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Experimental Investigation of the Structural Coloured Reflections from Elytra of the *Megacephala Regalis Citernii*

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Abstract: This article is devoted to the study of the structural layers origin of the mixed color blue, yellow-green and red reflections from elytra of the *Megacephala Regalis Citernii*, a bug species. So, we proceed by scanning electron microscope (SEM) and spectrophotometry characterization of these layers to explain the origin of the mixed color blue, yellow-green and red of the elytra. We also use a numerical method to simulate the spectrum measured. Indeed, the measurements spectrum gives three main pic reflectance wave length is respectively: λ_1 = 491,5 nm, λ_2 = 624,5 nm, and λ_3 = 654,5 nm and are the area of the color of blue, yellow-green and red. The calculation of the dominant wavelength is estimated at λ_1 = 515 nm, λ_2 = 551,04 nm; λ_3 = 621,68 nm. The numerical results show also three main peak at the spectrum calculation: λ_1 = 493 nm, λ_2 = 581,2 nm, λ_3 = 625,68 nm. These results confirm that structure responsible the mixed color of the elytra of the *Megacephala Regalis Citernii*, is a multilayer. Finally, these multilayers are iridescent. It is possible to consider artificial reproduction for the multilayer through a process of deposits in order to manufacture materials at nanometer scale with selective reflection.

Keywords: Reflectance, Structural Color, Iridescent

1. Introduction

Over millions of years of evolution, nature has developed an enormous variety of microstructures present in the cover tissues of insects and animals, plants and that interact with the incident light and give rise to attractive structural colors [1-3]. Optical mechanisms such as multilayer interference, scattering, and diffraction often govern the reflected response of such tissues, thus producing remarkable effects such as iridescence and metallic appearance [4-6]. In the study of the complex color form living organisms, by the natural world, that we are interested a bug, called *Megacephala Regalis Citernii*. The back face of the bug is characterized by two pairs of membranous wings protected by elytron. This elytron has a green metallic color ranging from blue to yellow green. Generally, this color is due to its multilayers. The color of the *Megacephala Regalis Citernii* plays an important role in the insect's life in its environment. The color shows the family membership and it helps in ensuring the species' reproduction. Therefore, an insect with many colors is genetically better fit for its race. The color enables one differentiate between the male and female. The objective of the male is to attract the female with its rich genetic. These, therefore, to its colors. On the other hand, the female is more discreet, and less colored, so as to escape predators. *Megacephala Regalis Citernii* is a phytophagous insect [7-9]. This specimen is from the collection of the Natural Historie Museum of Burkina Faso National Centre for Scientific Research and Technology. The long storage period in the museum hasn't altered the elytron color of the *Megacephala Regalis Citernii*. This, however, is a further evidence of a structural coloring, which is contrary to pigment coloring. Indeed, the pigment coloring is sensitive to ultraviolet. This makes it very degradable during storage. Also, the multilayers are interesting in trapping nanometer scale light. Today, with the Nano-photonic group deposition methods, they can make new materials. During our study, we are investigating the origins of the metallic green coloring of the elytra. For this, we use an experimental approach by the Spectrophotometer and the Scanning Electron Microscope (SEM). Finally, we use matrix transfer method to modeling measured spectrum.

2. Scanning Electron Microscopy Observations

Scanning Electron Microscopy SEM (3D Laser Scanning Microscope. VK-X100/X200 Series. Keyence-VK-X100). The high resolution allows us to both observe and measure the structures that cause the coloring phenomena of *Megacephala Regalis Citernii*. During the review with SEM, samples of 0.20 x 0.20 cm are subject to electronic load bombarding**.**

Figure 1. *Image Megacephala Regalis Citernii. The complex pattern of colors of this insect contains iridescent parts which, according to the viewing and illumination angles appear.*

The SEM observations at very low scale of a piece of the scales of *Megacephala Regalis Citernii* elytra show a stack of layer of heterogeneous and parallel length, with respective thickness of $\eta_1 = 116.3\,\mu m$. $\eta_2 = 128.6\,\mu m, \eta_3 = 123.6\,\mu m$ are represented in Figure 2. These different layers are composed of chitin and chitin-air mixed layers. The number of layers is estimated to 16 to 20, which means there is a multilayer.

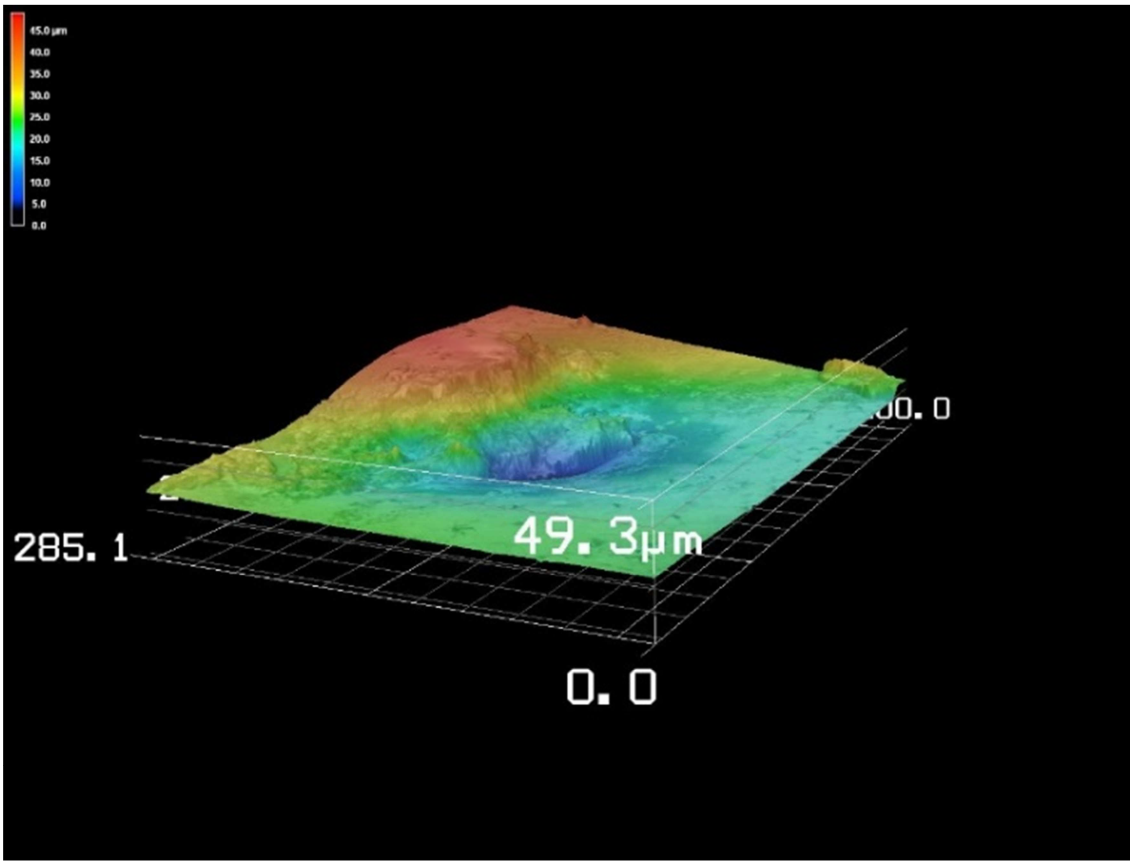

Figure 2. *Observed SEM image of the elytra in 3D.*

The SEM image analysis shows that the multilayer structure is responsible for the mixed color of the *Megacephala Regalis Citernii* elytra. This is a very thin membrane about 200 nm. Also, we notice three colors from the SEM image in Figure 2. This mixed color is blue, yellow-green and red. This multilayer have an interesting property because it diffuses part of the rays to its surface but also inside; the refracted rays are diffused toward the outer surface.

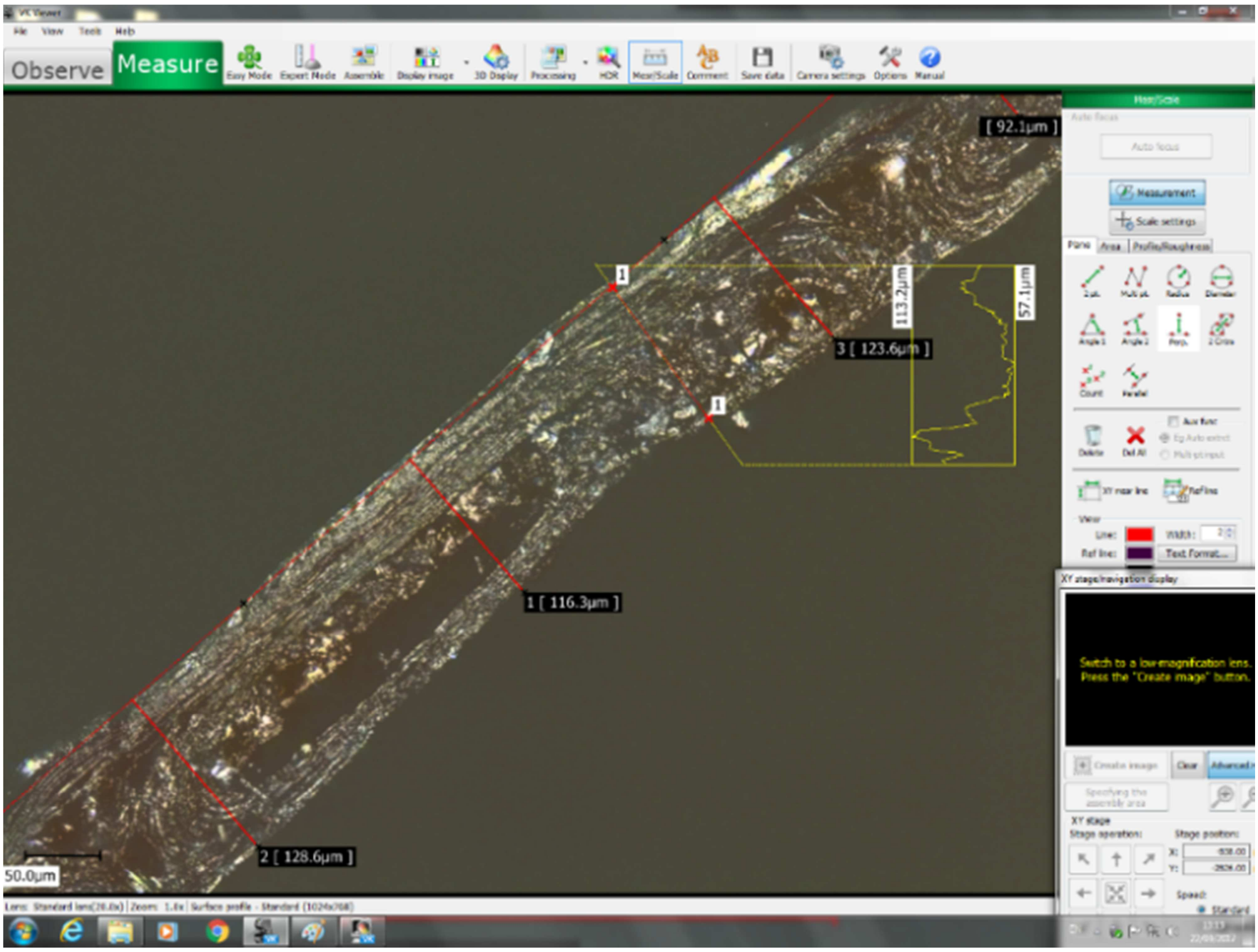

***Figure 3.** Observed SEM image profil of the elytra.*

2.1. Spectroscopic Measurements

A dry sample of the dorsal area of *Megacephala Regalis Citernii* is collected and analyzed in a spectrophotometer-Avaspec-2048 optical fiber. The spectral range of this unit extends from 250 nm to 900 nm. Its main advantage is its ease of use and speed of acquisition of the spectrum. Indeed, the entire spectrum, reflectance or transmission is achieved instantly. In the case of Avaspec-2048, the reference is a white diffuser and the material of reflectance spectrum is greater than 98% in the visible spectra. The measurements are performed on samples of 0.20 x 0.20 cm that are cut in the dorsal elytra surface of the *Megacephala Regalis Citernii* specimen. We measure the sample spectrum for incidence angles θ=0° to 60°, used to find the reflected or transmitted intensity. We present results for θ=35° and θ=45° because, if θ< 35° and θ> 45°, we don't have additional information. Figure 3 shows spectrum for a piece of dorsal scales of *Megacephala Regalis Citernii* elytra. We notice three main peaks representing the three colors of Figure 2. The dominant reflected wavelength is respectivly $\lambda_1 = 491{,}5\,nm$, $\lambda_2 = 624{,}5\,nm$, and $\lambda_3 = 654{,}5\,nm$. If we compared the reflected wavelength to the chromaticity diagram established by the International Commission on Illumination. We can determinate the differents colors form the elytra. We have three reflected colors, the blue, yellow-green and red.

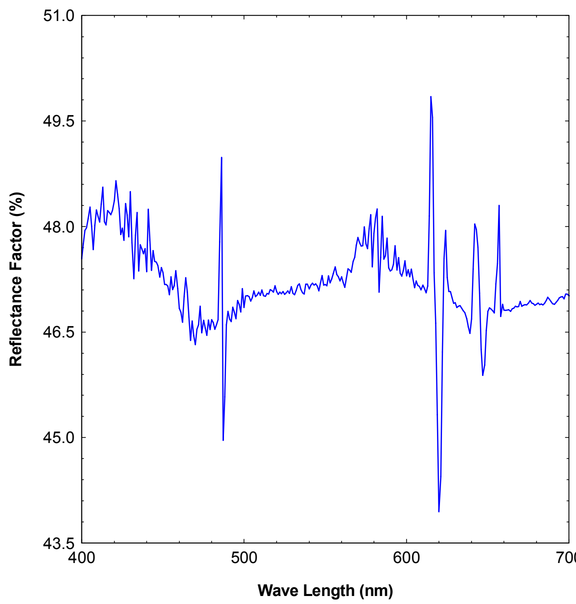

***Figure 4.** Megacephala Regalis Citernii reflectance spectrum measured at an incident angle θ=35°.*

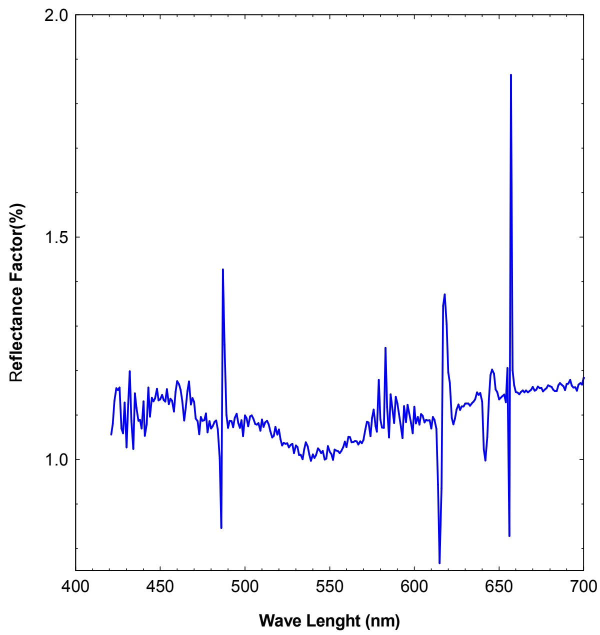

Figure 5. *Megacephala Regalis Citernii reflectance spectrum measured at an incident angle θ=45°.*

2.2. The Dominant Reflected Wavelength

It is possible to determine the dominant wavelength reflected from the multilayer Megacephala Regalis Citernii, by the following formula [10-12]:

$$\lambda_1 = \frac{2\omega_1\sqrt{\bar{n}^2 - sin^2\theta}}{m} \quad (1)$$

$$\lambda_2 = \frac{2\omega_2\sqrt{\bar{n}^2 - sin^2\theta}}{m} \quad (2)$$

$$\lambda_3 = \frac{2\omega_3\sqrt{\bar{n}^2 - sin^2\theta}}{m} \quad (3)$$

Note that θ=45° is defined as an angle of incidence relative to the surface of the multilayer. The period is determined by using SEM images, ω_1=185 nm, ω_1=195 nm, ω_1=225 nm, with the different thickness of the multilayer: $\eta_1 = 116.3\,\mu m$. $\eta_2 = 128.6\,\mu m, \eta_3 = 123.6\,\mu m$. We use the values of thicknesses supplied by the SEM images and the dielectric constants found in the literature for air and chitin. In real, we don't proceed with the refractive indices, but with dielectric constants. For the next step, we combine the different thicknesses with the periods. So, we suppose $\bar{n}$=$\bar{\varepsilon}$, with $\bar{n} =$ average refractive indices and $\bar{\varepsilon} =$ Dielectric constant average. Then $\bar{n} = \sqrt{\bar{\varepsilon}}$. $\bar{n} = 1.58$. Also, $m = 1$ (m is a integer). The wavelength is estimated at λ_1 =515 nm, $\lambda_2 = 551{,}04\,nm$; $\lambda_2 = 621{,}68\,nm$ and remains in the area of the color of blue, yellow-green and red [13, 14].

The calculation of the dominant wavelength in reflection gives a result that is fairly close to the results of measurements. It only allows us to account for the main peak of the reflectance spectra, and beyond this value no wave reflection is possible; it is also called the Bragg mirror. For the modeling method, we use the method of transfer matrices to numerical reproduce the reflectance spectrum of the. The method involves solving Maxwell's equations, which reveals a possible separation of the field components. This is a Magnetic Transverse Mode (MTM) and the Electric Transverse Mode (ETM) [15, 16]. Knowledge of the transfer matrices of the two polarization modes ETM and MTM are used to calculate the coefficients of reflectance and transmittance.

A computer code was developed to calculate the reflectance and the transmittance spectrum of the multilayer [17]. The numerical modeling results by the above method are presented in Figure 6 shows the results of the numerical calculations. The main peak was estimated at $\lambda_1 = 493$ nm, $2 = 581{,}2\,nm, \lambda_1 = 625{,}68\,nm,$ which is within the range of blue, yellow-green and red.

The Figure 6 shows the two comparative results of experiments spectrum and calculations spectrum. We contact a good agreement. The difference between the spectrum measured and calculated can be explained by the disorder present in the real structure, responsible for the variation of thickness and refractive indices of the multilayer. The numerical method confirms that the multilayer observed with the SEM is responsible for the mixed color, blue, yelow-green and red of Megacephala Regalis Citernii elytra.

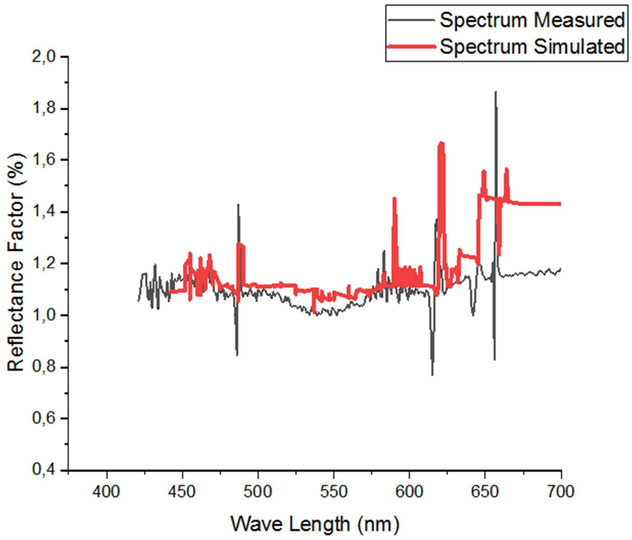

Figure 6. *Megacephala Regalis Citernii reflectance spectrum measured and simulated at an incident angle θ=45°.*

3. Conclusion

In conclusion, the investigation of the elytra color from *Megacephala Regalis Citernii* show a mixed of blue, yellow-green and red color. The SEM image in 3D also shows a multilayer is the structural responsible the coloration. The images allow highlighting the structure which is at the origin of the coloration. This structure is thin with about 200 nm and iridescent under incident angle observation. After the SEM, we use the spectrophotometer measurements the reflectance wave length. In the case *of Megacephala Regalis Citernii*, we show three main peak at incident angle *θ=45°*. The three main pic reflectance wave length is respectively: $\lambda_1 =$

$491{,}5\ nm$, $\lambda_2 = 624{,}5\ nm$, and $\lambda_3 = 654{,}5\ nm$ and are the area of the color of blue, yellow-green and red. The calculation of the dominant wavelength is estimted at $\lambda_1 = 515$ nm, $\lambda_2 = 551{,}04\ nm$; $\lambda_3 = 621{,}68\ nm$ and remains in the area of the color of blue, yellow-green and red. The numerical results show also three main peak at the spectrum calculation: $\lambda_1 = 493$ nm, $\lambda_2 = 581{,}2\ nm, \lambda_3 = 625{,}68\ nm$, which is within the range of blue, yellow-green and red. We think that this result is a good agreement between experimental and numerical methode. Finally, we can consider the reproduction of the visual rendering of multilayer of the *Megacephala Regalis Citernii* elytra, by deposition techniques to achieve an artificial multilayer.

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