Characterization of a 10 GHz harmonically mode-locked erbium fiber ring laser using SHG FROG

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Active, harmonic mode-locking of Erbium Fiber Ring Lasers (EFRLs) is an established technique for obtaining short pulses at GHz repetition rates [1, 2]. To date all reports on the characterization of such lasers have used techniques that provide incomplete information on the pulse shape and quality, e.g. autocorrelation with optical spectrum, streak camera etc.. Whilst this is largely adequate, direct measurements of pulse amplitude and phase would be extremely useful, facilitating the optimization and detailed understanding of the operation of such lasers [3].

Over the past few years Frequency Resolved Optical Gating (FROG) has become an established technique for fully characterizing ultrashort pulses. So far, it has been mainly used, and associated with, high peak-power pulsed laser sources of relatively low repetition rate. However, the power requirements and resolution are in fact fully commensurate with telecommunication grade fiber laser requirements. In this paper we report what is to the best of our knowledge the first FROG characterization of a high repetition rate picosecond pulse EFRL, characterizing in detail the intracavity pump power dependent pulse shaping.

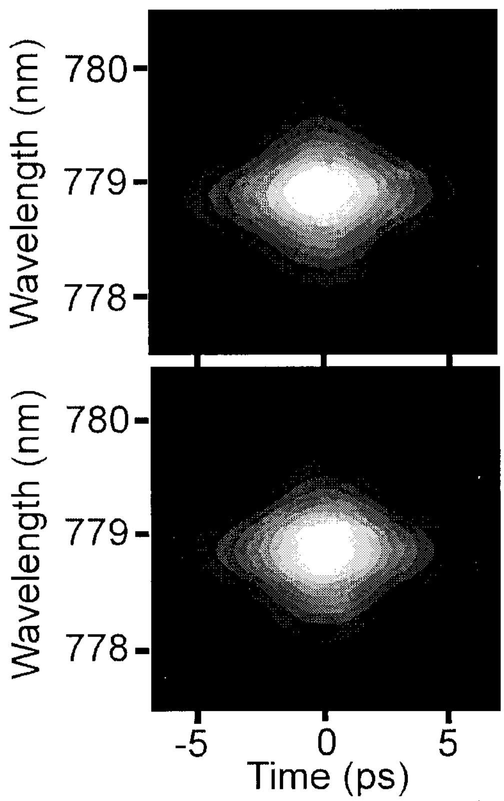

Fig 1: Measured (upper graph), and retrieved spectrogram (lower graph) of the EFRL pulses for a pump power of 60 mW (normalized linear scale, 0.1/contour); the error of the fit is less than 0.2%.

The actively and harmonically mode-locked EFRL is of a conventional design [1]. The ring is ~500 m long and consists solely of polarization-maintaining (PM) fibers and components to give optimum environmental stability. The exact pulse repetition rate is actively controlled around 10 GHz by a phase-lock loop (PLL) to match the mode-locking frequency. The key to obtaining ultrashort pulses is soliton shaping effects within the ring, enhanced by the inclusion of a long length of dispersion-shifted fiber (DSF). Interplay between self-phase modulation (SPM) and the low, anomalous dispersion of the DSF gives rise to soliton compression of the circulating pulses [1, 2]. The pulse width of the pulses thus becomes a strong function of the laser pump power.

The laser pulses, after being amplified to an average power of ~50 mW, were characterized for a full range of laser pump powers. Fig. 1 shows the experimental and retrieved spectrograph for a laser pump power of 60 mW, close to the optimal operating conditions, illustrating the quality of the fit of the data. In Fig. 2 we plot retrieved pulse profiles for laser pump powers of 45, 60 and 85 mW, which illustrate the pulse deformation that occurs at higher levels. The slight linear chirp of the pulses at lower powers is, we believe, due to residual dispersion (~0.15 ps/nm) within the booster amplifier used at the FROG system input. Characterization of this pulse deformation in terms of pulse duration and the time-bandwidth product (TBP) is shown in Fig. 3. Observation of power dependent pulse quality degradation was reported in Ref. [2], but only from the observed behavior in the autocorrelation trace/optical spectrum.

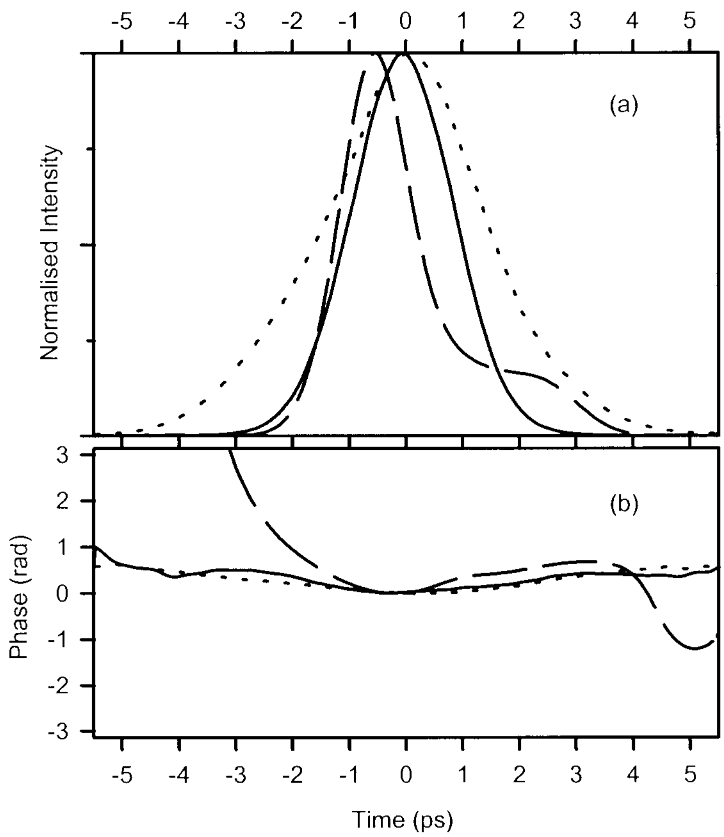

Fig. 2: Temporal intensity (a) and phase (b) for different powers of the laser pump diode; dotted curves correspond to 45 mW, solid curves to 60 mW, and dashed curves to 85 mW of pump power.

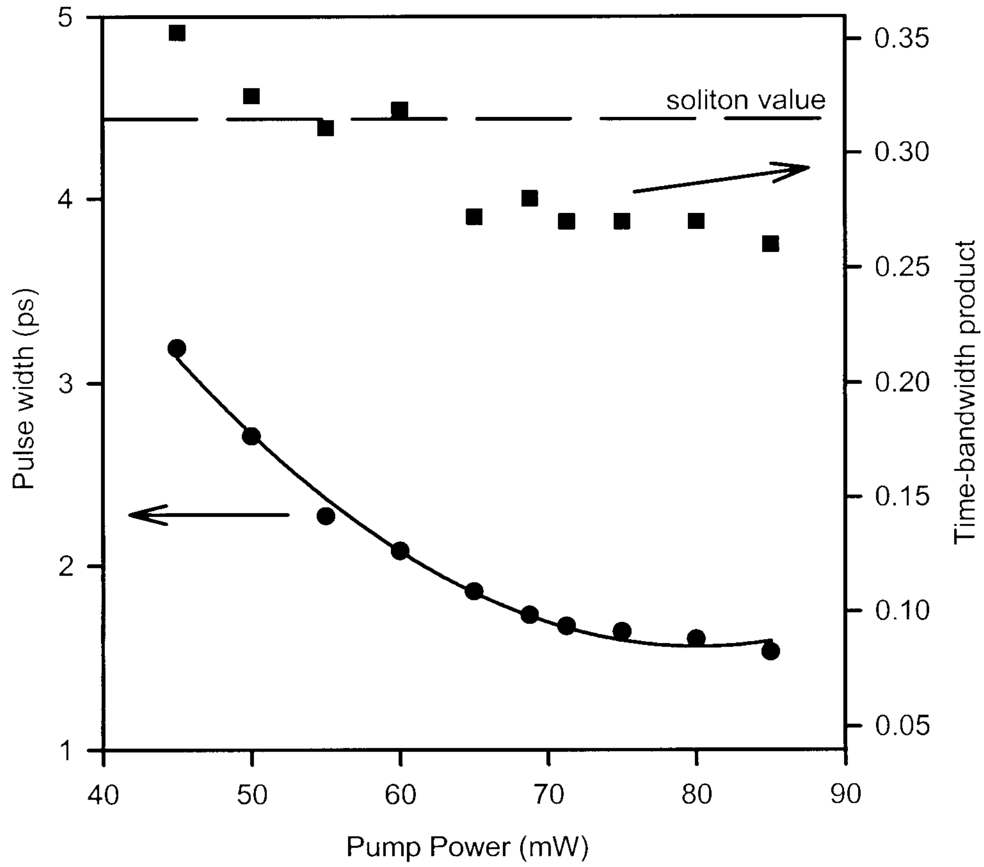

Fig. 3: Variation with pump power of the temporal FWHM and TBP of the EFRL pulses, using spectral half-widths and pulse durations from the SHG-FROG measurements.

In conclusion, we have characterized low-energy picosecond pulses at high repetition rates using the SHG-FROG technique, determining in detail the power dependent pulse shaping in a soliton fiber laser. Our measurements highlight the applicability and value of the FROG technique as applied to fiber systems. The measurements provide information which is essential for pulse propagation experiments and impossible to obtain with more commonly applied methods.

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References

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