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Block Copolymer Photonic Crystals for Self-Powered Touch-Sensitive Displays: Mechanisms, Devices, and Perspectives

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Abstract. As flexible, low-power, and multifunctional human-machine interfaces become increasingly prevalent, conventional touchscreens encounter intrinsic limitations: their rigid, multilayer structures complicate device integration and limit adaptability. Thus, this review investigates the use of block copolymer (BCP) self-assembly for combining touch sensing and color display in a single thin-film platform. Through the fabrication of one-dimensional photonic crystals ntegrated with humidity-responsive hydrogels or ionogels, the BCP films concurrently convert tactile stimuli into triboelectric voltage signals and induce perceptible structural color changes without external power.By reviewing recent relevant literature, key fabrication strategies, dual-mode sensing mechanisms, and representative device prototypes, including 3D touchless displays, self-powered gesture recognition, and sweat-responsive wearable platforms, are highlighted. Besides, it emphasizes the advantages of this material platform, identifies challenges like response speed, large-area integration, and stability, and outlines future perspectives for multifunctional, self-powered photonic displays. The results reveal that BCP-based photonic films provide a promising route toward fully self-powered, flexible, and multifunctional touch-sensitive display technologies.

Keywords: Block Copolymer, Photonic Crystal, Structural Color, Triboelectric Sensing, Self-Powered Display

1. Introduction

With the rapid development of wearable and deformable electronics, display systems must combine visual output, touch sensing, and mechanical flexibility within a compact architecture. However, conventional touchscreens achieve these functions through physically separated sensing and display modules, including indium tin oxide electrodes, capacitive layers, and light-emitting units, which increase structural complexity and restrict integration with curved surfaces and wearable platforms [1]. These limitations drive the development of lightweight and multifunctional display materials capable of integrating optical output, sensing functions, and mechanical flexibility without relying on rigid multilayer architectures. In this context, structural color generated by light interference in periodic nanostructures provides an alternative display strategy without the need for backlights or color filters [2]. When the photonic structure is designed to respond to external stimuli through changes in periodicity, the same material can simultaneously function as a color display and sensing interface. To achieve such structures, block copolymers (BCPs), which spontaneously form periodic

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nanostructures through microphase separation, provide a scalable and low-cost approach [3-5]. Therefore, this review examines recent progress in BCP photonic displays, covering self-assembly and fabrication methods, dual-mode sensing mechanisms, representative device designs, and key barriers to practical applications.

2. Fabrication and dual-mode sensing mechanisms of BCP photonic crystals

2.1. Block copolymer self-assembly and fabrication

By leveraging microphase separation between covalently linked polymer blocks, BCPs can form periodic nanostructures with tunable optical responses. In lamellar BCP photonic structures, the periodic spacing governs the reflected wavelength according to the Bragg–Snell relationship [3]:

$$\lambda=2(n_1d_1+n_2d_2)=2n_{eff}d \quad (1)$$

where n_{eff} is the effective refractive index and d represents the lamellar period. Thus, the control of domain spacing enables the tuning of structural colors. As illustrated in Figure 1, the variation in periodic spacing shifts the reflection peak, thereby allowing adjustable color responses [2].

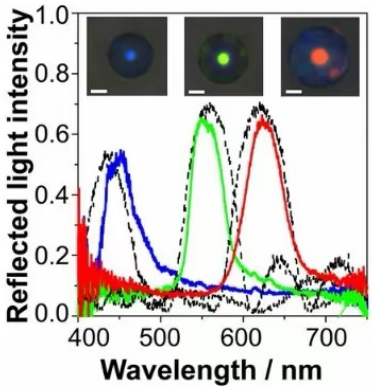

Figure 1. Reflectance spectrum

The photonic periodicity of BCP structures can be regulated through molecular weight, block composition, and blending of BCPs with different block lengths. For example, Eoh et al. showed that binary PS-b-P2VP blends achieved continuous control of interlamellar spacing from 46 to 91 nm, thus enabling visible color tuning after swelling with a non-volatile ionic liquid [3]. In addition, supramolecular assembly further enabled multicolor patterning from a single BCP formulation [4]. More recently, cyclic block copolymers exhibited faster self-assembly kinetics and an extended tuning range of periodic spacing from 172 to 224 nm compared with linear BCPs [6]. Thus, these approaches provide control over BCP periodicity and the resulting optical responses.

2.2. Integrated touch-sensing and color-display mechanisms

Through the coupling of electrical signal generation and structural color modulation, BCP photonic films achieve simultaneous touch sensing and visual display within a single platform. In this design, the ionogel-containing BCP film couples two functional pathways, in which ionic domains generate sensing signals and the periodic photonic structure provides visual feedback.

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For the sensing pathway, touch detection touch detection relies on the triboelectric effect, where charge transfer is triggered between materials with different electron affinities during contact and separation [7]. In ionogel-based BCP systems, triboelectric signals generated upon interaction with human skin can be collected by electrode arrays to locate touch events without external power input [7, 8].

For the display pathway, the photonic structure converts external stimuli into visible outputs through reversible modulation of its periodic structure. And this modulation leads to changes in the reflected wavelength and generates structural color variations, as shown in Figure 2 [9]. Thus, the electrical pathway provides stimulus detection, while the photonic pathway delivers visual feedback, enabling integrated touch-display functionality in a single BCP platform.

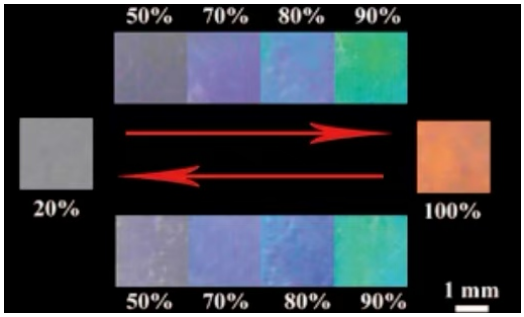

Figure 2. Structural color transition under different relative humidity conditions

3. Typical devices enabled by block copolymer photonic platforms

3.1. 3D touchless finger position display

Through the conversion of finger position into optical outputs without direct physical contact, BCP photonic crystals enable touchless spatial sensing. For instance, Kang et al. reported a 3D touchless display based on multi-order Bragg reflection in a PS-b-P2VP photonic crystal [10]. In this system, the BCP photonic film functions as both the sensing interface and visual output layer, allowing the position of a hovering finger to be identified directly from the generated color pattern.

To enable three-dimensional position recognition, the device maps finger position through the relationship between spatial location and the optical response of the photonic film, as illustrated in Figure 2 [10]. As the finger approaches different locations or heights, distinct optical patterns are generated, which provide information about both the lateral position and vertical distance of the finger. By calibrating the optical response with the corresponding spatial coordinates, the film converts a hovering gesture into a direct visual representation of three-dimensional position.

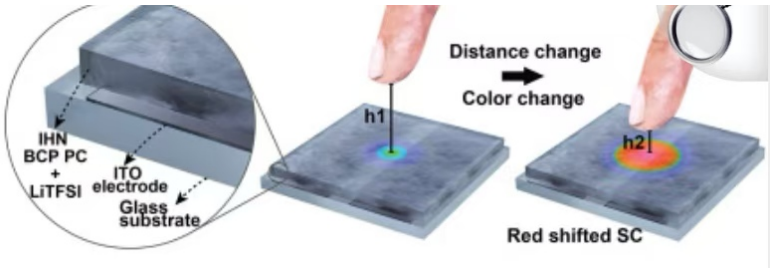

Figure 3. Structural color shift driven by finger proximity

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In addition, the system removes the requirement for physical contact and integrates sensing and visual feedback within a single BCP photonic film [10]. And the optical response directly reflects the spatial information of hovering fingers, allowing the same photonic layer to perform position recognition and visual indication without additional display components.

3.2. Self-powered finger motion sensor display

For dynamic interactions beyond simple touch detection, gesture recognition requires both motion sensing and visual feedback. Accordingly, Kim et al. reported a self-powered finger-motion-sensing display based on an interpenetrating hydrogel network block copolymer (IHN-BCP) film [7]. By combining triboelectric sensing with structural color modulation, the device enables real-time recognition and visualization of finger motions without external power input.

For gesture recognition, electrical signals provide quantitative information on finger motion. Specifically, finger movements, including sliding and tapping, generate distinct triboelectric signals, with voltage characteristics reflecting motion-related parameters such as speed and direction. These electrical outputs allow the device to distinguish different motion patterns.

Meanwhile, the photonic pathway converts the detected motion into visible patterns on the BCP film. The generated color distributions correspond to the location and trajectory of finger movement, enabling direct visualization of dynamic gestures. In addition, the temporary retention of structural color after stimulus removal provides a short-term memory effect, enabling reversible "erasable color writing" on the BCP film [7]. Similarly, Zhang et al. reported a related photonic encryption approach, in which temperature-dependent chirality inversion generates different optical states for authentication and decryption [11].

3.3. Sweat-responsive wearable structural color display

To enable wearable sensing with BCP photonic displays, material modifications are required to improve their response to physiological signals. For this purpose, Kim et al. incorporated single mobile ion (SMI) crosslinked polymers into a BCP ionogel matrix to enhance sweat electrolyte sensitivity [8]. As a result, this modification improved the ionic response of the film, enabling more effective detection of electrolyte-related changes.

Based on this improved ionic sensitivity, the modified ionogel supports dual-mode sensing by combining triboelectric signals with sweat-induced ionic responses. In this dual-mode configuration, mechanical interactions are detected through triboelectric outputs, while electrolyte variations from sweat provide additional chemical information. Meanwhile, the photonic structure converts these stimuli into visible color changes, allowing electrical and optical signals to be integrated within the wearable device.

To maintain device performance under mechanical deformation, the photonic film was further designed with a kirigami-patterned structure. In this design, the introduced cuts redistribute strain during stretching, thereby improving flexibility while preserving sensing and optical responses. The integration of ionically responsive BCP materials with strain-adaptive structures enables wearable structural color displays for simultaneous physiological monitoring and visual feedback [8].

4. Existing challenges and future directions in BCP photonic displays

For practical device applications, BCP photonic displays integrate self-assembly, structural color tuning, and interactive sensing within a single material platform. However, further development

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toward practical devices requires addressing limitations in response dynamics, device integration, optical control, and long-term stability.

In particular, stimulus-induced color modulation remains restricted by slow response speed. In current hydrogel-containing BCP systems, color switching is primarily governed by water or ion diffusion within the polymer network. Although structural color changes can occur within hundreds of milliseconds, achieving video-rate operation requires reducing the characteristic diffusion time [12]. Thus, possible strategies include decreasing active layer thickness, introducing hierarchical porous structures to accelerate transport pathways, or developing alternative actuation mechanisms such as electrically driven ion migration or electrothermal stimulation [13].

Furthermore, large-area, high-resolution display fabrication continues to face scalability issues. Although supramolecular assembly and BCP blending enable multicolor structural patterns, their application to addressable pixel arrays remains challenging [3, 4]. This requires flexible electrode architectures, scalable patterning techniques, and precise control of nanoscale domain orientation while maintaining mechanical compliance.

Moreover, the optical and mechanical stability of BCP photonic films remains a critical concern. The inherent viewing-angle dependence of structural color can be exploited for angle-sensitive encoding and sensing, but it also introduces challenges for uniform display performance [5]. In addition, long-term operation requires preventing delamination, irreversible swelling, and ionic liquid leakage through improved crosslinking strategies, encapsulation methods, and more stable ion-conducting materials.

Beyond touch sensing, BCP photonic platforms can be coupled with iontronic, electronic, and biointerface components for detecting multiple stimuli, like temperature, pressure, and biochemical signals [5, 14]. Further improvements in materials design and manufacturing processes will expand their applications in flexible displays, wearable sensors, and interactive interfaces.

5. Conclusion

BCP-based photonic films integrate sensing and display functions by combining triboelectric signal generation with stimulus-responsive structural color modulation. Through BCP self-assembly, the periodic nanostructure are tuned for optical responses, while hydrogel and ionogel incorporation enables mechanical and chemical stimulus detection. Thus, recent demonstrations of touchless 3D displays, self-powered gesture recognition, and sweat-responsive sensors show the integration of electrical sensing and visual feedback in a single BCP thin film. Despite these advances, several challenges remain before BCP photonic displays can achieve practical applications. Key challenges include response speed, large-area and high-resolution fabrication, and long-term optical and mechanical stability. Solutions such as optimized polymer architectures, accelerated ion transport pathways, scalable patterning methods, and robust encapsulation strategies are required to improve device performance. Future advances in material design and integration technologies will enable BCP-based photonic films to combine sensing, display, and wearable functions in a single flexible platform.

References

[1] Jung, H., Sim, S., & Lee, H. (2023). Biometric authentication security enhancement under quantum dot light-emitting diode display via fingerprint imaging and temperature sensing. *Scientific Reports, 13*(1), 794.

[2] Vogel, N., Utech, S., England, G. T., et al. (2015). Color from hierarchy: Diverse optical properties of micron-sized spherical colloidal assemblies. *Proceedings of the National Academy of Sciences, 112*(35), 10845-10850.

DOI: 10.54254/2755-2721/2026.36649

[3] Eoh, H., Jung, Y., Park, C., et al. (2022). Photonic crystal palette of binary block copolymer blends for full visible structural color encryption. *Advanced Functional Materials, 32*(1), 2103697.
[4] Deng, S., Deng, R., Mao, X., et al. (2023). Kinetically controlled supramolecular block copolymer self-assembly: Multicolor photonic crystal patterns from a single formulation. *CCS Chemistry, 5*(10), 2301-2311.
[5] Park, T. H., Yu, S., Park, J., & Park, C. (2023). Interactive structural color displays of nano-architectonic 1-dimensional block copolymer photonic crystals. *Science and Technology of Advanced Materials, 24*(1), 2156256.
[6] Ziegler, K., Schlichter, L., Post, Y., Gröschel, A. H., & Ravoo, B. J. (2024). Photoresponsive block copolymer nanostructures through implementation of arylazopyrazoles. *ACS Macro Letters, 13*(8), 1065-1071.
[7] Kim, T., Lee, J. W., Park, C., et al. (2022). Self-powered finger motion-sensing structural color display enabled by block copolymer photonic crystal. *Nano Energy, 92*, 106688.
[8] Kim, T., Park, T. H., Lee, J. W., et al. (2024). Self-powered sweat-responsive structural color display. *Advanced Functional Materials, 34*(22), 2314721.
[9] Tian, E., Wang, J., Zheng, Y., et al. (2008). Colorful humidity sensitive photonic crystal hydrogel. *Journal of Materials Chemistry, 18*(10), 1116-1122.
[10] Kang, H. S., Han, S. W., Park, C., et al. (2020). 3D touchless multiorder reflection structural color sensing display. *Science Advances, 6*(30), eabb5769.
[11] Sun, Y., Le, X., Shang, H., Shen, Y., Wu, Y., Liu, Q., ... & Chen, T. (2024). Dual-mode hydrogels with structural and fluorescent colors toward multistage secure information encryption. *Advanced Materials, 36*(28), 2401589.
[12] Kang, H. S., Park, C., Eoh, H., et al. (2022). Visualization of nonsingular defect enabling rapid control of structural color. *Science Advances, 8*(10), eabm5120.
[13] Zhang, Y., Tang, J., Chen, J., Zhang, Y., Chen, X., Ding, M., ... & Xue, G. (2023). Accelerating the solar-thermal energy storage via inner-light supplying with optical waveguide. *Nature Communications, 14*(1), 3456.
[14] Zhang, W., Min, J., Wang, H., Wang, H., Li, X. L., Ha, S. T., ... & Yang, J. K. (2024). Printing of 3D photonic crystals in titania with complete bandgap across the visible spectrum. *Nature Nanotechnology, 19*(12), 1813-1820.