from the material resonance. For $\lambda_{laser} = 800$ nm and $\lambda_0 = 200$ nm, this leads to $T_R \approx 0.1$ fs.

Calculated TBC energy transfer with T_R equal to and much shorter than the pulse duration are shown in Fig. 2. If the sign of the chirp is inverted, the signal is inverted. Fractional energy transfer of 10^{-3} is expected with nanojoule-energy pulses if the response time equals the pulse parameter t_0 (Fig. 3). For faster responses, the signal levels decrease dramatically. For $T_R = 0.01t_0$, the magnitude is only 10^{-8}. Therefore, measurement of electronic TBC will not be possible with a 10-fs modelocked laser. However, it should be possible with cavity-dumped or amplified sources. Such an experiment could be performed in materials in which Raman scattering is forbidden, to isolate the electronic response.

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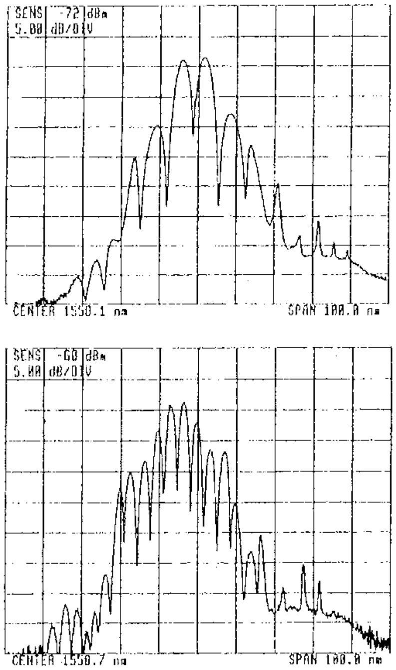
QWG4 11:15 am

Observation of bound solitons in a passively mode-locked fiber laser

D.Y. Tang, P.D. Drummond, W.S. Man,* H.Y. Tam,* M.S. Demokan,* *Center for Laser Science, Physics Department, The Univ. of Queensland, Brisbane, Australia*

Recently B.A. Malomed theoretically predicted the existence of bound states of solitons in the dissipatively perturbed nonlinear Schrödinger equation. He showed that the interaction of slightly overlapping solitary pulses in the system could lead to the formation of bound solitons with a discrete, fixed separation.[1] It is well known that the dynamics of a passively mode-locked fiber soliton laser can be modeled by the dissipatively perturbed nonlinear Schrödinger equation, provided that the soliton pulse shaping within one round trip is small. The same equation describes soliton propagation in optical fibers. However, to the best of our knowledge, so far no bound solitons have been observed in these systems. In this talk we report on the first experimental observation of bound soliton states in a passively mode locked fiber soliton laser.

Multiple soliton operation is a generic feature of passively mode-locked fiber soliton lasers and has been reported by many authors.[2,3] However, the observed multiple solitons are characterized by either being far away from each other separated so that there is no interaction between them, or else they are in constant, random motion. In fact two effects in fiber soliton lasers prevent the formation of the predicted bound states. One is the soliton Raman effect. Theoretically it has been shown that the existence of a strong Raman effect destroys bound solitons.[4] Another effect is the random phase variation between solitons.



QWG4 Fig. 1. Spectra of bound states of soliton observed experimentally.

We have found that in the case of a fiber soliton laser, the influence of the Raman effect can be significantly reduced due to laser gain dispersion. Random phase variation of solitons can also be controlled by using a novel phase locking technique involving a tunable cw background field. We have succeeded in observing two bound states of solitons with fixed soliton separation in our laser. Figure 1 shows the soliton spectra of the bound states. The soliton pulse duration in our laser is about 480 fs, and the measured soliton pulse separation for one bound state is about 1160 fs, for the other one about 2280 fs. Experimentally we found that no matter what the experimental conditions are, only these two bound states are observed in our experiments. The two observed bound states have the relation that the soliton separation in one state is half of the other.

In Fig. 1 the existence of the soliton bound states is indicated by the presence of interference fringes. The soliton separation can be measured either by the fringe period, or else by using a direct auto-correlation method. Both measurements agree with each other. The soliton separation was the same at more than one measurement location around the ring fiber laser cavity.

We note the very symmetrical soliton spectral modulations shown in Fig. 1, which suggests strongly that the phase differences between the bound solitons are π. The observed bound states are very stable in our experiment. Once they are formed, they can remain there for several hours even in a noisy environment. Trains of bound states are also observed in our experiment, and it was found that all the bound states in a train have the same soliton separation.

**The Hong Kong Polytechnic Univ., Hong Kong*

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QWG5 11:30 am

Self-phase modulation of few-optical-cycle pulses and sub-cyclic pulse compression

V.P. Kalosha, J. Herrmann, *Max-Born-Inst. for Nonlinear Optics and Short Pulse Spectroscopy, Max-Born-Str. 2a, 12489 Berlin, Germany; E-mail: kalosha@mbi-berlin.de*

Self-phase modulation (SPM) of optical pulses is the physical reason for a large variety of phenomena as optical solitons, spectral broadening and others. One of the most exciting applications is the utilization of SPM in a Kerr medium followed by propagation in a dispersive delay line for pulse compression. While the nonlinear propagation of pulses with the duration of many cycles is rather well studied, the physical phenomena in the ultrashort (few-cycle and sub-cycle) regime are yet not well understood. In this region widely used approximate methods, as a truncated Taylor series approximation for dispersion and the slowly varying envelope approximation (SVEA), are no longer adequate to describe the pulse propagation. In the present talk we investigate this regime and study the possibility to extend the method of pulse compression into the optical subcycle regime. We solve the exact Maxwell equations without the use of the SVEA and apply a global approach to dispersion with a modified Sellmeyer expansion. In such a way dispersion effects, infrared losses due to vibrational modes as well as other higher-order effects as self-steepening owing to intensity-depending group velocity are adequately taken into account. With the help of this approach the character and the limitation of ultrawide spectral broadening by SPM and the frequency-dependence of the phase (chirp) during propagation are studied. As a result we show that pulses with a duration of 0.5 fs or approximately half of a cycle can be generated by SPM in a dispersive Kerr medium, whereby chirp compensation can be achieved by the use of a liquid-crystal modulator.

We consider the interaction of an ultrashort few-cycle pulse with a dispersive, nonresonant nonlinear optical material as fused silica. The polarization in the medium is separated into a linear (P_x^L) and a nonlinear part (P_x^{NL}): $P_x = P_x^L + P_x^{NL}$. The Fourier component for P_x^L is represented by $P_x^L(\omega, z) = \varepsilon_0\chi(\omega)E(\omega, z)$, where the linear refractive index and the linear loss can be modeled rather precisely by a modified Sellmeyer fit. The dispersion of the nonlinear susceptibility in wide-gap solids can be described by $\chi^{(3)}(\omega) \approx \chi_0^{(3)}(1 + 2.8\omega^2/\omega_g^2)$,[1] where $E_g = \hbar\omega_g$ is the bandgap. For fused silica, ω_g^{-1} is about 0.03 fs and the dispersion of $\chi^{(3)}$