On the wing of a butterfly

Why is General Electric Global Research so interested in the optical properties of butterfly wings? **Rachel Won** spoke to Radislav Potyrailo about the recent findings of his team that the wing's nanostructures act as a high-performance optical sensor for detecting vapours.

What inspired you to conduct this research?
The demand for vapour sensors that can analyse the contents of urban, industrial and indoor air is growing fast. Apart from sensitivity, selectivity — the ability to distinguish different types of vapours — is a very important feature, but unfortunately one that is very hard to achieve with the current designs of nano-engineered sensors. Our research into butterfly wings was inspired by the review article written by Vukusic and Sambles in *Nature* in 2003, where the authors described the nanometre-scale photonic structures in the wing scales of the *Morpho* butterfly and the striking blue iridescence that they generate[1]. We realized that the underlying physics of this iridescence should be strongly influenced by the gas environment surrounding the nanostructures. As a result, sensors that mimic a butterfly wing could potentially offer a route to highly selective vapour sensing.

Why are butterfly wings so selective to vapours?
The bright iridescence from butterfly scales is a result of the combined effects of diffraction and interference of light that originate from hierarchical nanostructures within a particular scale. Different parts of the scales, such as ridges, lamellae, ribs and microribs, react differently upon interaction with different types of vapours producing remarkably diverse and distinct differential reflectance spectra. This is the key to achieving a highly selective response to individual vapours. Interestingly, the least colourful *Morpho* butterfly (*Morpho sulkowskyi*) is most useful because it provides a broader wavelength bandwidth for the vapour interaction.

What types of vapour have you sensed to date?
We started with very diverse vapours (water, toluene, ethanol, 1,5-dichloropentane, acetonitrile, and so on.) and quickly appreciated the unique selectivity of the spectral response. Inspired by these results, we attempted to discriminate a difficult combination such as methanol, ethanol and water vapours as well as three isomers of

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Inspired by nature: scientists from General Electric Global Research and the University at Albany have shown that the nanostructures on a butterfly's wing produce an optical reflectance spectrum that is highly selective to different types of vapours. The team (from left to right): Radislav Potyrailo, Alexei Vertiatchikh, Eric Olson, James Cournoyer, Katharine Dovidenko and Helen Ghiradella.

dichloroethylene. We achieved the smallest detectable concentrations of 1–2 p.p.m. for methanol, ethanol and water vapours, but the response to dichloroethylene was 4–6 times lower.

What is so appealing about the qualities of the butterfly scales?
At present, photonic vapour sensors typically consist of colloidal photonic-crystal films, porous silicon or other nanostructures, but in order to make them responsive to a particular vapour, they need to be customized by adding specific chemical compounds into the structures. To selectively sense more than one vapour, arrays of such customized sensors are typically needed. In contrast, the *Morpho* butterfly scale provides high selectivity for several vapours that is purely based on the intricate shape of a single photonic structure. The scales can discriminate closely related vapours spectrophotometrically through changes in the reflectance spectra.

What are the limitations and how can the sensors be improved?
A vapour sensor based on an exact replica of the butterfly-scale design will most probably be unable to selectively quantify more than ten individual vapours from their mixture. A man-made nanostructured vapour sensor inspired by our results could be improved in two obvious directions — sensitivity and selectivity. To enhance the sensitivity of the vapour response, hierarchical substructures with higher surface area would have to be introduced. In addition, tailoring the surface properties of features with a particular spatial periodicity could further improve the selectivity of the sensor. In this case, the vapour of interest would preferentially interact with only those portions of the sensing surface that have a certain surface functionality and spatial periodicity.

What are the key challenges for practical use?
Fabricating the type of hierarchical photonic nanostructures found in the butterfly scales for use in man-made sensors is very challenging. If successful, it could launch a new direction in the design of highly selective chemical sensors with straightforward colorimetric readout that could replace current complicated sensor arrays. As vapour response depends on the integrity of the nanostructure, robustness against mechanical damage and surface contamination are the other two challenges for practical use. Care should also be taken not to irreversibly 'poison' the sensor with volatile and non-volatile compounds that will destroy the sensing functionality of the photonic nanostructures. We foresee that this kind of sensor could be in the market within the next five years. Of course this depends on the advances in fabrication technologies and further detailed testing.

Reference

1. Vukusic, P. & Sambles, J. R. Photonic structures in biology. *Nature* **424,** 852–855 (2003).

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Potyrailo and his co-workers have an article on butterfly photonics on p123 of this issue.