JOURNAL OF NANO- AND ELECTRONIC PHYSICS
Vol. **15** No 4, 04005(5pp) (2023)

ЖУРНАЛ НАНО- ТА ЕЛЕКТРОННОЇ ФІЗИКИ
Том **15** № 4, 04005(5cc) (2023)

Investigation of the Electronic and Optical Properties of Nanostructured Glasses and Composites

P. William[1], M.A. Jawale[1*], A.B. Pawar[2], Sachin K. Korde[3], Dhananjay S. Rakshe[4], Neeta Deshpande[5]

[1]Department of Information Technology, Sanjivani College of Engineering, SPPU, Pune, India
[2]Department of Computer Engineering, Sanjivani College of Engineering, SPPU, Pune, India
[3]Department of Information Technology, Pravara Rural Engineering College, SPPU, Pune, India
[4]Department of Computer Engineering, Pravara Rural Engineering College, SPPU, Pune, India
[5]Department of Computer Engineering, R H Sapat College of Engineering, Management Studies and Research, SPPU, Pune, India

(Received 10 June 2023; revised manuscript received 16 August 2023; published online 30 August 2023)

Due to technical hurdles in a developed society, there has been a growing need to create new materials and technologies. Nanomaterials are among the emerging materials with exceptional optical and electrical characteristics, making them ideal for various applications. The current work focuses on recent developments in the visual and electrical characteristics of nanostructured (Ns) glasses and composites. The process for making nanostructured glasses has been briefly discussed. The analysis of optical elements reveals that Ns glasses exhibit both a direct and indirect band gap and that the degree of the samples' nanostructuring affects how the band gap is tuned. Compared to their bulk counterparts, the electrical characteristics of glasses with nanostructures demonstrate improved electrical conductivity. According to published research, nanostructuring increases phonon boundary scattering, which lowers thermal conductivity. In light of their uses, more attention has to be paid to the thermal and thermoelectric characteristics, which have received little attention in the context of nano glasses. The investigation of the features and creation of novel nano-glasses may enable the creation of technologies that will improve humankind's future. These nanostructured glasses are a good choice for various scientific and commercial applications because of their structural composition, grain size, flaws, and other factors. From the complete study noticed that it has some drawbacks which includes the production of vast numbers of nano glasses with well-managed microstructures requires highly developed economic approaches.

Keywords: Optical and Electrical Properties, Nanostructured Glasses and Composites, Electrical Conductivity

DOI: 10.21272/jnep.15(4).04005 PACS numbers: 42.70.Ce, 72.80.Ng, 78.66.Jg

1. INTRODUCTION

Researching new materials for novel qualities and uses in the ever-evolving environment is critical. There have been several discoveries of novel materials with intriguing attributes for use in science. Nanostructured materials have distinguished themselves as a blessing to humanity among these substances [1-3]. Over the last decade, scientists have devoted much attention to investigating the exciting properties of materials by altering their nanostructures. The most prevalent types of nanomaterials are solid Ns materials. Based on how they look, solid Ns materials are loosely divided into "four categories: powder, fiber, film, and bulk". They may be 0, 1, or 2-dimensional Ns (0D, 1D, 2D, 3D). All three dimensions are quantized to the nanoscale in 0D Ns, also known as quantum dots [4]. Only two sizes, for instance, nanowires, are limited to the nanoscale in a 1D Ns while 3D Ns are not quantized, one dimension in 2D Ns is quantized to a nano regime (for example, nanofilms). These are also referred to as bulk nanomaterials. This 3D, 2D, 1D, and 0D materials have received much attention in research [5]. Nanomaterials' characteristics may also be changed regarding their pore size, with dimensionality control ranging from 0D to 3D. They have macropores, mesopores, or micropores, and their performance may be altered. They are used in solar cells, supercapacitors, rechargeable batteries, gas sensors, and electro- and photocatalysis, among other things. Crystalline materials are where significant advancements in the nanostructuring of materials are taking place. Numerous types of research have examined nano-crystalline materials' varied traits and use [6].

The nano structurization of glasses is crucial because it will alter these materials' electrical, optical, and other characteristics, leading to new applications. However, making these glasses at "the nanoscale is difficult because atomic manipulation is useless in a disordered structure. In contrast, making atomically flat surfaces in crystalline materials are simple since each atom can be controlled individually [7]. Furthermore, compared to crystalline materials, Ns glasses provide a more comprehensive range of characteristics since they do not have bonding restrictions caused by crystalline unit cells. Numerous significant advancements have been made in the last ten years to understand the aspects of Ns glasses better. These glasses are constructed quite differently

* jawale.madhu@gmail.com
The results were presented at the 3rd International Conference on Innovative Research in Renewable Energy Technologies (IRRET-2023)

from their bulk cousins. In certain instances, these Ns glasses exhibit medium-ranges "ordered structure rather than short-range order"; it has also been discovered [8]. Therefore, it is clear that the characteristics of these glasses may be adjusted as needed by manipulating Ns creation. The free volume also has a significant impact on Ns glasses. Nanoglasses have a more excellent free book than bulk quenched glasses.

The structure and characteristics of these glasses are impacted by free volume, which is also affected by changes in temperature or stresses. As a result of their increased free volume, nano glasses exhibit significantly changed glass transition, plastic deformation, structure, and characteristics [9]. These modifications have given these Ns glasses new interest levels since they possess various valuable features. The glassy core and glass-glass interface are two glassy Ns in the nano glasses. Solid materials known as nano-glasses comprise glassy or crystalline areas with dimensions smaller than a nanometer joined by interfaces between the two materials. Researchers' desire to learn about and alter the characteristics of glass via nano structurization has increased as a result. Plastic deformation is one such method, which enables alternative atomic configurations at the nanoscale than the glass that has not undergone plastic deformation [10].

The current article details recent advancements in different Ns glasses and composites' characteristics. Recent studies on these materials' optical and electrical parts have been addressed.

2. RELATED WORKS

The study [11] examines the state-of-the-art Ns glass-ceramic materials with electrical (ionic or electronic) conductivity that are noticeably increased or have a more comprehensive temperature stability range than conventional high-temperature crystalline phases. These materials were produced synthetically by thermally nano-crystallizing specific electrically conductive oxide glasses. The study's topic is the production, structural, and spectral characterizations of ZnS-CdS composite nanopowders doped with transition metal ions [12]. ZnS and CdS exhibit X-ray diffraction patterns indexed to the cubic crystalline phase, and Scherer's formula indicates that the average crystallite size belongs to the nanometer range. X-ray diffraction (XRD) was employed to analyze the powder under study and establish its structural features. Investigations have been done into how addiction dyes, namely perylene dye and thiophene dye, affect the optical characteristics of nickel-cadmium ferrite. The band gap energies are calculated using the visual research UV-Visible [13]. The article [14] outlines the two main synthesis methods – melt-quenching and sol-gel processing – that scientists use to create these composite materials. It highlights the study's findings, stressing the contribution of carbon nanostructure (CNs) to improving host matrix functionalities.

The properties, foundations, benefits, and principles of several kinds of polymer electrolytes were initially explored in the article [15]. Then, based on specific crucial and recently published papers, the properties and performance of distinct polymer hosts were outlined. New advancements in several methods of examining the optical characteristics of polymer electrolytes were highlighted. The solution casting process created polymer composite films of chitosan doped with various fullerene weight ratios. Examined the thermogravimetric analyses of chitosan with multiple concentrations and weight ratios of fullerene sheets. A quick and ecologically friendly approach to creating chitosan and silver nanocomposites is presented in the research. Fourier-transform infrared spectroscopy (FTIR) was used to analyze the produced organic matrix and establish its structural composition. According to a study, barium doping has been used to modify the optical characteristics of CdO Ns films for use in optical windows. Spray pyrolysis created Ns films of barium-doped cadmium oxide (Ba: CdO). FT-IR, UV-Vis-NIR, and X-ray diffractometers analyzed the produced nFs. The XRD examination demonstrates that the cubic crystalline structures are present in the plain and Ba: CdO Ns films.

3. PREPARATION OF NANOSTRUCTURED GLASSES

Over the last several years, many Ns materials have been created for various uses. The literature provides several preparation techniques for nanomaterials. At an elevated pressure of approximately 106 Torrs, most of the source material is evaporated into a lower-density gas using resistance warming. Where the substrate is put, the heated sample's vapors go upward. Liquid nitrogen is often used to continuously chill the substrate, allowing the model to be deposited on the cooled substrate by a mix of convection and diffusion.

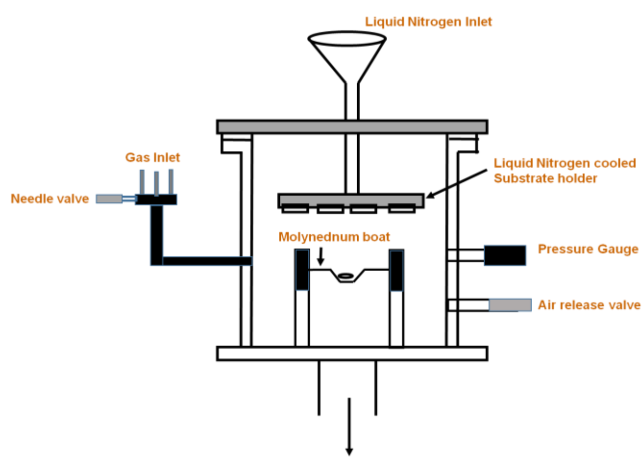

Fig. 1 – Thermal evaporator

The substrate cools, which causes the equilibrium vapor pressure to drop quickly and reach high supersaturation. It is generally known that the vapors quickly nucleate under high supersaturation, producing vast numbers of very tiny particles with a diameter of only a few nanometers. Brownian coagulation aids in the development of nuclei. The literature documents this technique's use for producing many kinds of nanomaterials. The representation design of a thermal evaporator used to create thin films with Ns on glassy substrates is shown in Fig. 1

To create Ns on thin films, a liquid nitrogen solution was sprayed over the backing layer as the film was being deposited. A molybdenum boat holds the originating material, and an approximately cleaned substrate made of glass is taped to a plate of steel at a 30 degree angle, 30 centimeters above the origin material, in the chamber with the vacuum. A 105 Torr vacuum was maintained within the room. After achieving the necessary vacuum, films were placed on the electrodes by applying L.T. current. In parallel with this procedure, liquid nitrogen was sprayed onto the circular steel plate via a gas inlet. This was done to create Ns in thin films and restrict the proliferation of particles. In addition to the IGC approach, several other techniques, including magnetron sputtering and the fusion of thermal and electron beam evaporation, have recently been used to create nano-glass sheets.

4. ELECTRONIC AND OPTICAL PROPERTIES OF NANOSTRUCTURED GLASSES AND COMPOSITES

Optical materials are naturally organized at various sizes, from molecules and atoms to crystals with a bulk mechanism. The structure, which may subsequently be utilized to regulate the distribution of the light field and the propagation of light, significantly impacts how materials interact with optical waves and photons. Additionally, electron confinement results in a modified absorption spectrum for semiconductor nanoparticles. The refractive index (RI) is subsequently changed. When the size of the Ns glasses is decreased below the excitonic size, their optical and electrical characteristics change dramatically, notably for nano-chalcogenides. The complexity of thin films' micro- and Ns might vary depending on the deposition method. "It is generally known that low-energy evaporation condensation processes based on heated crucibles or e-beam guns produce columnar thin films for most materials". In general, the RI of thin films of Ns glasses is lower than that of the bulk substance. Notably, the packing density of columnar thin films may be significantly lower than one. Packing density is defined as the amount of space filled by the bulk material about the total volume of the layer.

4.1 Film Thickness and Refractive Index Calculations

The optical constants of the thin film sample are calculated using a transmittance-based theory. The hypothesis predicts that the transmittance will depend on the parameters $(\alpha, \lambda, m, m_g)$, and ($t$).

$$D = \frac{Ey}{E - Vy\cos\phi + Ty^2}, \tag{1}$$

where $E = 16m^2 m_g, P = (m+1)^3(m + m_g{}^2), V =$

$= 2(m^2 - 1)(m^2 - m_g{}^2), T\ (m+1)^3(m + m_g{}^2), \phi = \dfrac{4\pi nd}{\lambda}$

and y is the absorbance given by $y = exp(-\alpha t)$.

t – homogeneous thin film of thickness, m = RI. Complex RI: $m_v = m - jr$, r – Extinction coefficient.

We assume the substrate has a thickness of many orders of magnitude greater than t and an RI of m_g. It is assumed that the RI of the ambient air is 1. When r^2 "m^2 is present, Equation (1) may be applied to thin film samples by considering all multiple reflections at the three interfaces. When the disruption criterion is set to $cos\emptyset = +1$ for the maximum (D_N) and $cos\emptyset = -1$ for the minimum (D_m), using Equation (1), one can calculate the frequency values at the highest and lowest of the interfering bands. The concept of constructing upper and lower interference fringe envelopes, the film's approximation of RI (m_1) in the area of medium and weak absorption, and the expression

$$m_1 = \left[M + \frac{(M^2 - m_g{}^2)1}{2}\right]^{\frac{1}{2}}, \tag{2}$$

where,

$$M = \frac{2m_g(D_N - D_n)}{D_N D_n} + \frac{m_g^2 + 1}{2}, \tag{3}$$

The upper and lower enclosures' most significant and lowest values at a particular wavelength are D_N and D_n, respectively, while the glass substrate's refractive index is m_g. Calculated using the commonly utilized relationship is the RI of the glass substrate m_g.

$$m_g = \frac{1}{D_g} + \frac{\left(\frac{1}{D_g^2} - 1\right)1}{2}, \tag{4}$$

The notation, in this case, denotes the glass substrate's transmittance spectrum D_g. If m_e and m_p are corresponding RI at two neighboring maxima at wavelengths λ_1 and λ_2, then the equation for film thickness,

$$t_1 = \frac{\lambda_1\lambda_2}{2(\lambda_1 m_p - \lambda_2 m_e)}, \tag{5}$$

The symbol for these values is t_1. The average value of the t_1 values, measured at various wavelengths, is written as t_1: From the fundamental interference fringes equation, the equation above is obtained.

$$2nd = n_o\lambda, \tag{6}$$

n_0 is a number for maxima and a half-integer for decreases as the order integer. Equation (6) is then applied to the t_1 and m_1 variables to get n_0 for various maxima and minima. By calculating the precise value of m associated with each maximum or minimum, it is now possible to determine the exact value of film thickness.

4.2 Determination of Optical Band Gap

One may get the absorption coefficient (α) by applying the relationship to the absorption spectra.

$$\alpha = \frac{1}{t} In\left(\frac{1}{Y}\right), \tag{7}$$

Y is the absorbance, and t is the film's thickness. Relationship between incoming photon energy (zc) and absorption coefficients (α).

$$(\alpha zc) = E(zc - A_s)^m, \tag{8}$$

A_s is the material's energy band gap, E is a constant, and exponent n depends on the kind of transition. Direct permitted, indirectly allowed evolution, and directly allowed are all given n values of 1/2, 2, and 3/2, respectively. By drawing a graph between $(\alpha zc)^{1/m}$) and zn, the energy band gap may be determined from the absorption spectra. The energy band gap may be calculated by extrapolating a straight line to the $(\alpha zc)^{1/m} = 0$ axis.

Over the last ten years, a lot of study has been done on the optical characteristics of *Ns* glasses. Nanorods with a diameter of 30 to 80 *nm* and a length of a few 100 *nm* were present in the thin films. For the samples, they reported an indirect band gap. Amorphous $Se_X Te_{100-X}$ (x = 3, 6, 9, and 12) glass nanorods aligned in thin films exhibit optical and structural phenomena as they are deposited. Fig. 2 displays FESEM images of a thin film made of $Se_X Te_{100-X}$.

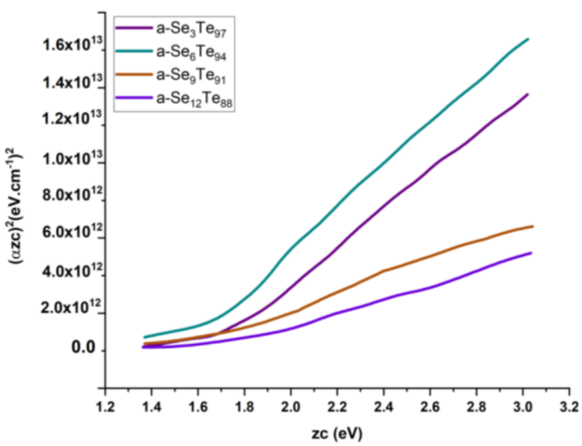

Fig. 2 – Aligned nanorods

These photos clearly show that "$Se_X Te_{100-X}$ thin films have a high yield of short and well-aligned nanorods". According to reports, the nanorods have a diameter of 10–20 nm and a length of several hundred nm. Aligned nanorods in a $Se_X Te_{100-X}$ films are shown in Fig. 2 as a plot of (a.hm) 2 against photon energy (hm). Their research shows that "the optical band gap becomes direct, and the optical" characteristics change dramatically due to the shrinking size.

Significant improvements are also made to the RI and extinction coefficient values. The phenomenon of the size effect is responsible for this improvement. The optical characteristics of $Te_{94}Se_6$ nanoparticle thin films produced utilizing the physical vapor condensation method at various Ar pressures. When the Ar pressure is reduced from 667 to 267 Pa, the size of the nanoparticles in these films rises from approximately ~12 to roughly 60 nm, as shown in SEM photos. It was discovered that the direct band gaps in these as-grown thin films decreased in value with increasing particle size. It was found that argon pressure worked well for regulating particle size. By raising the Ar pressure, the diameters of the produced nanoparticles were dramatically lowered. The optical characteristics of thin films with Ns $Se_{77}Sb_{15}Ge_8$ were suggested in research. The typical particle size is between 30 and 60 nm. The optical transition is indirect, according to a careful analysis of the optical absorption data.

This was attributable to the system's high proportion of unsaturated bonds and structural flaws. The optical band gap progressively becomes smaller due to the increased number of localized states caused by the more significant concentration of defect states. Fig. 3 depicts the transmission spectra of thin films of $Se_{80-X}Te_{20}Bi_X$ ($0 \le x \le 12$) glasses that include nanorods. In comparison to a bulk sample with practically the same structure, it was found that the band gap is more indirect and narrower. The optical characterization is one of the authors' further research projects in this area of Ns $Ge_{1-X}Sn_XSe_{2.5}$ (x = 0, 0.3, 0.5) films, optical properties of Ns $Se_{58}Ge_{39}Pb_3$ and $Se_{58}Ge_{36}Pb_6$ thin films and structural and optical study of Ns $Se_{80-X}Te_{20}Sb_X$ ($0 \le x \le 12$) thin films.

In contrast, a novel method for the nanostructuring of glassy Selenium $(g - S_e)$ has been addressed, which involves the use of silver nanoparticles (A_gNP_s) as a precursor. They used silver nanoparticles in their synthesis to create the nanostructured $g - S_e$. They incorporate A_gNP_s into a glass matrix containing $g - S_e$, forming trigonal Selenium $d(t - S_e)$ nanowires. They have also measured the electrical features of Ag-doped glassy nanocomposite substance, including its current-voltage features, *d.c.* Conductance, microhardness, and kinetic parameters related to the glass/crystal phase transition.

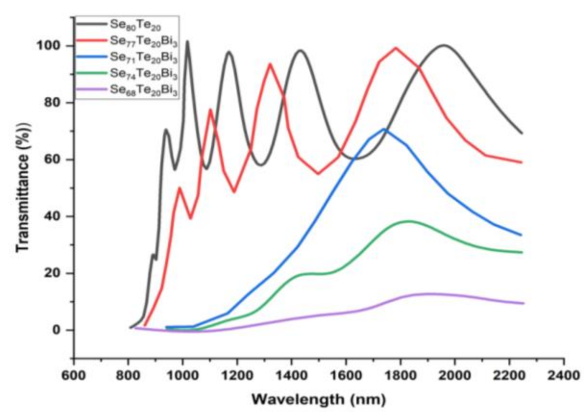

Fig. 3 – Transmission spectra of Ns of $Se_{80-X}Te_{20}Bi_X$ ($0 \le x \le 12$) glassy alloys

According to their calorimetric findings, $g - S_e/A_gNP_s$ nanocomposite has the superior glass-forming ability and thermal stability compared to $Se_{98}Ag_2$ glass. The Vickers hardness measurements, which measure the material's abrasiveness, also show that the nanocomposite sample is more complex than the $g - Se_{98}Ag_2$ alloy. *Ns* metallic and oxide glasses, in addition to the chalcogenide glasses outlined above, have also been the subject of some research into their optical characteristics.

5. CONCLUSION

Nanostructured glasses and composites' electrical and optical characteristics have been thoroughly reviewed. IGC is the most straightforward technique for creating Ns glasses. Absorption, transmission, and reflection spectra may be used to examine the optical characteristics of these glasses. The Ns glasses have a direct and indirect band gap, as demonstrated. According to the research, size reduction results in a significant shift in the kind of energy band gap. The sample's nano structuration will determine whether the band gap is direct or indirect. Some studies find a reduction in the energy band gap, while others report an increase due to sample Ns creation. The decline in band gap is ascribed to increasing band tails and system faults, while the rise was caused by a decrease in disorder and defects in the system. I-V characteristics at various temperatures were used to examine the electrical characteristics of the Ns glasses described in the literature. The According to a literature review on the thermal characteristics of Ns glasses, temperature, grain boundaries, grain size, and the presence of defects all impact these parameters.

REFERENCES

1. X. Chen, D. Wang, T. Wang, Z. Yang, X. Zou, P. Wang, W. Luo, Q. Li, L. Liao, W. Hu, Z. Wei, *ACS Appl. Mater. Interface* **11** No 36, 33188 (2019).
2. L.C. Jia, Y.F. Jin, J.W. Ren, L.H. Zhao, D.X. Yan, Z.M. Li, *J. Mater. Chem. C* **9** No 8, 2904 (2021).
3. J. Lin, J. Hu, W. Wang, K. Liu, C. Zhou, Z. Liu, S. Kong, S. Lin, Y. Deng, Z. Guo, *Chem. Eng. J.* **407**, 125783 (2021).
4. Z. Ding, H. Yang, M. Du, X. Ruan, J. Luo, S. Chen, D. Li, *Nanosci. Nanotechnol. Lett.* **11** No 10, 1366 (2019).
5. H. Lu, Y. Zhu, Y. Yuan, L. He, B. Zheng, X. Zheng, C. Liu, H. Du, *J. Mater. Sci.: Mater. Electron.* **32**, 5898 (2021).
6. J.N. Tiwari, R.N. Tiwari, K.S. Kim, *Prog. Mater. Sci.* **57** No 4, 724 (2012).
7. X. Zhou, B. Liu, Y. Chen, L. Guo, G. Wei, *Mater. Adv.* **1** No 7, 2163 (2020).
8. L. Wang, G. Yang, S. Peng, J. Wang, W. Yan, S. Ramakrishna, *Energy Storage Mater.* **25**, 443 (2020).
9. Z. Dai, T. Liang, J.H. Lee, *Nanoscale Adv.* **1** No 5, 1626 (2019).
10. C.Y. Tsai, H.C. Tai, C.A. Su, L.M. Chiang, Y.Y. Li, *ACS Appl. Nano Mater.* **3** No 10, 10380 (2020).
11. T.K. Pietrzak, M. Wasiucionek, J.E. Garbarczyk, *Nanomaterials* **11** No 5, 1321 (2021).
12. M. Jonnalagadda, V.B. Prasad, A.V. Raghu, *J. Molecular Struct.* **1230**, 129875. (2021).
13. A.M.A. Henaish, A.N. El-Sharkawy, S.A. Shama, O.M. Hemeda, R. Ghazy, *J. Phys.: Conf. Ser.* **1253** No 1, 012024 (2019).
14. M. Kaur, J. Bharj, R.S. Bharj, *Trans. Indian Institute Met.* **76** No 4, 887 (2023).
15. S.B. Aziz, M.A. Brza, M.M. Nofal, R.T. Abdulwahid, S.A. Hussen, A.M. Hussein, W.O. Karim, *Materials* **13** No 17, 3675 (2020).

Дослідження електронних та оптичних властивостей наноструктурованих стекол і композитів

P. William[1], M.A. Jawale[1], A.B. Pawar[2], Sachin K. Korde[1], Dhananjay S. Rakshe[2], Neeta Deshpande[3]

[1] *Department of Information Technology, Sanjivani College of Engineering, SPPU, Pune, India*
[2] *Department of Computer Engineering, Sanjivani College of Engineering, SPPU, Pune, India*
[3] *Department of Computer Engineering, R H Sapat College of Engineering, Management Studies and Research, SPPU, Pune, India*

Завдяки технічним потребам в розвиненому суспільстві зростає потреба у створенні нових матеріалів і технологій. Наноматеріали є одними з нових матеріалів із унікальними оптичними та електричними характеристиками, що робить їх ідеальними для різноманітних застосувань. Тематика статті зосереджена на останніх розробках у візуальних та електричних характеристиках наноструктурованого (Ns) скла та композитів. Коротко розглянуто процес виготовлення наноструктурованих стекол. Аналіз оптичних елементів показує, що у стеклах Ns спостерігається як пряма, так і непряма заборонена зона, а ступінь наноструктурування зразків впливає на ширину забороненої зони. Порівняно з масовими аналогами, електричні характеристики наноструктурованого скла демонструють покращену електропровідність. Відповідно до опублікованих досліджень, наноструктурування збільшує розсіювання фононних меж, що знижує теплопровідність. При використанні таких матеріалів більше уваги слід приділяти тепловим і термоелектричним характеристикам, яким приділялося мало уваги в контексті наностекол. Дослідження особливостей і створення нових наностекол дозволить розробку технологій для різноманітних наукових і комерційних застосувань через їх структурний склад, розмір зерна, недоліки та інші фактори. Також відмітимо, що виробництво наноскла з добре керованою мікроструктурою вимагає високорозвинених економічних підходів.

Ключові слова: Оптичні та електричні властивості, Наноструктуровані скло та композити, Електропровідність.