Crystallographic mapping of the single gyroid phase in butterfly wings

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The phenomenon of structural colour in the wings resulting from the periodic structure in the scales of some insect wings has been described for some time.[1] The periodic structure in wing scales interacts with light, and due to the differential interaction with the incident spectra of ambient light, provides the perception of colour to the observer. While there are different methods for investigating the periodic structure, real space methods such as serial sectioning and electron microscopy [2] and tomography [3] provide an unambiguous real space 3-D reconstruction of the arrangement of chitin and pore space within the wing scales responsible for structural colour. For these methods characterisation of the statistical variations in structure, for example natural variability, is always limited by the practicality of sampling methods. This limitation is serious when investigations of the inherent variability, such as variation in lattice parameters within a single wing, or between individuals of the same species of an insect, are planned.

Small angle X-ray scattering (SAXS) is also suitable for characterisation of the periodic structure in insect wings. In the characterisation the X-ray beam is rastered across a wing surface, the result is an efficient data acquisition over a single wing (Figure 1 left hand side), and simple sample preparation. Data acquired on a 2D detector and provides a representation of the Fourier transform of the density correlation function [4] in 3 dimensions over the volume of the wing sampled by the X-ray beam. Such studies are challenging in view of the large size of unit cells, usually of the order of 200–400 nm, and therefore the very small values and density of points of the scattering vector which are needed to accurately characterise Bragg peak shape due to the periodic structure. Often these patterns are anisotropic and the pinhole geometry measurements are a prerequisite.

Figure 1. The right hand side shows a typical setup for SAXS measurements at ID02. The centre shows a typical 2D SAXS pattern from a butterfly wing. Typical scattering 1D azimuthally averaged SAXS patterns for 3 different species and peak indexing. Here we report on pinhole SAXS diffraction measurements made at the ID02 beamline at the European Synchrotron Research Facility (Grenoble, France). Although 2D scattering patterns (Figure 1b) report some degree of anisotropy some important insights can be gained from the automated fitting of lattice parameters to azimuthally averaged 1D patterns (Figure 1c) provided the limitations of such an approach are acknowledged. A particularly important point is the effect of crystallographic orientation on the relative intensities of different peaks. The automated routine assumes that the 1D pattern is a Porod decay with a number of Bragg peaks superimposed (Figure 1c). From the fitting we extract the unit cell size of the single gyroid, and given the assumption of small size broadening of Bragg peaks according to the Scherrer equation in a direction normal to that crystallographic axis, some indication of the crystallite size within the wing scale. Previous studies have reported on the variation of lattice parameters between single measurement spots on wings from different species [5]. This work puts those variations in the context of variations within different spots on the same wing and between different members of the same species.