produced by simply aligning the resonator such that lasing occurred simultaneously on two transverse modes (usually $\text{TEM}_{00}$, $\text{TEM}_{05}$). With appropriate group velocity dispersion compensation using a pair of intracavity Brewster-angled prisms, chirp-free pulses having durations around 60 fsec have been produced by this method.

The key evolution and shortening kinetics of the laser pulses are attributable to the resonator and the intensity-dependent optical nonlinearities in the titanium-sapphire gain medium itself. Therefore, the tunability is limited primarily by the reflectivity characteristics of the mirrors used. For example, with two commercially available mirror sets (for Spectra Physics, Model 3900) a typical tuning range is 750-950 nm, where other mirrors can be used for spectral extension to shorter or longer wavelengths if desired. A number of related implementations on this scheme have already been reported. Its practicality is highlighted by the fact that four laser manufacturers can now offer fully-engineered ultrashort-pulse Ti:sapphire laser products that are based on the self-modelocking principle.

As a more comprehensive understanding of self-modelocking becomes established, it is likely that this technique will be applicable to other laser types. In particular, the diode laser pumpable new gain media such as $\text{Cr}^{3+}:\text{LiSrAlF}_6$ may lead to especially attractive low-phase-noise, reliable, and robust laser systems. Additionally, by combining the attributes of high peak power pulses with the current availability of highly efficient nonlinear crystals (e.g., BBO, LBO) a range of frequency-doubling, frequency mixing, and optical parametric oscillator procedures can be exploited. By this means, the prospect of all solid state sources of coherent femtosecond pulses having wavelengths from the ultraviolet to the mid-infrared becomes very real. As a direct consequence, the opportunities for enlarging the applications potential of such pulses from basic time-domain spectroscopy to the technology of digital optics is likely to grow vigorously during this decade. In this expected growth, the self-modelocking technique will undoubtedly have played a role as an important catalyst in respect of the development of ultrashort pulse laser sources. This surely represents a good return on the simplistic approach.

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**BALLISTIC 2D-IMAGING THROUGH TISSUE SCATTERING WALLS**

BY L. WANG, P.P. HO, R.R. ALFANO, THE CITY UNIVERSITY OF NEW YORK

For earlier cancer diagnosis, it is important to image ultrasmall growths with a size of one millimeter or less. Optical radiation offers a new method to image a small tumor hidden inside the human body. Transillumination, a technique using light to image breast cancer, was introduced many years ago. However, the ability to observe this image is severely limited by light scattering that forms the image shadow and contributes to the noise. When photons migrate through a turbid medium, there are three main signal components: diffusive (incoherent), ballistic (coherent forward scattered that arrive by traveling over the shortest path), and snake (quasi-coherent photons that arrive within the first $\delta t$). When the tumor is too small (~1 mm), it may not be observed by the transillumination technique. By adding an ultrafast time gate, the detectability of small tumors located inside the breast can be significantly improved. Time-resolved techniques such as the Kerr effect and holography can be used to separate out the ballistic and snake components (least distorted image) from the diffusive component (most image information lost).

Using a 2-D picosecond optical Kerr gate imaging system, time-gated 2-D ballistic images of ~100 µm dimension in highly scattering media including a 3.5 mm thick human breast tissue, a 3 mm thick chicken breast tissue, and a 5 cm thick water cell with suspended polystyrene balls have been observed at CCNY. The experimental setup consists of a modelocked Nd:glass laser with 8 ps duration at 1054 nm, a $\text{Cs}_2$ Kerr shutter, and a 2-D image intensified CCD readout system. The second harmonic 527 nm is used to illuminate the hidden object.

A sequence of measured time-dependent 2D Kerr gate video images of a bar chart placed hidden behind 3.5 mm thick human breast tissue are displayed in the figure. The bars of the test chart (5 line pairs/mm) were illuminated by 8 ps, 527 nm laser pulses. Part (a) displays the image of the test chart in air. Part (b) represents the image pictures obtained from standard transillumination imaging (no time-gate) of the chart behind the tissue sample—no clear image can be observed in any of these cases. Part (c) represents Kerr-gate bar images of the ballistic and snake signals at the gating time of $T=0$. Clear bar images with dimension of ~0.1 mm (separated by 0.2 mm) can be resolved. As the gating time was delayed by 22 ps, the collected images were gradually broadened and blurred as shown in Part (d).

To use the time gating technique to measure phantoms of ~1 mm dimension in a thick scattering wall such as a 60
mm thick breast, one estimates the need of shorter pulses ~1 ps for the gate. In addition, a cooled CCD detector, a high repetition rate multiple pulses, and a multi-stage cascade time gate can increase the S/N by an additional factor of $10^8$. It is estimated that 2D low-level signal images with an attenuation factor of $e^{-28}$ through a scattering wall can be obtained. This makes time-gate imaging technique viable for the future optical mammography and tomography.

**References**