produced by simply aligning the resonator such that lasing occurred simultyaneously on two transverse modes (usually TEM_{00} TEM_{05}).[5] 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.[5]

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 Cr^{3+}:$LiSrAlF_6$ 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

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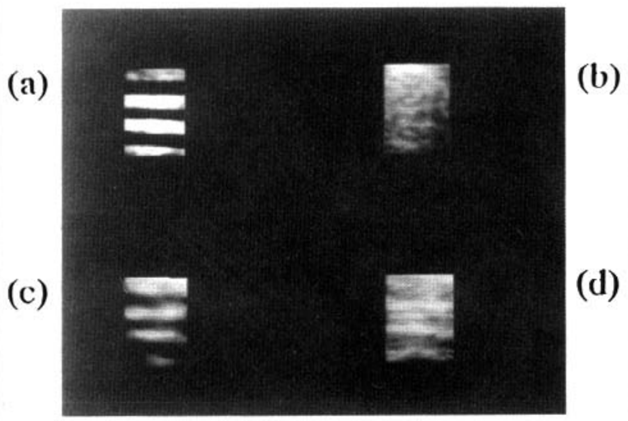
For earlier cancer diagnosis, it is important to image ultrasmall growths with a size of one millimeter or less. Optical radiation[1-5] offers a new method to image a small tumor hidden inside the human body. Transillumination,[3] a technique using light to image breast cancer, was introduced many years 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:[1,4] diffusive (incoherent), ballistic (coherent forward scattered that arrive by traveling over the shortest path), and snake (quasi-coherent photons that arrive within the first δt). When the tumor is too small (~1mm), 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[6] and holography[7,8] 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[1,6] 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 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



2-D IMAGES OF TEST CHART BEHIND A 3.5 MM THICK HUMAN BREAST TISSUE ILLUMINATED BY 8 PS 530 NM LASER PULSES. TEST OBJECT IS A 5 LINE PAIRS/MM TARGET FROM AN AIR FORCE BAR TEST CHART. DARK BARS ARE THE OBJECT AND WHITE AREA IS THE TRANSPARENT BACKGROUND. THE WIDTH OF EACH BAR IS ~100 μM. PART OF THE IMAGE NON-UNIFORMITY CAN BE ACCOUNTED FOR BY THE LASER BEAM NON-UNIFORMITY AND THE SAMPLE: REFRACTIVE INDEX VARIATION AND INTERNAL STRUCTURES. (a) REFERENCE IMAGE (TISSUE REMOVED); (b) NO TIME GATE (STANDARD TRANSILLUMINATION) (c) T_D=0, TIME GATE AT ZERO DELAY TIME; (d) T_D=22-PS, TIME GATE AT 22-PS DELAY TIME.

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.

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ELECTRONIC HOLOGRAPHY FOR IMAGING THROUGH TISSUE USING FEMTOSECOND GATED PULSES

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Imaging through and into highly scattering media is a major problem of optics. One potential application is for medical imaging—to see through biological tissue. One imaging method uses short pulses (picosecond or subpicosecond) and the principle of the first arriving light.[1] Here, a short pulse of light enters the medium and emerges as a greatly elongated pulse. The light that is scattered least emerges first, and the more scattered light emerges later. The least scattered light, being distorted the least, will form the best image of any absorbers located behind or embedded within the material. Gating methods are then used to separate this first arriving light from the rest.

A wide range of different methods have been used or proposed. Holography is one of the methods. As carried out by Abramson, Bjelkhagen, and Spears,[2] a hologram is made of the scattered light, using very short pulses (or equivalently, a short coherence light source) and the reference beam path delay is adjusted so that the reference beam interferes only with the first arriving light. This is the basis of their Chrono-coherent process. Others, including Alfano and his group at The City College of New York, have used other methods.

We have combined the holographic method with electronic holography, which avoids some of the limitations of conventional holography and is uniquely matched to the present problem.[3] We form the hologram on the detector of a cooled CCD camera.

The diffusing medium may be inherently stable, as with most solids, or unstable, as with living tissue. To make a hologram of an unstable object requires a pulse laser, where the total light needed for the exposure is delivered in a short time, perhaps about a ms. This can pose a problem, since inconveniently high light levels could be required. A second problem is that, for several reasons, the image will be noisy. First, the later arriving light, which does not interfere with the reference beam, nonetheless