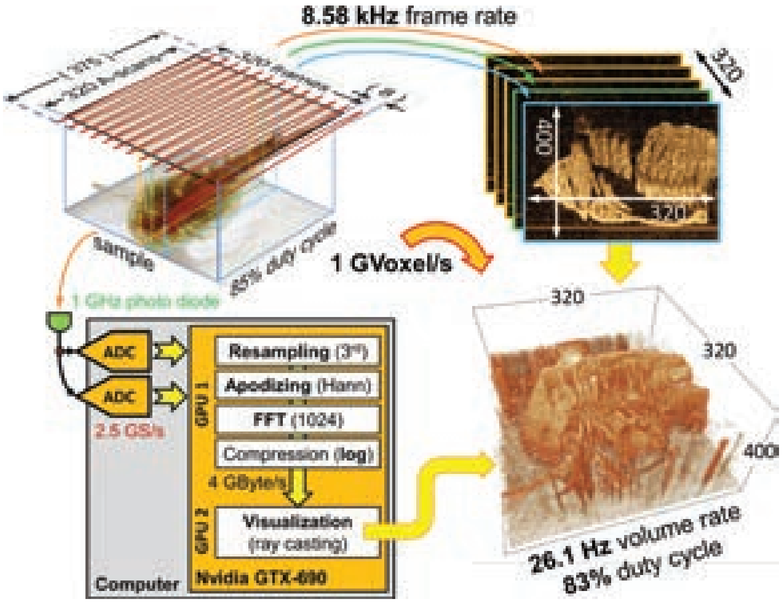
OPTICAL COHERENCE IMAGING

A 4-D OCT Engine with 1 GVoxel/s



Scanning protocol for 1 GVoxel/s 4-D real-time OCT system.

Optical coherence tomography (OCT) is a depth-resolved imaging modality that provides micrometer-scale cross-sectional and 3-D information on the scattering properties of biological samples.[1] Video rate real-time 3-D volumetric OCT (4-D-OCT) could generate a new class of optical tools in clinical practice, like surgical guidance.[2] This challenge requires us to combine a high-speed OCT imaging setup, ultrafast data acquisition and adequate real-time data processing to process and visualize the vast amount of data.

Although 4-D-OCT has long been a dream for researchers, only a few groups have successfully implemented 4-D volumetric OCT imaging with real-time visualization—usually with low resolution, and sometimes with a massive amount of dedicated hardware that prohibits widespread use.[3,4] In 2014, we presented a major advance: a real-time 4-D swept-source OCT system featuring more than 1 GVoxel/s—nearly an order of magnitude faster than previous systems (approximately 125 MVoxels/s).[4, 5] With a volume size of 320 × 320 × 400 and a flicker-free 3-D volume rate of 25 Hz, this system represents a breakthrough in real-time OCT. Notably, a resolution that had previously been in the realm only of smooth 2-D imaging is now available for smooth 3-D volumetric imaging.

The system applies a Fourier-domain mode-locking (FDML) laser with a sweep rate of 3.2 MHz.[6] All computations are performed on a single, consumer-grade GPU card in a standard desktop computer equipped with two high-speed (2.5 GS/s) PCIe digitizer cards. Dedicated electronics trigger these cards in volume interleave mode and synchronize the FDML laser with the resonant galvo scanners. Self-developed multithreaded software reassembles the OCT data and transfers a stream of about 2 GBytes/s to the GPU card, which performs all OCT computations as well as high-quality 3-D visualization via ray casting.

The system's high speed makes it useful for capturing and understanding fast dynamics. The volume acquisition rate can be doubled to 50 Hz by reducing the volume size (320 × 160 × 400), which enables "slow-motion OCT" playback and allows the study of these dynamics.

The 4-D-OCT presented here has the potential to create new applications for OCT, like the study of fluid dynamics or capturing 3-D movements and morphology. It will allow new insights through fast, high-quality, depth-resolved imaging modalities. OPN

Visit **www.osa-opn.org/optics-in-2014** to view the video that accompanies this article.

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OPTICAL COHERENCE IMAGING

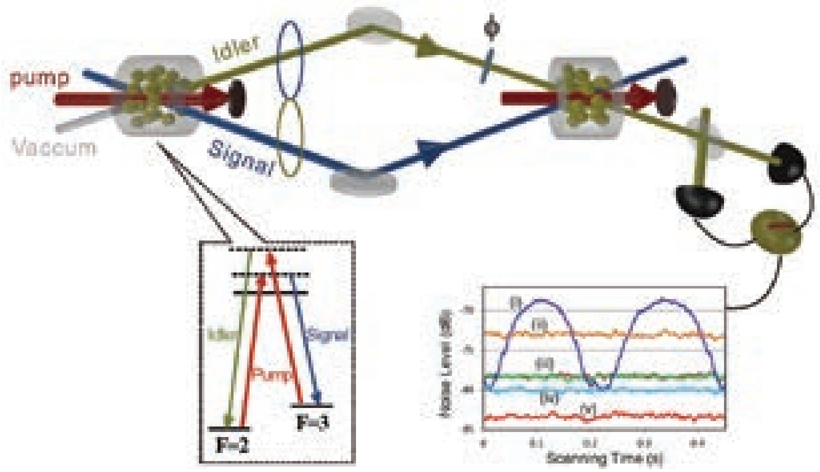
Photon-Correlation Interferometer for Quantum Metrology

Interferometers are fundamental devices; they are irreplaceable elements in precision measurement and have wide applications in modern metrology. The laser interferometer for gravitational wave detection is the current state-of-the-art. But because of the vacuum quantum noise injected into the unused port, the sensitivity of the interferometers in precision phase measurement is restricted to a fundamental limit, i.e., the shot noise limit.

In 1981, C.M. Caves pointed out that the vacuum noise can be suppressed by using the squeezed state of light.[1] Soon after, sub-shot-noise-limit interferometry was demonstrated experimentally. This strategy was applied to the Laser Interferometer Gravitational Wave Observatory (LIGO) project in 2008.[2] Following these advances, different types of quantum states with special noise behaviors have been studied for quantum-noise suppression in order to improve the sensitivity of interferometers. Another approach for precision phase measurement was adopted by Yurke et al., who proposed the so-called SU(1,1) interferometer in the quest for the Heisenberg limit.[3] It utilizes a nonlinear process for beam splitting and recombination. Until now, no one has created an experimental implementation for such an interferometer.

This year, our team succeeded in experimentally demonstrating the SU(1,1) interferometer for precision phase measurement. In this new type of interferometer, the beam splitting and recombination elements are parametric amplifiers that generate photon-correlation beams.[4,5] We observed an improvement of 4.1±0.3 dB in signal-to-noise ratio compared with a conventional interferometer under the same operating conditions, which is a 1.6-fold enhancement in RMS phase measurement sensitivity beyond the shot noise limit.

The beam splitters in our SU(1,1) interferometer are replaced by parametric amplifiers, which amplify the incoming signal beam and generate a correlated idler beam through nonlinear interaction. In the present realization, the parametric amplifier is based on non-degenerate four-wave mixing (FWM) in hot Rb-85 atomic-vapor cells. Since nonlinear processes are involved in this interferometer, they can couple a variety of different waves and form new types of hybrid interferometers, opening a door to many applications in quantum metrology. OPN



Experimental setup for the photon-correlation interferometer. The first four-wave mixing (FWM) in the atomic-vapor cell generates photon-correlated beams. The beams are decorrelated by the second FWM. The noises are analyzed with homodyne detection. (Inset) The FMW process in the atomic vapors.

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