Ultrashort and Powerful

Femtosecond Fiber Lasers for Microscopy and Microfabrication

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Ultrashort laser pulses allow for various experiments in basic and industrial research. The pulsed operation is able to generate very high peak intensities, simplifying everyday procedures like ophthalmology or material processing, or even "exotic" experiments like plasma physics or particle acceleration. Some ultrashort pulse lasers also provide attosecond pulses for time-resolved pump-probe-measurements in order to study processes on ultrashort timescales.

The duration of a laser pulse is not the only parameter that matters. The wavelength of the laser, or the central wavelength of a pulse spectrum, is also crucial for a variety of applications. In ophthalmology or material processing, a wavelength of around 1000 nm is commonly used, whereas optical microscopy or high-resolution lithography require shorter wavelengths below 800 nm. For this wavelength range, titanium-sapphire (TiSa) lasers have proven to be useful tools for experimental research because they provide inherently short and "clean" pulses with a relatively high output power and wide wavelength tuning range.

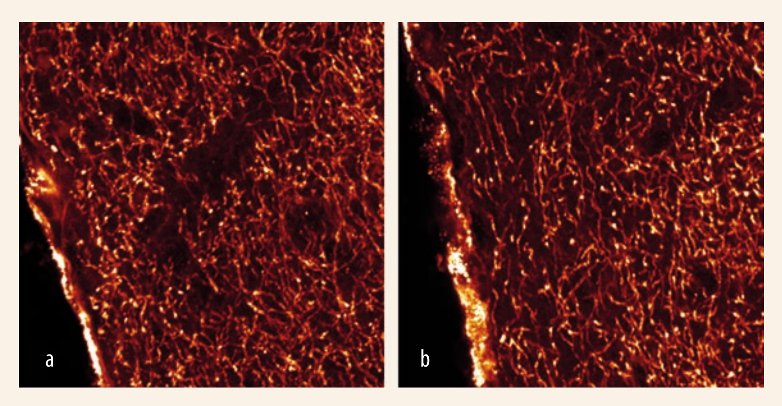

Fig. 1 Comparison between two different laser sources in two-photon microscopy of receptor neurons. In the sample, the Alexa 488 fluorophore is excited via two-photon absorption of two photons with a central wavelength of 780 nm. As a consequence, the fluorophore emits light that can be captured using a microscope. A titanium-sapphire laser with an output power of 16 mW was used in (a), whereas in (b) a FemtoFiber pro NIR from TOPTICA with an output power of 10 mW was used. The achieved image quality is identical in both cases regarding spatial resolution and image contrast.

When wanting to integrate a TiSa system into a commercial product, there are some things that must be considered. Two of the most important factors are water-cooling and regular maintenance. Water-cooling is a necessity, although it increases the space required for the TiSa laser, while regular maintenance is crucial to achieve a reliable operation, i.e. frequent realignment and periodic cleaning of the optics. Also, a TiSa laser has a relatively high cost of ownership.

Fiber-based laser systems are effective alternatives to TiSa lasers, especially when it comes to the integration in commercial set-ups. They have several advantages that guarantee a reliable operation since they are completely hands-free and require only air-cooling. In addition, fiber lasers meet the technical requirements for many applications by providing ultrashort laser pulses with the necessary parameters at a push of a button. They are also more cost-effective, priced much lower than a comparable TiSa laser.

One example of a successful integration of fiber lasers into an existing application is in multiphoton microscopy, which plays an important role for the imaging of structures in Biophotonics. This process is based on the absorption of two (or more) photons of the incident laser pulse by a fluorescent marker in the studied sample. The nonlinear character of this excitation enables higher resolution and deeper penetration depth compared to conventional microscopy. The absorbed energy is re-emitted after the absorption process, i.e., the fluorophores start to fluoresce, which makes it possible to take an image of the sample.

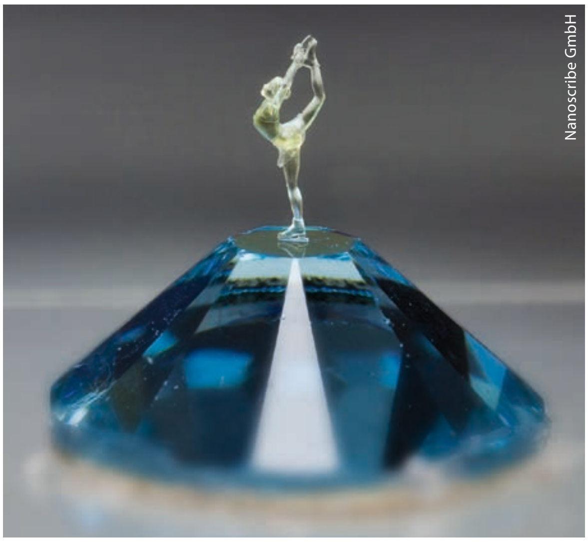

Fig. 2 With femtosecond fiber lasers of TOPTICA's FemtoFiber pro-series it is possible to produce extremely small three-dimensional structures. The shown figure has a height of about 3 mm, and is really standing on the blade of the ice skate. The applied process to generate such structures is a 3D-printing method which relies on two-photon polymerization (2PP). It uses the IP-S photoresist from Nanoscribe.

Fig. 1 visualizes microscopy images of receptor neurons that were excited by femtosecond lasers. In both cases, the incident laser wavelength was 780 nm which caused a two-photon excitation of the Alexa 488 fluorophore. In one case, a TiSa laser with an output power of 16 mW was used (**Fig. 1a**). The image in **Fig. 1b** was taken using a FemtoFiber pro NIR femtosecond fiber laser from TOPTICA, with an output power of only 10 mW. Although the output power was much lower than in the first example, the quality of both images is identical regarding spatial resolution and contrast. Obviously, the femtosecond fiber laser is best suited for this demanding application.

Fiber lasers also benefit other industrial processes, such as two-photon polymerization, which is a three-dimensional microlithographic application used for "rapid 3D-prototyping". This is where light-sensitive monomers or weakly linked polymers are transformed into a three-dimensional network of strongly linked polymers by irradiation of laser light, which can create three-dimensional objects of micrometer size from a liquid just by light irradiation. This is caused by a chemical reaction induced by ultrashort laser pulses. Two objects that were produced with this process are shown in **Fig. 2** and **Fig. 3**. For both objects, a FemtoFiber pro NIR femtosecond fiber laser from TOPTICA was utilized.

Multiphoton lithography and nonlinear microscopy are two recent examples of applications where fundamental insights from research have been integrated into commercial products. Femtosecond fiber lasers are best suited for these applications, not only because they possess the technical requirements, but they also have some major economic advantages. They enable an easy operation and a high reliability as subcomponents in their respective devices.

TOPTICA developes and manufactures femtosecond fiber lasers for more than 10 years. Because of this extensive experience, they are able to offer a broad product range of laser systems with various parameters. Their lasers are designed for sophisticated applications with the highest demands regarding beam quality and reliability.

TOPTICA's latest fiber laser "FemtoFiber ultra NIR" accomplishes a new output power level of more than 500 mW (**Fig. 4**). The FemtoFiber ultra NIR provides pulses with a central wavelength of 780 nm, pulse duration below 150 fs, and 80 MHz repetition rate, making it the ideal alternative for TiSa lasers at 780 nm, especially as a femtosecond laser source for applications in Biophotonics. Providing more than 500 mW, this fiber laser is powerful enough for in-vivo experiments, its short pulse duration is ideal for microscope optical systems, and its central wavelength is in the central operation range of a TiSa laser.

The FemtoFiber ultra NIR's easy handling and compact dimensions – comparable to the size of a shoebox – ensures a straightforward integration into existing systems. Due to low power consumption of less than 350 W, the NIR requires no elaborated power supply, unlike TiSa lasers. It also operates with air-cooling, which makes additional cooling devices like water-cooling redundant, as well as their maintenance. The FemtoFiber ultra NIR also has an integrated Ethernet connection that enables easy controlling of the system via a standard interface.

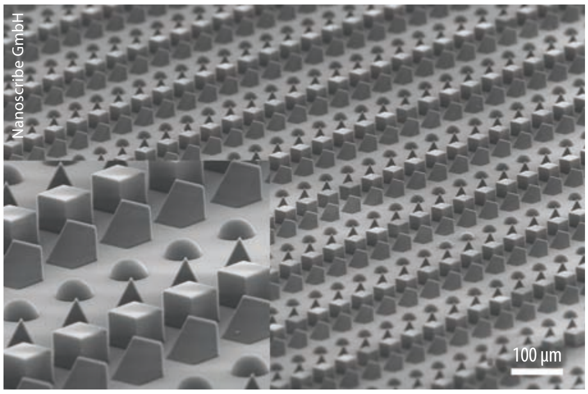

Fig. 3 The same method applied for the microstructure in **Fig. 2** allows the fabrication of micro-optics with a size of only a few microns. Such small structures are particularly challenging for the lithography process and the applied components including the femtosecond fiber laser.

The high output power level that is introduced by the FemtoFiber ultra NIR paves the way for a multitude of new applications. In Biophotonics, not only is the aforementioned two-photon excitation possible with high efficiency, but different nonlinear imaging techniques like third-harmonic generation (THG) are also achievable, for example efficient excitation of fluorescent proteins such as Tryptophan at 260 nm. New procedures in material testing, like semiconductor inspection or surface examination, are possible due to the high output power and effective frequency-conversion using the powerful femtosecond fiber lasers. TOPTICA's FemtoFiber ultra NIR is the ideal laser source for developing reliable and cost-effective devices.

Fig. 4 TOPTICA's recent FemtoFiber ultra NIR is a femtosecond fiber laser that provides pulses at a central wavelength of 780 nm with a pulse duration of 150 fs at 80 MHz and an output power above 500 mW.