Electronic Supplementary Material (ESI) for Soft Matter.

Supplementary Information

Broadband Omnidirectional Light Reflection and Radiative Heat Dissipation in White Beetles *Goliathus goliatus*

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Supplementary Figures

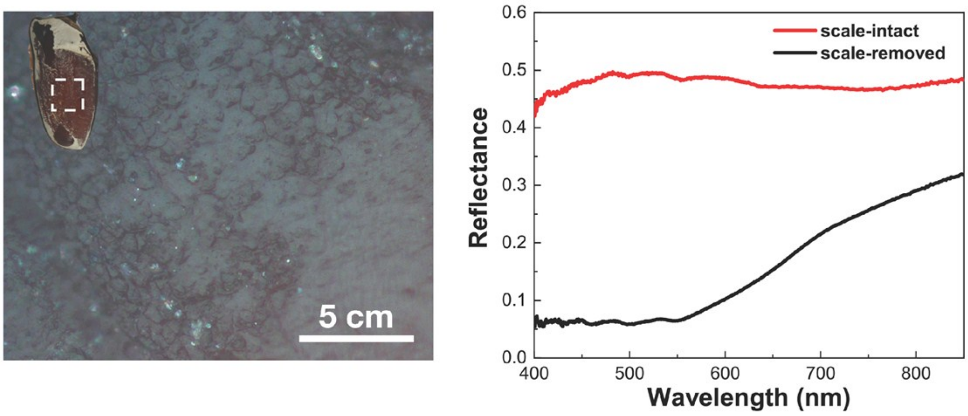

Fig. S1 Optical property of the elytra after the removal of white scales. Scales on elytra were removed by surgical knife and rinsed with ethanol solution to remove the surface impurities. The result shows that after the removal of white scales, the brown exocuticle was exposed to air and the reflection decreased from ~ 47% to ~ 16%.

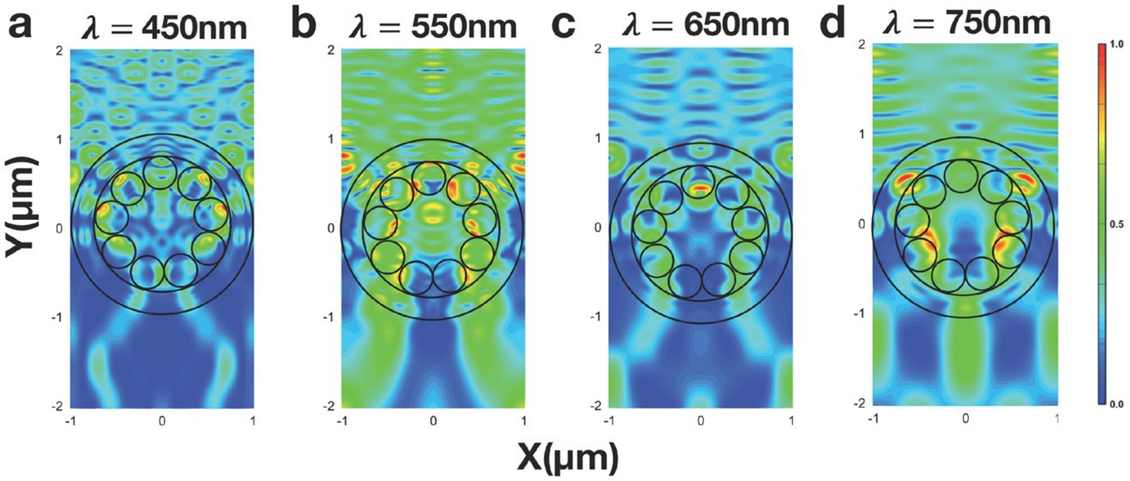

Fig. S2 Mie resonance and total reflection in the shell/hollow cylinders structure. Cross-sectional view of a two-dimensional distribution of a light field around a shell/hollow cylinders under the wavelength of (a) 450nm (b) 550nm (c) 650nm (d) 750nm. The results show that multiple Mie resonance peaks around interior hollow cylinders in the shell/hollow cylinders structure. Combined with Fig. 3d, the shell/hollow cylinders structure can increase the reflection through total reflection.

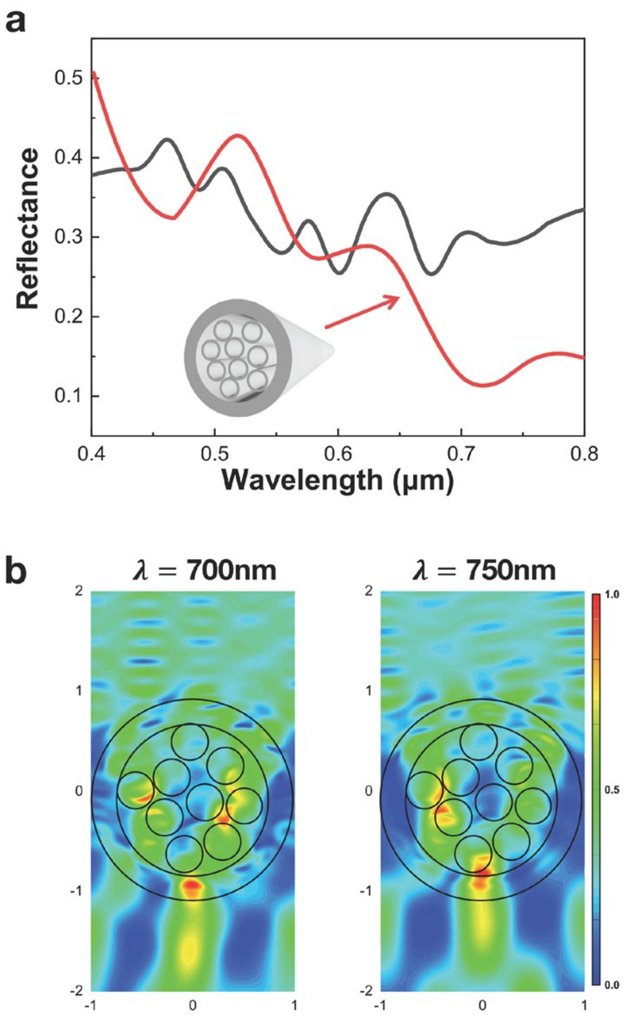

Fig. S3 Randomly distributed major air voids in the shell/hollow cylinders structure. (a) Simulated reflectance spectra of the shell/hollow cylinders structure (black) and randomly distributed air voids structure (red). (b) Poynting vector maps of randomly distributed air voids structure under 700 nm and 750 nm incident light. When the major air voids are randomly distributed in the structure, the broadband reflection is remarkably lower in visible light regime and light transmit the shell/hollow cylinders structure. Therefore, the total reflection is partially attributed to the major air when they are packed around the exterior shell.

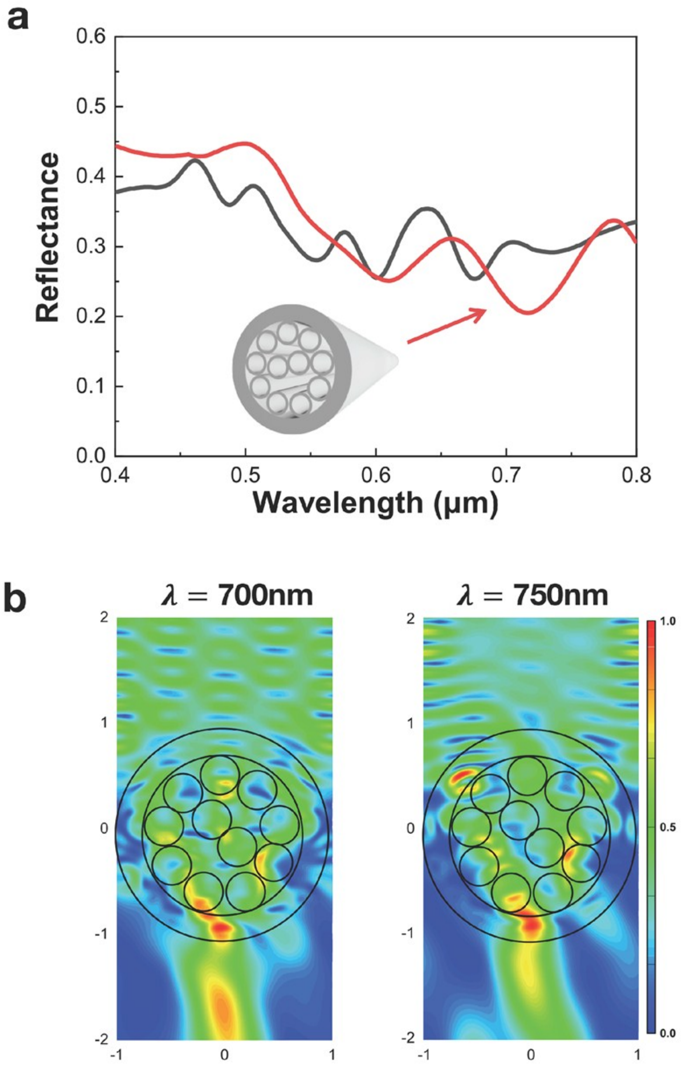

Fig. S4 Effect of the central air void in the shell/hollow cylinders structure. (a) Simulated reflectance spectra of the shell/hollow cylinders structure (black) and porous structure with additional air voids in center (red). (b) Poynting vector maps of randomly distributed air voids structure under 700 nm and 750 nm incident light. In comparison with the original structure, reflection in the long wavelengths regime is lower. Great transmission of ~ 700 nm light was observed. It is evident that the central void plays an imperative role in improving the reflectance in the long wavelength range.

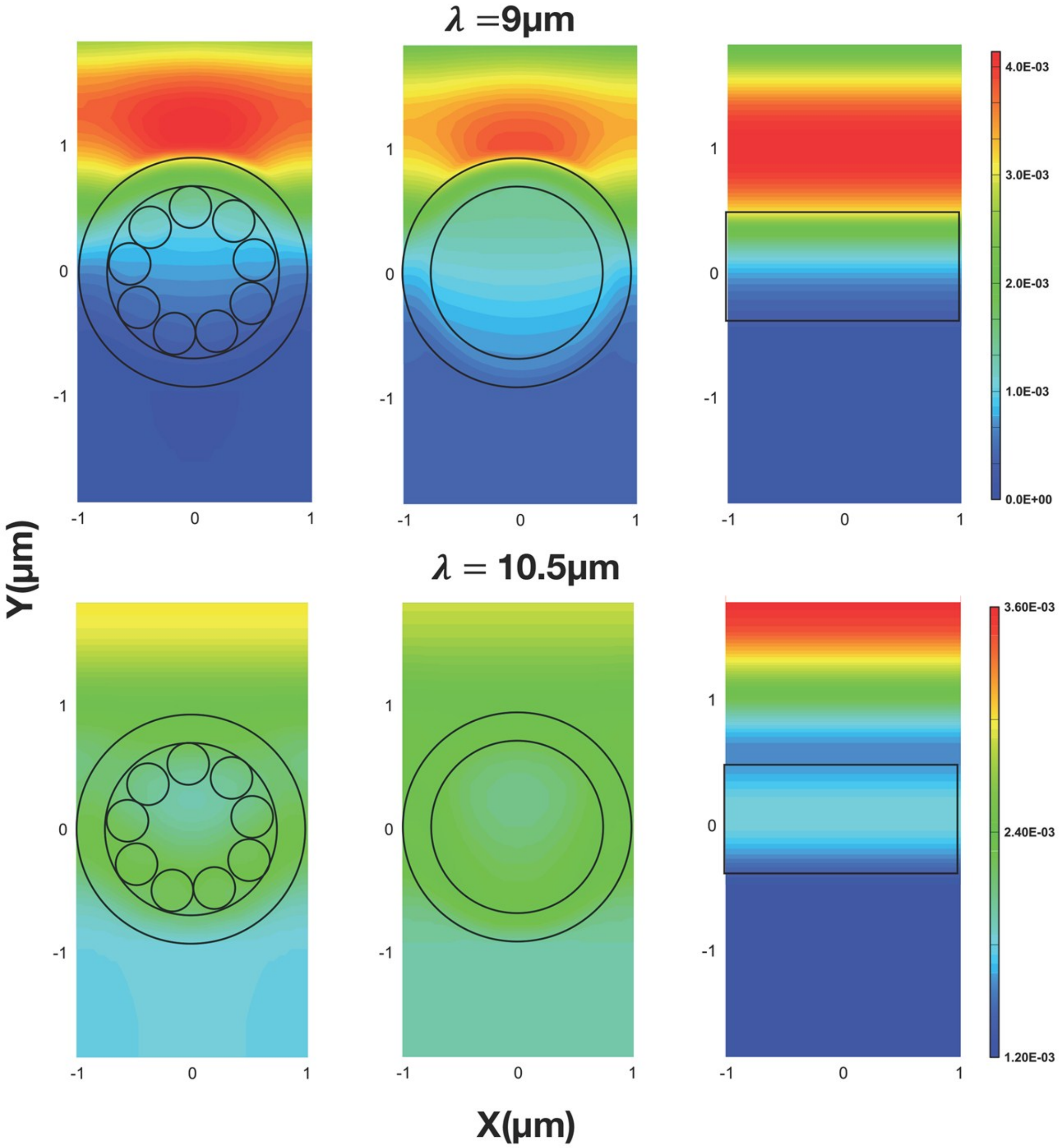

Fig. S5 Analysis of MIR antireflective property in the scales. Poynting vector maps of three structures under (a) 9μm and (b) 10.5μm incident light. Compared with the simple slab, the shell/hollow cylinders structure and shell structure both possess the continuous refractive index gradient between air and medium. As shown in the Poynting vector maps, the shell/hollow cylinders structure and shell structure adsorb more MIR light rather than reflect. Moreover, the intensity of reflected MIR light above the shell/hollow cylinders structure and shell structure is lower than that of the slab, clearly indicating the MIR antireflective property.

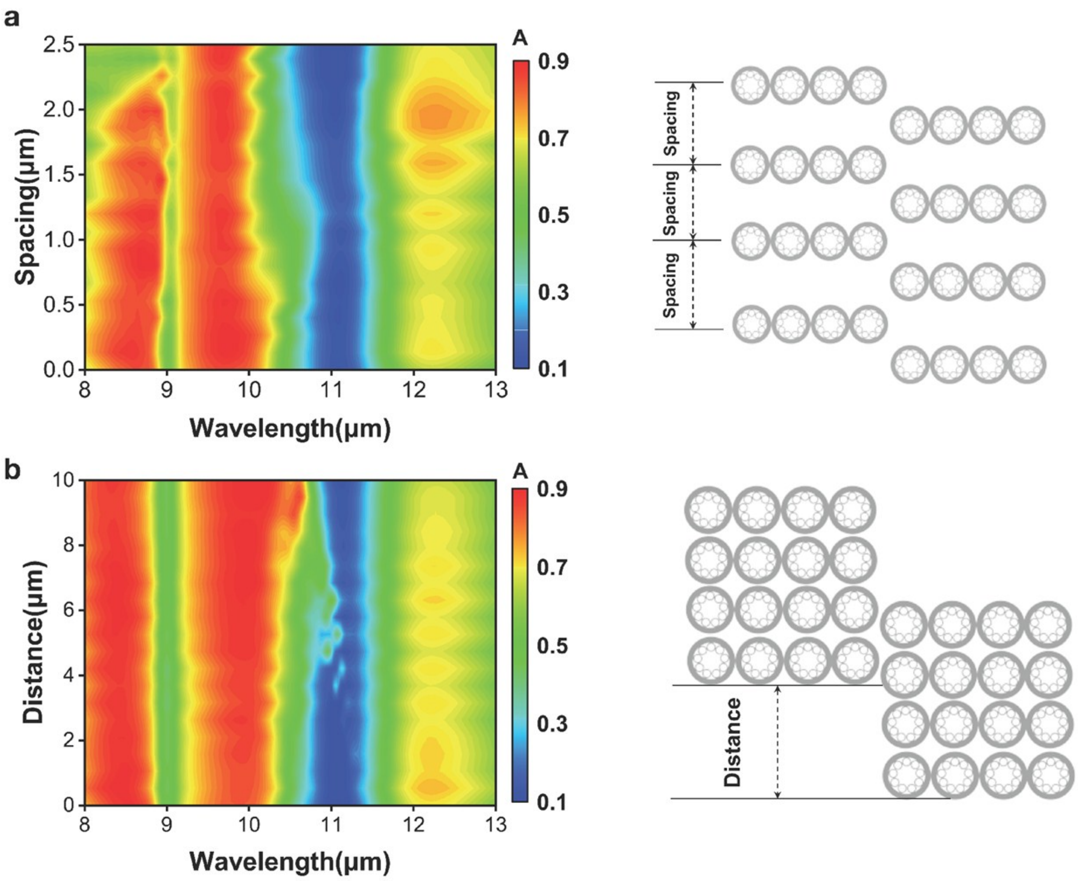

Fig. S6 Analysis of the influence of the arrangements in the scales. Spectral color maps of the shell/hollow cylinders layers as a function of (a) spacing and (b) distance. Although different arrangements of scales produce a structure that is comparable to MIR wavelength, we found that spacing and distance between scales layers only influence the absorption performance slightly in MIR range.

Supplementary Tables

Table S1 Values of dimensions in Fig. 3a.

	D	d	t	t’
Value (μm)	2	0.26	0.25	0.06

Table S2 IR absorption wavelengths of molecular vibration mode in chitin[1].

Molecular Vibration	C-O stretching	C-N stretching	aromatic C-H bending	S=O stretching
Wavelength(μm)	7.7-10	8.2-9.8	7.8-14.5	9.4-9.8

Supplementary Notes

Note S1 Heat transfer calculation.

Thermal transfer at equilibrium state in our thermodynamic experiment can be described by the following equation[2]:

$$C\frac{dT}{dt} = \varepsilon\sigma T^4 s - \alpha P s - \alpha'\sigma T_a^4 s + hs(T - T_a) \tag{1}$$

C dT/dt is the pure rate of change in thermal energy, C is thermal capacity of butterfly wing. $\boldsymbol{\varepsilon\sigma T^4 s}$ is the radiative power emitted by specimen, ε is the emissivity averaged over the surface of specimen, σ is the Stefan-Boltzmann constant 5.67×10^{-8} W $\mathrm{m}^{-2}\mathrm{K}^{-4}$, T is the temperature of the specimen. $\boldsymbol{\alpha Ps}$ is the absorbed light source power, α is the absorptivity over the spectrum of light source medially, P is the intensity of light incident on the specimen, s is the surface area of specimen. $\boldsymbol{\alpha'\sigma T_a^4 s}$ is the incident environmental radiation absorbed by butterfly wing, α' is the averaged absorptivity for environment and T_a is the environmental temperature. $\boldsymbol{hs(T-T_a)}$ is power transferred through thermal convention, h is the heat transfer coefficient.

In order to simplify the calculation, we used the average temperature $\overline{T}$ to linearize the first term of equation (1) in right part:

$$\varepsilon\sigma T^4 s = \varepsilon\sigma s(T + \overline{T} - \overline{T})^4 = \varepsilon\sigma s\overline{T}^4(1 + \frac{T - \overline{T}}{\overline{T}})^4 \approx 4\varepsilon\sigma s\overline{T}^3 T - 3\varepsilon\sigma s\overline{T}^4 \tag{2}$$

Allowing for the radiation from environment was small compared with that from light source and the vacuum condition in experiment, equation S3 can be rewritten as

$$C\frac{dT}{dt} = 4\varepsilon\sigma s\overline{T}^3 T - (3\varepsilon\sigma s\overline{T}^4 + \alpha P s) \tag{3}$$

Solve this differential equation, the temperature T of specimen can be expressed as

$$T \propto \pm\exp(\frac{4\varepsilon\sigma s\overline{T}^3}{C}t) \tag{4}$$

where

$$\tau = \frac{C}{4\varepsilon\sigma s\overline{T}^{3}} \tag{5}$$

is the time constant characterizing the temperature change of specimens.

Supplementary Movies

Movie S1 The whiteness reappeared on the surface of scale as ethanol solution evaporated.

References

1. B. Stuart, *Kirk-Othmer Encyclopedia of Chemical Technology*, 2000, 1-18.
2. N. N. Shi, C.-C. Tsai, F. Camino, G. D. Bernard, N. Yu and R. Wehner, *Science*, 2015, **349**, 298-301.