large-amplitude oscillation of a completely free electron is not possible. Instead the laser-dressed motion of the electron in the conduction band is believed to lead to a current with nonlinear components that is the principle source of the emitted harmonics[8]. In the experiment of Ghimire *et al.*, the amplitude of the laser-driven motion exceeds the zinc oxide lattice spacing (d = 2.8 Å), and so the recombination to a hole site different from the ionization site is possible; the periodicity of the lattice ensures the process remains coherent. The team used a simplified model for the band energy (expressed in k space), describing it with a superposition of cosinusoidal terms $\varepsilon(k) = \Sigma[c_n\cos(nkd)]$ with terms up to $n = 3$ to account for the laser-dressed conduction band of the ZnO crystal. The resulting nonlinear current driven by the field leads to the harmonics and the model predicts that the cut-off scales simply as $neEd$, which with $n = 3$ is in good agreement with the observation. This preliminary analysis implies that the cut-off is sensitive to the form of the laser-dressed band energy, which may open to study the strong-field dressed dynamics of the crystal. Fuller analysis and further measurements are still required to confirm the details of the suggested mechanism.

An important technical advantage of HHG from solid-state crystals is the potential for fabricating elaborate micrometre-scale structures, not possible in gas phase, that may readily lend themselves to implementing the periodic modulation required for quasi-phase matching, which can greatly enhance output[9]. An important question not yet addressed is whether the harmonic emission retains a subfemtosecond character; that is, is it confined only to certain moments within the optical cycle? The observed bandwidth of the emission (~9 eV) is sufficient to support subfemtosecond pulses. Interestingly, an earlier theoretical treatment of HHG from a model double-well potential in a quantum dot hints at mechanisms that may lead to time-confined HHG emission[10] — it is possible that related mechanisms may be more generally important in HHG from solids. ❐

Jon P. Marangos is at the Blackett Laboratory, Imperial College London, South Kensington, London SW7 2AZ, UK.
e-mail: j.marangos@imperial.ac.uk

References

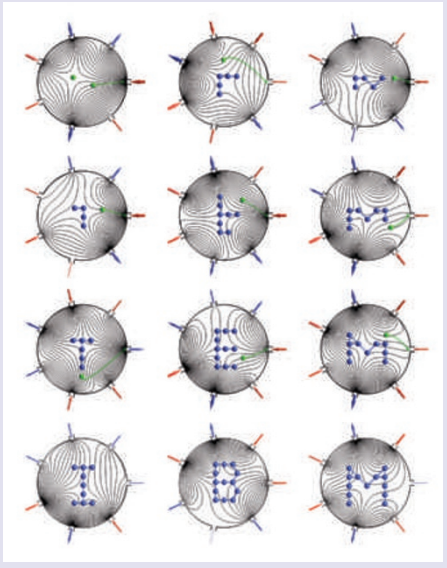
1. Ghirmire, S. *et al. Nature Phys.* **7,** 138–141 (2011).
2. Corkum, P. B. *Phys. Rev. Lett.* **71,** 1994–1997 (1993).
3. Schafer, K. J., Yang, B., DiMauro, L. F. & Kulander, K. C. *Phys. Rev. Lett.* **70,** 1599–1602 (1993).
4. Krausz, F. & Ivanov, M. *Rev. Mod. Phys.* **81,** 163–234 (2009).
5. Baker, S. *et al. Science* **312,** 424–427 (2006).
6. Lein, M. *J. Phys. B* **40,** R135–R173 (2007).
7. Vozzi, C. *et al. Appl. Phys. Lett.* **97,** 241103 (2010).
8. Golde, D., Meier, T. & Koch, S. W. *Phys. Rev. B* **77,** 075330 (2008).
9. Armstrong, J. A., Bloembergen, N., Ducuing, J. & Pershan, P. S. *Phys. Rev.* **127,** 1918–1939 (1962).
10. Haljan, P., Fortier, T., Hawrylak, P., Corkum, P. & Ivanov, M. Yu. *Laser Phys.* **13,** 452–456 (2003).

MICROFLUIDICS

Solutions for assembly

There are many different ways to construct complex structures from small particles. One is to use optical traps or tweezers to grab hold of and manipulate individual particles (*Lab Chip* **8,** 2174–2181; 2008). Another is to engineer the interactions between particles in some way, such as by chemically functionalizing their surfaces, so that they self-assemble to form the desired structure (*Science* **295,** 2418–2421; 2002). The former approach enables almost any structure to be built, but is too slow for bulk fabrication of multiple copies. And although the latter is ideally suited to bulk synthesis, exerting sufficient control over interparticle interactions to get them to organize themselves into arbitrary shapes without direction is challenging.

As an alternative that has the ease and control of techniques based on directed assembly and the high throughput of those based on self-assembly, Tobias Schneider and colleagues have explored a variety of algorithms for building complex structures in a microfluidic assembly line (*Phys. Rev. Lett.* in the press; preprint at http://arXiv.org/abs/1101.3791). The idea is to use the flow fields generated in a microfluidic chamber, which is fed by a series of inlets and outlets distributed around it, to steer particles suspended in the chamber into position. By controlling individually the rate of flow in or out of each inlet or outlet, the shape of these fields can be intricately controlled. This in turn can be used to guide the flow of suspended particles, and, by using particles that stick together when they come into contact, could be used to guide the formation of complex structures.



The authors first considered the conditions needed to guide simultaneously the movement of N particles confined in two dimensions in a circular Hele-Shaw cell. The number of inlet/outlet ports needed to achieve this is $2N+1$, placing a modest limit on the number of particles that can be manipulated in a cell of given size. But they found that a more stringent limit is imposed by the fact that, as the number of particles is increased, the rate of flow needed through each port rises sharply. In simulations, this prevented them from being able to manipulate more than six particles at a time with moderate flows.

To overcome this, rather than manipulate many particles simultaneously, Schneider *et al.* instead built structures sequentially, one particle at a time. To do this in two dimensions, they find that only seven ports are needed — which they demonstrate by simulating the sequence of flows needed to construct letters of the English alphabet (pictured). And their analysis suggests that extending to the building of structures in three dimensions could be possible with just 11 ports.

ED GERSTNER