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Editorial

Special Issue "Specialty Optical Fibers, Fiber Lasers and Their Applications"

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Citation: Aleshkina, S.; Gumenyuk, R.; Filatova, S. Special Issue "Specialty Optical Fibers, Fiber Lasers and Their Applications". *Photonics* **2022**, *9*, 274. https://doi.org/10.3390/photonics9050274

Received: 23 March 2022
Accepted: 14 April 2022
Published: 19 April 2022

The unique properties of optical fibers enable the realization of the state-of-the-art fiber lasers, which surpass other laser sources in many characteristics and act themselves as an exceptional platform for harnessing emerging technologies. Thus, advanced fiber-based methods for directed light illumination and collection drive the microscopy to the unpreceded level of resolution empowering non-invasive investigations of living tissue cells, diagnosis, and treatment of different diseases, including cancerous tumors, vision correction surgery and others. The development of high peak power fiber lasers with ultrashort (picosecond and sub-picosecond) pulse duration with ultimate beam quality has made dramatic progress in the field of hard and soft materials processing. Newly demonstrated powerful fiber lasers, emitting at transparent for the outer atmosphere spectral ranges, get promotion in LIDAR systems for precision remote sensing and imaging.

The tendency for further increase of fiber lasers output power, dictated by the growing requirements of the current and potential applications, initiate the development of new large-mode-area fiber designs with complex geometrical architecture, fiber preform fabrication techniques for the realization of perfectly flat core refractive index profile, a beam profile self-cleaning approaches, and new methodology for power scaling by efficient coherent combining of laser radiation from several sources. Moreover, although the significant technological leap was demonstrated in fiber-based ultrafast laser technology, the recent theoretical works showed vast possibilities for further dramatic advancement in this field. In addition, there is a high demand in the expansion of wavelength range and, in some cases, emission of several wavelengths simultaneously from a single laser output. The multi-wavelength lasers have a great potential for sensing applications to resolve fast-moving objectives, while the mid-IR lasers are essential for further development of bio-imaging in the fourth biological window.

This Special Issue presents a collection of 11 original state-of-the-art studies and review articles highlighting the recent progress in specialty optical fibers, new beam-cleaning techniques, coherent beam combining methods in fiber-based laser systems, approached for the realization of high-power continuous wave (CW) and pulsed fiber lasers and amplifiers operating at different spectral ranges, and their practical applications, a new methodology in a high repetition rate pulsed lasers development, and application of the fiber techniques for non-invasive inner tissue investigation and early diagnostic of diseases.

Due to the fundamental limitations dictated by the self-focusing effect, the power scaling in fiber lasers cannot overcome the barrier of ~4 MW of peak power in a single-mode regime. Therefore, special attention has been directed to developing additional techniques to overcome this limit. One of them is the coherent beam combing of several laser beams emitted from different laser channels. Therefore, in the present Special Issue, the comprehensive review by H. Fathi [1] describes the progress of coherent beam combining and state-of-the-art techniques for power scaling in fiber-based laser systems.

At the same time, the route to reach the fundamental limit in a single channel is also challenging in fiber lasers owing to associated nonlinear effects such as transverse mode instability or Stimulated Raman or Brillouin scattering. The promising approach to elevate thresholds for nonlinear effects is to enlarge the core size of the active fiber in the final amplification stage of the laser scheme, thereby decreasing optical intensity density in the active fiber core area. However, in most cases, increasing the core diameter in the conventional step-index fibers is accompanied by dramatical degradation of the spatial beam quality. The problem can be resolved in bi-tapered conventional multimode fiber via nonlinear coupling of modes induced self-cleaning effect as described in a feature paper by X.-J. Lin [2]. A simple, low-cost and robust solution can be implemented to improve the beam quality of high-power systems.

One more approach for further progress in high power fiber lasers is to decrease the number of amplification stages that can be implemented by developing new fiber-based seed master oscillators directly delivering high-power pulsed emission. A novel operation mechanism for generating high-repetition-rate pulse trains is discovered in a feature paper by A. Abramov [3]. The kilowatt peak power picosecond pulses are transformed from low-amplitude, weakly modulated continuous wave signals via nonlinear mechanisms in a cascaded cylindrical waveguide structure.

Recently in advancing high-power systems, special interest is addressed to laser systems with light emission beyond rare-earth dopants operating wavelength range. One of the primary focuses is Raman fiber lasers based on graded-index multimode fibers (GRIN-fibers). The paper by A. Kuznetsov [4] reviews recent results in the cascaded Raman conversion. The article discusses that the first and higher-order Stokes radiation can be obtained in the linear cavity configuration composed of Fiber Bragg Gratings inscribed in the core and random distributed feedback via Rayleigh backscattering along with the fiber. It is worth mentioning that in such a fiber laser, the output beam of the generated Stocks can be close to the diffraction limit.

The impressive progress in developing fiber and laser technologies is followed by their active involvement in various applied areas. One of the most dependent on laser-induced technologies nowadays is medicine. Consequently, the number of research on the development and exploitation of different fiber lasers or fiber-based systems for medical purposes is actively growing every year. Therefore, part of the Special Issue manuscripts considers the medical application of methods based on optical fibers. For example, the work of Y. Maklygina et al. [5] discloses such vital issues as the non-invasive investigation of brain tissues, recognizing the cellular composition of the brain tumor tissue, namely the ratio of cancer and immunocompetent cells and their mutual localization, which is an important factor for the development of methods for early disease diagnosis and effective anticancer therapy. In another work [6], the authors study the problem of the inflammatory process in the neuroport area using spectral methods and the technique of fiber-optic fluorescence analysis of photosensitizers in nanoform. For these purposes, an intracranial neurosystem with an internal fiber-optic structure is preliminarily implanted into the mice's brain to access to the tumor bed and perform in vivo measurements. Fluorescence spectroscopic analysis is performed in vivo on experimental animals, i.e., under conditions of active immune system intervention, as well as on cell cultures in vitro to judge the role of the immune system in the implant interaction. The authors show that photosensitizers' spectral characteristics can be used to evaluate of the inflammation process in the implant area and detect of the immunocompetent cells' local presence. This study opens up the possibility of local immunosuppression using phototherapy, which may positively affect the treatment of serious diseases. The work [7] by Kopyeva et al. present the results on exposure of a simple, robust, and compact Holmium-doped all-fiber system operating at a wavelength of 2.1 μm on the ex vivo porcine longissimus muscle tissues in a wide range of applied energy. The authors propose a simple universal fiber source of 2-micron radiation as an alternative to bulky Tm:YAG and Ho:YAG lasers providing similar exposure results on the soft tissues.

Another direction of the active research is the development of Erbium-doped fiber lasers emitting near 1.55 μm. Interest in these sources is caused by the fact that radiation with a wavelength of near 1.55 μm belongs to the eyes-safe spectral range, and falls into the atmosphere's transparency window. By now, such lasers have demonstrated a number of real and prospective applications, for example, for atmospheric communication, determining the concentration of atmospheric gas, light detection and ranging, etc. The manuscript [8] presents a method for obtaining Q-switched dual-wavelength radiation in an Er-doped seed fiber laser. The authors propose the simple approach to separate and control two lasing spectral lines by using the fiber Bragg gratings and fixing one of them while applying mechanical strain-stress to another one.

One more developing research area is the creation of high peak and high average power fiber lasers that deliver radiation with diffraction limited beam quality. Application at the final amplification stages of conventional step-index regular large-mode-area fibers essential for an increase of nonlinear effects threshold, is limited by technological issues, deteriorating output beam quality with core diameter growth and accompanying effects of mode instability. Therefore, in work [9], the authors investigate the tapered Er-doped fiber with varying along the fiber length core diameter (from 15.8 µm in the thin fiber part to 93 µm in the thick fiber part). A tapered fiber as an active medium of the main amplifier allows to achieve above 200 kW peak power (limited by self-phase modulation) with a slope pump-to-signal conversion efficiency of 15.6% for 0.9 ns pulses with spectral width below 0.04 nm.

The development of pulsed laser sources with a high repetition rate has attracted massive attention in recent years due to their widespread applications in the industry and great potential in various aspects of scientific research. Recently a cylindrical waveguide structure with the running refractive index wave has been demonstrated as a prospective method for the generating high-repetition-rate pulse trains. The operation mechanism involves a proper combination of the frequency modulation and modulation instability simultaneously experienced by the input continuous wave signal as it propagates through the cylinder waveguide. In [10], the authors propose to use such fibers as a part of the cascaded optical fiber configuration comprising both passive and active optical fiber segments. According to the achieved results, such a laser scheme allows improvement of the pulse train formation control and a decrease of requirements for the CW signal power simultaneously. The main feature of the proposed method for high repetition rate pulse generation is providing an additional optical gain for pulse peak power scaling. Moreover, in [11], the authors detailed the mechanism responsible for transforming continuous wave radiation into high-frequency pulsed radiation with a linear chirp. In particular, the dynamical evolution of frequency-modulated optical signals propagating through the fiber configuration comprising active fibers with the anomalous dispersion, which is nonuniformly distributed (with increasing and then decreasing) over the fiber length, is investigated. This approach opens up the possibility for generated pulse compression and achievement of peak powers increase (~6 orders of magnitude) compared to that of the input optical signal and a 100-fold narrowing of the pulse duration.

In conclusion, it should be noted that this Special Issue represents only a small digest of the current trends and advances in the field of fiber-based coherent sources and its applications. The publications reflect a complex and multilateral view into the progress in the field of fiber optics, showing perspectives for the evolution of high-power fiber lasers delivering emissions with good beam-quality, novel operation mechanisms for a pulsed laser system with superior parameters and the newest applications for fiber-based methods. The further progress in new lasing operational regimes, leading to generation at new wavelengths, methodologies for output power scaling and novel tools exploiting unique optical fiber properties with large variability of the parameters, reveals the ways towards unsurpassed technological advances in a vast range of applications.

Conflicts of Interest: The author declares no conflict of interest.

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