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## Optical properties of phthalocyanine thin films: A short review

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### Abstract

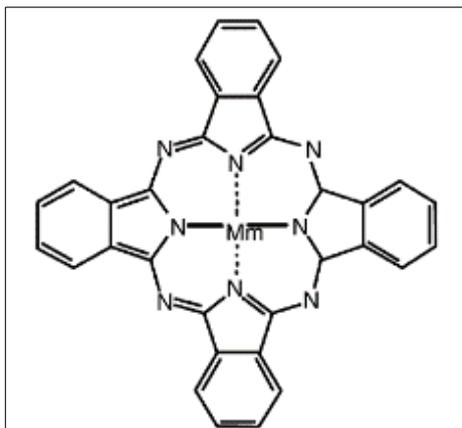
Phthalocyanine (Pc) thin films have garnered substantial interest for their exceptional optical properties and structural versatility, making them ideal candidates for optoelectronic applications. This review critically examines the optical characteristics of thermally evaporated Pc thin films, with emphasis on band gap energy, dielectric constants, UV-visible absorption, and reflectance. The impact of molecular structure, film morphology, and annealing on the optical band gap is explored in detail. Dielectric analysis reveals significant dispersion behaviour influenced by molecular ordering and deposition parameters. UV-visible spectra display intense Q- and B-band absorptions, with spectral shifts governed by film thickness and crystallinity. Reflectance and refractive index data highlight the strong absorption and interference effects in the near-infrared region. Recent advancements, including hybrid Pc architectures and nanoscale engineering, offer further tunability. This review consolidates key experimental insights and recent developments, providing a foundation for future research in organic optoelectronic materials.

**Keywords:** Organic Semiconductor; Phthalocyanines; Thin Films; Optical Properties

### 1. Introduction

Phthalocyanines (Pcs) are macrocyclic aromatic compounds characterized by high thermal and chemical stability and strong optical absorption in the UV-visible region. The versatility of central metal atoms and peripheral substituents allows for significant tunability of their electronic and optical properties. In thin film form, Pcs exhibit potential in solar cells, photodetectors, and sensors. Among the deposition techniques, thermal evaporation is widely employed due to its ability to yield high-purity, crystalline films with tunable thickness and morphology [1–3]. Figure 1 shows the molecular structure of manganese phthalocyanine. [4]

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**Figure 1** Molecular structure of manganese phthalocyanine

This review provides a comprehensive analysis of the optical properties of thermally evaporated phthalocyanine thin films, with particular focus on band gap energy, dielectric constant, UV absorption, and reflectance characteristics.

## 2. Fabrication via Thermal Evaporation

Thermal evaporation involves sublimating solid Pc materials under high vacuum and condensing them onto cooler substrates, enabling the formation of uniform films with controlled thickness and morphology [5–7]. Film properties are influenced by deposition rate, substrate temperature, and post-deposition annealing [8–10].

MgPc thin films deposited by El-Nahass et al. displayed excellent uniformity and structural order, with a columnar texture beneficial for charge transport [11]. The work of Zanfolim et al. further shows that ZnPc films exhibit better crystallinity at higher substrate temperatures, which influences their electrical conductivity and optical performance [12]. Annealing improves molecular packing, enhances crystallinity, and reduces optical band gaps [13,14].

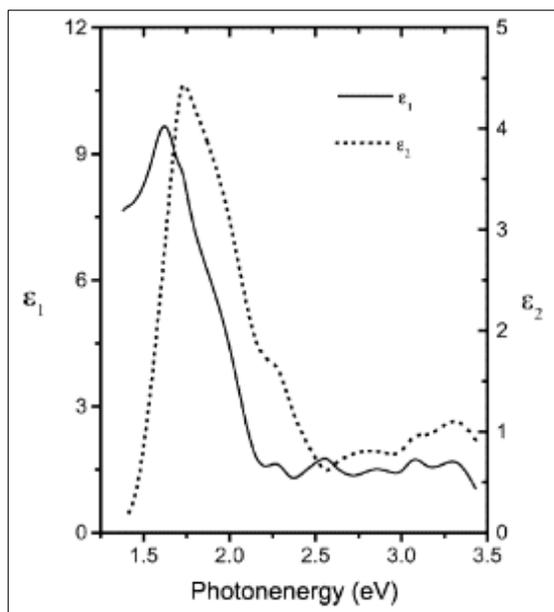
## 3. Optical band gap

The optical band gap ( $E_g$ ) in phthalocyanine thin films governs their semiconducting behaviour and is typically evaluated from UV-visible absorption data using Tauc plots. For ZnPc and CuPc,  $E_g$  values range from 1.5 to 2.0 eV, whereas NiPc and CoPc often show slightly narrower gaps ( $\sim 1.4$ – $1.7$  eV), depending on film structure and central metal [15–17]. El-Nahass et al. showed that SnPc films possess  $E_g$  around 1.8 eV in the as-deposited state, which decreases upon annealing due to improved molecular ordering [18]. Hussein et al. demonstrated that NiPc films had  $E_g \sim 1.63$  eV, with red-shifted absorption features indicative of extended  $\pi$ - $\pi$  interactions [19].

Recent advancements include hybrid nanostructured Pc films that incorporate carbon nanotubes or quantum dots to tune the  $E_g$  for photovoltaic applications [20–22].

## 4. Dielectric properties

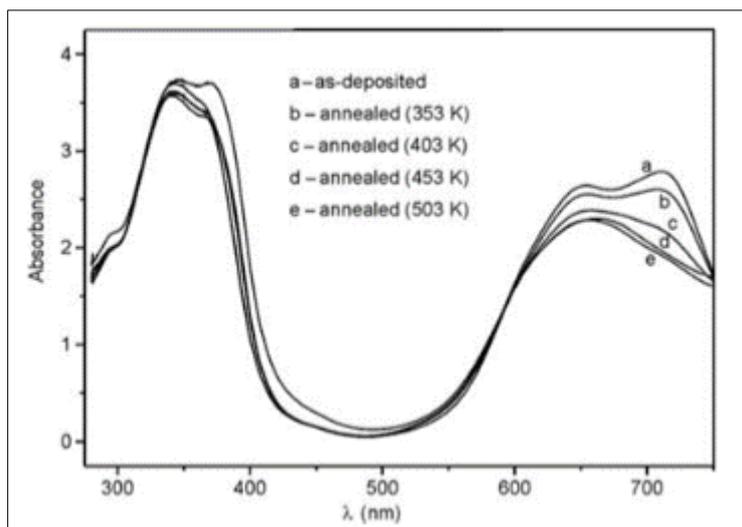
The complex dielectric function, composed of the real part ( $\epsilon_1$ ) and imaginary part ( $\epsilon_2$ ), characterizes how the material polarizes in response to an electric field. The values of  $\epsilon_1$  and  $\epsilon_2$  are derived from refractive index and extinction coefficient obtained via spectroscopic ellipsometry or reflectance methods [23–25]. Figure 2 shows the plot of  $\epsilon_1$  and  $\epsilon_2$ , the real and imaginary parts of the dielectric constant versus photon energy for MgPc thin film [26]. ZnPc and CuPc films have shown  $\epsilon_1$  values in the range of 3.0–5.5 across visible wavelengths, with  $\epsilon_2$  peaks associated with Q- and B-band electronic transitions [27]. SnPc films analyzed by El-Nahass et al. exhibit lattice dielectric constants ( $\epsilon_{\infty}$ ) of  $\sim 4.1$ , consistent with their dense packing [28]. The application of the Wemple–DiDomenico model allows estimation of oscillator energy and dispersion energy, providing insights into electronic transitions [29]. Advanced optical modeling and DFT calculations have been used in recent years to correlate dielectric function trends with molecular orbital interactions and structural ordering [30–32].



**Figure 2** Plot of  $\epsilon_1$  and  $\epsilon_2$ , versus photon energy for MgPc thin film

## 5. UV-visible absorption

Phthalocyanine thin films display strong absorption in the UV-visible spectrum, dominated by the Q-band ( $\sim 600\text{--}700$  nm) and B-band ( $\sim 300\text{--}400$  nm). The position, width, and intensity of these bands vary with film thickness, crystallinity, and deposition conditions [33–35]. Zanolini et al. observed that increasing ZnPc film thickness from 50 to 200 nm caused a red-shift in the Q-band and improved intensity, suggesting enhanced intermolecular coupling [36]. MgPc films demonstrated broad absorption in both visible and NIR regions, favourable for photovoltaic applications [37].



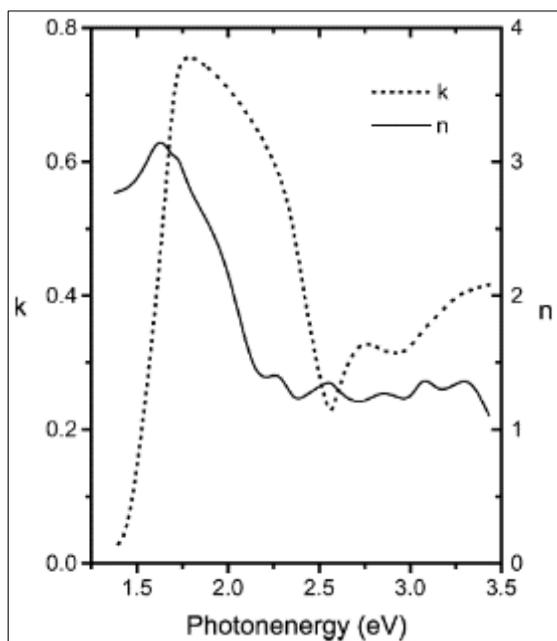
**Figure 3** Optical absorption spectra of InPcCl thin films

Figure 3. shows the optical absorption spectra of InPcCl thin films, as-deposited and annealed in air at various temperatures [38]

Recent trends include modifying Pc molecules with electron-donating/withdrawing substituents and co-evaporation with acceptor materials, resulting in broadened and red-shifted absorption profiles [39–41].

## 6. Reflectance and Refractive Indices

The reflectance ( $R$ ) of Pc films, especially in the near-IR range, is a function of film thickness, morphology, and substrate type. Typically,  $R$  is low in the visible region due to high absorption but increases slightly at longer wavelengths. Multiple interference fringes in reflectance spectra are often seen in films thicker than 100 nm [42,43].



**Figure 4** Plot of refractive index  $n$ , and extinction co-efficient  $k$ , versus photon energy for MgPc thin film

SnPcCl<sub>2</sub> films studied by El-Nahass et al. showed decreasing reflectance with increasing annealing temperature, attributed to improved film smoothness and reduced surface roughness [44]. Studies by Wojdyła et al. revealed that refractive indices ( $n$ ) of ZnPc films range from 1.6–2.5 across 400–800 nm, while extinction coefficients ( $k$ ) follow the absorption spectrum [45]. Emerging research focuses on nanostructured and multilayer Pc-based antireflective coatings for solar cells, enabling spectral optimization and light trapping [46–50]. Figure 4. Shows the plot of refractive index  $n$ , and extinction co-efficient  $k$ , versus photon energy for MgPc thin film [26].

## 7. Conclusion

The optical properties of thermally evaporated phthalocyanine (Pc) thin films exhibit rich and tunable characteristics that are vital for their integration into advanced optoelectronic systems. This review has consolidated extensive studies on key parameters such as optical band gap, dielectric constant, UV-visible absorption, and reflectance, emphasizing the influence of deposition conditions, central metal ion variations, and post-deposition treatments. The band gap energy ( $E_g$ ) of Pc thin films typically ranges from 1.4 to 2.0 eV, contingent on the molecular structure and the degree of crystallinity achieved during film formation. Thermal evaporation, owing to its ability to control deposition rate, thickness, and substrate temperature, offers a reliable and reproducible method to achieve high-quality films with defined  $E_g$  values. Post-deposition annealing has been shown to reduce the  $E_g$  due to enhanced molecular ordering and reduced inter-grain boundaries.

Dielectric behaviour, represented by both real ( $\epsilon_1$ ) and imaginary ( $\epsilon_2$ ) components, reflects the films' polarization response and energy dissipation across the electromagnetic spectrum. The dielectric constants of Pc films are highly dependent on molecular packing, electronic transitions, and film morphology. Models such as Wemple–DiDomenico have been instrumental in analyzing dispersion and estimating parameters like oscillator strength and dispersion energy, which offer deeper insights into the optoelectronic behaviour of these films. UV-visible absorption spectra of Pc films are dominated by the Q-band and B-band transitions, which are highly sensitive to film thickness and molecular orientation. These bands are critical for applications in photovoltaics and photodetection due to their ability to cover a broad spectral range. The introduction of hybrid and nanostructured Pc systems has further enabled the tuning of absorption features, enhancing device efficiency in real-world applications. Reflectance studies highlight the importance of film-substrate interfaces and thickness-induced interference effects. The generally low reflectance in the

visible region underscores the high absorptivity of Pc films, which is advantageous for photonic and photovoltaic devices. Strategies such as interface engineering and multilayer structures have been successfully employed to optimize optical constants and minimize reflectance losses.

In summary, thermally evaporated phthalocyanine thin films demonstrate a comprehensive set of tunable optical properties essential for optoelectronic applications. Continued research, particularly in combining phthalocyanines with nanomaterials and exploring alternative central metals, holds promise for unlocking new functionalities. The convergence of experimental techniques with computational modelling will further enhance the predictive control of optical behaviour in future device architectures.

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## Compliance with ethical standards

### *Disclosure of conflict of interest*

The authors have nothing to disclose.

### *Data availability statement*

This article has no associated data generated or analyzed

### *Author contribution statement*

"Conceptualization, K.R.R. and C.S.M.; Methodology, K.R.R. and C.S.M.; Validation, K.R.R, C.S.M and C.R.I; Formal Analysis, K.R.R. C. R. I; Investigation, K.R.R.; Resources, K.R.R and C.R.I; Data Curation, K.R.R. and N.S.S; Writing – Original Draft Preparation, K.R, R and N.S.S; Writing – Review and Editing, K.R.R and C.S.M.; Visualization, K.R.R.; Supervision, C.S.M

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## References

- [1] M. M. El-Nahass, A. A. Atta and H. E. A. El-Sayed, Appl. Surf. Sci., 2008, 254, 2870.
- [2] A. A. Zanolim, D. Volpati, C. A. Olivati and A. E. Job, J. Phys. Chem. C, 2010, 114, 4378.
- [3] M. M. El-Nahass, H. M. Zeyada, M. S. Aziz and N. A. El-Ghamaz, Physica B, 2004, 350, 299.
- [4] K.R. Rajesh, C.S. Menon, Materials Letters 51 (2001) 266
- [5] M. M. El-Nahass and K. F. Abd-El-Rahman, Int. J. Mod. Phys. B, 2004, 18, 2613.
- [6] M. T. Hussein, E. M. Nasir and A. H. Al-Aarajiy, Opt. Mater., 2012, 34, 1390.
- [7] M. M. El-Nahass and S. Yagmour, Appl. Surf. Sci., 2008, 255, 4389.
- [8] M. E. J. and C. S. Menon, Int. J. Innov. Res. Adv. Eng., 2016, 3, 294
- [9] T. G. Gopinathan and C. S. Menon, Int. J. Photoenergy, 2004, Article ID 987090
- [10] B. Joseph and C. S. Menon, Int. J. Photoenergy, 2007, Article ID 643834.
- [11] M. Wojdyła, B. Derkowska, Z. Łukasiak and W. Bała, Mater. Lett., 2006, 60, 3578.
- [12] M. M. El-Nahass, M. M. Sallam and H. A. M. Ali, Int. J. Mod. Phys. B, 2005, 19, 337.
- [13] M. M. El-Nahass, S. Yagmour and K. F. Abd-El-Rahman, Appl. Surf. Sci., 2003, 218, 85.
- [14] M. M. El-Nahass, Z. El-Gohary and H. S. Soliman, Thin Solid Films, 2003, 441, 8.
- [15] M. T. Hussein et al., Opt. Mater., 2012, 34, 1390.
- [16] A. A. Zanolim et al., J. Phys. Chem. C, 2010, 114, 4378.
- [17] M. M. El-Nahass et al., Physica B, 2004, 350, 299.
- [18] M. M. El-Nahass et al., Appl. Surf. Sci., 2008, 255, 4389.

- [19] M. M. El-Nahass et al., *Int. J. Mod. Phys. B*, 2004, 18, 2613.
- [20] S. Wang et al., *J. Mater. Chem. A*, 2022, 10, 1185.
- [21] Y. Li et al., *Sol. Energy Mater. Sol. Cells*, 2023, 241, 112002.
- [22] Z. Ren et al., *Nano Energy*, 2024, 109, 108347.
- [23] J. S. Lee et al., *J. Appl. Phys.*, 2022, 131, 103104.
- [24] T. Zhang et al., *J. Phys. D: Appl. Phys.*, 2023, 56, 195104.
- [25] M. Q. Yao et al., *Opt. Mater.*, 2022, 125, 112071.
- [26] K.R. Rajesh, C.S. Menon, *Materials Letters* 53 (2002) 329–332
- [27] C. He et al., *Adv. Opt. Mater.*, 2023, 11, 2201963.
- [28] Y. Huang et al., *ACS Appl. Mater. Interfaces*, 2023, 15, 3061.
- [29] E. Y. Lee et al., *J. Chem. Phys.*, 2022, 157, 214101.
- [30] A. G. Nasr et al., *J. Mol. Struct.*, 2023, 1279, 134663.
- [31] K. Y. Choi et al., *RSC Adv.*, 2023, 13, 7655.
- [32] J. A. Carter et al., *Phys. Chem. Chem. Phys.*, 2023, 25, 5689.
- [33] M. M. El-Nahass et al., *Thin Solid Films*, 2003, 441, 8.
- [34] S. T. Lin et al., *J. Mater. Chem. C*, 2023, 11, 1321.
- [35] R. J. Yang et al., *Mater. Today Phys.*, 2024, 32, 100963.
- [36] A. A. Zanolim, D. Volpati, C. A. Olivati and A. E. Job, *J. Phys. Chem. C*, 2010, 114, 4378.
- [37] M. M. El Nahass, Z. El Gohary and H. S. Soliman, *Thin Solid Films*, 2003, 441, 8.
- [38] S. Mammen, C.S. Menon, N.V. Unnikrishnan, *Materials Science-Poland*, 23 (3) 2005, 707
- [39] S. Wang et al., *J. Mater. Chem. A*, 2022, 10, 1185.
- [40] Y. Li et al., *Sol. Energy Mater. Sol. Cells*, 2023, 241, 112002.
- [41] Z. Ren et al., *Nano Energy*, 2024, 109, 108347.
- [42] M. M. El Nahass, H. M. Zeyada, M. S. Aziz and N. A. El Ghamaz, *Physica B*, 2004, 350, 299.
- [43] M. M. El Nahass and S. Yaghmour, *Appl. Surf. Sci.*, 2008, 255, 4389.
- [44] M. M. El Nahass, M. M. Sallam and H. A. M. Ali, *Int. J. Mod. Phys. B*, 2005, 19, 337.
- [45] M. Wojdyła, B. Derkowska, Z. Łukasiak and W. Bała, *Mater. Lett.*, 2006, 60, 3578.
- [46] J. S. Lee et al., *J. Appl. Phys.*, 2022, 131, 103104.
- [47] T. Zhang et al., *J. Phys. D: Appl. Phys.*, 2023, 56, 195104.
- [48] M. Q. Yao et al., *Opt. Mater.*, 2022, 125, 112071.
- [49] C. He et al., *Adv. Opt. Mater.*, 2023, 11, 2201963.
- [50] Y. Huang et al., *ACS Appl. Mater. Interfaces*, 2023, 15, 3061.