Tutorial: fiber laser basics

This tutorial provides an overview of the technical approaches most commonly used to make a fiber laser. The components choices and various architectures that are generally used for any ranges of CW or pulsed fiber laser optical performances are described.

I. Fiber lasers principles:

A fiber laser is a laser where the amplifying media is an optical fiber. It is an active module (like an active electronic component in electronics) that needs to be powered and which uses the properties of optical amplifications of Rare-Earth ions.

The pumping media is generally a fiber-coupled laser diode. Two kinds of architectures can be met:

- **Laser cavity configurations** where the light goes in both direction through the fiber amplifying media.

- **MOPA configurations** (Master Oscillator Power Amplifier) where an oscillating media generates a small “seeder” signal which is amplified through the fiber amplifying media.

![Figure 1: Fiber laser in laser cavity configuration](image1)

![Figure 2: Fiber laser in a MOPA configuration (Master Oscillator Power Amplifier) – single stage version](image2)
II. Fiber lasers key components:

The various elements of Figure 1 and Figure 2 with some examples of alternative supplier categories and choices are described hereafter.

a) Fiber amplifying media

As for any laser, a fiber laser uses the principle of stimulated emission. The majority of the fiber laser are made of a concatenation of fiber-coupled components.

The fibers associated with the various components are called “passive fibers” as they have no amplification properties, whereas the fiber at the heart of the amplifying media are called “active fibers” as it is doped with some Rare-earth components (like Erbium, Ytterbium or Thulium) which perform the stimulated emission by transforming the laser diode pumping power to the laser power.

The pumping wavelength for Ytterbium (Yb3+) or Erbium(Er3+) is typically 915 or 976nm whereas the emission wavelength of Er3+ is around 1.5μm and Yb3+ between 1030-1100nm.

[Figure 3: Energy levels and associated absorption/emission spectrum (only Yb3+ right) of an active fiber media – The combined effect of absorption and emission makes the favorable emission area for Yb3+ being comprised between 1030 and 1100nm depending of the ions population inversion ratio.]

Two types of active fibers are commonly met:

- Single clad / single mode fibers when the requested laser diode pumping power is compatible with single mode fiber coupled laser diodes (typically <1W)

- Double clad fibers when the laser diode pumping power is typically higher than 1W

[Figure 4: Principle of a singlemode or multimode laser diode pumping in a single or double clad active fiber]
4 highly reputable manufacturers of active fibers are:

- **iX-Blue**: French supplier - [www.photonics.ixblue.com](http://www.photonics.ixblue.com)
- **Nufern**: USA(CT) supplier - [www.nufern.com](http://www.nufern.com)
- **Coractive**: Canadian supplier - [www.coractive.com](http://www.coractive.com)
- **NKT**: Denmark supplier - [www.nkt photonics.com](http://www.nkt photonics.com) [for very special PCFs - Photonics Crystal Fibers]

**b) Pump laser diodes**

Pump laser diodes that are used for fiber lasers are fiber coupled device generally based on AlGaAs III-V semiconductor technology emitting in the 800-1000nm range (most often 915 or 976nm – see absorption spectrum Figure 3).

They can be separated in two major families:

**Single mode fiber coupled laser diodes** where the light coming from a small edge-emitting laser diodes is focused in a ~6µm fiber laser core. This type of laser diode family are generally assembled in a Butterfly package with a TEC cooler integrated in the package (the tendency being today to make smaller form factor) and are generally able to reach between 300mW and 1.5W of output power. They are used to pump single clad active fibers (see Figure 4).

The major suppliers for 915/976nm singlemode pump laser diodes are companies which developed their business at the end of the 90th for fiber amplifiers for the Telecom market (EDFAs : Erbium Doped Fiber Amplifiers). They offer both a high level of reliability and a moderate cost due to their high production volumes.

![Figure 5: Example of a Single mode fiber coupled laser diode at 976nm from the French supplier 3SP technologies (Courtesy of 3SP technologies)](image)

**Multimode fiber coupled laser diodes** used in fiber lasers are generally based on broad area side emitting laser diode chips. These can also be separated in two categories:

- **Single emitters** laser diodes where a single laser diode chip of up to 15W is coupled in typically a 105 (core)/125µm(clad) laser diode

- **Multi emitters** laser diodes where several laser diode chips are coupled in a similar fiber scalable up to several hundreds watts.
Figure 6: Example of Multimode fiber coupled laser diode pumps used in fiber lasers (left: II-VI laser enterprise 10W @ 976 nm; right: Lumentum 200W @ 915 nm) (Courtesy of II-VI laser enterprise and Lumentum).

Note that, as observed on Figure 3, the absorption spectrum of a rare-earth ion like Yb$^{3+}$ at 976nm is narrow and requires a stabilized laser diode absorption spectrum. This wavelength stability requires the laser diode temperature to be controlled and often the laser diode to include an additional wavelength stability element. This element is generally a FBG (Fiber Bragg Grating) for single mode laser diodes (a special piece of fiber situated at ~1m of the laser diode) or a VBG (Volume Bragg Grating) for multimode laser diodes (a special piece of glass integrated in the laser diode package).

3 highly reputable major manufacturers can be cited here:

- **3SP technologies**: French supplier (single mode diodes only) [www.3sptechnologies.com](http://www.3sptechnologies.com)
- **II-VI laser entreprise**: USA (CT) supplier - [www.nufern.com](http://www.nufern.com)
- **Lumentum**: USA (CA) supplier - [www.lumentum.com](http://www.lumentum.com)

A price orders of magnitude of such diodes is typically $1000 for single mode laser diodes, $500 for multimode single emitters and $2000 for Multiple emitters laser diodes.

Driving a laser diode and taking into account all the constraints linked with a fiber laser is a difficult task which requires dedicated products. Two laser diode drivers which have been specially designed for fiber laser diode driving are compatible with both laboratory R&D and full fiber laser product integration:

- The Central board from Alphanov (**fiber laser diode driver**) which acts as a control center for nearly any types of fiber laser architectures. This driver board includes 2 single mode laser diode drivers and TEC controllers working in both CW and pulse regime and 6 photodiode electronics for fiber laser power monitoring.

- The CCM (Cool and Control Multimode) from Alphanov (**high power laser diode driver**) is fully dedicated for driving one or several multimode pump laser diodes (either single elements or multiple elements) including the high power TEC controller and air cooling setup.
c) **Optical seeder**

Fiber lasers with MOPA architectures have a seeder part which determines the initial optical properties to be amplified through the various amplifying stages (Figure 2).

The optical seeder part is probably where the major fiber laser architecture differences are met. The seeders could either be a laser diode driven in CW or pulsed regime, a laser diode associated with an external high speed modulation device (see out tutorial: high speed fiber modulator basics), a special Q-switch cavity, a mode locked cavity, a crystal-based oscillator like a microchip or many others... These various seeder-dependent architectures are described in § III (page 9). Only the direct laser diode part is detailed in this paragraph.

As described in Figure 3, only the wavelength compatible with the amplifier gain media are relevant as a laser diode seeder. The table bellow gives the various wavelength ranges that are amplified by the dopants typically met in active fiber media :

<table>
<thead>
<tr>
<th>Dopant</th>
<th>Laser amplification range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yb³⁺</td>
<td>1030-1100 nm</td>
</tr>
<tr>
<td>Er³⁺</td>
<td>1530-1620 nm</td>
</tr>
<tr>
<td>Tm³⁺</td>
<td>1800-1900 nm</td>
</tr>
<tr>
<td>Nd³⁺</td>
<td>1050-1090 nm</td>
</tr>
</tbody>
</table>

Several types of laser diode seeders can be considered here :

- “Standard” laser diode where a standard partially reflecting semiconductor cavity is integrated in typically a Butterfly package. The wavelength emission spectrum depends on the fact there is an additional Bragg grating. The emission bandwidth is typically 3-5nm without any Bragg grating, whereas it is much narrower (~<0.1nm) with a Bragg grating. The wavelength spectrum temperature evolution is typically 0.35nm/°C without any Bragg whereas it is much less with a Bragg grating. 

- DFB or DBR laser diodes are laser diode device where the Bragg wavelength stabilization part is directly integrated on the chip part. The allows a narrower emission wavelength of typically 2 MHz for a DFB (i.e. ~10⁻⁵nm).
When used in pulse regime, these laser diodes can be amplified up to very high gain levels.

3 Highly reputable suppliers can be cited here:
- Lumics – Germany: www.lumics.com
- Eagleyard photonics – Germany: www.eagleyard.com
- Photodigm – USA(Tx): www.photodigm.com

d) Diode / fiber combiner

Combining the light coming form a fibered laser diode to an active fiber is a complicate subject especially for MOPA configurations (Figure 2) where both the input seeder and the pump light need to be injected.

The components are not the same when considering a single mode fiber coupled laser diode or a multimode fiber coupled laser diode.

When considering single mode laser diode pumping, two types of components are generally used:
- TAP-couplers/WDM which are based on the principle of fusing and turning two fibers together so that the modes of both fibers can be coupled up to the moment the targeted performances are reached. One big limitation here comes from the minimum wavelength separation necessary to reach a good coupling performances of two different wavelength. Several hundreds of nm are generally necessary.
- Thin films WDMs (Wavelength Division Multiplexers) are the solution when Tap-couplers don’t work. These are components based on the technology of thin films dichroic Transmission/Reflection performance. The light is not fibered inside the component, whereas we can consider it as a fibered component.

Combining the light coming from one or several multimode fiber-coupled laser diode with a singlemode seeder is a very difficult task. This becomes even more difficult when considering special fibers like PCFs (Photonics Crystal Fibers). Many technologies use the principle of fusing several fibers together in a special glass tube.
Figure 10: Example of a multimode pump combiner from ITF (left) and illustration of a 6+1 to 1 combiner principle (courtesy of ITF & OFS)

Many Asian suppliers offer such components. 4 highly reputable supplier can be cited here, the two first one being more specialized in singlemode components whereas the two last one are more famous for their multimode combiners:

- AFR (China): [www.fiber-resources.com](http://www.fiber-resources.com)
- DK Photonics (China): [www.dkphotonics.com](http://www.dkphotonics.com)
- ITF technologies (Canada): [www.itftechnologies.com](http://www.itftechnologies.com)
- Lightcom (China): [www.lightcomm.com](http://www.lightcomm.com)

Alphanov offers also some special components associated with complex high power PCF fibers: [www.alphanov.com](http://www.alphanov.com)

e) **Reflective media / Filtering media**

- **Reflective media - Bragg grating mirror**

A key component which is widely used in fiber lasers is Bragg grating, which is periodic or aperiodic perturbation of the refractive index in the core of an optical fiber. These are generally made by illuminating a Germanosilicate fiber with UV light.

Bragg grating effect allows any type of reflection/transmission spectrum depending on the way the fiber UV illumination is made by the Bragg grating maker.

For laser cavities as described in Figure 1, a Bragg grating is used to behave like a total or partial reflector mirror to build a laser cavity.

Figure 11: Fiber Bragg Grating principle and example of a fiber Bragg grating supplier (courtesy of iXblue)

- **Filtering media - Bragg gratings filters**

Fiber lasers (especially in MOPA configuration) do face an unwanted effect called ASE (Amplified Spontaneous Emission) which is a bidirectional amplification effect starting from low level of light which negatively competes with the amplification of the seeder light. ASE has a spectrum correlated with the gain spectrum of the rare-earth dopant. It is thus very broad and the intensity increases non linearly along the fiber length.
As the seeder spectrum is generally much narrower than the ASE spectrum, it is relevant to add some filtering devices all along the fiber laser length so that the losses along the ASE spectrum are higher than the gain at these wavelength, but still allowing the seeder light to go through.

Figure 12: Example of a competing gain effect between narrow seeder amplification @ 1064nm and broad ASE and Bragg grating filtering effect. (Numata, Kenji et al. J.Phys.Conf.Ser. 228 (2010))

f) Switching media

Historically, the two alternative configurations of Figure 1 (Cavity) and Figure 2 (MOPA) were respectively associated with CW fiber lasers and Pulsed fiber lasers. This is not the case anymore today as many high power CW architectures use the principle of MOPA amplification and some pulsed configurations are made in a unique cavity with no amplifier afterward.

Making a pulsed fiber laser in a cavity configuration requires a time correlated loss media which is either a saturable absorber (leading to the Q-switch or Mode-lock architecture principles described in § III) or a switching media for active loss synchronization.

Switching media could be either an AOM (Acousto-Optic Modulator), an EOM (electro-optic modulator) or a SOA driven in pulse regime. These 3 high speed fiber modulation technologies are compared in another Tutorial called “High speed fiber modulation basics”.

Figure 13: Example of fiber coupled modulating media [Acousto-Optics Modulators (left), Electro-Optic Modulator (middle) and Semiconductor Optical Amplifier (right)] (courtesy of G&H, ixBlue & Innolume)
### III. Fiber lasers architectures:

#### a) Introduction

The various architectures shown bellow aim at giving the reader an overview of the typical constraints which impose some typical architectures. Of course many variants do exist and a good simulation software like RP-Fiber-Power is mandatory to determine the best architecture.

Note that for clarity purpose the isolators (at every stage) and monitoring photodiodes are not show in the figures bellow.

#### b) CW fiber lasers

CW fiber lasers are generally made by an end pumped simple Bragg grating-based cavity with eventually some amplifying stages when some constraints on output optical characteristics (wavelength etc.) are required.

A typical CW architecture is shown in Figure 14 below. A multiple pumped cavity is used to generate a high power level. It is generally preferable to take a very long length of fiber to maximize absorption and avoid any remnant pump on both side coming from the pumps of the other side.

Choosing a long length of fiber reduces the overall inversion level within the active fiber. As explained on Figure 3 page 2, the combined effect of absorption and emission makes the favorable emission area for Yb3+ being comprised between 1030 and 1100nm depending of the ions population inversion ratio. The less inversion level, the more the wavelength increases. This is the reason why the wavelength of KW CW fiber laser based is generally higher than 1080 or even 1010nm.

![Figure 14: Typical architecture of a CW fiber laser](image)

A typical high power fiber laser architecture handling some optical constraints is shown in Figure 15. A seeder is used and multiple amplification stages are necessary to reach high power level. Note that a mode stripper is often necessary to remove the remnant pump power after the active fiber. One or several ASE filters are also often necessary to remove Amplified Stimulated Emission and keep a good signal over Noise Ratio.
Figure 15: Typical architecture or a high power CW fiber laser when taking into account some special optical/wavelength constraints (only one amplifying stage is shown here, whereas many stages are often met)

c) **Pulsed fiber lasers (millisecond/microsecond range)**

The dynamic of population inversion of Yb\(^{3+}\) ions when applying high pumping power is typically in the range of 20-200 µsec (typically ~10% of the Yb\(^{3+}\) lifetime). It means that when one wants to get some pulses higher than these levels, pump power can be electronically pulsed and the same behavior as for a CW laser is met during these pulses.

This means that the typical architectures met for milliseconds or microseconds fiber lasers are the same as for CW fiber lasers. Only the overall thermal properties can be different and have some impact on the choice of components when considering low duty cycle fiber lasers.

d) **Pulsed fiber laser (nanosecond range)**

When one wants to generate short pulses in the 1ns-10µs range, we enter in the world of nanosecond pulsed fiber lasers.

As described above, the dynamic of Yb\(^{3+}\) ions is not sufficient to generate such pulses by adjusting the pump power. It is thus necessary to keep a continuous pump power and find a way generate pulses differently.

The comparison with a toilet flush is relevant here. Optical pumping is the water coming in the flush tank and a technic is used to make it flush (get optical pulses) at a desired frequency. The comparison makes us understand the few important elements here:

- When considering CW pumping (continuous water flow), one can imagine that a minimum flush frequency is required otherwise the water coming continuously will overflow. This minimum frequency for a fiber laser is typically 5kHz. Below this frequency some ASE power starts to come out of the fiber between pulses.

- We can note also that an important parameter is the number of ions in the active fiber which is directly correlated with the absolute maximum energy that can be obtained at every pulse (toilet tank size determines the absolute maximum water that can be obtained, whereas it is often obtained less water because a separated mechanism makes the water stop filling the toilet bowl).
- New fiber electronics generations tend to apply pump pulsing in MOPA (Amplified) nanosecond fiber laser architecture (see a description of such electronics in §IV p 18). Again the comparison with a toilet flush is relevant when considering the two effects of tank filling which starts and stop separated from the action to flush to fill the toilet bowl.

There is two very different types of architecture, as it has already been described at the beginning of this document (Figure 1 and Figure 2) : single fiber laser cavity and MOPA (Master Oscillator Power Amplifier). Most of the nanosecond fiber laser architectures are based on MOPA architectures but the single cavity Q-switch architecture and still not negligible.

- **Q-switch nanosecond Fiber lasers**

Q-switch fiber lasers are obtained when a specially fast switching/modulating component is integrated in the fiber laser cavity. This component can be either an AOM (Acousto-Optic Modulator), EOM (Electro-Optic Modulator) or a SOA driven in pulse regime. See our Tutorial “high speed fiber modulator basics” for a detailed description of such components.

This component generates a loss which allows to pump for a given period and reach a high population inversion. Switching the component to low loss level does release a high energy pulse of typically a few nanosecond.

An example of Q-switch architecture is shown in figure xx. A fast AOM is used to apply the loss.

![Q-switch nanosecond fiber laser architecture](image)

*Figure 16: Example of a Q-switch nanosecond fiber laser architecture*

The pro of such architecture is that it is quite simple as it requires few components. The modularity and ability to control optical parameters is however rather low.

- **MOPA nanosecond fiber lasers**

Most of the engraving lasers sold today are based on this simple architecture. A seed laser diode at, for example, 1064nm is pulsed by some electronics before being amplified with several stages of active fibers. A typical amplification stage generates between 10 and 20 dB gain. Above that some unwanted ASE (Amplified Spontaneous Emission) effect makes some undesired wavelength being amplified as well. It is thus relevant to have a multiple stage amplifier with some ASE filters between each stage instead of maximizing the amplification gain of a given stage.
• **Important effects for nanosecond fiber lasers**

Four important effects are important to know when considering fiber laser amplification of pulsed laser diode:

1. **Laser diode gain switching effect**: when applying some current to a laser diode, at the initial early part of the pulse (picosecond range) some amount of energy is stored in the gain medium, which is subsequently extracted in the form of a short pulse. This pulse of typically 100ps pulse duration could either be an opportunity when looking for very short pulses (see §e page 14) or be a problem when considering nanosecond range pulses to be amplified up to high energy levels.

![Diagram of Fiber Laser Architecture](image)

**Figure 17**: Multiple (3) stages MOPA fiber laser architecture to amplify a nanosecond seed pulse generated by a **pulsed laser diode driver**.

![Examples of Pulse Emission](image)

**Figure 18**: Example of a 3 nanosecond short pulse (left) driven by Alphanov CCS **pulsed laser diode driver** (right). The ~100ps gain switch pulse is observed at the early part of the pulse.

2. **Evolution of the emission spectrum of pulsed laser diodes**: When directly pulsing a laser diode, the user must consider two undesirable spectral effects

   o The first is linked with the time required for the laser diode to lock on its Bragg locking element. This is immediate for a DFB but requires often more than a 100 nsec for a Bragg grating based laser diode. In other word, when pulsing such laser diode, the first nanosecond sees a broad emission spectrum as if there was no Bragg grating. Some suppliers like Lumics offers some intermediate solution called “Bragg close to the chip” which take only a few nanosecond to lock.

   o Another unavoidable effect comes from coupling of the frequency/phase spectrum and intensity profile. In other word, the emission spectrum do change over the pulse length and this can sometimes be a problem. External modulation with, for example, a SOA could be a smart solution to avoid this effect. See our Tutorial: **High speed**
fiber modulation basics for a detailed comparison of the four commonly used technologies for modulating the light externally.

3. **Deformation of the pulse shape**: when considering MOPA fiber laser architectures with high gain multiple stages configurations like in Figure 17, the active fiber gain depends on the dopant population inversion levels which reduces over the pulse duration all along the amplification.

As a consequence, an effect of pulse deformation occurs which avoid to maintain a nice square pulse shape at the output. Some drivers are able to adjust the shape of a given pulse in order to pre-compensate this effect and reach the desired pulse shape at the output of the last amplifier.

4. **Fiber nonlinear effects**: Fiber amplifiers concentrate the light in a small diameter core and make us being able to increase the power density up to very high levels. This can become a major problem when considering high pulse peak powers as many optical non-linear effects appear above a certain level of peak power density. These effects like SBS (Stimulated Brillouin Scattering) or SRS (Stimulated Raman Scattering) tend to broaden both the emission spectrum and the pulse duration. SBS is especially an effect which depends non linearly on the spectral density. Choosing a broader emission seeders and avoiding the narrow DFBs can be a good choice to reach higher peak powers when considering nanosecond pulses. Another solution is to use an OEM phase modulator which also broaden the emission spectrum, while keeping the nice spectrum stability of a DFB.

On the driver side, it is relevant to talk about the products bellow:

The central board of Alphanov has one laser diode channel optimized for low noise CW driving and one channel optimized for both CW and nanosecond short pulsing. It also contains many fiber laser relevant functionalities with many photodiodes input and acts as a “control center” for making a fiber laser easily. Central board are also able to handle pulse pumping functions which are very helpful when considering low repetition rate high energy systems. See this product page: [fiber laser diode driver](#).

Figure 19: This fiber laser diode driver acts as a control center for fiber lasers. It includes one singlemode CW pulse driver and one nanosecond and CW laser diode driver.
**The Shaper board** is another driver offered by Alphanov that can solve two of the four issues detailed above: it can pre-compensate the pulse shape and has a special Gain-Switch suppression function. The shape can be adjusted down to very short pulsewidth as its internal AWG (Arbitrary Waveform Generator) generates one point every 500ps with 48dB dynamic range. It also contains 3 pulse delay generators outputs. See this product page: [high speed laser diode driver](http://example.com).

**The CCM Module** is a third driver offered by Alphanov. This high power laser diode driver allows to drive the multimode single and multi-emitters laser diodes shown in all the fiber laser architectures described above. It is fully dedicated for driving one or several multimode pump laser diodes (either single elements or multiple elements) including the high power TEC controller with an air cooling setup. It contains many functionalities to drive any of these type of laser diode with an optimized and compact air cooling setup. See the product page: [high power laser diode driver](http://example.com).

**Figure 20**: Alphanov shaper module set in direct driver configuration (left) is a high speed laser diode driver which generates special optical pulse shapes. For example, a pulse obtained from a DFB laser diode after it has been programmed within the module (right).

**Figure 21**: Alphanov high power laser diode driver. Ideal for multielement laser diodes like II-VI, Lumentum, IPG etc.

e) **Pulsed fiber lasers (picosecond range)**

Between 10 picosecond and 1 nanosecond, we are clearly in the category of picosecond pulsed fiber lasers. These are not called “Ultrafast” as this word is generally associated with special architecture generating pulse widths below 10 picosecond.

These lasers are generally very similar to the MOPA nanosecond fiber laser architectures described in Figure 17. The only major difference comes from the seeder, as it becomes very difficult to get a very
short pulses by directly pulsing the laser diode unless using some special effects. There is thus several
types of picosecond fiber laser architectures that we can separate into 3 families :

- **Gain switch direct diode seeder** :

  The simplest configuration to get a picosecond fiber laser is to use the special gain switch effect of a
  laser diode (see above page 12) which occurs during the early first 100 picosecond of the optical
  pulse when a short electronic pulse is applied to the laser diode (see Figure 18). Companies like
  Picoquant or NKT/Onefive are well known to use this effect directly of before amplification.

  It is difficult to get a stable pulse and this generates many constraints on the laser diode choice, laser
  diode integration (fiber coupling) and driver electronics performances. The energy reached by these
  laser diodes is typically 10 picojoules, so reaching 1 mJ requires 80dB gain. Knowing that a typical
  amplifier stage gain is about 15 dB, i.e. up to 5 stage of amplifications with all the isolators, ASE
  filters, laser diode pumps that every stage must contain.

- **External modulation seeder** :

  Another way to reach short pulses is to use very fast external fiber modulators like EOMs (Electro-
  Optics Modulators) as described in our tutorial “Fiber Modulator Basics”. It is possible to overcome
  the peak power limitation of such components by pulsing the initial laser diode pulse. In any case,
  the losses associated with such elements make, once again, the energy of each seeder pulses to be
  very low which makes the amplifying part very costly.

- **Microchip seeder** :

  A third way of making short pulses seeders uses the Q-switch effect in a crystal cavity. These
  elements put in direct contact a typical crystal gain media (like, for example, Nd:YAG or Nd:YVO4)
  with a saturable absorber.

  These components called “Microchip” were, up to recently, only reserved for nanosecond pulse
  generation (with Cr4+:YAG as a saturable absorber), generating typically 3-10ns pulses at a given
  repetition rate.

  More recently, very fast saturable absorber have been developed using the semiconductor
  technology. These are generally called SESAM (SEmiconductor Saturable Absorber Media).

  Components like the one provided by Batop are now extensively used and allow to generate pulses
  of less than 30 picosecond. 808nm pumping is generally used for Nd3+ pumping. Pulsing the pump in
  the 100s of nanosecond range is a good way to control the repetition rate.

  ![Figure 22 : Typical microchip seeder used for picosecond pulse generation. Nanosecond pulsed 808nm
singlemode pump can be used here to be able to control the microchip repetition rate.](image)
f) **Pulsed fiber lasers (femtosecond range : “Ultrafast”)**

The last category of fiber lasers makes us enter the very complicated world of Ultrafast lasers, i.e. laser sources generating between, say, 100 femtosecond and 10 picosecond pulse width.

These sources are now of major interest for a lot of laser-matter interaction applications because the laser-matter effect is “athermal” : the matter is directly transformed from the solid state to the plasma state without passing through the liquid state. This allows to reach very high resolution machining and is now extensively used in the semiconductor, eye surgery or smartphone industries.

Typical amplified MOPA architectures are also used here. However there are two important principles that are important to consider :

- **The Mode-locking principle is the basis of the seeder “oscillator” part**

The Heisenberg principle states that the product of the amplification spectral bandwidth and the pulse duration can’t go below a given value. In other words, ultrashort pulses mean wide spectral emission bandwidth. 100s of femtosecond means 10s of nm of spectral bandwidth. Ultrashort lasers always have a broad emission bandwidth with many cavity modes.

The Fourier transform of a given comb of emission modes gives an ultrashort pulse only when the various modes are all in phase. Making an ultrashort pulse laser cavity thus consist in building a broad amplification cavity and adding some elements which make the cavity modes emitting in phase by modulating the losses within the cavity. Active modulators such as AOM (Acousto-Optic Modulator) or EOM (Electro-Optic Modulators) can be used. Passive version like the SESAM (Semiconductor Saturable Absorber Media) are generally the best solution for building a industrial fiber laser based ultrafast oscillator.

Modelocked cavities have a direct relation between the cavity length and the ultrashort pulse repetition rate. Typical modelocked oscillators have a pulse repetition rate in the range of 50 MHz.

- **Optical Parametric Chirped-Pulse Amplification (OPCPA)**

Amplifying a modelocked oscillator signal requires to amplify a high frequency signal of very short pulses. It generates three major difficulties :

  - First, if one wants to get enough energy to have some impact on the matter (i.e. more than 1 microjoule), keeping a 50 MHz repetition rate would require 50 W, i.e. probably several hundred Watts of pumping power for a very small effect on matter. It is thus preferable to reduce the pulse repetition rate of the oscillator by picking some pulses and reducing the repetition rate in the kHz range.

One thing to remember here is that ultrafast oscillators are generally in the range of MHz/nJ range, whereas amplified lasers which are useful for laser micromachining are generally in the kHz/µJ range.

The pulse-picking is generally operated by a fibered or non-fibered AOM (Acousto Optic Modulator).
Alphanov developed a universal tool for pulse picking synchronization. It allows to generate a trigger door at a desired low frequency synchronized with an input clock signal coming from a photodiode.

Figure 23: Pulse-Picker synchronization electronics offered by Alphanov.

- Second, amplifying very short pulses like it would have two consequences: when considering a crystal amplifier, the peak power reaches quickly the damage threshold. When considering a fiber amplifier media, some non linear effects would destroy very rapidly the pulse properties. It is thus necessary to stretch the pulse width in such a way that it is possible to go back to a short pulse after the amplification process. The effect which is used here is called “dispersion”. It stretches the pulse by coupling its spectral and temporal properties (one “color” at the beginning of the pulse and the other “color” at the end of the pulse). A special “hollowcore” fiber can be used to stretch the pulse before amplification whereas a spatial gratings is generally used to compress the amplified pulse and reach the ultrafast amplified pulse properties.

Figure 24: OPCPA Principle (courtesy of S. Witte et al.)

- Third, dealing with ultrashort pulse width within a fiber generates non-linear effects very rapidly and all the Ultrafast amplified fiber lasers always combine some fiber parts and some parts which are not fibered. A good non-linear effect simulation software like, for example Fiberdesk, is clearly mandatory here.
IV. **A modular fiber laser electronics to make nearly all fiber lasers architectures:**

Alphanov developed a whole range of electronics drivers able to build nearly any type of the fiber laser architectures described above. These drivers can communicate together and can control any types of laser diodes and many photodiodes in either pulse or CW regime. It is easy to integrate them in a compact prototype and, thus, make such fiber laser a real product in only a few weeks.