https://doi.org/10.1017/S1551929518000494 Published online by Cambridge University Press

Carmichael's Concise Review

Would You Expect to Find the Smallest Natural Rainbow on a Spider?

Stephen W. Carmichael
Mayo Clinic, Rochester, MN 55905

carmichael.stephen@mayo.edu

Color produced by wavelength-dependent light scattering is a key component of visual communication in nature and plays a particularly important role in visual signaling by structurally colored animals during courtship. This is true in the avian peacock and its namesake, the male rainbow peacock spider. *Maratus* is a spider genus of the family Salticidae (jumping spiders), which are commonly referred to as peacock spiders. Recently an international, multi-disciplinary team headed by Bor-Kai Hsiung [1] used scanning electron microscopy (SEM) and transmission electron microscopy (TEM) to determine what is responsible for the rainbow-hued visible light signal from two species of these spiders, *M. robinsoni* and *M. chrysomelas*.

Both species have two types of visually distinct abdominal scales: rainbow-iridescent scales and velvet black scales. SEM revealed that the black scales are brush-like and randomly oriented, whereas the iridescent scales are aligned in a more orderly fashion (Figure 1a). At higher magnification, SEM showed the

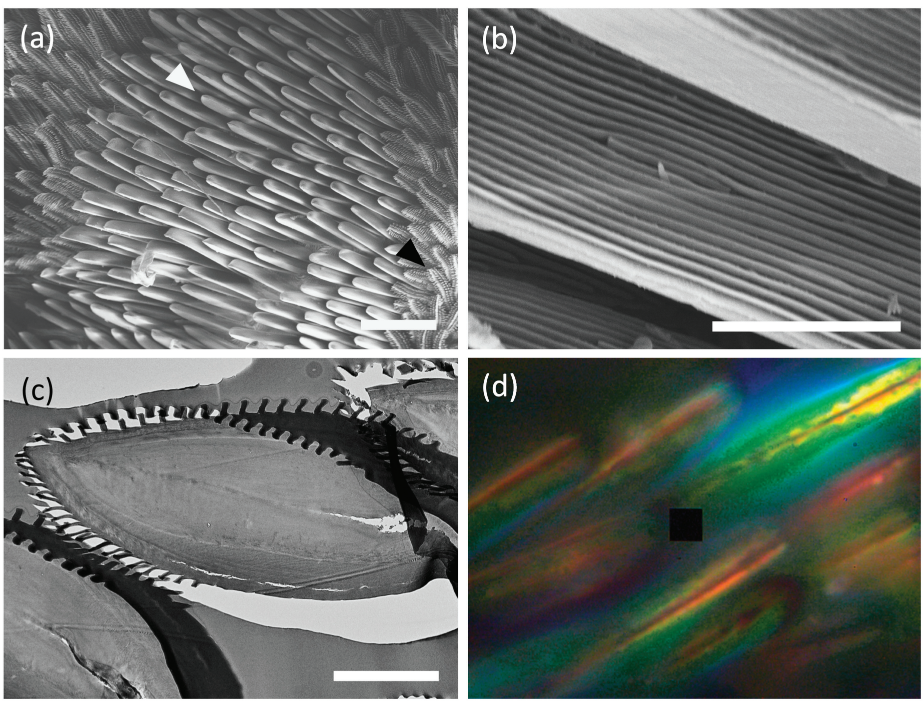

Figure 1: Male rainbow peacock spider *M. robinsoni*. (a) SEM image of iridescent scales (white arrowhead) and black scales (black arrowhead). Scale bar = 200 µm. (b) SEM image showing periodic grating structures on the surfaces of the iridescent scales. Scale bar = 5 µm. (c) TEM image showing regular binary-phase surface gratings on the surface of a scale with an airfoil profile. Scale bar = 5 µm. (d) Visible light image showing that each iridescent scale (about 40 µm × 10 µm) hosts two microscopic rainbows (center black square is 4 µm × 4 µm). Images courtesy of Bor-Kai Hsiung.

doi:10.1017/S1551929518000494

https://doi.org/10.1017/S1551929518000494 Published online by Cambridge University Press

iridescent scales have parallel grating structures on each individual scale. The gratings were more regularly spaced on the scales of *M. robinsoni* (Figure 1b). It is probably not a coincidence that the iridescence is more intense on this species. TEM of the transverse section of the iridescent scales revealed a complex structure that had the profile of an airfoil. The surfaces of airfoil-shaped scales are covered by prominent binary-phase grating structures (Figure 1c). The grating configuration of each scale on the *M. robinsoni* disperses the visible spectrum over a small angle, such that at short distances the entire visible spectrum is resolved, and a static microscopic rainbow pattern distinctly emerges (Figure 1d). Based on the SEM/TEM images, Hsiung et al. hypothesized that the acute angle-sensitive rainbow-iridescence of these male spiders results from the interaction of the surface nanograting and microscopic airfoil-shape of the scales. The investigators also used analytical and finite-element optical simulation to identify the mechanism of color production.

Since controlling light through photonic micro- and nano-structures is vitally important in human technology (such as communications, security, computing, etc.), Hsiung et al. attempted to fabricate structures with the properties exhibited by these spiders. They used two-photon nanolithography, which is essentially miniaturized 3D printing, to closely replicate the optical properties of the spiders.

To appreciate the role of these properties in peacock spider courtship, it is helpful to visualize the small size of these spiders. They are about 2.5 mm in length, which is about the thickness of a nickel coin. The male wiggles his abdomen in the presence of a potential mate thereby displaying the full rainbow—which must be one of the smallest found in nature. It is the first rainbow-iridescent signal in nature to be identified and is likely a direct product of sexual selection through female choice.

Whereas these observations are interesting, the more important contribution of this study is the inspiration this natural structure provides for manufacturing a structure to mimic it. This powerful bioinspired approach could allow engineers to design and develop optical devices, especially spectrometers that far exceed the capability of any current device. Such improvements would have significant impact on fields ranging from life sciences and biotechnology to materials science and engineering. [2]

References

[1] B-K Hsiung et al., *Nat Commun* 2278 (2017), DOI 10.1038/s41467-017-02451-x.

[2] The author gratefully acknowledges Dr. Bor-Kai Hsiung for reviewing this article.

MT