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Research on surface lossy electromagnetic scattering of the scales of *Morpho rhetenor* butterflies

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ABSTRACT

In view to the attenuation of the electromagnetic (EM) wave propagating energy in media, the EM scattering of the simple model of the iridescent tropical butterfly *Morpho rhetenor* in visible light irradiation is investigated by using finite-difference time-domain (FDTD) method, combined with extensive surface technique. And it is compared with that of the lossless media, and prospective scattering characteristics are verified. As the scattering performance of the structure is characteristic with not only the structural stealth but also the material stealth characteristic, taking all kinds of factors that influence the properties of the media into account, it will help to accurately select and develop late-model high performance stealth material to make a further investigation.

1. Introduction

Many organisms in nature show or control their own colors via characteristics to light owned by their complex structure. Further study indicates that the color is formed by the physical action like diffraction or interference on light with its own structure, generally called "structural color" [1,2], rather than by absorbing the light and so on. The structural color's study has caused widespread concern around the world since mid-17th century, especially in recent years, with the development of science and technology and the production of new research tools such as electron microscopy, the study gets more mature and scientific.

Recent years, *Morpho rhetenor*, a kind of tropical butterfly draws scientists' attention. The study found that the wings of the butterfly can emit brilliant blue under the irradiation of natural light. By observing the structure of the butterfly's wings with electron microscopy and testing its scattering properties, scientists found the following characteristics [3]: (1) When the natural light irradiates perpendicular to the wings which are only in the offset 30–60° range, the scattering is stronger and the back scattering is weaker; (2) The blue light reflection is stronger just for the lights whose wave lengths are less than 550 nm, or the electromagnetic scattering is relatively weak, when the wave lengths are more than 550 nm.

Research on the loss-less scattering properties of this blue butterfly microstructure has been conducted using finite-difference time-domain (FDTD) method [4], proving the features character of blue butterfly structure above. But in general, the medium has conductivity, $\sigma \neq 0$, since the certain lossy of the actual medium even when the electromagnetic wave propagates. Electromagnetic wave's propagation in a medium has a certain energy loss. This article studies the loss electromagnetic scattering properties of the blue butterfly wing structure by finding the relationship between conductivity and refraction rate. Then the author compares them with that of the lossless one. By doing the research, we can understand and optimize the electromagnetic scattering characteristics of the periodic structure and make it share both advantages of modern stealth technology called architecture stealth and materials stealth. The research can also provide scientific reference for the development of new stealth materials in a long way.

In this paper, the author analyzes and calculates the Radar Cross Section (RCS) of tropical blue butterfly *M. rhetenor* in loss situation by using FDTD method. Take the perfectly matched layer (PML) and large-surface technique to truncate the computational domain and study the RCS electromagnetic scattering characteristics of the blue butterfly structure under two-dimensional electromagnetic wave's irradiation [5,6]. Compare the results with that of the lossless ones, proving the structure has the features above.

2. Structural analysis of tropical blue butterfly *Morpho rhetenor*

In natural light irradiation, tropical blue butterfly *M. rhetenor*'s wings present gorgeous blue, shown in Fig. 1 [3]. In 1999, Vukusic

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Fig. 1. *Morpho rhetenor* sample.

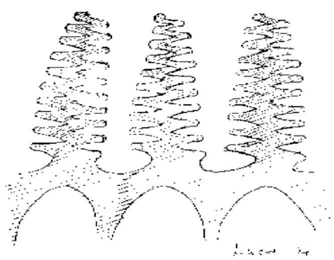

Fig. 2. The section figure of the *Morpho rhetenor*'s wings under the electronic microscope.

found that there is a ridge structure layer periodically arranged like the pine on blue butterfly's wings with an electronic microscope. It is measured by experiments that the cycle interval of these tree ridge is (675 ± 75) nm. On both sides of each ridge there are approximately ten layers of branches whose thickness is about 90 nm arranging in equal intervals. The intervals between the sticks are also about 90 nm, shown in Fig. 2 [3].

Since the structure's length on the cross section larger than the height and the cycle of ridge, it can be simplified as a two-dimensional model. Based on the experiments done by Vukusic et al., in 2004, Luca Plattner and his partner calculated and analyzed the structure of *M. rhetenor*'s wing using numerical methods. Four computing models are given to simulate the structure based on the previous experimental results. The results are acquired using electron microscope and laser camera and processed according to the statistical law. The models are shown in Fig. 3 [7].

In Fig. 3, the ten-storey, seven-column black rectangular portions equivalent to the ridged structure medium on the blue butterfly's wings, its refraction rate for light is [3]: $n = (1.56 \pm 0.01) + (0.05 \pm 0.01)i$, the rest is air. Fig. 3 shows four different models: Model (I), whose inter-column spacing and the dielectric block length are 675 nm in total, is shown in Fig. 3(a). The thickness of the dielectric block and the air in between are both 90 nm. Model (II) shown in Fig. 3(b) is different from model (I) in that the length of the rectangular block in each layer decreases by step with the symmetry axis of its perpendicular bisectors. Model (III) shown in Fig. 3(c), differs from the first one, its blocks, placed in stagger and all half-the-length compared with in Model (I), are in the same size. Model (IV) in Fig. 3(d) can be seen as each column of model (II) being divided into two parts according to the perpendicular bisectors and then placed in stagger. In Fig. 3(a) and (c), medium parts accounts for 30% of the total space, while in Fig. 3(b) and (d), it accounts for 16.75%.

3. FDTD method

In isotropic homogeneous medium, the differential Maxwell equations and constitutive relations are: [8–10]

$$\nabla \times \mathbf{H} = \frac{\partial \mathbf{D}}{\partial t} + \mathbf{J} \tag{1}$$

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t} - \mathbf{J}_m \tag{2}$$

$$\mathbf{D} = \varepsilon \mathbf{E}, \quad \mathbf{B} = \mu \mathbf{H}, \quad \mathbf{J} = \sigma \mathbf{E}, \quad \mathbf{J}_m = \sigma_m \mathbf{H}, \tag{3}$$

where ε is the dielectric constant, μ is permeability, σ is electrical conductivity, σ_m is the permeability, all the above are scalars. The scattering properties of lossy medium and lossless medium are discussed in this article, and the complex permittivity is introduced. For lossless media, the imaginary part of the complex permittivity is zero.

Transform formulae (1) and (3) from time domain to frequency domain:

$$\nabla \times \mathbf{H} = j\omega\varepsilon \mathbf{E} + \sigma \mathbf{E} = (j\omega\varepsilon + \sigma)\mathbf{E} = \tilde{\varepsilon}\mathbf{E} \tag{4}$$

In the lossless medium, $\sigma = 0$, formula (4) can be changed into:

$$\nabla \times \mathbf{H} = j\omega\varepsilon \mathbf{E} \tag{5}$$

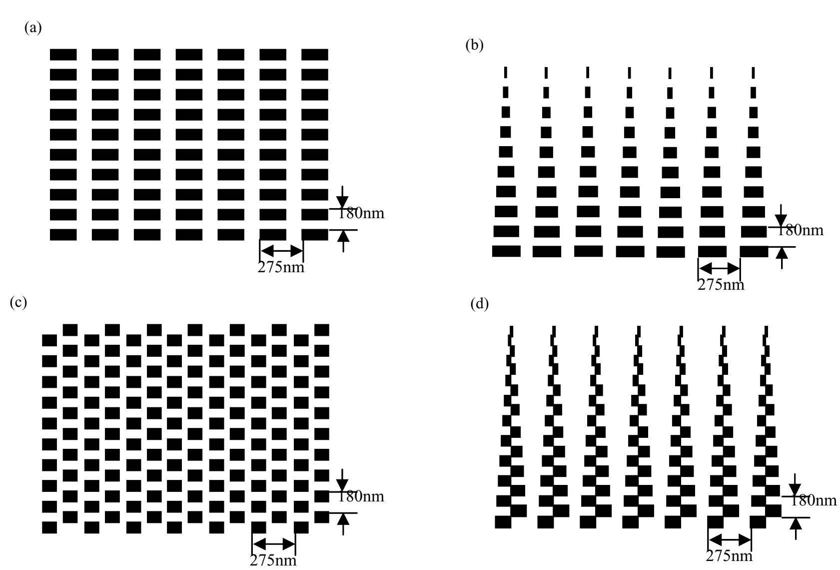

Fig. 3. Figure of model calculated of *Morpho rhetenor* wings; (a) model (I); (b) model (II); (c) model (III); (d) model (IV).