Unveiling Mechanisms of Common Kingfisher’s Non-Iridescent Structural Colors and Proposing Innovative Biomimetic Approaches

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Avian structural colors possess inherent advantages over pigmented colors, including their ability to display vibrant hues in sunlight and their remarkable resistance to UV radiation, chemical degradation, and environmental factors [1]. Extensive research spanning several decades has been dedicated to the analysis of structural colors in avian feathers and the development of effective mimicking strategies [2, 3]. However, a comprehensive understanding of the precise mechanisms underlying the production of non-iridescent structural colors remains elusive because of their complex interaction between disordered nanostructures and light, so the mimicking strategies continue to pose ongoing challenges.

Therefore, the primary objective of this study was to address these scientific inquiries by characterizing the disordered nanostructures observed in avian feathers exhibiting non-iridescent color and to mimic the nanostructures and their structural colors in energy-efficient ways like nature. And among various birds, we focused on Common Kingfisher, which exhibited unusual interactions with light, unlike other avian feathers that produce various colors with different pitches, which are comparable with visible wavelengths. Through additional measurement with a scanning electron microscope (Jeol JSM-7100F) and optical simulation (Ansys Lumerical FDTD) of the nanostructures, it was found that the width of the keratin nanochannel undergoes changes rather than the pitch. This phenomenon occurs due to the presence of numerous air voids within the disordered nanochannel structure, which allows for a transition in color from dark blue (471 nm) to cyan (498 nm). Remarkably, these alterations in color occur while the pitch remains constant.

Based on the revealed mechanism, our study introduced novel strategies for color modulation of non-iridescent structural colors by precise control of nanostructures. The various artificial inverse photonic glass with distinct effective refractive indices were fabricated by self-assembly of polydisperse polystyrene nanoparticles (diameter of 243 nm) with a dip-coating method and by deposition of alumina through atomic layer deposition. By adjusting the deposition cycles from 50 to 300 cycles, we achieved different alumina thicknesses ranging from 15.6 to 32.5 nm, mimicking the Common Kingfisher’s mechanism. Consequently, the color transitioned from dark blue to cyan as the deposition thickness and effective refractive index increased. This bottom-up approach establishes an energy-efficient methodology that minimizes the need for synthesizing new nanoparticles and allows for facile post-modulation of nanostructures.

In conclusion, this study advances our understanding of non-iridescent structural colors in avian feathers by uncovering the underlying mechanisms and introducing innovative strategies for biomimicking the nanostructures. The findings contribute to the growing body of knowledge in this field, with implications for applications in optics, biomimicry, and materials science.
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