TeraXion

BLOG ARTICLE

Design challenges of industrial femtosecond lasers – Part 1: Overview

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In this series of articles, I lay down a few of my thoughts about the constraints influencing the design of femtosecond industrial lasers and parameters I believe should be considered before even starting the design process. I'd like to state that I am not a laser design expert; I spent the last 15 years developing and commercializing components for high-power and ultrafast lasers. The observations I write about come from my own experience and discussions I held with different stakeholders over the course of the last few years. I hope they will lead to interesting discussions and hopefully help a few of you with the design of your lasers.

Let's start by laying the basis of this series of articles by answering the following question: which building blocks are industrial femtosecond lasers built from?

Femtosecond lasers have the ability to process almost any material with high accuracy and minimal thermal effects, making them strong assets in the manufacturing of valuable products, such as OLED displays and semiconductors. This is due to the fact that their pulse duration is short enough that ablation happens before the deposited energy can be transferred to the material as heat –what is sometimes referred to as "cold ablation".

Mode-locked oscillators are capable of creating ultrashort pulses. However, the energy of the pulses they generate is insufficient for most industrial applications, which restrains the use of the standalone versions of these lasers to applications such as spectroscopy and imaging. Mode-locked oscillators have design constraints of their own, a topic which won't be covered in this blog series.

In order to reach the energy levels needed for industrial applications, the pulses must be amplified. Even though pulse amplification is a well-known and widely used concept in different applications, ultrashort pulse amplification comes with its own challenges. Despite their low energy, these pulses exhibit sufficient peak power to induce undesired nonlinear effects in the amplification stage and can even damage the amplifier.

To protect the amplifier and maintain maximum peak power, the chirped pulse amplification (CPA) technique can be used (see Physics Nobel Prize 2018). The seed pulse – a pulse generated by the mode-locked oscillator – is stretched in the time domain before the amplification stage to reduce its peak power. After amplification, the pulse is then recompressed near its Fourier-transform-limited pulse duration, which is the theoretical minimum duration of a pulse for a given spectral content. A precise control of the system's overall chromatic dispersion is required in order to achieve this duration.

The architecture of a typical industrial femtosecond laser can be divided into a few individual building blocks:

- A mode-locked laser that generates short, low-energy pulses at high repetition rate
- A pulse picker that reduces the repetition rate and manages burst modes, according to the specific application requirements
- A pulse stretcher that decreases the peak power before the amplification stages
- Several amplification stages, which amplify the seed pulses by up to six orders of magnitude
- A pulse compressor that recompresses the amplified pulse into a extremely high peak power pulse
- An optional frequency converter that converts the infrared (IR) light from the CPA into visible or UV light for improved absorption or spatial accuracy

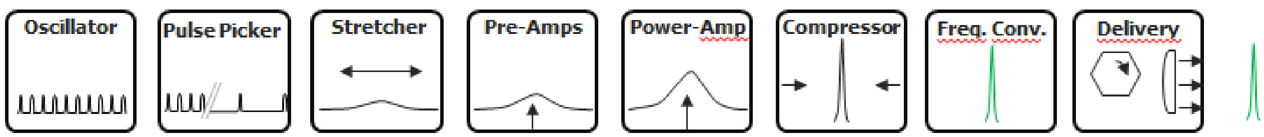

Figure 1: Building blocks constituting a typical industrial femtosecond laser

In order to build a reliable, competitively priced, high-performance laser, each of the components making these building blocks must be carefully chosen. In the next few blog posts, I will discuss parameters that I believe should be considered before even starting the design process of an industrial femtosecond laser. These parameters include:

- Pulse energy/Peak power
- Pulse duration
- Average power
- Rep rate/Burst-mode capability
- Frequency conversion

My next blog post will discuss the pulse energy/peak power parameters and how they are relevant when designing the amplification stage of an industrial femtosecond laser. In the meantime, I'd be interested in reading your own thoughts about ultrafast designing. What parameters are you normally looking at when starting a laser design project?

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