Full Characterisation of Low Power Picosecond Pulses From 
a Gain-Switched Diode Laser using Electro-Optic 
Modulation Based FROG

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Abstract: We use a linear FROG technique based on electro-optic modulation to fully characterise for the first time pulses from a 1.06 µm FP laser diode and design a grating to provide optimum pulse compression.  
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1. Introduction

Gain-switched distributed feedback (DFB) and Fabry–Pérot (FP) lasers were primarily developed for telecommunications applications which require only limited pulse powers. However, recently they have also been used as seed lasers for high-power cladding-pumped rare-earth doped fiber amplifiers emitting at 1.55 µm [1] and at 1.06 µm [2]. At 1.06 µm average powers of 321 W have been reported, the largest ever for a picosecond pulsed system.

An inherent characteristic of pulses produced by gain-switching is that they are highly chirped. It is important to be able to characterise this chirp in order to design components, such as fiber Bragg gratings, which will efficiently compress the seed pulse. FROG techniques based on nonlinear processes (e.g. SHG-FROG) are poorly suited for the characterisation of picosecond pulses from these diodes because of the relatively low peak power. Here we use a FROG technique developed initially for telecoms, based on linear gating [3]. This technique is highly sensitive, allowing characterisation of long duration, low energy pulses. It also has the advantages of simplicity and convenience, being achievable with fully fibreised components and using only electronic delays. To the best of our knowledge, this is the first time this technique has been used to characterise pulses at ~1.06 µm.

2. Setup

The fiberised FP diode laser operating at around 1060 nm, was driven by an RF driver with a sinusoidal electrical signal at approximately 1 GHz to produce gain-switched pulses. The diode was self-seeded to promote lasing on a single longitudinal mode. The Side Mode Suppression Ratio was ~40 dB. The average output power was about 5 mW, corresponding to ~5 pJ pulse energy. The pulses had a bandwidth of 0.13 nm and a duration of 82 ps (as measured with fast scope) yielding a TBW product of ~2.8, showing that the pulses were highly chirped, as expected for a gain-switched diode.

![Fig. 1. picosecond FROG setup](image)

The output of the diode was fed, via a fiber polarisation controller, to a fiberised Electro-Optic Modulator (EOM). The modulator was driven by a square wave generator triggered by a signal from the diode driver. The square-wave generator was controlled by a PC and could vary the pulse duration and delay of the pulse from the trigger signal. This creates a timing window for transmission of the light from the diode. The minimum gate time was ~200 ps, determined by the response of the EOM. The output of the EOM went to an Optical Spectrum Analyser (OSA) with 0.01 nm resolution. In this way, the signal could be spectrally resolved as a function of delay to produce
a spectrogram. The system was fully fibreised and all delays were electronic rather than optical. Numerical retrieval was carried out on the spectrogram and independently recovered the diode signal and the EOM sampling function. Pulse information can be retrieved even for pulses which are shorter by a factor of >10 than the gating time [4].

3. Analysis of pulses from diode and compression

As shown in fig 2 a), the retrieved FROG data corresponds closely to the trace obtained from a fast oscilloscope, confirming the accuracy of the technique. Fig 2 b) displays the retrieved gate function of the EOM. The fact that we do not have to separately measure the response of the gate, but can retrieve it simultaneously with the pulse, is a considerable advantage of this technique, particularly as the EOM bias can drift slowly as a result of environmental conditions unless actively stabilized.

In simulation, we progressively applied a linear chirp to the pulse measured by FROG until we reached a minimum pulse duration. The simulated pulses obtained were of good quality, with most of the power in the main peak. We fabricated a fibreg grating with a linear chirp of 0.0025 ps$^{-2}$. This was spliced to the output of the diode via a 50:50 coupler and the reflected pulses were analysed with the FROG. The retrieved FROG trace, shown in fig. 2 c), was in excellent agreement with the simulated results, yielding pulses with a duration of 18 ps (TBWP=0.7) and ~90% of the pulse energy in the main peak.

![Fig. 2. a) Amplitude (solid) and phase (dashed) of uncompresed pulses retrieved by FROG and fast oscilloscope trace (dotted) for comparison, b) amplitude of EOM gate function simultaneously retrieved by FROG, e) pulse shape simulated from adding a linear chirp to the pulse from the diode (dotted) and the retrieved amplitude (solid) and phase (dashed) of pulses after reflection from the chirped grating.](image)

4. Conclusion

We used a highly sensitive linear FROG technique, originally developed for telecoms applications at 1.55 µm, to analyse pulses from a picosecond FP laser diode operating at 1.06 µm, and used this data to design a fiber Bragg grating for optimum pulse compression. The experimental setup for the FROG measurements is simple to construct using standard fibreised components, completely alignment free and fully computer controlled, and works well with low energy, long duration pulses which are difficult to characterise using techniques based on optical nonlinearities.

5. References