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CThK7 **11:45 am**

Two-fold spatial resolution enhancement by two-photon exposure of the photographic film

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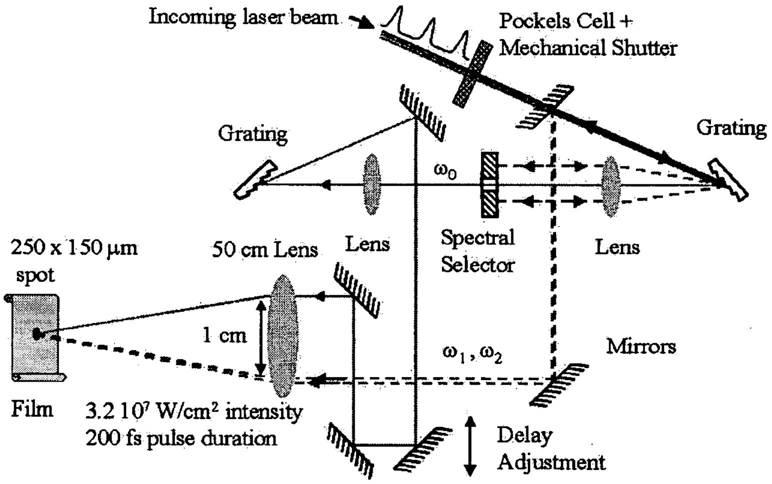
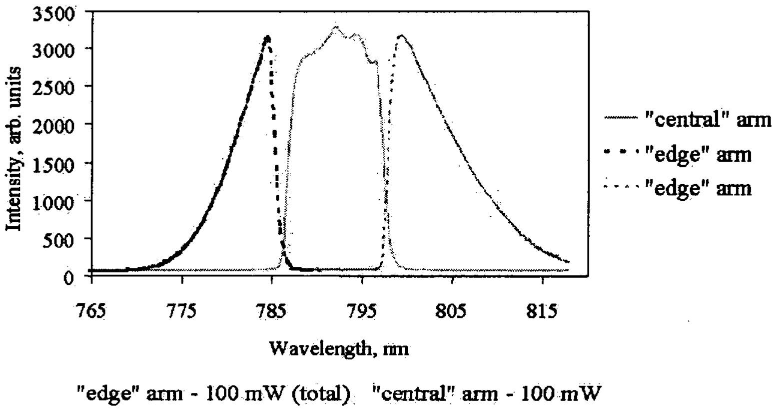
Two-photon exposure can be advantageous for the improving of spatial resolution of an image. Two-photon exposure uses the square of the pulse intensity profile, resulting in ???2 decrease of the spot size. More important, it has been shown recently,[1,2] that multi-frequency beams can interfere with each other to produce a doubling of spatial resolution (although at 2:1 pedestal) if the media exposure is due to two-photon.

We performed our experiments using Kodak Commercial Film (Catalog No. 198 7874). This type of film is blue sensitive (up to 470 nm) and has very low sensitivity at 790 nm—operational wavelength of our Ti:sapphire laser system (80 fs single pulse duration, 82 MHz repetition rate, 0.6 W average output power). Single pulse parameters at the output of the system ~7 nJ energy and 90 kW power. The total exposure time was controlled by a combination of the Pockels cell and a mechanical shutter. It has been shown in,[3] that similar type of photographic film can be exposed due to two-photon absorption. First we made sure that the intensity of our laser source was enough to induce two-photon exposure of the media. We focused the beam into 400 × 250 μm spot (10^{-3} cm^2 area) by 1 m lens and made calibrated exposures. It happened that the film saturation occurred at 20 μsec total exposure time. Then we intentionally destroyed the mode-locked mode of operation of the Ti:sapphire system making it CW (the same average output power) and repeat the measurements. At that time the saturation occurred only at 100 μsec exposure time. It shows that two-photon effects were about 5 times stronger than single-photon ones. That allowed us to estimate the parameters of one- and two-photon absorption of the photographic film. For the case of two-photon absorption the saturation parameter is the product of total absorbed energy E_{total} and peak intensity of the single pulse I_{peak}. In our experiment it was $E_{total}\ I_{peak} = 1.2\ 10^6$ JW/cm^2. In the case of one-photon absorption the saturation parameter is the total absorbed energy E_{total}. It was $E_{total} = 60$ mJ/cm^2. At the peak of absorption curve (350 nm) the one-photon sensitivity of the film is ~1 μJ/cm^2.

Experimental set-up is shown in Fig.1. The broad-band radiation from femtosecond Ti:sapphire laser was reflected by diffraction grating toward spectral selector (a mirror with a 3.5 mm hole in the center). Central part of the spectrum passed through the hole and was recombined into a collimated beam by the second grating. The edge portions of the spectrum were reflected back and were recombined into a collimated beam by the first grating. The transmitted beam consisted of the radiation with ω_0 frequency and the reflected one—with ω_1 and ω_2 frequencies. The position and the diameter of the central hole were chosen such that $2\omega_0 = \omega_1 + \omega_2$. An extra delay line was used to recombine pulses in both arms in time. Optical spectrum after the system is shown in Fig.2. Since we limited spectral bandwidth in both arms, the corresponding pulses were inevitably broader -200 fs each. Average intensity in each arm was 100 mW. Both beams were made parallel (1 cm distance between them) and then focused into a single spot (250 × 150 μm) by 0.5 m lens. Fig. 3 shows the averaged (to decrease the effect of finite grain size) intensity profile of the developed film at 5 μsec exposure. The averaging was made along the direction of the fringes. One can see a set of major and minor maxima. The distance between major maxima (44 μm) corresponds to "normal" interference spacing. The presence of the minor maxima indicates the effect of two-photon absorption. The relatively low intensity of the minor maxima is probably due to the fact that one- and two-photon effects are comparable to each other. Unfortunately, we were not able to increase the intensity of our radiation by using a lens with shorter focus due to insufficient spatial coherence of the beams.



CThK7 **Fig. 1.** Experimental set-up.



CThK7 **Fig. 2.** Optical spectrum of the radiation focused on film.

It would seem advantageous to use a high-energy system similar to one described in.[3] One can estimate that for 1 psec pulse focused into 1 × 1 mm spot, its energy should be in 100 – 200 μJ range to achieve a predominant two-photon exposure. That can be easily provided by Ti:sapphire amplifier.

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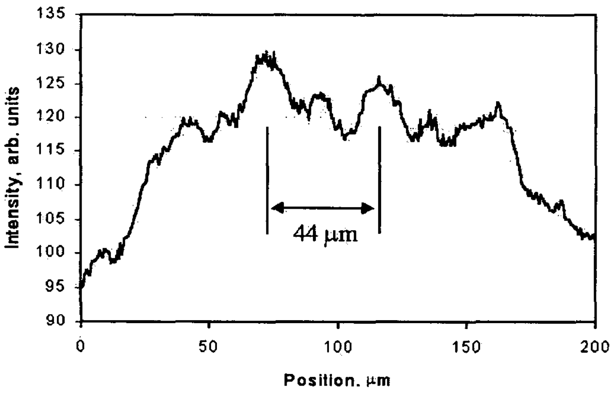

CThK7 Fig. 3. Intensity profile averaged over ~20 grains. Total exposure time 5 µsec.

CThL 1:00 pm–2:30 pm
Room Exhibit Ha

Poster Session 3

CThL1 1:00 pm

Experimental investigation of pulse propagation through RMS width and pulse quality factor

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By using the analogy between paraxial free space diffraction and second-order dispersion, it has recently been proposed[1,2] that the propagation of short laser pulses in dispersive materials could be characterized by the same tools that are used for beam propagation.[3] It was shown that the temporal duration and spectral width of short laser pulses could be specified by the root-mean-square (rms) widths obtained through the evaluation of second-order moments. The evaluation of the rms temporal width can be done directly using the data from standard autocorrelation measurements; there exists a simple relationship between the rms width of a pulse and the rms width of its autocorrelation trace, irrespective of the pulse shape. Hence the approach is free from any assumption on the functional form of the pulse temporal profile; furthermore it does not require the full characterization of the amplitude and phase of the pulse.

Based on the analogy with laser beams, we will introduce the definition of a Pulse Quality Factor proportional to the product of the spectral and temporal rms widths. Such a definition eliminates subjective interpretations of autocorrelation traces and allows the definition of a generalized dispersion length. We will show that the Pulse Quality Factor is more representative of the pulse quality than the more conventional time-bandwidth product. The measurement of the Pulse Quality Factor is easily accessible through already widespread measurement techniques.

We will present experimental results obtained with pulses from 10- to 25-fs duration obtained with a prism-controlled Ti:sapphire laser. The purely dispersive (linear) propagation of these pulses in bulk fused silica is studied around the temporal waist. We have compared the measured temporal rms width as a function of the propagation distance with the predictions of a propagation law for the temporal rms width using explicitly the Pulse Quality Factor. The results are shown in Fig. 1; the pulse spectra are shown in Fig. 2. The excellent agreement between theory and experiment shows that the approach is applicable for various pulse spectra, even those with a strong asymmetry. To eliminate the sensitivity of second-order moments to noise, we have made the estimation of the rms widths using the fractional power concept.[4] The residual chirp on a pulse can be estimated by comparing the rms width computed from the Fourier transform of the pulse spectrum and that measured from the autocorrelation trace, as shown in Fig. 3.

In summary, the approach described here is an objective way to characterize the duration and quality of any type of short laser pulses. The agreement between the propagation law and the measurements indicates the practical validity of the proposed definition of the Pulse Quality Factor. It leads to non-negligible corrections to the more conventional analysis of autocorrelation traces without having recourse to the complete characterization of amplitude and phase. The effects of third- and fourth-order dispersion will be discussed. The generalization of the concept of rms width to nonlinear optical interactions is presently investigated.

References

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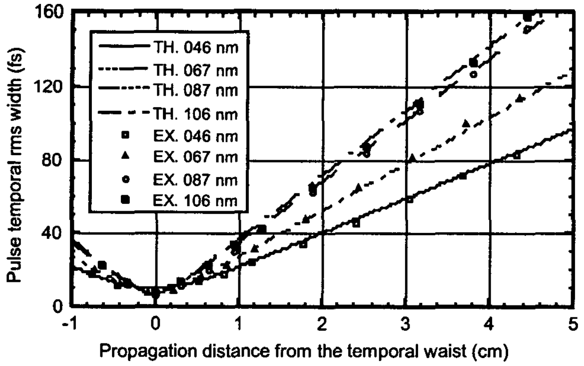
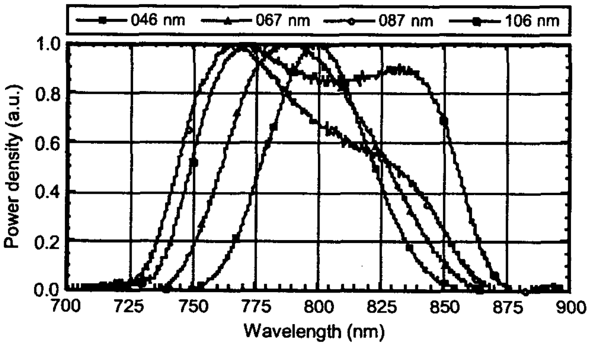


CThL1 Fig. 1. Temporal width (rms) of short pulses as a function of propagation distance in fused silica. The curves are drawn from the propagation law involving the Pulse Quality Factor; the experimental measurements are indicated by discrete points. The corresponding pulse spectra are shown in Fig. 2.



CThL1 Fig. 2. Spectra of the pulses used for the measurements shown in Fig. 1. Each spectrum is identified by its full-width-at-half-maximum (FWHM).