Supercontinuum sources

The emergence of convenient sources of broadband light spanning the visible and near-infrared is proving increasingly useful for applications involving spectroscopy, imaging and metrology, reports **Neil Savage**.

Lasers are useful because they produce powerful beams of collimated, coherent light. The fact that laser light is monochromatic (narrowband spectral output) is an advantage much of the time, but sometimes, for example in medical imaging applications or the testing of optoelectronic devices for telecom networks, researchers need a broadband source of light. Although lamps and thermal sources of radiation have a broad spectral output, the brightness (spectral density) of the light is not sufficient for many applications and has been a severe limit in the past.

The recent emergence of commercial fibre-based supercontinuum sources has changed the situation. These sources make use of optical nonlinear effects in specially designed optical fibres to create light with a wide spectrum that can span the visible and near-infrared, typically from around 400 to 2,000 nm.

Such sources are useful for testing lasers and amplifiers or measuring optical attenuation in fibres and waveguides in telecom equipment, for instance. They're also valuable for three-dimensional imaging of biological tissue through methods such as optical coherence tomography or confocal microscopy. And they can support fast acquisition of spectroscopic data in a wide variety of scientific uses.

Previously, researchers generated a supercontinuum in glass, but now they generally use photonic crystal fibres — optical fibres, which feature wavelength-scale periodic structures. A laser pulse is fired into the fibre, and nonlinear effects from the photonic crystals broaden the wavelength. Crystal Fibre A/S (Birkerod, Denmark) is a major supplier of such fibre to makers of supercontinuum sources.

One drawback to the sources has been their so-called 'blue deficiency', the fact that it was difficult to produce wavelengths shorter than about 450 nm. But researchers at the University of Bath, UK, have recently come up with a method that overcomes that limitation. By changing the design of the photonic crystal in the fibre, they have generated wavelengths as low as 380 nm.

Another issue is noise, which Ruben Zadoyan, director of Newport's Technology and Applications Center, says is a fundamental, quantum characteristic that is very difficult to overcome. "In order to control the noise, you have to control the parameters of the laser precisely, which is almost impossible," he says. That, along with relatively low brightness, has been holding the sources back from widespread commercial use, and mostly limited them to laboratory applications, Zadoyan says. But they do hold promise, offering ease of use and wider spectral ranges than most tunable lasers. And they are appealing for applications such as coherent anti-Stokes Raman scattering (CARS) microscopy, a way of making three-dimensional images of living cells. CARS microscopy requires the use of two wavelengths, where the difference in their frequencies matches the resonance of the molecule being studied. It allows scientists to image living cells without using toxic dyes. Supercontinuum technology "is being used in broader and broader areas of research," says Zadoyan. "Everybody wants to play with it and see what they can do."

KOHERAS

PRODUCT ROUND-UP

Koheras A/S (Birkerod, Denmark) offers the SuperK Extreme, which it says is the brightest visible supercontinuum source available. The source, with the highest power the company offers, has a broad spectrum, from 460 to 2,400 nm, and provides a spectral power density of more than 3 mW nm^{-1} in the visible wavelength range. Combining the source with a tunable filter allows a user to tune up to eight simultaneous laser lines independently across the visible spectrum. The master source offers a pulse width of 5 ps. At a fixed repetition rate of 80 MHz, the device offers total output power of more than 4.5 W, with total power in the visible (460-850 nm) of over 1,200 mW and a visible power density of over 4 mW nm^{-1}. At a fixed repetition rate of 40 MHz, total output power is >3 W, with a total power in the visible of >600 mW (visible power density of >1.5 mW nm^{-1}). The output is unpolarized and has a beam quality of $M^2 < 1.3$. The source offers fibre-coupled output with a beam diameter of ~1 mm in the visible, ~2 mm at 1,100 nm, and ~3 mm at 2,000 nm. Power stability over a one-hour period is specified as within ±1.5%. When the source is used in conjunction with a broadband acousto-optical tunable filter, it provides a wavelength range from 450 to 700 nm, with four or eight tunable lines. The bandwidth at 480 nm is 3.5 nm, and at 650 nm is 7 nm. The polarization of the output light is linear, and a fibre-coupled output is optional and available if required. Both the source and the tunable filter are computer-controlled. Applications for this source include confocal fluorescence microscopy, fluorescence lifetime imaging, flow cytometry, and applications such as spectroscopy and optical coherence

tomography, and semiconductor alignment and inspection tasks.
www.koheras.com


FIANIUM

The SC500-FC supercontinuum source from **Fianium** (Southampton, UK) is a low-cost, mode-locked fibre laser generating supercontinuum radiation in the spectral band from 500 to 1,700 nm, with an average power in excess of 250 mW. The master source for the laser is the FemtoMaster 1060, a custom-made, high-power fibre amplifier, and a length of highly nonlinear optical fibre. The lasers have single-mode fibre-delivered output that can be spliced or connected to a system or device under test. Pulse width from the master source is 5 ps, with a repetition rate of 20 MHz. Spectral density is more than 100 μW nm^{-1}, and spectral flatness is better than 6 dB. Maximum power consumption is less than 10 W. The device measures 210 × 250 × 80 mm and weighs 900 g. Performance can be tailored to meet a customer's requirements, with customized values of spectral bandwidth and output power available on request. Typical applications for the supercontinuum source include the characterization of optoelectronic components, metrology and biomedical uses, as well as fundamental studies.
www.fianium.com

Menlo Systems GmbH (Munich, Germany) makes a broad-spectrum source in which the broadband spectrum is emitted by the laser, rather than broadened by a photonic crystal fibre. The Octavius has a bandwidth >300 nm centred around 800 nm (spectral width for –10 dB power points). The 1G version, which measures 255 × 196 mm, has a repetition rate of 1 GHz and power of 300 mW at a 6.5-W pump power. The 85M version, which measures 513 × 267 mm, has a repetition rate of 85 MHz and power of 200 mW at a 5-W pump. Both have a carrier envelope offset frequency of over 30 dB ($f/2f$) in a 100 kHz bandwidth. The wide spectrum of the Ti:sapphire lasers allows for carrier offset frequency stabilization without external spectral broadening. The high repetition rate is useful for high-cycling pump-probe experiments, such as synchronous optical sampling, and frequency comb applications. The 85-MHz version is most suited for amplifier seeding, particularly for optical parametric chirped pulse amplifiers, and for attosecond pulse generation. The laser cavities contain dispersive octave-spanning mirror pairs for highly precise group delay control over an octave-wide bandwidth. The mirror pairs are designed with more than 100 individual layers to guarantee smooth and well-behaved dispersion. The high intensity of the short pulses within the cavity induces self-phase modulation, which creates intracavity spectral broadening beyond the gain bandwidth of Ti:sapphire. The interplay between the modulation and the dispersion generated by the mirror pairs creates stable, ultra-short pulses, with better than 30 dB signal-to-noise ratio in a 100-kHz bandwidth. The lasers are also useful for frequency metrology and phase-sensitive nonlinear optics.
www.menlosystems.com

Newport (Irvine, California, USA) offers the SCG-TS-KT supercontinuum kit, allowing buyers to build their own supercontinuum-generating system using a Ti:sapphire laser. The aim is to assist and educate researchers in part selection and design of supercontinuum experiments in their laboratories. The key element is the company's SCG-800 supercontinuum fibre module, a polarization-maintaining device for use with 800-nm femtosecond lasers. It contains a 12-cm length of highly nonlinear, polarization-maintaining, photonic crystal fibre with a zero-dispersion wavelength of 750 nm. The fibre ends are sealed and mounted in quartz ferrules, with their polarization axis carefully aligned. The fibre is mounted in a robust, 25-mm diameter, 120-mm long aluminium housing that can easily be mounted onto a translation stage. The end facets have built-in beam expansion for easy coupling of the laser input beam. The kit also includes a Faraday isolator, two steering mirrors, and a half-waveplate and polarizer combination for variable attenuation of the pump-laser power. The device is designed for maximum stability of the laser beam so it will stay aligned to the 1.6-μm fibre core inside the module. The kit allows users to assemble the pre-selected and certified off-the-shelf components and put them together. The company has tested various parts, including its own lasers, to make sure they work together. To help users, the company offers Application Note 28, Supercontinuum Generation in SCG-800 Photonic Crystal Fiber. The note offers a more detailed explanation of the kit, alignment procedures, recommended operating parameters, and a detailed characterization of the supercontinuum generated as a function of launched pump power and wavelength. Applications for the kit include ultrafast spectroscopy, carrier envelope phase stabilization, optical coherence tomography, metrology and coherent anti-Stokes Raman scattering microscopy.
www.newport.com


ARCTIC PHOTONICS

The MQO-SC is the world's first component-level supercontinuum source, according to its manufacturer, **Arctic Photonics** (Jorvas, Finland). It is distributed in North America by RPMC Lasers (O'Fallon, Missouri, USA) and designed for integration into original-equipment-manufacturer systems and instruments. It uses a hermetically sealed design with telecom-grade packaging. Based on a miniature Q-switched oscillator, the MQO-SC offers a wavelength range from 750 nm to more than 1,750 nm in a TEM_{00} spatial mode with a beam quality of $M^2 < 1.1$. Pulses are 2 to 3 ns in width with an energy >3 μJ per pulse, at a repetition rate of 20 KHz. Average power on exit from the fibre is ~60 mW. Output is provided by means of a standard single-mode fibre, with or without a fibre connector. The MQO-SC features variable repetition rates and constant energy and pulse width. Drive electronics are included in the ultra-compact package. Applications of the device include measurement of components, measurement of optical networks, spectroscopy, and bio-instrumentation.
www.arcticphotonics.com

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