# Quasicrystalline overlayers with crystallographic orders of rotational symmetry

**Sam Coates[1], Stuart Thorn[1], Joe A Smerdon[2], Ronan McGrath[2], Hem Raj Sharma[1]**

[1]*Surface Science Research Centre and Department of Physics,*

*University of Liverpool, Liverpool, L69 3BX*

[2]*Jeremiah Horrocks Institute for Mathematics, Physics and Astronomy,*

*University of Central Lancashire, Preston, PR1 2HE, UK*

*hemraj@liverpool.ac.uk*

Quasicrystals (QCs) are a class of materials with non-periodic long-range order [1]. They have been discovered in a range of phases including colloids, perovskites, and intermetallic alloys [2]. These phases exhibit 'unusual' orders of rotational symmetry, i.e. rotational symmetries which are not permitted by conventional crystallography, such as 5-fold, 10-fold, and 12-fold. Here, we present a series of QC substrate-adsorbate systems that display 'allowed' orders of rotational symmetry yet retain quasicrystalline structure.

First, the two-fold surface of an icosahedral Al-Pd-Mn QC has been used to grow a quasicrystalline molecular film of $C_{60}$. The $C_{60}$ molecules form a Fibonacci square grid – a structure which is quasicrystalline yet has 4-fold rotational symmetry [3]. This is the first unfabricated (i.e. natural) example of the Fibonacci square grid. Scanning Tunnelling Microscopy (STM) and Low Energy Electron Diffraction (LEED) are used to compare a structural model of the clean surface, whilst STM is used to uncover the $C_{60}$ ordering, Figure 1. The refined model structure predicts a network of Mn atoms that form a Fibonacci square grid. The $C_{60}$ molecules adsorb exclusively at this network [4].

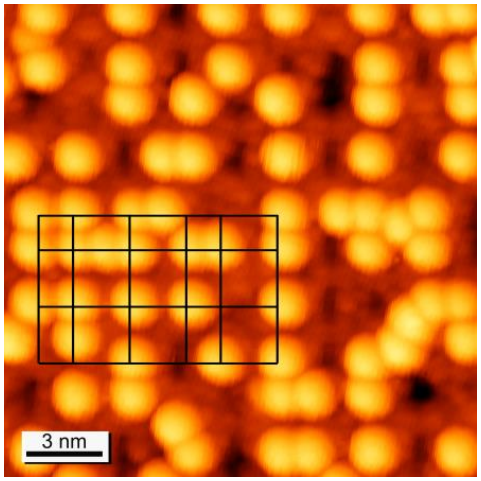


**Figure 1.** STM image of $C_{60}$ forming a Fibonacci square grid at the 2-fold AlPdMn surface

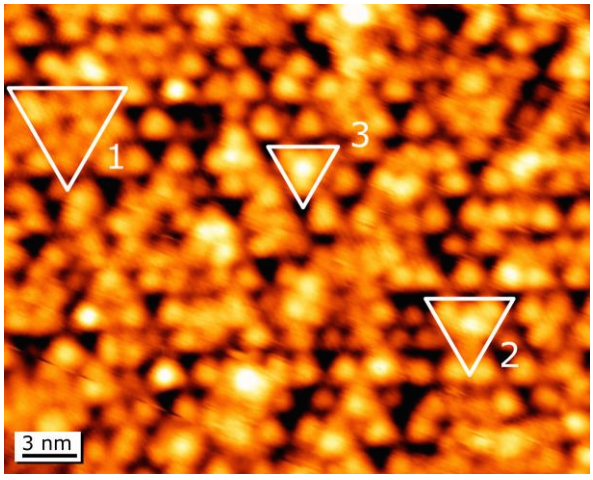


**Figure 2.** STM image of Pb on 3-fold AgInYb. Highlighted are 4 τ-scaled motifs, where 1 = 2*τ, 2 = 3*τ etc.

Second, the 3-fold surface of the Ag-In-Yb system has been used to grow 3-dimensional quasicrystalline nano-structures of Pb. This is to directly compare with previous work in the group, in which we explored the growth mode of Pb on the 5-fold Ag-In-Yb surface [5]. There, Pb grows in QC multi-layers, with each layer's structure dependent on vacant sites of rhombic-triacontahedron (Tsai-type [6]) clusters which are created by surface truncation. The 3-fold surface was investigated to ascertain whether this was a phenomenon unique to the 5-fold orientation. Using STM, we find that Pb does indeed grow on the 3-fold termination in the same fashion, yet not in a layer-by-layer manner. The first layer of Pb is dense and completed before the second layer starts to grow, Figure 2. However, the second and third layer appear to grow almost simultaneously, in a quasi-island-growth manner, resulting in sparse triangular nano-structures. A new 3-fold aperiodic tiling is also introduced to complement the experimental results.

Finally, these observations will be compared with other similar systems, such as Pb/2-fold Ag-In-Yb [7].


1. D. Shechtman, I. Blech, D. Gratias, J. W. Cahn, *Phys. Rev. Lett.*, **53**, (1984), 1951.

2. S. Förster, K. Meinel, R. Hammer, M. Trautmann, W. Widdra, *Nature.*, **503**, (2013), 215.

3. R. Lifshitz, *Journal of alloys and compounds.*, **342**, (2002), 186.

4. S. Coates, J. A. Smerdon, R. McGrath, H. R. Sharma, *Under review for publication.*

5. H. R. Sharma, K. Nozawa, J. A. Smerdon, P. J. Nugent, I. McLeod, V. R. Dhanak, M. Shimoda, Y. Ishii, A. P. Tsai, R. McGrath, *Nat. Comms.*, **2715**, (2013).

6. H. Takakura, C. P. Gomez, A. Yamamoto, M. De Boissieu, A. P. Tsai, *Nat. Mat.*, **6**, (2007), 58.

7. S. Coates, S. Thorn, R. McGrath, H. R. Sharma, *To be published.*