.0 nm, the standart deviation is 2.5 nm.

The effect of sodium chloride on the average particle thickness of cadmium sulfide powder is complex. The minimum particle thickness (9.1 nm, Fig. 6) can be obtained only at a content of 0.2 M NaCl, while in all other cases in the presence of NaCl the particles are larger.

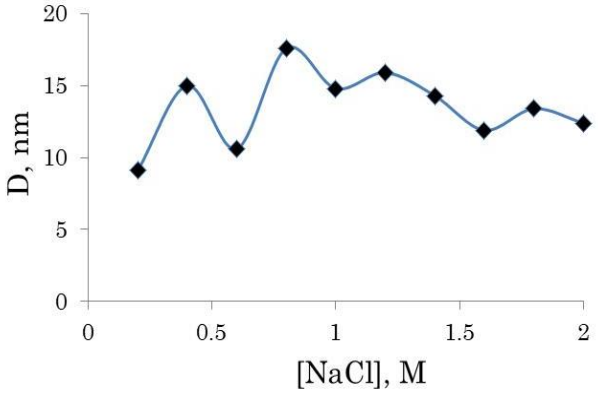

Fig. 6 – Dependence of the thickness of electrolytically synthesized cadmium sulfide (wurtzite) particles (nm) on the concentration of NaCl (M) in the presence of PVA at peak 28.3

The average density of cadmium sulfide particles was calculated using vicoric acid instead of various modifications of cadmium sulfide for formula:

$$\bar{D} = X(sph) \cdot D(sph) + X(wurt) \cdot D(wurt)/100$$

Table 5 – Results of determination of the average diameter of cadmium sulfide particles

No	Xsph,%	Xwurt,%	$\bar{D}$
1	14.5	9.1	10.6
2	17.1	15.0	15.6
3	17.4	10.6	12.0
4	19.4	17.5	17.9
5	19.9	14.8	15.2
6	22.5	15.9	16.5
7	20.8	14.3	15.0
8	17.4	11.9	12.5
9	23.1	13.4	14.8
10	23.1	12.4	14.3

The average of the thickness of CdS is 14.4 ± 1.7 nm, the standart deviation is 2.2 nm.

From the SEM images it is clear that the particles have a scaly shape with different size distribution. From this it can be concluded that the Scherrer method calculates the average thickness of the particles. In terms of thickness, all synthesized particles are nanosized.

Fig. 7 shows graphical dependences of the diameters of scaly particles on the PVA content. It can be seen from them that the diameters of the smallest particles are in the range from 40 to 60 nm. The diameters of the largest particles are in the range from 180 to 200 nm. To determine the distribution of particles by thickness, the

number of particles, their diameters, average number and average particle sizes were calculated in the ranges 0-20; 20-40; 40-60; etc. to the last range of 180-200 nm. The average diameters of scaly particles for each sample were also determined.

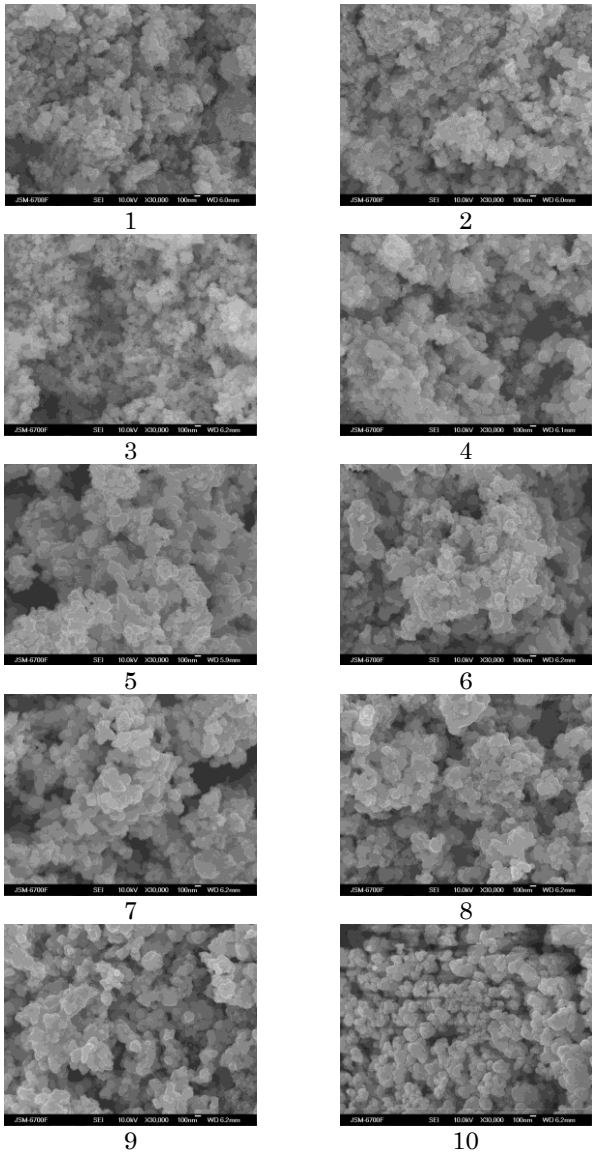

Fig. 7 – SEM images of cadmium sulfide samples

Table 6 – Results of determining the quantities of CdS particles with different NaCl concentrations in the presence of PVA

№	40-60	60-80	80-100	100-120	120-140	140-160	160-180	180-200
1	9	39	49	87	8	8	0	0
2	7	34	53	92	8	6	0	0
3	9	44	50	90	6	1	0	0
4	3	37	48	93	15	3	1	0
5	2	23	39	92	26	16	2	0
6	4	43	59	69	14	11	0	0
7	0	13	28	105	27	22	4	1
8	3	14	38	100	27	17	1	0
9	1	11	28	112	30	15	3	0
10	0	0	15	67	41	47	17	13

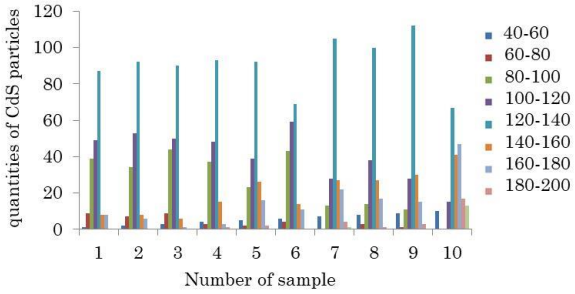

Fig. 8 – The results of determining the quantities of CdS particles with different NaCl concentrations in the presence of PVA

By the number of particles (Fig. 8), the diameter range of 100-120 nm prevails among all size ranges.

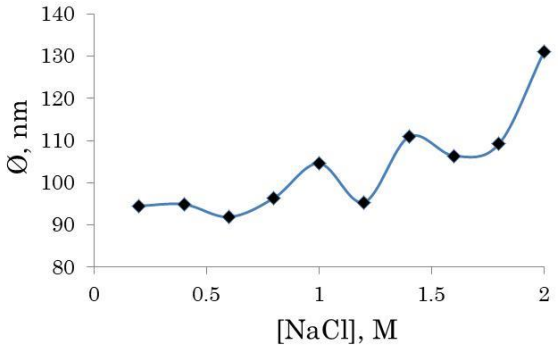

Fig. 9 – The average diameter of flaky particles with different NaCl concentrations in the presence of PVA

In the presence of PVA (Fig. 9), the nanoparticles are nanoscaled in three directions. The increase of the concentration of NaCl leads to increasing of the average diameter of the particles for except 1.2 M.

4. CONCLUSION

In conclusion, X-ray phase analysis has established that all powders synthesized by electrolysis are pure cadmium sulfide in the sphalerite modification (space group CdS_$F\bar{4}3m$) and wurtzite modification (space group $P6_3mc$). According to the investigation, the smallest particles come from powders with a NaCl concentration of 0.2 M. The largest thickness of the particles is obtained from a NaCl concentration of 0.8 M (~17.9 nm). As the NaCl concentration increases, so does the thickness of the particles. SEM analysis has shown that the particles of cadmium sulfide powders have a flaky morphology. There is a significant variation in particle sizes, ranging from 20 to 200 nm, and a tendency for the average particle diameters to increase with higher concentrations of NaCl (from 100 to 120 nm). The increase of concentration of NaCl leads to more wurtzite modification and it may improve the non-linear

properties of the materials.

The obtained cadmium sulfide materials, owing to their controlled particle size and morphology, are promising for applications in optoelectronic devices, such as photodetectors, solar cells, and light-emitting diodes (LEDs). The ability to tailor the crystallographic phase and particle dimensions through NaCl concentration makes the synthesized CdS powders suitable for use in nanoelectronics and sensor technologies, where precise control over surface properties and nanostructure is critical.

ACKNOWLEDGEMENT

Authors would also like to express their gratitude the organizers of the II European Chemistry School for Ukrainians (Dr Joanna Gostianska, Dr Stefan Wuttke, Dr Oleksandr Grygorenko), and wonderful speakers for interesting chemistry lessons and in-depth discussion https://acmin.agh.edu.pl/en/detail/s/ii-european-chemistry-school-for-ukrainians.

REFERENCES

1. I. Khan, K. Saeed, I. Khan, *Arab. J. Chem.* **12** No 7, 908 (2019).
2. O.V. Smitiukh, O.M. Yanchuk, O.V. Marchuk, Ju.O. Khmaruk, M.M. Yatsyshyn, O.A. Vyshnevskyi, I.I. Velymchanitsa, *J. Nano- Electron. Phys.* **17** No 1, 01015 (2025).
3. S. Faisa, H. Jan, S.A. Shah, S. Shah, A. Khan, M.T. Akbar, M. Rizwan, F. Jan, Wajidullah, N. Akhtar, A. Khattak, S. Syed, *ACS Omega* **6** No 14, 9709 (2021).
4. S.K. Dhoke, *Res. Chem.* **5**, 100771 (2022).
5. O.M. Smitiukh, O.V. Marchuk, O.M. Yanchuk, Yu.O. Khmaruk, *J. Nano- Electron. Phys.* **16** No 1, 01024 (2024).
6. R.A. Ismail, K.S. Khashan, A.M. Alwan, *Silicon* **9**, 321 (2017).
7. C. Martínez-Alonso, C.A. Rodríguez-Castañeda, P. Moreno-Romero, C. CoriaMonroy, H. Hu, *Int. J. Photoenergy* **2024**, 453747 (2014).
8. A. Samadi-Maybodi, M.R. Sadeghi-Maleki, *Spectrochim.. Acta Part A Mol. Biomol. Spectrosc.* **152**, 156 (2016).
9. S.S. Talwatkar, Y.S. Tamgadge, A.L. Sunatkari, A.B. Gambhire, G.G. Muley, *Solid State Sci.* **38**, 42 (2014).
10. R. Bhattacharya, S. Saha, *Pramana* **71** No 1, 187 (2008).
11. A.B. El- Bially, R. Seoudi, W.H. Eisa, A.A. Shabaka, I. Soliman, Abd El-Hamid R.K. Preparation, *J. Appl. Sci. Res.* **8** No 2, 676 (2012).
12. Q. Yao, X. Tao, B. Tian, Y. Tang, Y.Shao, L. Kou, J. Gou, X. Li, T. Yin, X.Tang, *Colloid. Surf. B Biointerface.* **113**, 92 (2013).
13. R.V. Korol, O.M. Yanchuk, O.V. Marchuk, V.F. Orlov, I.A. Moroz, O.A. Vyshnevskyi, *Phys. Chem. Solid State* **22** No 2, 380 (2021).
14. M. Wiśniewska, I. Ostolska, K. Szewczuk-Karpisz, S. Chibowski, K. Terpiłowski, V.I. Zarko, *J. Nanopart. Res.* **17** No 1, 12 (2015).
15. B. Zuo, Y. Hu, X. Lu, S. Zhang, H. Fan, X. Wang, *J. Phys. Chem. C* **117** No 7, 3396 (2013).
16. K. Ozga, O.M. Yanchuk, L.V. Tsurkova, O.V. Marchuk, I.V. Urubkov, Y.E. Romanyuk, O. Fedorchuk, G. Lakshminarayana, I.V. Kityk, *Appl. Sur. Sc.* **446**, 209 (2018).
17. J. Ebothé, J. Michel, I.V. Kityk, G. Lakshminarayana, O.M. Yanchuk, O.V. Marchuk, *Physica E* **100**, 69 (2018).
18. P. Scherrer, *Math-Phys. Kl.* **2**, 98 (1918).

Вплив концентрації NaCl на розмір наночастинок CdS в присутності ПВС

О.В. Смітюх[1], О.М. Янчук[1], О.В. Марчук[1], О.А. Вишневський[2]

[1] *Волинський національний університет імені Лесі Українки, 43025 Луцьк, Україна*
[2] *Інститут геохімії, мінералогії та рудоутворення ім. М.П. Семененка НАН України, 03142 Київ, Україна*

Дослідження присвячено синтезу порошків сульфіду кадмію (CdS) шляхом електролізу, що дозволяє виявити їхні структурні та морфологічні характеристики. Електрохімічним методом ми отримали суміш наночастинок з двома модифікаціями – сфалеритом та вюрцитом, де вюрцит є переважаючим. Рентгенофазовий аналіз підтвердив, що всі синтезовані порошки є чистим сульфідом кадмію як у модифікаціях сфалериту (просторова група *CdS_F43m*), так і вюрциту (просторова група *P63mc*). Використовуючи параметри піків дифрактограм та метод Шеррера, ми розрахували середню товщину частинок. Частинки сфалериту більші за вюрцит: середній розмір частинок сфалериту становить 19,5 нм, вюрциту – 13,5 нм, а загальна товщина – 14,4 нм. Вплив концентрації NaCl не є суттєвим у присутності полівинілового спирту (ПВС). Аналіз за допомогою скануючої електронної мікроскопії (СЕМ) виявив лускату морфологію зі значними варіаціями розмірів частинок, від 20 до 200 нм, та середнім збільшенням діаметра від 100 до 120 нм при вищих концентраціях NaCl. Найбільші частинки з'являлися при концентраціях NaCl 1,8-2,0 моль/л. Крім того, включення полівінілового спирту (ПВС) до електроліту призвело до помітного збільшення середнього діаметра частинок. Оскільки синтезуються частинки з великим діапазоном розмірів, можна припустити, що ПВС має незначний вплив як стабілізатор. Ці результати сприяють розумінню синтезу та властивостей наночастинок CdS, що має значення для їх потенційного застосування в різних галузях.

Ключові слова: Електрохімічний синтез, Наночастинки, Сульфід кадмію, Структура.