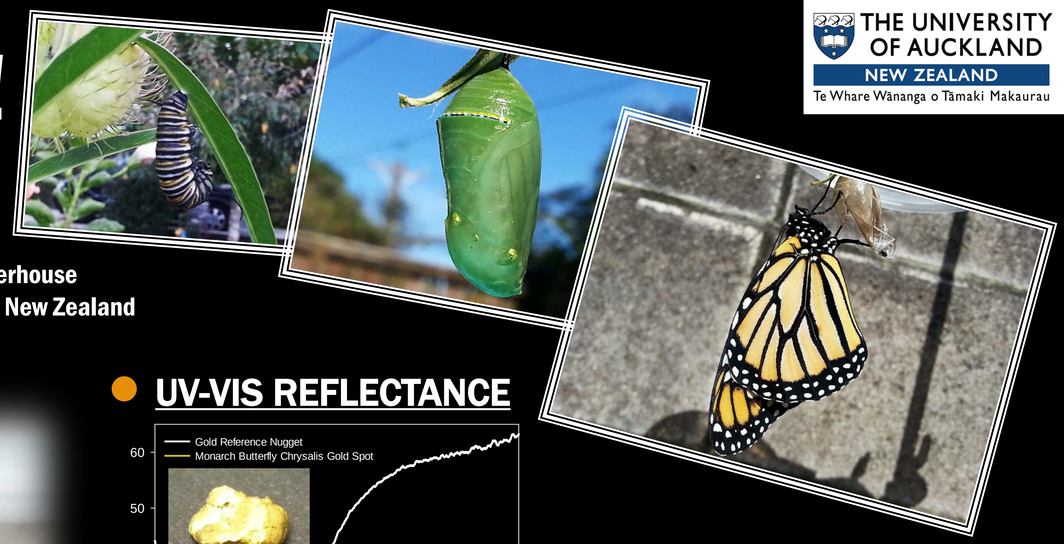
What Makes These Nipples GOLD?!
A Structural Investigation.



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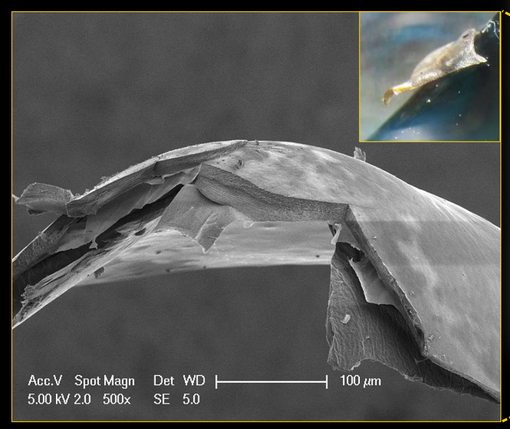
INTRODUCTION

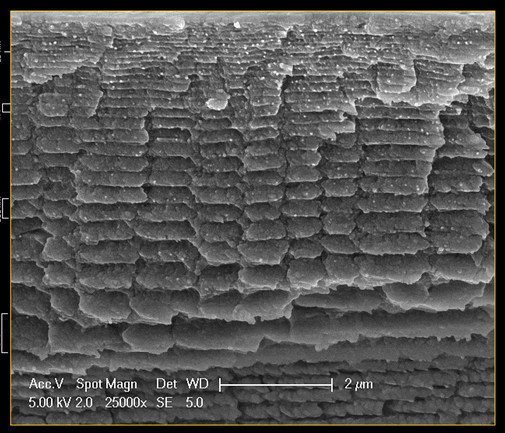
The chrysalis of the Monarch butterfly, *Danaus plexippus*, has piqued the interest of people of all ages. A recurring set of questions surrounding the systematically distributed gold spots, or nipples, include; 'Why are there gold spots on the chrysalis?', 'what are they for?' and 'what makes the spots gold?' Foolishly, some people assumed for decades that the spots were made of gold. Here, we attempt to address the latter question from a structural point of view. With the advent of electron microscopy, the mystery behind the gold spots may be unveiled.

SCANNING ELECTRON MICROSCOPY (SEM)

A representative gold nipple was fractured using a scalpel while viewed under a dissection microscope then Pt sputter coated for SEM analyses. **NOTE**: no Monarch butterflies were harmed in this study.

The fractured gold spot is shown to the right. Two distinct subsections were found to make up the gold spot; a well-ordered multilayer structure (~6 µm thick) on top of a layered chitin stack (average spacing of 190 nm). The progressive increase in sheet thickness is accord with what is termed a 'Chirped multilayer structure' which have been found in the wing cases of gold and silver reflecting beetles [1]. Chirped structures in beetle shells show a progressive reduction in sheet thickness whilst here, the opposite is observed suggesting gold reflectivity is independent of the order of thickening.

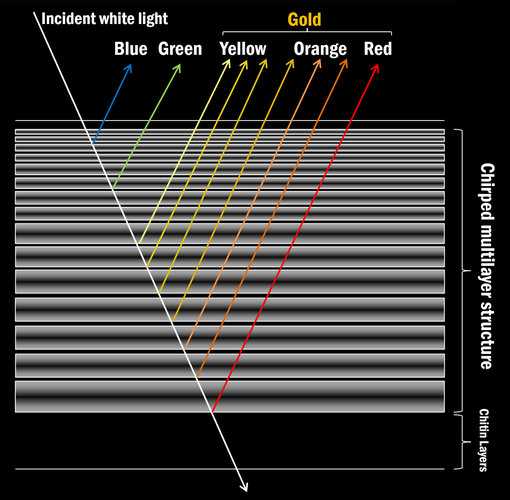




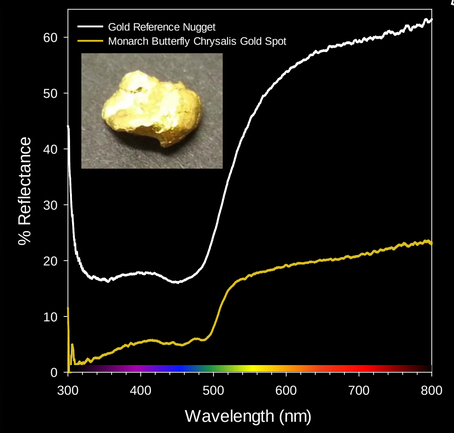
All layers in the chirped structure have thicknesses on the same order as visible light wavelengths (100-700 nm), which results in broadband reflection over the visible to near-IR regions. This is schematically shown to the right.

The 25 layers that make up the chirped structure found in the chrysalis nipple allows reflection over the yellow-orange-red region which collectively results in gold colouration.

Interestingly, having more than 40 layers achieves reflection over the entire visible spectrum, perceived as silver colouration by humans [1].

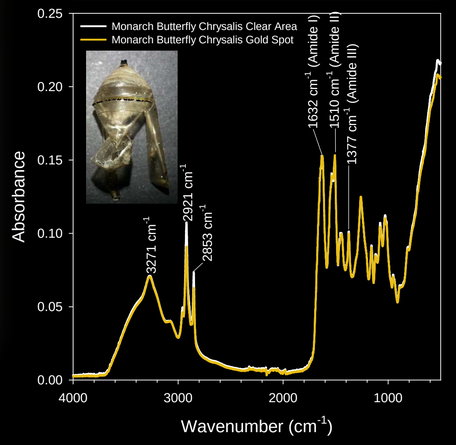


UV-VIS REFLECTANCE



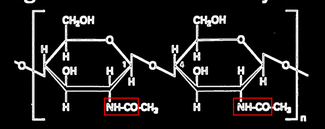
The optical properties for the gold spot matches the UV-Vis data obtained for a gold reference nugget in terms of spectra shape. The significantly reduced reflected intensity for the gold spot is due to the chrysalis posessing a transparent chitin foundation, thus much of the reflected light is lost via transmission. This is fitting with the gold spots semi-visibility on the chrysalis after the Monarch butterfly emerges.

FT-IR SPECTROSCOPY



FT-IR spectroscopic analyses were carried out on the gold spots and clear parts of the Monarch butterfly chrysalis husk. No obvious spectrochemical differences between the gold and clear parts of the chrysalis were observed. Both regions show a spectral profile that is consistent with the presence of the optically transparent material chitin [2]. The similarity in FT-IR spectral patterns suggests the gold colour is of structural origin rather than pigment derived colour in agreement with SEM analyses.

Molecular structure of chitin



CONCLUSIONS:

- Gold appearance of the chrysalis spots are a result of incident white light constructively interfering over a broad range of wavelengths with organic chitin sheets arranged in a chirped multilayer structure.
- Thus, do NOT cremate any chrysalis in attempt to farm metallic gold!
- Future work: WHAT is the function of the gold nipples?

REFERENCES

[1] Neville, A. C., Metallic gold and silver colours in some insect cuticles. *Journal of Insect Physiology* **1977**, *23*(10), 1267-1269,1271-1274.
[2] Liu, S.; Sun, J.; Yu, L.; Zhang, C.; Bi, J.; Zhu, F.; Qu, M.; Jiang, C.; Yang, Q., Extraction and characterization of chitin from the beetle Holotrichia parallela motschulsky. *Molecules* **2012**, *17*(4), 4604-4611.