'dictates' that the photon must take both paths at once, thereby entangling the optical modes at the two fibre outputs. If we place a photon detector at each of the splitter outputs (each, say, 10 km from the quantum dot source), we don't know *a priori* which of the detectors will 'click' to register the arrival of the photon — but we do know with 100% certainty that if one of the detectors clicks, then the other will not.

Achieving entanglement over larger distances requires a hybrid system of a single-photon source and a slow-light medium. Owing to photon losses in long optical fibres, entanglement between distant locations must be implemented through a series of shorter segments. No photon travels the distance of more than one segment, and entanglement is implemented for each segment individually, in the manner explained above. The segments are then combined pair-wise, eventually achieving entanglement over the full distance of the network (a 'quantum repeater'[8]). Photons in different segments of the network must be synchronized with one another, and this is exactly where the slow-light medium comes into play. Because quantum measurements always involve probabilities — outcomes are rarely certain — it might take several attempts to successfully combine and entangle a pair of segments, whereas another pair might be successfully combined in a single attempt. A photon in the latter segments must be put on hold until a photon in the former segment pair is prepared and ready. The first-ready photon can be 'stored' in a slow-light medium until the second photon is ready, thereby synchronizing the two segment pairs of the network. A joint measurement on the two photons can then be performed to combine the segment pairs, and, if the measurement is successful, the entanglement distance is increased to span the full distance of the two segment pairs. Hence, by copying the set-up of Akopian *et al.* multiple times and replacing the 1.5 m of free space between the quantum dot and the slow-light medium with optical fibres, we will be a good part of the way towards implementing a real quantum network.

It should be mentioned that the observed optical delay times — in the nanosecond regime — are not yet large enough to allow quantum keys to be shared over very large distances (it takes almost 0.1 ms for a light pulse to travel a distance of 10 km in an optical fibre). In the future, it would be very interesting to augment this hybrid system by coupling quantum-dot-generated single-photon pulses into atom clouds in the form of ultracold Bose–Einstein condensates. These atomic gases are ideal for optical manipulation because they allow exquisite control of energy levels and quantum states, which can lead to very dramatic effects[2]. In such atom clouds, optical pulses can be converted to matter copies that in turn can be isolated and 'put on the shelf' for long-term storage. The bandwidth and storage time can also be dynamically and rapidly controlled. This system could also form the basis for powerful quantum information processing. Converting single-photon pulses (quantum bits) to matter would allow rapid processing in two-bit quantum gates because the speed would be determined not by nonlinearities between single-photon (optical) pulses, but rather by the much stronger nonlinearities that govern atom–atom interactions. Finally, using a slow-light medium generated by atoms in a nanotrap may allow the hybrid system introduced by Akopian *et al.* to be fully chip-integrated on the nanoscale. ❐

Lene Vestergaard Hau is at the Department of Physics and the School of Engineering and Applied Sciences, Harvard University, Cambridge, Massachusetts 02138, USA.
e-mail: hau@physics.harvard.edu

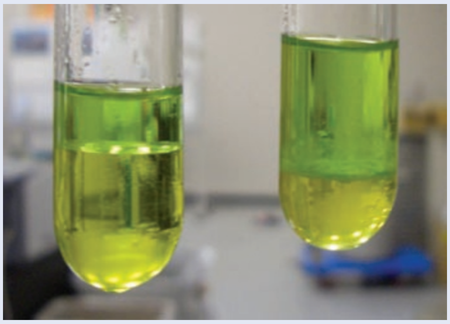
References

1. Hau, L. V., Harris, S. E., Dutton, Z. & Behroozi, C. H. *Nature* **397,** 594–598 (1999).
2. Ginsberg, N. S., Garner, S. R. & Hau, L. V. *Nature* **445,** 623–626 (2007).
3. Camacho, R. M., Park. M. V., Howell, J. C., Schweinsberg, A. & Boyd, R. W. *Phys. Rev. Lett.* **98,** 153601 (2007).
4. Wu, B. *et al. Nature Photon.* **4,** 776–779 (2010).
5. Akopian, N., Wang, L., Rastelli, A., Schmidt, O. G. & Zwiller. V. *Nature Photon.* **5,** 230–233 (2011).
6. Michler, P. *et al. Science* **290,** 2282–2285 (2000).
7. Ekert, A. K. *Phys. Rev. Lett.* **67,** 661–663 (1991).
8. Briegel, H.-J., Dür, W., Cirac, J. I. & Zoller, P. *Phys. Rev. Lett.* **81,** 5932–5935 (1998).

BIOPHOTONICS

Spinach fuels organic LEDs

Although the value of spinach as part of a healthy diet is well-known, its potential role in the optoelectronics industry is only now being understood. Naoki Ohtani and co-workers from Doshisha University in Kyoto, Japan, have successfully fabricated organic light-emitting diodes (OLEDs) that contain chlorophylls extracted from spinach as their active ingredient (*Jpn. J. Appl. Phys.* **50,** 01BC08; 2011). The researchers first spin-coated a 100-nm-thick film containing chlorophylls *a* and *b* onto a glass substrate coated with the transparent electrode material indium tin oxide. They then vacuum-deposited aluminium on top of the organic layer to form the top electrode. No photoluminescence was seen from the sample, which the team attributed to concentration quenching from the chlorophylls. By repeating their experiments using a blend of chlorophyll *a* and the conductive polymer poly(phenylene vinylene), the team successfully created OLEDs that emitted both blue–green and red light when electrically pumped. The blue–green emission peaking at around 500 nm was attributed to the polymer, whereas the longer-wavelength red emission peaking at around 680 nm was attributed to the chlorophyll. The researchers comment that the extraction and fabrication method are important for achieving good results, with chlorophyll prepared in the form of a fat-soluble solution performing much better than that of an acetone or methanol solution. "The OLEDs fabricated using the fat-soluble solution emitted electroluminescent signals for more than one minute, whereas the OLEDs fabricated using the methanol solution worked for less than five seconds," comment the researchers. "The long operation times of OLEDs fabricated using a fat-soluble solution can be attributed to the antioxidant activities of carotenoids."



NAOKI OHTANI

OLIVER GRAYDON