Suan Sunandha Science and Technology Journal
©2025 Faculty of Science and Technology, Suan Sunandha Rajabhat University

Study of Physical and Optical Properties of Cobalt Oxide-Doped Glass Prepared by Microwave Melting Technique

Pattraporn Saengka[1,2], Nakarin Singkiburin[1,2], Keerati Kirdsiri[1,2], Nattapon Srisittipokakun[1,2*]

[1]Physics Program, Faculty of Science and Technology, Nakhon Pathom Rajabhat University, Nakhon Pathom, 7300 Thailand
[2]Center of Excellence in Glass Technology and Material Science (CEGM), Nakhon Pathom Rajabhat University, Nakhon Pathom, 73000, Thailand
***Corresponding author e-mail:** Nattapon2004@gmail.com

Received: *2 January 2025* / **Revised:** *17 March 2025* / **Accepted:** *6 April 2025*

Abstract
This research investigates the physical and optical properties of cobalt oxide-doped glass prepared using the microwave melting technique. The glass composition was formulated according to the ratio (50-x)B_2O_3 : 10SiO_2 : 30ZnO : 10Na_2O : xCoO, where x represents the cobalt oxide concentration (0.00, 0.01, 0.05, 0.10, 0.15, and 0.20 mol%). Glass samples were prepared using the microwave melting technique, applying 1,000 watts of power for 20 minutes. The melted glass was then poured into a graphite mold and annealed at 500°C. The results showed that both density and refractive index increased with rising CoO concentration, while molar volume decreased. The absorption spectra of the glass, in the wavelength range of 250-1,100 nm, increased with higher CoO concentrations. Additionally, the CIE L*a*b* values indicated a blue color.

Keywords: Microwave melting technique, CoO, Glass, Physical and Optical properties

1. Introduction

Glass has a homogeneous appearance and a fine texture consisting of small, independent crystalline structures that reduce the likelihood of breakage. Generally, glass materials possess hardness, good optical transparency, high chemical resistance, and a low coefficient of thermal expansion, while other materials tend to be opaque and have a high coefficient of thermal expansion (Naresh, Naga, Raju, Gandhi, Piasecki & Veeraiah, 2014). Glass is an amorphous solid. Over time, research on glass has led to the development of new products. Today, glass materials have a wide range of applications, including packaging, mirrors, laboratory glassware, lead crystal glass, lenses, glass fiber, optical fiber, porous glass, and sealing glass, among others (Singkiburin, Jaimiwhang & Srisittipokakun, 2023). The traditional glass production process involves melting in an electric furnace for 3–5 hours at a temperature of 1,200°C, followed by annealing at 500°C for 3 hours (Singkiburin *et al.*, 2023). Currently, in addition to using electric furnaces, glass can also be melted using microwave technology. A microwave oven, a newer type of high-temperature furnace, uses 1,000 watts of power and heats the glass in about 25 minutes.

The microwave oven is a new type of high-temperature furnace for glass melting. It uses 1,000 watts of power (Yamchumporn & Boonin, 2023) and heats the glass in about 25 minutes, producing small pieces of glass and making the process easier compared to melting glass in an electric furnace. Microwave ovens are compact, safe, convenient, energy-efficient, environmentally friendly, and highly efficient, making them excellent tools for glass processing. They are particularly suitable for medium and small industries involved in glass production.

Cobalt-doped glass materials exhibit the highest absorption intensities in the visible range compared to other transition metal-doped materials (Tang *et al.*,2018, Raghuvanshi *et al.*, 2025), Particularly, CoO is a promising transition metal used for various important applications. It has two valence states Co^{3+} and Co^{2+}. Co^{2+} ions produce a color center with an absorption band at about 560-570 nm producing different degrees of blue glass. Additionally, Co ions doped glasses are used in many appliances such as lithium batteries, gas sensors, laser devices (Sadeq & Ibrahim, 2021, Bolundut *et al.*, 2020), solar energy inverters, optical filters in a variety of industrial applications, solar selective absorbers, decorative materials and much more (Sallam, Abdel-Galil & Moussa, 2023).

Given the importance of these advantages, researchers are interested in studying the physical and optical properties such as density, molar volume, refractive index, X-ray diffraction (XRD), Fourier transform infrared (FTIR) spectra, absorption, and color values of CoO-doped glass, and concentrations of x = 0.00, 0.01, 0.05, 0.10, 0.15, and 0.20 mol% were prepared using the microwave melting technique. This research aims to provide guidelines for further development of glass products in various fields.

2. Materials and Methods

This research investigates the physical and optical properties of cobalt oxide-doped glass prepared using the microwave melting technique. The glass composition was developed according to the ratio (50-x)B_2O_3 : 10SiO_2 : 30ZnO : 10Na_2O : xCoO, where x = 0.00, 0.01, 0.05, 0.10, 0.15 and 0.20 mol%, with a total weight of 15 gram per sample. The samples were prepared using the microwave melting technique. The prepared sample was placed into a microwave kiln and then heated in a microwave (EMM30D510EB, Electrolux) at 1,000 watts for 25 minutes. The molten glass was then poured into a graphite mold and annealed at 500°C, allowing it to cool to room temperature (Yamchumporn & Boonin, 2023). The glass was polished to a size of 1.0 × 1.5 × 0.3 cm^3. Preparation of glass use the microwave melting technique as shown in Figure 1. The physical and optical properties, including density (Densitometer, A&D HR-200), molar volume, refractive index (Abbe refractometer, Atago), absorption spectrum (UV-VIS-NIR Spectrophotometer, Shimazdu UV-3600) and color coordinate (UV-VIS spectrophotometer, Cary-50), were then studied.

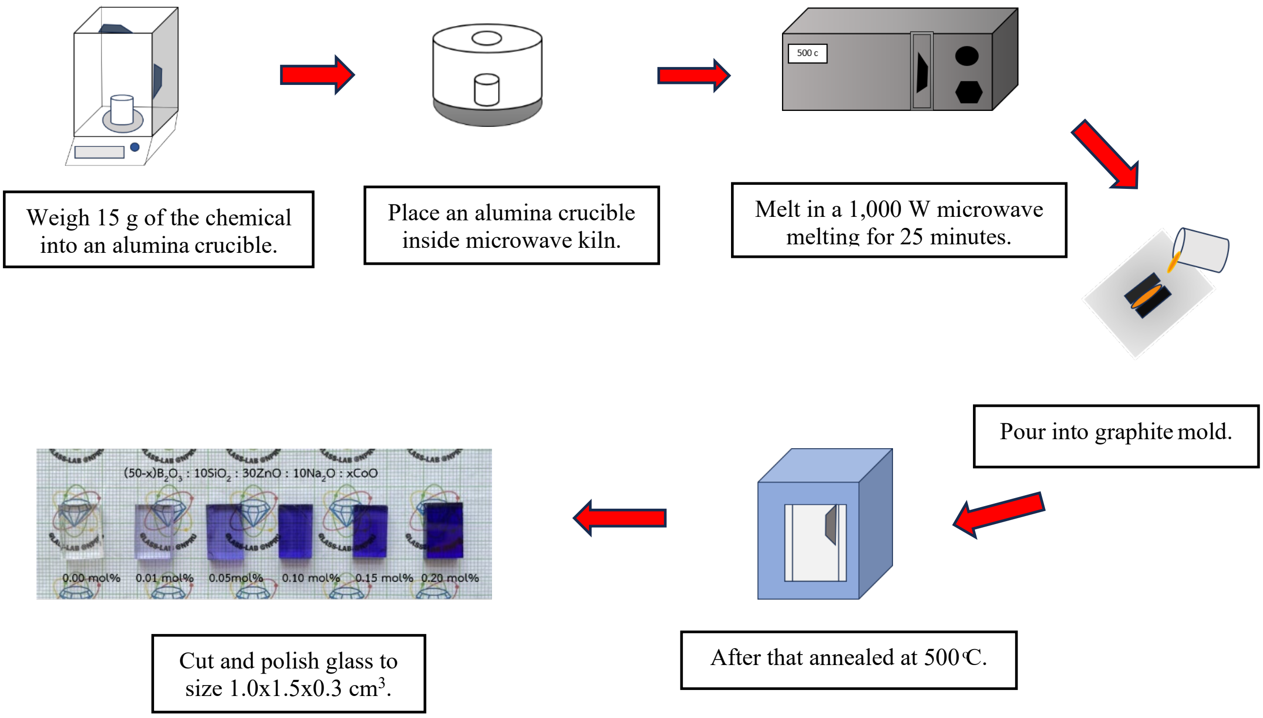

Figure 1. Preparation of glass use the microwave melting technique**.**

3. Results and Discussion

The glass samples doped with CoO in the ratios of (50-x)B_2O_3 : 10SiO_2 : 30ZnO : 10Na_2O, where x = 0.00, 0.01, 0.05, 0.10, 0.15 and 0.20 mol%, were clear and colorless. As the CoO concentration increased, the glass turned blue as shown in Figure 2.

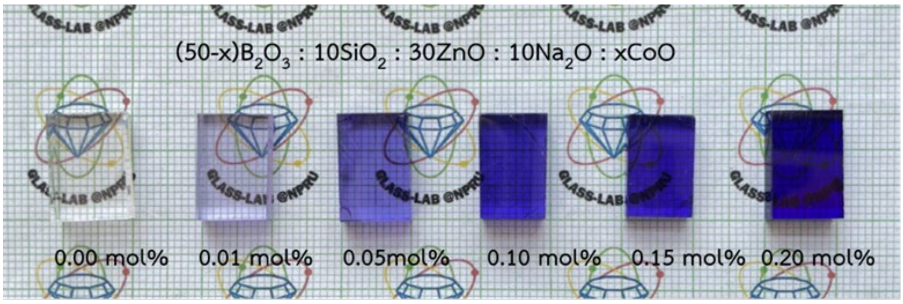

Figure 2. Glass doped with various concentrations of CoO.

Analysis of the density of glass doped with CoO at concentrations of 0.00, 0.01, 0.05, 0.10, 0.15, and 0.20 mol% using Archimedes' principle revealed that the density tended to increase as the CoO concentration increased, as shown in Table 1. The density values ranged from 2.8838 ± 0.0001 to 2.9287 ± 0.0026 g/cm³. This increase is due to the higher molecular weight of CoO replacing B_2O_3 oxides. When these values were used to create a graph of the relationship between density and CoO concentration, a linear relationship was observed with a correlation coefficient (R^2) of 0.9932. The molar volume, based on the ratio of molecular weight to the glass density, showed a decreasing trend with increasing CoO concentration (Fayad, Shaaban, Abd-Allah & Ouis, 2020), as shown in Table 1, ranging from 24.3920 to 24.7679 g/cm³. It was found that CoO introduces more bridging oxygen in the glass structure, resulting in a reduction in the molar volume of the glass with increasing CoO concentration, as shown in Figure 3.

Table 1. Density, molar volume and refractive index of glass doped with various concentrations of CoO.

Concentration (mol%)	Density, ρ (g/cm³)	Refractive index	Molar volume, V_M (cm³/mol)
0.00	2.8838 ± 0.0001	1.5785 ± 0.0001	24.7679
0.01	2.8894 ± 0.0005	1.5793 ± 0.0001	24.7198
0.05	2.9019 ± 0.0001	1.5811 ± 0.0001	24.6144
0.10	2.9094 ± 0.004	1.5824 ± 0.0001	24.5519
0.15	2.9177 ± 0.0002	1.5837 ± 0.0001	24.4828
0.20	2.9287 ± 0.0026	1.5848 ± 0.0000	24.3920

The refractive index of CoO-doped glass at concentrations of 0.00, 0.01, 0.05, 0.10, 0.15 and 0.20 mol% was measured using an Abbe refractometer. It was found that the refractive index increased with the CoO concentration, as shown in Table 1, with values ranging from 1.5785 ± 0.0001 to 1.5848 ± 0.0000. This behavior is consistent with the relationship observed in density values. According to classical dielectric theory, the refractive index depends on the density (Singkiburin, Jaimiwhang & Srisittipokakun, 2023) and the polarity of the atoms in the material. When the obtained values were used to create a graph of the relationship between refractive index and CoO concentration, the resulting graph showed a linear relationship, with a correlation coefficient (R^2) of 0.9729, as shown in Figure 4.

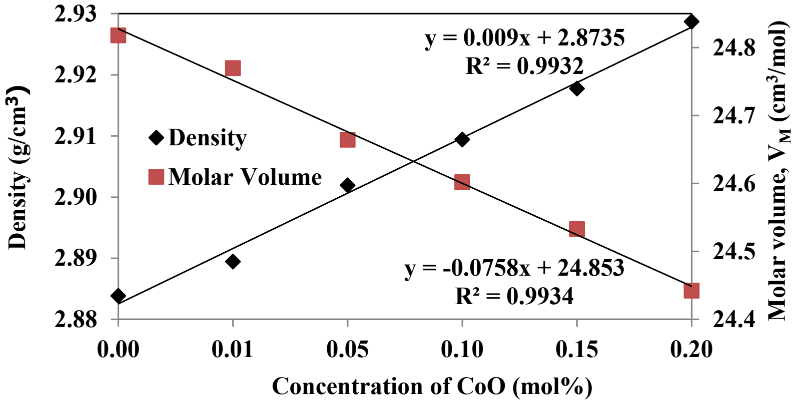

Figure 3. Density and molar volume of glass doped with various concentrations of CoO.

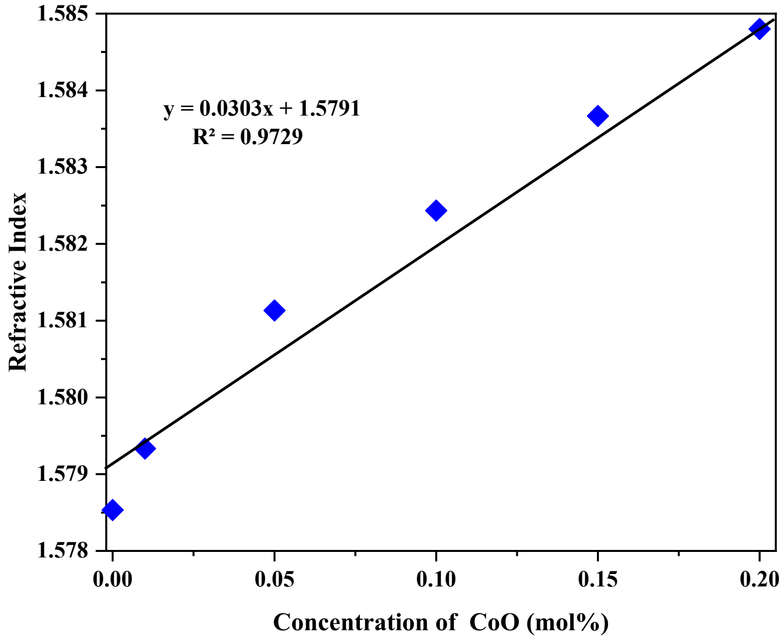

Figure 4. Refractive index of glass doped with various concentrations of CoO.

The X-ray diffraction (XRD) analysis of the CoO-doped glass revealed that the XRD pattern consisted of fluctuations and lacked sharp peaks, indicating an amorphous structure (Elbashar, Rayan, ElGabaly, Shimaa & Mohamed, 2020). Therefore, no significant changes were observed before and after the sequential addition of cobalt oxide, as shown in Figure 5.

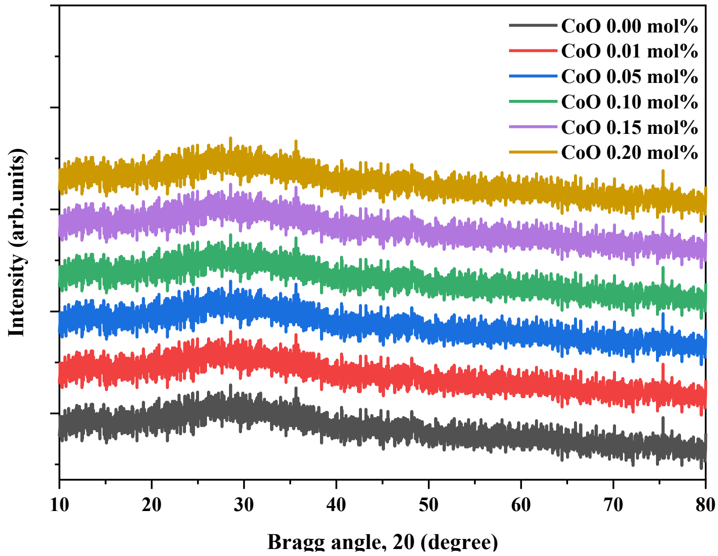

Figure 5. X-ray diffraction (XRD) of glass doped with various concentrations of CoO.

The Fourier transform infrared (FTIR) analysis of the CoO-doped glass spectra revealed peaks at approximately 530, 685, 904, and 1,244–1,360 cm⁻¹. In borate glasses, these peaks are typically associated with BO_3 and BO_4 units, and their positions can vary depending on the additives used. Specifically:

- The band at 685 cm⁻¹ may be attributed to the bending of B-O-B linkages, and this peak shifts to a longer wavelength upon the addition of CoO.
- The band at 904 cm⁻¹ likely corresponds to B-O stretching vibrations in BO_4 units, which are present in various borate groups; this peak shifts to a shorter wavelength with the addition of CoO.
- The band observed at approximately 1,244–1,360 cm⁻¹ is associated with B-O stretching vibrations of [BO_3] in pentaborate, pyroborate, and orthoborate groups, and this band shifts to a shorter wavelength as the CoO content increases (Ali, Rammah, El-Mallawany & Souri, 2017, Al-Mokhtar, 2020), as shown in Figure 6.

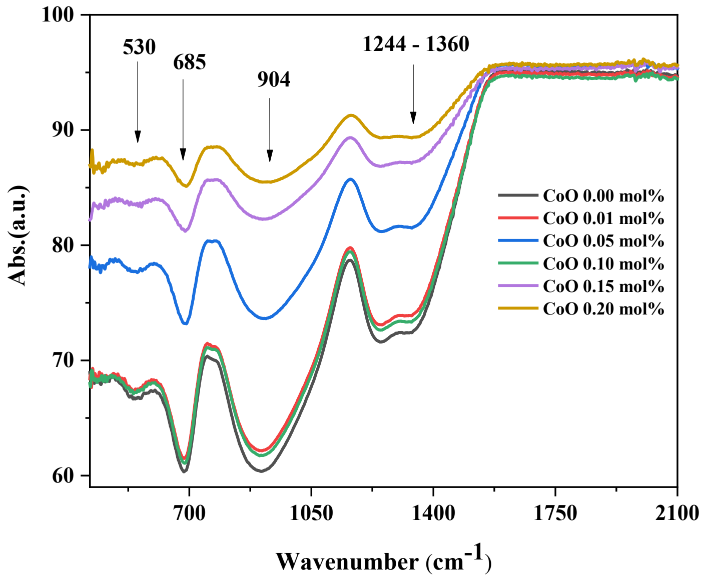

Figure 6. FTIR absorption spectra of glass doped with various concentrations of CoO.

The optical absorption spectra of CoO-doped glass, measured in the wavelength range of 250–1,100 nm for concentrations of 0.00, 0.01, 0.05, 0.10, 0.15 and 0.20 mol%, revealed absorption peaks at approximately 521, 576 and 630 nm. These peaks are attributed to energy level transitions of CoO: $^4T_{2g}(F) \rightarrow {}^2T_{1g}(H)$,

$^4A_2(^4F) \rightarrow {}^4T_1(^4F)$ and $^4T_2 \rightarrow {}^4E_1$ (Farouk, 2017). The intensity of these peaks tends to increase with higher CoO concentrations, as shown in Figure 7.

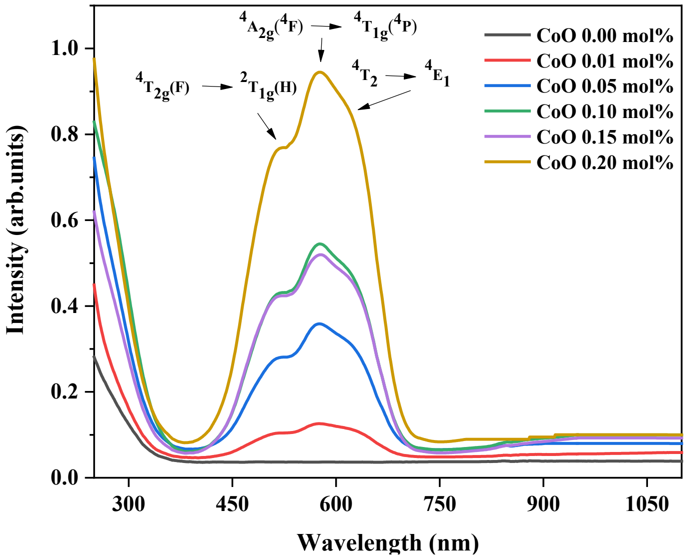

Figure 7. Absorption spectra of glass doped with various concentrations of CoO.

Results of color analysis in the system CIE L*a*b*

From the color analysis in the CIE L*a*b* system of glasses doped with CoO at concentrations of 0.00, 0.01, 0.05, 0.10, 0.15, and 0.20 mol%, it was found that the lightness (L*) values decreased with increasing CoO concentration, ranging from 46.72 to 92.61. The a* values ranged from -1.39 to 16.73, and the b* values ranged from -53.32 to 3.27, as shown in Table 3. The color values are located on the +a and -b axes, with -b value increasing with increasing CoO concentration, indicating more blue glass, corresponding to the absorbance value. The high peak is range of 450-700 nm, is the visible light spectrum from green to red, which is the range of maximum absorption, no appear light was visible . However, in the range of 400-450 nm, the corresponds to violet and blue light the colors are revealed, causing the glass samples to appear blue, as shown in Figure 8.

Table 2. Color analysis in the CIE L*a*b* system of glass doped with various concentrations of CoO.

Concentrations (% mol)	Color measurement		
	L*	a*	b*
0.00	92.61	-1.39	3.27
0.01	75.41	-0.73	-13.04
0.05	62.22	3.44	-32.12
0.10	59.75	5.37	-36.91
0.15	55.69	7.66	-40.87
0.20	46.72	16.73	-53.32

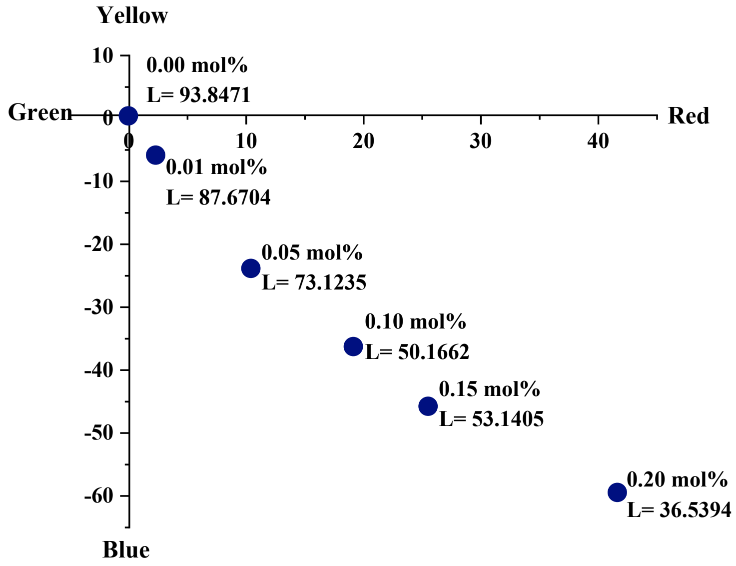

Figure 8. Color analysis in the CIE L*a*b* system of glass doped with various concentrations of CoO.

4. Conclusions

In this research, the physical and optical properties of glass doped with CoO were studied at the ratios of (50-x)B_2O_3 : 10SiO_2 : 30ZnO : 10Na_2O : xCoO, where x = 0.00, 0.01, 0.05, 0.10, 0.15 and 0.20 mol% using microwave melting technique. It was found that the glass obtained was transparent, colorless and when the concentration of CoO increased, the glass became blue. The density and refractive index values showed an increase in the concentration of CoO, while the molar volume values decreased. It was also found that the glass obtained had an amorphous structure before and after doping with CoO. Therefore, microwave melting is another process that can produce glass easier than melting glass in an electric furnace. It is also small, compact, safe, convenient and energy-saving.

Acknowledgements

Thank you to the Center of Excellence in Glass Teachnology and Materials Scienec (CEGM), Nakhon Pathom Rajabhat University that provides assistance with tools and equipment used in the synthesis and verification of properties.

References

Ali, A.A, Rammah, Y.S, El-Mallawany, R. & Souri, D. (2017). FTIR and UV spectra of pentaternary borate glasses data set. *University of Measurement, 105*, 72–77. doi: org/10.1016/j.measurement.2017.04.010.

Al-Mokhtar, K. M. (2020). FTIR and optical absorption studies of [B_2O_3]-[Na_2O]-[Li_2O]-[CuO] doped with [MgF_2] nanoparticle. *Journal of Nanotechnology & Advanced Materials*, *8*(2), 45-51.

Bolundut. Liviu, Pascuta. Petru, Culea. Eugen, Bos. Maria, Pop, Lidia & Stefan. Razvan, (2020). Spectroscopic study of some new cobalt-doped tellurite glass–ceramics. *Meterials Science, 55,* 9962-9971. doi: org/10.1007/s10853-020-04749-6.

Elbashar, Y.H., Rayan, Diaa., ElGabaly, Shimaa G. & Mohamed, A.A., (2020). Optical Spectroscopic Study of Cobalt Oxide Doped Boron Glass and Its Ion Effect on Optical Properties. *Chemistry, 63,* (6), 2111 – 2124. doi: 10.21608/ejchem.2019.17471.2072.

Farouk, M., (2017). Effect of Co^{2+} ions on the ligand field, optical, and structural properties of ZnLiB glasses. *Optik, 140*, *186–196.* doi: org/10.1016/j.ijleo.2017.04.042.

Fayad, A. M., Shaaban, Kh. S., Abd-Allah, W. M., Ouis, M., (2020). Structural and Optical Study of CoO Doping in Borophosphate Host Glass and Efect of Gamma Irradiation. *Inorganic and Organometallic Polymers and Materials, 30,* 5042–5052. doi.org/10.1007/s10904-020-01641-3.

Naresh, P., Naga Raju, Gandhi, G.Y., Piasecki, M. & Veeraiah, N., (2014). Insulating and other physical properties of CoO-doped zinc oxyfluoride-borate glass-ceramics, *The American Ceramic Society, 98,* (2), 413–422. doi: 10.1111/jace.13301.

Raghuvanshi, Vasundhara., Rashmi, I., Ingle, Avinash, Shashikala, H.D. & Nagaraja, H.S., (2025). A study on the influence of geometric coordination of cobalt ions on the structural, physical and optical properties of borosilicate glass. *Ceramics International*, *51*, (2), 1661-1673. doi.org/10.1016/j.ceramint.2024.11.142.

Sadeq, M.S & Ibrahim, A., (2021). The path towards wide-bandgap and UV-transparent lithium phosphate glasses doped with cobalt oxide for optical applications. *Non-Crystalline Solids, 569,* (1), 120983. doi.org/10.1016/j.jnoncrysol.2021.120983.

Sallam, O.I., Abdel-Galil, A., Moussa, N.L., (2023). Tuning of smart cobalt doped borate glasses by electron beam as band-pass filters. *Optics and Laser Technology, 162,* 109262. doi.org/10.1016/j.optlastec.2023.109262.

Singkiburin, N., Jaimiwhang, J. & Srisittipokakun, N., (2023). Effect of zirconium dioxide on refractive index in soda lime borosilicate glass. *The 15th NPRU National Academic Conference 2023* (p.2-8); Nakhon Pathom, Thailand. https://publication.npru.ac.th/jspui/handle/123456789/1885.

Singkiburin, N., Srisittipokakun, N., Rajaramakrishna R., Kothan, S., Intachai, N. & Kaewkhao, J., (2023). Investigation of europium oxide (Eu_2O_3) doped in cobalt boro-silicate glasses from waste glass for photonics material application, *Optik, 291,* 171146. doi: org/10.1016/j.ijleo.2023.171146.

Tang, Wufu., Zhang, Qian., Luo, Zhiwei., Yu, Jingbo., Gao, Xianglong., Li, Yunxing. & Lu, Anxian., (2018). CoO-doped $MgO–Al_2O_3–SiO_2$-colored transparent glass–ceramics with high crystallinity, *Applied Physics A, 124,* 191. doi: org/10.1007/s00339-017-1537-6.

Yamchumporn, P. & Boonin, K., (2023). Enhance the value of used glass bottles from microwave. *The 15th NPRU National Academic Conference 2023* (p.2-5); Nakhon Pathom, Thailand. https://publication.npru.ac.th/jspui/handle/123456789/1889.