

millikelvin. These limitations make one wonder if the Pockels effect may, after all, be a viable option at such temperatures if one can incorporate high-quality optical and microwave resonators in a Pockels cell to enhance the three-wave mixing.

The cryogenic operation temperature and the narrow conversion bandwidth that results from using resonators suggest that this electro-opto-mechanical technology is unlikely to go commercial any time soon. But there are scientific applications that can eventually benefit from it, such as clock-signal distribution<sup>4</sup> and quantum information transfer. The potential to transfer quantum information between optical and microwave photons is especially

exciting to the quantum information processing community. Superconducting microwave circuits have shown great promise for quantum computing, while quantum optics is better at transmission and quantum measurements — combining the two would vastly expand our ability to process and communicate information at the quantum level for computing and security purposes<sup>5</sup>.

A quantum internet<sup>6</sup> is still a distant dream, but if it ever becomes a reality it will involve hybrid architectures, like our current version of the internet. The kind of hybrid device demonstrated by Andrews *et al.* may well become a crucial component in this future. □

Mankei Tsang is at the Department of Electrical and Computer Engineering and the Department of Physics, National University of Singapore, Singapore 117583, Singapore, and the Department of Physics, National University of Singapore, Singapore 117551, Singapore. e-mail: eletmk@nus.edu.sg

#### References

1. Strekalov, D. V., Savchenkov, A. A., Matsko, A. B. & Yu, N. *Opt. Lett.* **34**, 713–715 (2009).
2. Andrews, R. W. *et al. Nature Phys.* **10**, 321–326 (2014).
3. Bochmann, J., Vainsencher, A., Awschalom, D. D. & Cleland, A. N. *Nature Phys.* **9**, 712–716 (2013).
4. Ye, J. *et al. J. Opt. Soc. Am. B* **20**, 1459–1467 (2003).
5. Xiang, Z.-L., Ashhab, S., You, J. Q. & Nori, F. *Rev. Mod. Phys.* **85**, 623–653 (2013).
6. Kimble, H. J. *Nature* **453**, 1023–1030 (2008).

Published online: 23 March 2014

## QUASICRYSTALS

# Making ends meet

It's impossible to tile a floor using only regular pentagons without leaving voids — a manifestation of five-fold rotational symmetry being incompatible with total spatial periodicity. Yet it is possible to tile a surface in a regular way, with five-fold overall symmetry, if you allow at least two different tile shapes — Roger Penrose came up with a few variants in the 1970s.

Synthesizing structures that display the symmetries of Penrose tilings, which

belong to the broader class of quasicrystals, presents a challenge for material scientists. Now Natalie Wasio and colleagues report in *Nature* that they have succeeded in making 2D quasicrystallites — through the self-assembly of ferrocenecarboxylic acid (FcCOOH) molecules on a gold substrate — that resemble the structure of a particular Penrose tiling (*Nature* **507**, 86–89; 2014).

The FcCOOH molecule consists of an iron atom sandwiched between a C<sub>5</sub>H<sub>5</sub>

ring and a C<sub>5</sub>H<sub>4</sub>COOH unit; the latter can be thought of as another C<sub>5</sub>H<sub>5</sub> ring with one of the hydrogen atoms replaced by a carboxyl (COOH) group, acting as a 'hook'.

Scanning tunnelling microscopy images of the FcCOOH molecules reveal flower-like patterns (pictured), and Wasio *et al.* have mapped patches of such images to a so-called P1 Penrose tiling, consisting of four different tiles: pentagon, star, boat and rhombus. They found that the origin of the molecules' self-assembly into five-fold symmetric motifs lies in the COOH groups — molecular endings that are known to engage easily in hydrogen bonds. Five FcCOOH molecules hook together into a pentamer structure with two hydrogen bonds between two neighbouring molecules. Calculations from first principles confirm that the pentamer arrangement corresponds to an energy minimum.

Analogous experiments with ferroceneacetic acid (having a CH<sub>2</sub>COOH group instead of a COOH group) result in dimers that pack into 'ordinary' 2D crystalline structures. It seems that the self-assembly into pentamers and quasicrystalline patterns requires the chemistry of specific side-groups; the extra CH<sub>2</sub> unit in the case of ferroceneacetic acid prevents the realization of the two hydrogen bonds that stabilize a five-fold symmetric pentamer.

BART VERBERCK

