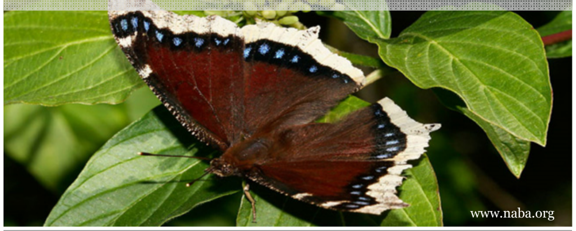
nanOntario

Centre for Nanomaterials in Manufacturing Innovation

Learning Nanotechnology from Ontario's Great Outdoors

Year 2 | Anti-Reflective Surfaces



Materials Science & Engineering
UNIVERSITY OF TORONTO

FACULTY OF APPLIED SCIENCE & ENGINEERING

Message from the Publisher

Professor **Uwe Erb**

Welcome to nanOntario's second year research theme: "**Bio-designed Anti-reflective Surfaces**." Inspired by the spectacular eye design found in some of Ontario's native butterflies, these antireflective surfaces are based on the **Moth Eye Effect**. This natural phenomenon, created by the precise nano-nipple structure on certain moth and butterfly eyes, reduces the reflection of light by the eye. The effect creates improved night vision for moths and better camouflage for some butterflies.

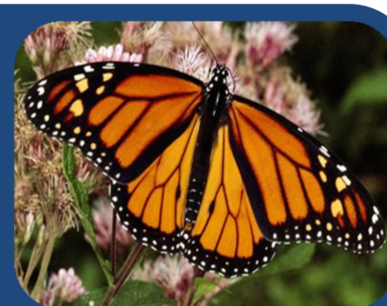
In examining the structure of the **Mourning Cloak Butterfly** and the **Monarch Butterfly** eyes, the **scanning electron microscope** was used to obtain high magnification images of their **compound eye** surfaces. The images show a relatively flat surface on the Monarch eye and an amazing nanostructure surface on the Mourning Cloak eye. This nano-nipple covered surface creates a refractive index gradient that reduces the reflection of light by the eye. Therefore, only the Mourning Cloak eye has an anti-reflective surface due to this **Moth Eye Effect**.

Knowing that a nano-structured surface pattern can reduce light reflection, many scientists and industries are now developing new technologies to improve the optical properties of current products and designing totally new products as well. The significant application possibilities include less glare on display devices as well as increased efficiency for solar cells. Such applications are examples as to what we can learn from nature and how nature can hold innovative solutions to engineering design.

1. The Nature

Both the Monarch and the Mourning Cloak butterfly are popular North American butterflies. While the Monarch has one of the largest wingspans, the Mourning Cloak enjoys a long lifespan of up to 11 months.

The significant difference between these two butterflies is found within their eye surface structure. The mourning cloak's eye surface structure shows the **moth eye effect** while the monarch's eye does not.



The Monarch Butterfly

The Mourning Cloak Butterfly

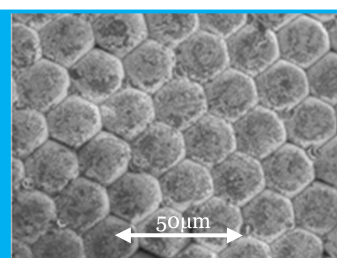
What is in the Mourning Cloak's Eye?

- There are approximately 15,000 ommatidia per compound eye
- There are approximately 13,000 nano-nipples per ommatidium
- In total, this adds up to approximately 200 million nano-nipples per compound eye
- It takes the butterflies only 10 days to create all these ommatidia and nano-nipples during its cocoon stage.

Your fingernails grow approximately 1 nanometre per second

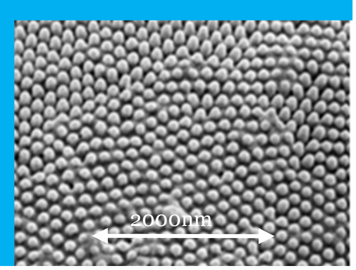
2.The Structure

The structure of an insect eye is vastly different than that of a human eye; insects have a type of eye called compound eye. Unlike the human eye structure that consists of a single spherical lens, insect eyes have a structure that consists of thousands of repeating units called **ommatidia** .These ommatidia are packed closely together and typically form the spherical or semi-spherical facet structure of an insect compound eyes.



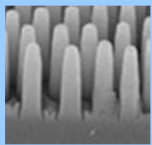
Close examination of the surface of the compound eye under the scanning electron microscope reveals an interesting surface structure on the Mourning Cloak eye.

The scanning electron microscope images reveal millions of nano-nipples on the surface of each Mourning Cloak eye that are responsible for the "**Moth Eye Effect**."



3. The Theory

The Moth Eye Effect

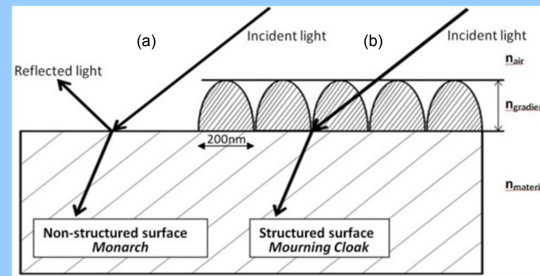


The outer layer of moth and butterfly eyes is made of a substance called **chitin**. In addition, certain moth and butterfly species have eyes that are covered with arrays of nano-nipples (nano-scale bumps). Therefore, for these species, light must pass through a layer of chitin nano-nipples before it reaches the corneal lens of each ommatidium. The reflectivity, R, for light traveling from air to chitin with a flat surface is 0.049 according to the equation

$$R = \left(\frac{n_2 - n_1}{n_2 + n_1}\right)^2$$

because n_2=1.57 (the refractive index of chitin) and n_1= 1.00 (the refractive index of air).

However, the nano-nipples create a gradient in which the refractive index increases gradually from the refractive index of air to the refractive index of chitin. As a result of n_1 increasing as light passes through the nano-nipple structure and enters the eye, the reflectivity gradually decreases. This leads to greater transmission of light into the eye which translates into improved vision for the butterfly. This effect of a structured, nano-nippled surface resulting in decreased reflectivity is called the **Moth Eye Effect**.



a)The **Monarch** butterfly eye surface is flat which results in a high value of light reflection.
b)The **Mourning Cloak** butterfly eye surface is covered with millions of nano-nipples which can greatly reduce reflection of light.

4. The Applications

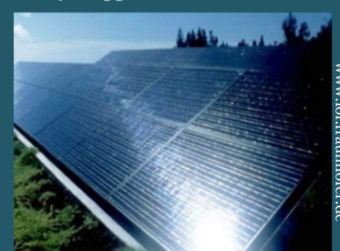
Moth Eye Structure for Reflection-Free Displays

Readability of display devices under sunlight conditions is an ongoing challenge in manufacturing. Anti-reflection properties for polymer surfaces are required in modern optical applications.
AR-plas® developed by Fraunhofer Institute for Applied Optics and Precision Engineering (IOF) has excellent anti-reflective properties for oblique incidence of light.

The ME Series anti-reflective films, developed by MacDermid Autotype, replicate an anti-reflection nanostructure into the hard surface of the films and have excellent anti-reflection properties with < 1% reflectivity over the entire visible spectrum.

Moth Eye Structure for Reduced Solar Cell Reflectivity

Conventional solar cells can be inefficient, with average solar cells having efficiencies of 6-20%. This is partially due to the light reflection of silicon, a substance widely used in solar cells and electronic devices. The moth eye nipple structure can be adapted for use in solar cell design, "creating a situation in which most of the light from the sun is absorbed and efficiently utilized instead of reflected uselessly" [1].



1] M. Marquit, "Moth Eyes May Hold Key to More Efficient Solar Cells", Physorg. Available: http://www.physorg.com/news122899685.html.

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