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[Short Communication]

Nanoprotuberance Array in the Transparent Wing of a Hawkmoth, *Cephonodes hylas*

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ABSTRACT—A highly ordered nanocomposite was discovered in the transparent wing of a hawkmoth, *Cephonodes hylas*. The protuberances, nipple-like shaped and 250 nm in height, are regular-hexagonally arranged with the center-to-center distance of 200 nm. This morphology is almost the same as those of "corneal nipple arrays" of some insect eyes. Nanocomposites closely similar to that of the *Cephonodes* wing were also found in transparent wings of some other moths (Sphingidae and Sesiidae) and cicadae.

INTRODUCTION

Over thirty years ago, Bernhard and Miller (1962) discovered in some insects that their ommatidia, structural units of compound eyes, have closely and regular-hexagonally arranged nanometer-size protuberances in their corneal surfaces. This protuberance array was found exclusively on the eye among the insect body parts (Bernhard *et al*., 1970). This is called a "corneal nipple array", and is demonstrated to function as an anti-reflective device to light over the broad wavelength band and consequently increase light transmittance (Bernhard *et al*., 1963, 1965). These optical characteristics are suggested to give the animals increased visibility and camouflage (or concealing ability) (Bernhard *et al*., 1965).

We report here that a nanocomposite with almost the same morphology as that of the corneal nipple array on the "eye" is also found on the other body part "wing": the fairly transparent wing of a hawkmoth, *Cephonodes hylas*. Nanocomposites closely resembling the *Cephonodes* one are also observed in the transparent wings of some other moths and cicadae. We refer to them as "wing nipple arrays".

MATERIAL AND METHODS

Dried wings of the animals collected in fields were used for examination with a scanning electron microscope (SEM) and a transmission electron microscope (TEM).

SEM study. Wing pieces cut with scissors were coated with thin membranes of gold (about 8 nm in thickness) using an ion sputtering device (JEOL, JFC-1500), and examined with SEM (JEOL, JSM-5300).

TEM study. Wing pieces were soaked in propyrene oxide, embedded in epoxy resin, and sectioned vertically to the wing plane. Sections were double-stained with uranyl acetate and lead citrate, and examined with TEM (JEOL, JEM-100CXII).

RESULTS AND DISCUSSIONS

The adult *Cephonodes* wing is transparent except for fairly small parts. This transparent part has no scales, since they are shed immediatly after eclosion. In the upper view of the transparent part (Fig. 1), there are circles arranged closely and regular-hexagonally. The center-to-center distance between neighboring circles is about 0.2 μm, irrespective of the apparent circle radia. As shown in the oblique view (Fig. 2) and the side one (Fig. 3), the circles in Fig. 1 are the upper views of almost homogeneous protuberances. Each protuberance is shaped like a dome or nipple and has a constriction around its middle height; a constriction that is not found in the corneal nipple (Bernhard *et al*., 1970). The reason for the size variation in the apparent circle radia in Fig. 1 is that foci of the micrograph are at different heights of the homogeneous protuberances probably due to a slight curvature of the wing surface. As shown in Fig. 3, the protuberance height is about 0.25 μm. The bases of the protuberances are also smoothly curved; spaces intervening the neighboring protuberances present concaves like reversed protuberances. Viewing the bottoms of the concaves as the boundaries between neighboring protuberances, the

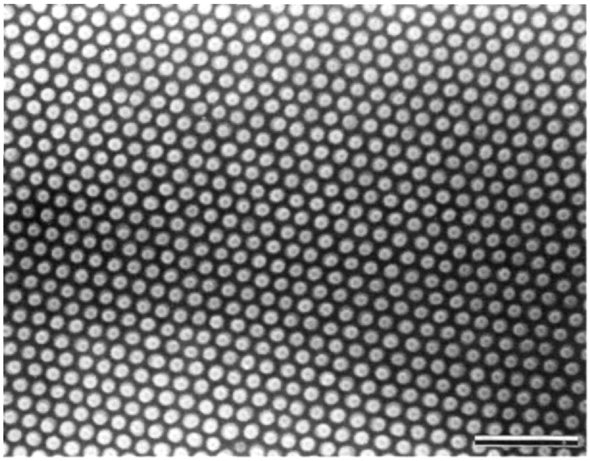

Fig. 1. A scanning electron micrograph of the upper view of the transparent *Cephonodes* wing, presenting the regular-hexagonal array of circles. Scale bar: 1 μm.

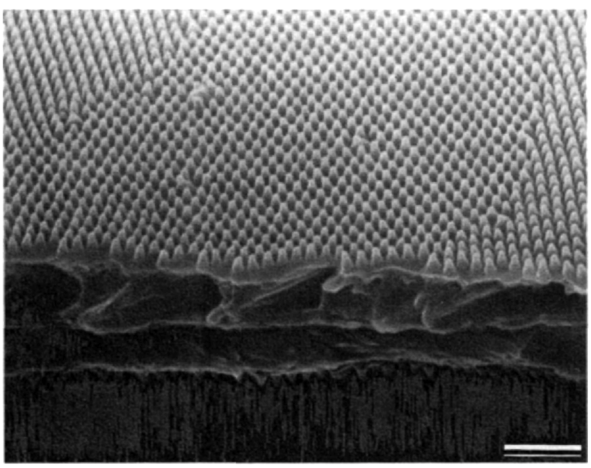

Fig. 2. A scanning electron micrograph of the oblique view of the transparent *Cephonodes* wing cut with scissors. The dorsal surface and the cut one are observed. Scale bar: 1 μm.

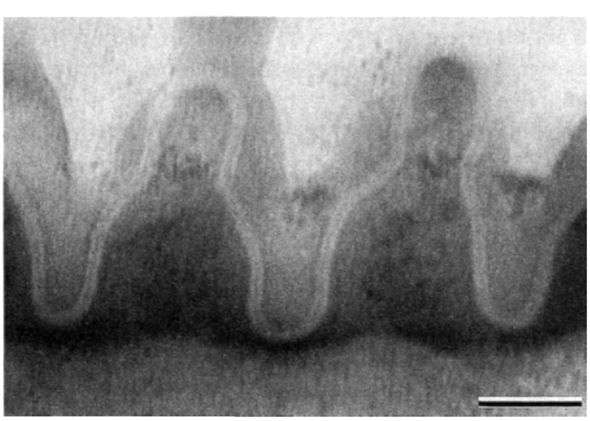

Fig. 3. A transmission electron micrograph of the cross section of the transparent *Cephonodes* wing, presenting side views of the protuberances. Scale bar: 0.1 μm.

protuberances arranged regular-hexagonally are thought to be most closely packed in two-dimensional space. These morphological characteristics are almost the same as those of the corneal nipple array in the nipple arrangement pattern, center-to-center distance between neighboring nipples, and the size and shape of nipples (Bernhard and Miller, 1962; Bernhard *et al.*, 1965; Bernhard *et al.*, 1970). In the *Cephonodes* wing, morphologies are indistinguishable between dorsal and ventral surfaces, fore and hind wings, and male and female animals. Besides *Cephonodes*, we have found the wing nipple arrays in the transparent parts of the wings of a hawkmoth, *Hemaris radians*, a clearing moth, *Synanthedon hector*, and some cicadae (e.g. *Oncotympana maculaticollis*). We have not found them in colored wings of most butterflies and moths, and some cicadae (e.g. *Graptopsaltria nigrofuscata*).

Since wing and corneal nipple arrays share the same morphology and are made from the same chemical substance (cuticle), it is assumed that they have the same physical characteristics. Bernhard *et al.* (1965) indicated that a corneal nipple array acts as an anti-reflective device to light over the broad wavelength band and consequently increase light transmittance, from a scaled model experiment, a theoretical calculation, and a comparative way. We demonstrated that a wing nipple array also presents the same optics as that of the corneal one, from a comparison between the reflection spectrum of the intact wing with nipples and that of the artificial wing without them (Yoshida *et al.*, unpublished data). Anti-reflection of the fairly transparent wing by the nipple array makes the wing nearly invisible. This concealing effect may make the insect less likely to be found by other animals including parasites and predators.

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