Innovative solutions to realize stable and reliable ultra-short pulsed lasers for industrial applications

PhD defended by Simon Boivinet (2016)

This work was carried out in the frame of the SIRIUS project, funded by the Walloon Region through the FIRST DoCA program.

Mode-locked (ML) lasers are currently used in many applications as diverse as microscopy, medicine, micromachining, or metrology. To achieve the phase locking and obtain the ML regime in laser cavity, the laser can be built in such a way that losses are high for continuous wave regime and reduced for pulsed regime. This loss modulation can be obtained by different phenomena but each mode-locking technique has its own drawbacks. Some applications like micro-machining require a low repetition rate (between few of tens kHz and few MHz) with picosecond pulses duration and most of the mode-locking techniques are not suitable to directly operate at this repetition rate. As a consequence, fiber laser oscillators are often subsequently pulse-picked and amplified to fulfill the end-user requirements. This is why in the last decades a lot of research work has been conducted to develop ML fiber lasers operating directly at low repetition rate while maintaining an ultrashort pulse duration. In these researches, the large amount of accumulated chromatic dispersion generally leads to pulses exhibiting quite large durations between few tens of picoseconds and up to few nanoseconds.

The subject of this thesis was to investigate new solutions for mode-locking a fiber laser and circumventing some of the classical impairments of this technology and ideally directly operate at low repetition rate. Our solution is based on a nonlinear mirror using NPE in birefringent fibers. This nonlinear mirror, also called all-fiber saturable absorber (AFSA), contains a polarizer, a long span of birefringent fiber and a Faraday Mirror (FM). The polarizer projects the linear polarization maintained by the birefringent fiber on the two axes of this latter. Nevertheless, the laser based on this mirror initially presented problems of reliability and reproducibility of the output laser parameters and it usually operates in a noise-like mode-locked regime. During this thesis we identified the origins of these drawbacks and we proposed solutions to solve this impairment.

In this thesis we first investigated the different pulsed dynamics obtained with a ML fiber laser operating at sub-megahertz repetition rate. A description of different pulsed regimes (including ML regime) that can be observed with the lasers based on the AFSA and the way to achieve them was discussed. The procedure required to achieve the ML regime was reported. Then the laser operating in this latter regime exhibits a periodic amplitude modulation of pulse train over a given pump power. The phenomenon is well-known as bifurcation, period doubling and route to chaos. This was for the first time, to the best of our knowledge, observed experimentally at 1 μ m wavelength. A numerical study of this ML laser was led to have a deeper insight into experimental observations and it showed the origin of the amplitude modulation of the pulse train. Finally, we also introduced a way to improve the achievement of the ML regime. We reported the cavity parameters required to systematically achieve the single pulse operations and the origins of the improvement.

We also proposed to study the impact of the injection angle of the linear polarization at the input of the AFSA on the ML regime. Through this study, we observed that the laser delivers pulses with different temporal and spectral shapes. The study highlighted that the pulse shape is impacted by the change of the injection angle and/or the pump power. A numerical work enables to understand the origin of the different pulse shapes.

Finally, a study of the impact of the chromatic dispersion and spectral filtering in the operation of our ML fiber laser based on NPE in birefringent fiber was reported. The influence of the shape and the spectral bandwidth of a filter, placed in the laser cavity, on the ML regime were experimentally and numerically investigated. Then, the pulse evolution according to the chromatic dispersion accumulated by the pulse during one round-trip of cavity was observed.