components and opposite quadrature components for the signal and idler are simultaneously satisfied. The non-degenerate PSA with phase-conjugate inputs can therefore provide (pump) phase-sensitive gain for signals anywhere in the complex plane. Conveniently, the idler created by a non-degenerate PIA is an exact phase-conjugate copy of the signal.

Tong *et al.* demonstrate modulation-format-insensitive phase-sensitive amplification using a differential quadrature phase-shift keying signal and its complex-conjugate idler. They report that using the non-degenerate PSA as the pre-amplifier for the differential quadrature phase-shift keying receiver provides a 5.5 dB improvement in sensitivity over a PIA pre-amplifier.

Useful insight is also gained through an experimental comparison of the noise figures achieved by amplified fibre-optic transmission links that use either non-degenerate PSAs or PIAs (EDFAs)[3,8]. As long as the loss of the link is sufficiently high, the link noise figure will continue to be dominated by the noise associated with fibre loss, which not only makes noise generated in the PIA copier negligible, but also causes the noise in the signal and idler signals to be uncorrelated. Tong *et al.* report that their non-degenerate PSA achieves a link noise figure improvement of 5.2 dB over a PIA.

Although such improvements are indeed impressive, the complexity of the operating requirements may hinder practical implementations in the near future. In particular, the requirement that all the inputs must be phase-locked may prove to be a major obstacle for fibre-optic communication systems. Coherent receivers that derive data bits from the phase of a signal became practical only recently when hardware phase-locking was replaced by digital phase estimation. Moreover, for the non-degenerate PSA to operate properly, the signal and idler must be kept equal in power and remain phase-conjugates of each other at the input. PSAs are also usually polarization-sensitive; dynamic trimming of amplitude, phase and polarization is significantly more difficult than achieving phase-locking alone.

Future work must start by addressing these issues if PSAs are to be deployed in optical communication systems. The effects and practical performance limits due to spontaneous Raman scattering and pump noise transfer must also be investigated.

The improved link noise figure can be used to increase the data capacity of fibre-optic links, but the increase in capacity will be logarithmic with the received SNR. Because the non-degenerate PSA requires twice the bandwidth of a PIA or degenerate PSA, the capacity of links using non-degenerate PSAs may actually decrease if the corresponding EDFA/Raman systems already operate at high spectral efficiencies.

The alternative is to use the improved link noise figure to extend transmission distances. It is known that links with distributed amplification perform better than those with discrete 'lumped' amplifiers. It would be interesting to explore the possibility of achieving even lower link noise figures using distributed non-degenerate PSAs with phase-conjugate inputs[6]. Finally, many long-haul fibre-optic transmission systems are migrating to digital coherent detection, in which there is no optical dispersion compensation. This makes phase trimming of the signal and idler very difficult and may prevent the use of non-degenerate PSAs in such systems. ❐

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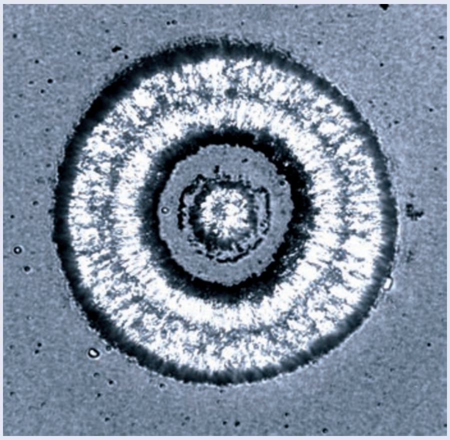
IMAGING

Shocking observation

Using intense laser pulses to generate strong shock waves is a well-known technique for compressing fuel pellets in laser fusion and strengthening critical metallic components such as turbine blades in jet engines. Unfortunately, however, visual observation of this process is not straightforward.

Scientists from the USA and France have now developed an ultrafast imaging technique that allows direct real-time observation of the generation, propagation and focusing of laser-driven shock waves in water (*Phys. Rev. Lett.* **106,** 214503; 2011).

Single-shot acquisitions collected by a camera revealed that such shock waves can reach supersonic speeds of Mach 6 (~2 km s^{-1}), which corresponds to a pressure of around 30 GPa at the shock focus.



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The researchers used an axicon conical prism and a lens to focus laser pulses of several millijoules (800 nm in wavelength and 300 ps in duration) to a 10-µm-wide, 200-µm-diameter ring in a 5-µm-thick water solution containing a 2 wt% suspension of carbon nanoparticles.

The incident light vaporized the nanoparticles and hence generated a shock wave. The researchers sent weak probe light pulses through the sample for collection at a CCD camera, which made it possible to record either two-dimensional spatial images, streak images using one axis of the detector as time, or interferometric images using a set of reference pulses. Features such as the shock focus and cavitation were clearly observable in the streak images.

The researchers say that they will now study shock waves in solid samples, as well as chemical and structural transformations at the shock focus.

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