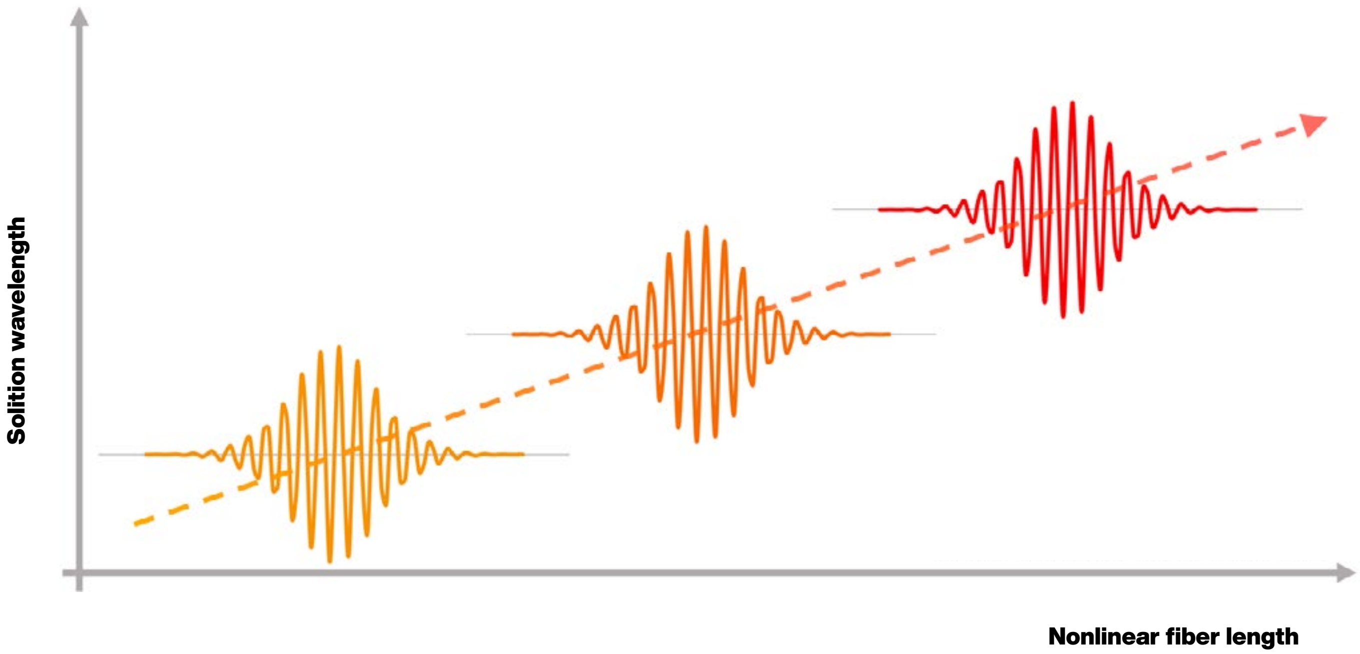
FIBRAIN

Free the solitons

make your femtosecond source tunable!



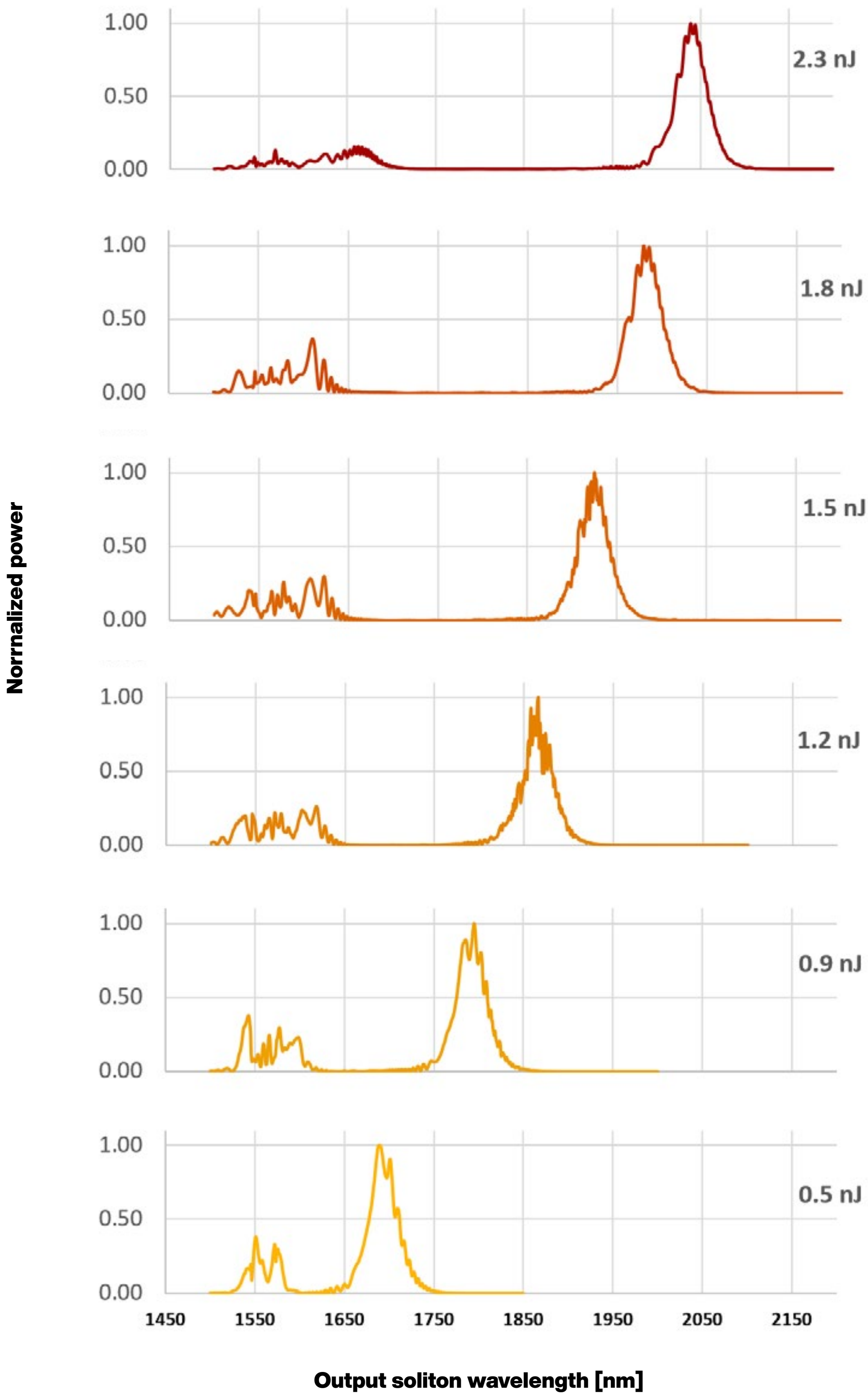
Femtosecond lasers have found home in many research labs and industries. They produce very fast optical pulses, typically in spectral windows corresponding to ytterbium (Yb) and erbium (Er), so in the 1045 nm and 1550 nm region, respectively. One femtosecond is equal to 10^{-15} second, so such lasers are often called ultrafast. Ultrafast laser are particularly tempting when they come in an all-fiber form, thanks to the inherent stability, maintenance-free operation and optical safety.

One of the drawbacks limiting the number of applications of femtosecond lasers however comes from the fact that the pulse wavelength is substantially fixed, as it is limited by the gain spectra of the active dopants. Of course other dopants are available (thulium, holmium) but commercial lasers using doping different than with Er and Yb are quite few and far in between at the moment. And even if Ho- and Th-doped sources were more readily available, there are still huge gaps in the spectrum which cannot be covered directly with the use of available gain media. Similarly, there are ways to coerce some tunability from the current femtosecond sources, but generally these methods are quite complex and expensive. And let's not even go here into grisly details of the woefully energy-inefficient supercontinuum with spectral slicing approach.

In contrast, Fibrain have introduced nonlinear optical fiber which allows anyone to convert their 1045 nm or 1550 nm fs lasers into wavelength-tunable sources, with a very broadband tuning range. You no longer have to be a photonic expert to spectrally tune your solitons. All is required is to turn up or down the output power. The magic takes place in the fiber optimized for the so-called soliton self-frequency shifting (SSFS) effect, which (although really this information is not necessary for you, if you don't plan on becoming a photonic guru) is a manifestation of the intrapulse stimulated Raman scattering. The extent of spectral shift depends on the length of the nonlinear interaction (or in human-speak, the fiber length) and on the peak power of the input solitons. For fiber to efficiently shift solitons, it should have large (and positive) anomalous dispersion, also in the spectral regions where silica fibers typically have negative dispersion coefficient. The fiber should also have small mode field diameter, low loss and be single-mode and polarization-maintaining. Only then it can guarantee stable operation, with well-defined, noiseless and short output pulses, of stable polarization and high coherency. In other words, it is not a typical off-the-shelf fiber, but has to be optimized for the job. And the SSFS fiber has to be connected with very small losses to the femtosecond laser (which is a bit tricky, considering typical differences in mode characteristics), making sure at the same time than no excessive chirp is introduced. If the last few sentences sound a bit intimidating don't worry, better try erasing them from memory and jump to the next paragraph, as really the niggly physical details are no longer relevant to the end user.

It has been already mentioned that absolutely zero photonic expertise is required to convert your femtosecond laser into tunable one and that's really the message to take home here. That's because Fibrain provide plug&play nonlinear modules, which you only need to connect to the output port on the laser panel. The modules are like magical black boxes, which transform fixed-wavelength sources into tunable ones. Just connect the input fiber to your laser and play with spectrally shifted copies of your initial solitons at the output! Fig. 1 shows the spectral evolution of output solitons. Clearly, the spectral purity is maintained and solitons keep their shapes regardless of their input energies (oh, and by the way, don't worry about the apparent noise in some of the plots, these are measurement artifacts. We are showing raw and unmassaged results here). By increasing the input power the spectral shift is increased. This is an extremely simple and cost-effective way to increase capabilities of your femtosecond system and open up doors to completely new applications.

Fig. 1 Spectral evolution of fundamental soliton



All of the sudden your old trusted 1060 nm Yb-laser can produce solitons tunable up to 1600 nm, or a 1550 nm Er-fiber femtosecond laser becomes a 2000 nm light source! And that's without any spectral gaps in between and achieving fully continuous tuning. Fig. 2 presents a representative tunability curve, for a particular example of input 25 fs pulses. Clearly tunability of more than 500 nm is now possible, only by turning the power knob, all thanks to a completely passive, totally plug&play module, smaller than a book. This is an immense capabilities multiplicator, at a fraction of cost of a new fs system. There is a little more happening behind the door – if you tell us about you requirements we can suggest the best module length for you, to optimize the performance and further minimize the cost. But really, this design amounts in practice to reading out the optimum module length from a simple plot like the one in Fig. 3.

Fig. 2 Spectral shift vs pulse energy; 25 fs pulses

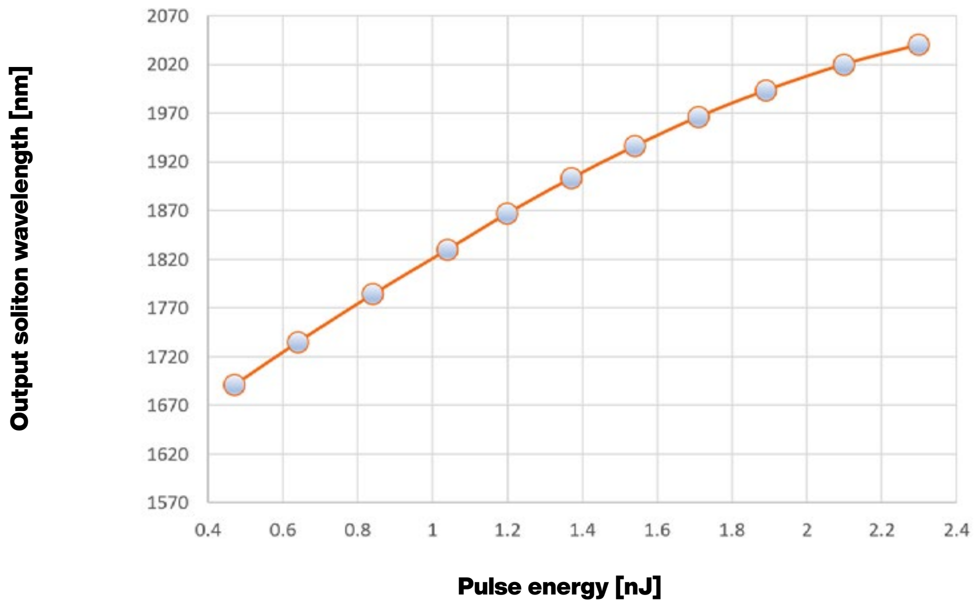
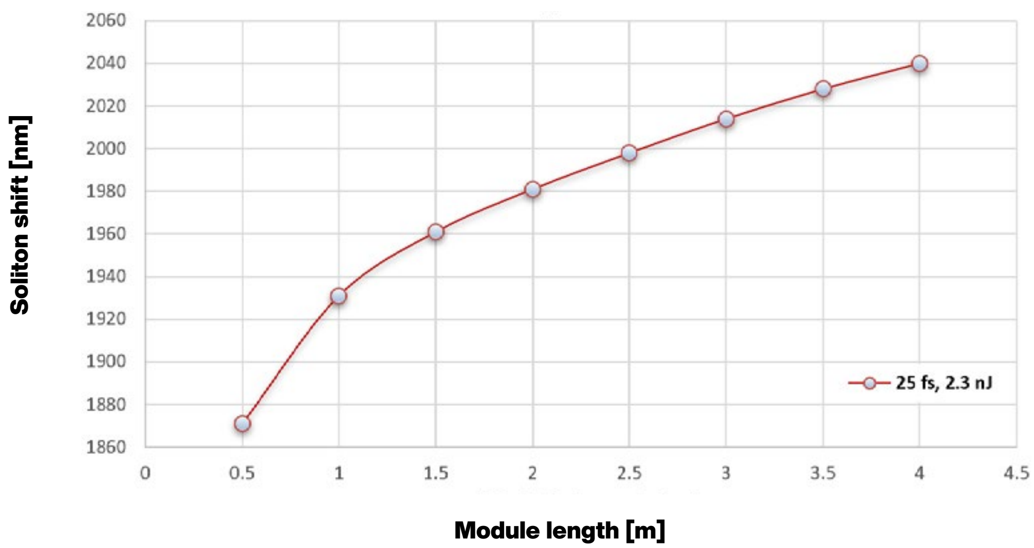
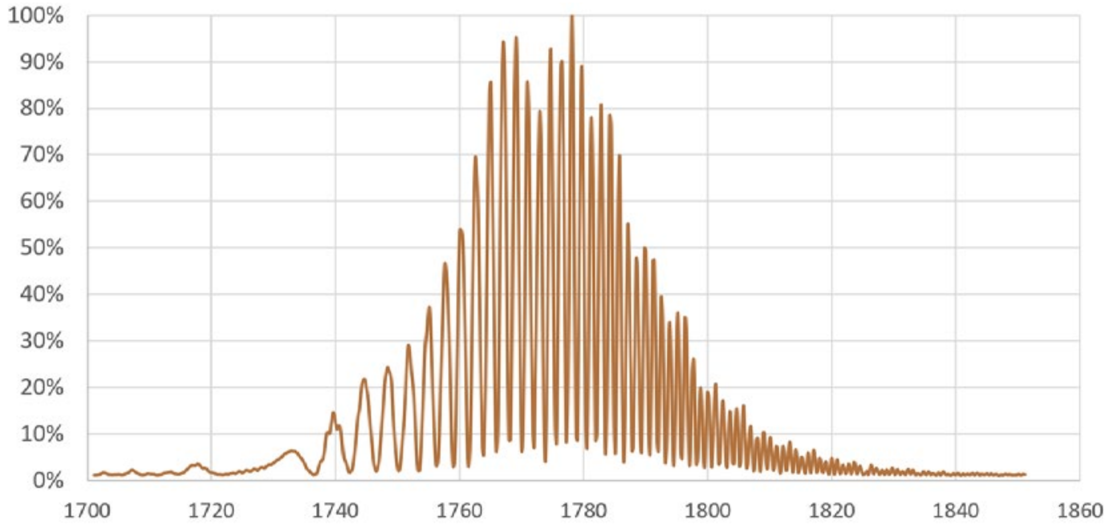


Fig. 3 Spectral shift vs module length; for given pulse duration and energy



Since the output spectrally-shifted solitons are highly coherent (don't just take our word for it, as Fig. 4 shows coherency characteristics of the typical output pulses) and of stable polarization, a host of new applications is now available. These capabilities can be used for example in biomedical applications, to perform virtual biopsies and multiphoton microscopy (e.g. deep-tissue two- or three-photon excitation fluorescence imaging), also in the 1350 nm or 1700 nm windows (for increased penetration depth), where thanks to a very broad tuning range very different fluorophores can be selectively excited. Other applications include nonlinear and time-resolved spectroscopies (for example PAF, SHF, SFG, or CARS), dual frequency comb generation (without the need to have, and synchronize, two femtosecond lasers), for terahertz generation, in sensing and trace-gas or combustion-products monitoring. With the use of our module, the much more-standard Er-doped lasers can do many of the jobs where holmium or thulium lasers would typically be called for. There are also obviously other applications in micromachining, laser ablation and inscription or in selective absorption (also in living cells, with the use of sensitizers) and minimum-invasive surgery. And of course a number of applications in the quantum, nonlinear optics, ultrafast measurements and photonics world. If you would like to discuss your application please drop us an email at **photonics@fibrain.pl**.

Fig. 4 Output soliton coherence - interferometric fringe visibility; 25 fs pulses



Wavelength [nm]

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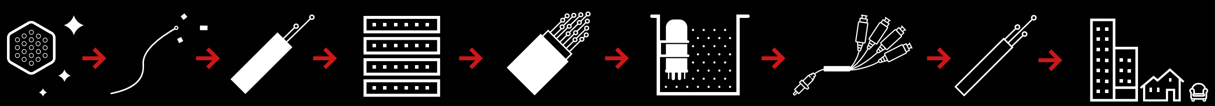
From a single fiber to millions of satisfied customers around the world.



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