measurement scales as the square root of the number of coincidences of photon pairs within a time delay τ, accumulated over a time T. Thus, for a photon detection rate of N counts per second, SNR $\approx (N\sqrt{\tau T})^{-1}$, giving SNR ≈ 1 for a delay time of $\tau = 1$ ns with 1,000 counts per second and an integration time of 20 minutes. This technique therefore allows for very high time resolution, but provides information only about the statistical properties of the spectral diffusion, averaged over the long integration time T. Real-time tracking of spectral diffusion on this timescale is impossible because the emission signal of a single emitter is so weak. A similar averaging technique is used in fluorescence correlation spectroscopy, which tracks single molecules in fluid solution.

Although the work of Sallen *et al.* gives reason for optimism, it is limited in several respects. First, the emitter must be sufficiently bright because the coincidence rate increases quadratically with the count rate. Second, the frequency shifts should not be too small, as bandpass filters have difficulty in discriminating photons shifted by less than a few terahertz (1 THz corresponds to a shift of ~1 nm at a central wavelength of 500 nm). The quantum dot used by Sallen *et al.* showed fast spectral diffusion but a remarkably stable resonance over long integration times. To apply this technique, the emission frequency must ideally fluctuate around a fixed central position ω_0 during the long times required for acquisition of the correlation function. Although it would be possible to compensate for slow frequency drifts by tuning the monochromators, this would be difficult to achieve for a random walk with sudden jumps.

The work of Sallen *et al.* may bring us closer to uncovering the origin of spectral diffusion. Research suggests that it probably arises from the rearrangement of charge carriers trapped in the imbedding material surrounding a quantum dot, as similar charge distributions lead to spectral diffusion and to blinking in colloidal quantum dots[5]. This work will also help to answer several other questions. For example, is spectral diffusion only caused by thermal fluctuations, or also partly by photo-induced processes following the absorption of a photon by a quantum dot? What is the dependence of spectral diffusion on temperature and light intensity? Will it be possible to monitor an individual emitter's frequency in real time, and at what frequency and time resolutions? Will it be possible to remove spectral diffusion completely, and how? If spectral diffusion is photoinduced, even in part, low temperatures will not suffice to eliminate it, as illumination is required for experimental interrogation of the nano-emitters. Thanks to the technique of Sallen *et al.*, these questions and many more will certainly be explored in the near future. ❐

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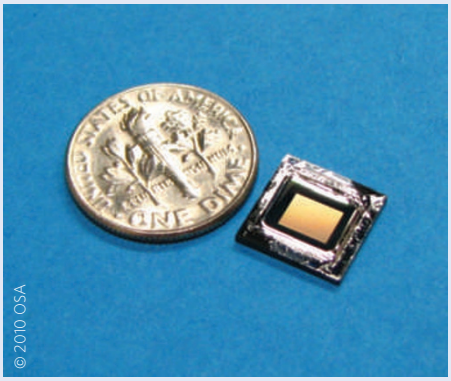
IMAGING

Phase sensor on a chip

An on-chip wavefront image sensor capable of measuring phase gradients would benefit a wide variety of applications, including phase contrast microscopy, adaptive optics and machine vision. Phase measurements are usually performed using Shack–Hartmann sensors, but the cost and size of these devices precludes their use in many applications.

Xiquan Cui and co-workers from Caltech and Harvard Medical School in the USA have now realized a cost-effective phase sensor on a semiconductor chip that may potentially suit mass-production (*Opt. Express* **18,** 16685–16701; 2010). The integrated device is made from a 280 x 350 array of circular apertures (each 6 μm in diameter) on top of a metal-coated CMOS sensor chip and has a sensing area of 3.08 mm × 3.85 mm. The metal coating is a 150-nm-thick layer of aluminium and the chip is comprised of 1,944 × 2,592 pixels, each 2.2 μm long.



A transparent spacer made from 10-μm-thick SU8 resin separates the apertures from the sensor. A spot forms under each aperture when a planar light wave is incident on the sensor. However, if the incoming wave is phase-tilted or distorted, the position of the spots changes according to the local phase gradient. The phase profile of a beam can then be determined by analysing the change in position.

Tests suggest that the sensor has a phase gradient sensitivity of 0.1 mrad and a measurement range of ±15 mrad. The researchers used the sensor in a microscope to generate high-quality phase gradient images of potato starch and starfish embryos. They say that the sensor can be easily adapted to fit most standard microscope systems without any major modification, and that it should be possible to mass-produce cheaply in large quantities, similar to how commercial image sensor chips are fabricated for use in digital cameras. They also comment that the phase images produced using their technique rival those captured by traditional differential interference contrast microscopes and are not prone to artefacts generated by birefringence.

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