Experimental demonstration of an optimized method to generate multi-pulse structures in mode-locked fibre laser

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Abstract. We present here an experimental demonstration of a new method to access the multi-pulse regime in mode-locked fibre laser. This method allows us to drastically reduce the pumping power, while having a stable train of multiple pulses.

1 Introduction

Fibre laser cavities can be used to generate a large variety of complex structures, such as bound state solitons called soliton molecules, resulting from an equilibrium between the constraints imposed in the cavity (gain, losses, dispersion, nonlinearity, etc.) [1-3]. These structures are generally produced by increasing the pumping power, in order to reach the multi-pulse regime of the laser [4]. However, we will see that this procedure can be improved by adding a band-pass filter with a proper bandwidth.

In this paper, we present an experimental demonstration of a new procedure, called 2D method, that allows us to generate a stable train of multiple pulses with a drastic reduction of pumping power.

2 Conventional pulse fragmentation

To reach the multi-pulse in mode-locked fibre laser, the standard procedure is to increase the pump power, as depicted in Figure 1. At first, the increase of pumping power above the mode-locking threshold will generally lead to a single-pulse regime. If the pumping power is further increased, the excess of energy given to the pulse will destabilize it, forcing it to split into two pulses of lower peak power in order to regain a stable state.

This process, called pulse fragmentation, can be obtained several times by increasing again the pumping power. As we will see, this procedure, referred here as the conventional method, can be greatly improved by the use of a proper tuned band-pass filter.

3 Optimized pulse fragmentation

We now consider the laser cavity depicted in Figure 2 (a). In this cavity, the amplification is achieved thanks to a 980 nm laser, injected via a wavelength division multiplexer (WDM) into a 1.2-meter-long erbium doped fiber (EDF). The mode-locking element is a Semiconductor Saturable Absorber Mirror (SESAM), after which 20% of light is extracted with an output coupler. The 80% remaining will then pass through a band-pass filter (BPF), and a dispersion compensating fibre (DCF). The latter is used in order to have an average dispersion in the cavity close to zero.

Simulation results depicted in Figure 2 (b) show that, for a filter bandwidth $\Delta \lambda$ greater than a critical value $\Delta \lambda_c$, the pumping power required for the pulse fragmentation jumps abruptly. This effect occurs when the filtering effect of the BPF becomes predominant compared to the filtering effect of the gain medium [5].

![Fig. 1 Principle of conventional pulse fragmentation.](image1)

![Fig. 2 (a): Laser cavity used in simulations and experiments (b): Pumping power required for fragmentation as a function of the filter bandwidth.](image2)
To take advantage of the reduction of pumping power allowed by the filtering effects, we propose the following procedure, called 2D method. Experimental results obtained with this method are depicted in yellow in Fig. 3. First, the bandwidth of the BPF is set at an optimum value $\Delta \lambda_{\text{opt}} = 2.5 \text{nm}$, for which the pump power is low. The multi-pulse regime is then reached by increasing the pump power to 179.3 mW (point $\pi$). The filter bandwidth is finally increased to the desired value, which is $\Delta \lambda = 6.4 \text{nm}$ in our case (point $F$). Intermediate steps at different filter width (between point $\pi$ and point $F$) are displayed in black dotted lines, showing that the laser remains in the multi-pulse regime during the whole process. To show the advantage of the 2D method, the experiment is also carried out with the conventional method, as depicted in blue in Fig. 3 In this case, the BPF is fixed at 6.4 nm, and the pumping power is increased until the multi-pulse regime is reached. The laser exhibits Q-Switch instabilities at point $F$, and the pumping power must be increased to 307.1 mW to operate in the single-pulse regime [6]. Finally, to reach the multi-pulse regime, the pumping power has to be increased to 338 mW. The 2D method thus allows a reduction of the pumping power by almost a factor 2, which is in good agreement with our numerical simulation.

![Fig. 3. Experimental results obtained for the conventional method (blue path) and the 2D method (yellow path).](image)

Figure 4 (a) and (b) show in more detail the temporal and spectral profiles corresponding to the point $F$ of the 2D method. It should be noted that the 63 GHz bandwidth of the oscilloscope is not sufficient to provide the real temporal profile of the pulses, whose duration is in the picosecond range. However, the temporal profiles can still be used to confirm that the laser operates in the multi-pulse regime.

![Fig. 4 Experimental spectral (a) and temporal (b) profiles corresponding to the point F of the 2D method.](image)

4 Conclusion

We have experimentally demonstrated a new method to reach the multi-pulse regime in mode locked fibre laser, by using a narrow band-pass filter. This 2D method allows us to drastically reduce the pumping power compared to the conventional method, while generating a stable train of multiple pulses. Our experimental results, in accordance with numerical simulations, show the interest of this new method.

References

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