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Review

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Fibre Lasers: Promising Solutions

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Abstract: This work analyses promising solutions for controlling the output radiation properties of fibre lasers. The design of fibre lasers is radically different from that of other laser types. This is why many conventionally used solutions and approaches are incompatible with fibre lasers. Furthermore, fibre lasers following "all-fibre" designs also allow certain solutions that are impossible in other types of lasers. This work discusses those solutions, highlighting the promising applications for all-fibre lasers. Both the advantages and disadvantages of the very low sensitivity of the fibre laser cavities to the external factors are covered. Solutions that are already available commercially or may be expected to be in the near future are highlighted. Various aspects of sensor and communications applications of fibre lasers are discussed.

Keywords: all-fiberized lasers; methods for controlling radiation parameters; electronic control

1. Introduction

The fibre-optical platform opens new possibilities of improved laser parameters. It has been mentioned many times that fibre lasers in all-fibre configurations have the advantage of alignment-free and maintenance-free cavity, as well as that of simpler laser architecture. Aside from this, fibre lasers possess, in principle, good fixed output beam quality and efficient heat removal in cases of relatively long active media. One may also note that no rigid volumetric cavity design is necessary and that the overall laser design is safer since no intra-cavity radiation is exposed in an all-fibre layout. Nevertheless, in addition to these relatively commonplace advantages, it is necessary to draw the reader's attention to certain attractive solutions presented solely by fibre lasers in order to more fully realise the potential of fibre-optical technologies. In addition, it seems appropriate to present a discussion regarding which applications may profit from the identified solutions, and which may not (Figure 1). Many solutions are invented in well-equipped laboratories and are only viable in such comfortable conditions. The application of these solutions for research is well justified and, in a certain way, holds promise. However, it must be understood that we are more interested in those prospects that may be realised in commercial fibre lasers used in a variety of environments, including outside of laboratories.

Despite our desire to consider solutions that are promising (and currently used) in commercial lasers, we are compelled to limit our analysis to solutions employed in laboratory fibre lasers, as these solutions are more easily identified and described in detail in numerous publications. Commercial lasers are almost always "black boxes", which is convenient for users but complicates the analysis of the solutions used in these lasers.

This analysis primarily concerns research fibre lasers whose functionality limits are constantly being expanded. In fibre lasers with fixed output parameters used for specific tasks, only some of the solutions discussed below may be applicable (or not applicable).

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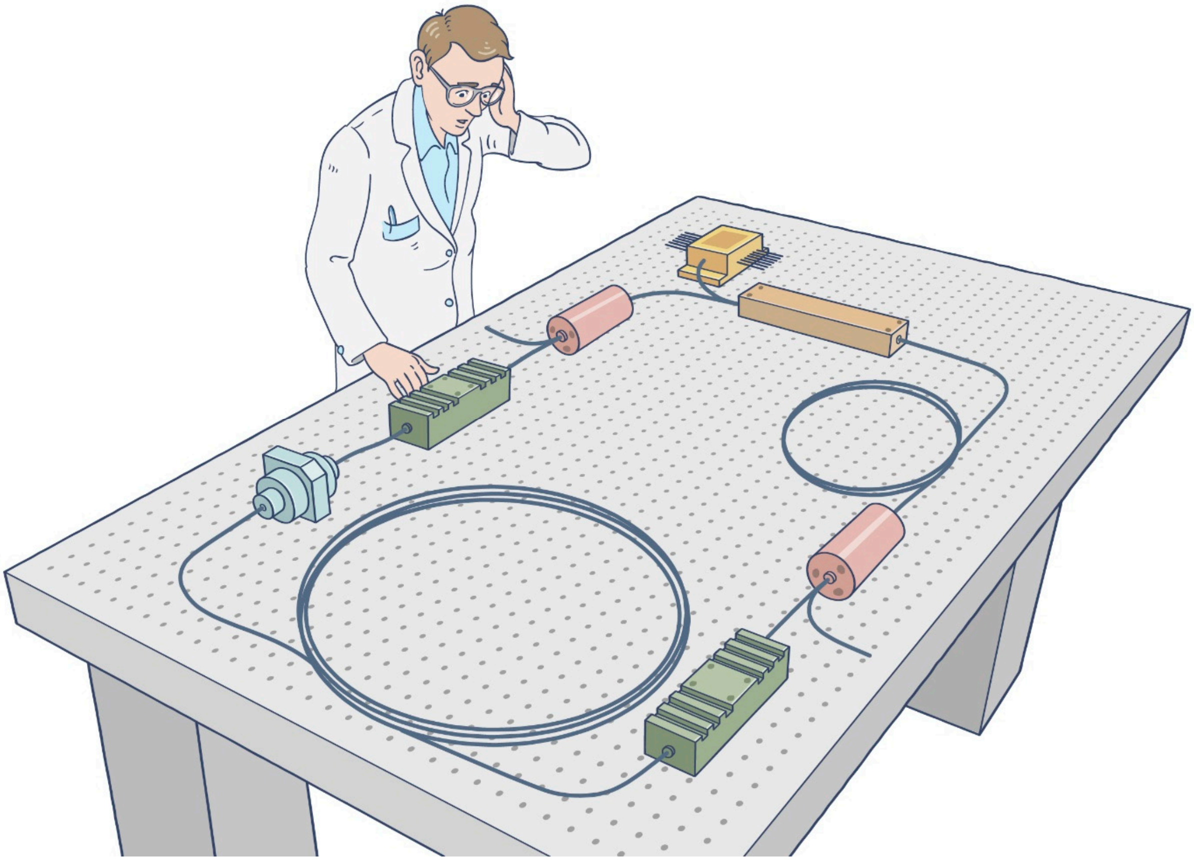

Figure 1. The scientist or developer often faces a dilemma; isolation from external factors complicates methods of control over the output radiation (the fibre laser configuration shown in the figure is illustrative; any resemblance to actual components is purely coincidental).

Overall, this review is concerned with those solutions that can be implemented, at least in laboratory lasers. In the following sections, we present a number of such solutions, which are not necessarily related to each other.

2. Short and Long Resonators

Today, large lengths of fibre laser cavities are no longer a rarity. Low radiation losses (especially around 1.5 μm) make it possible to elongate the laser cavity to tens and hundreds of kilometres [1–3] (Figure 2). The upper limit of the fibre cavity length around a wavelength of 1.5 μm is related to the existence of distributed feedback from Rayleigh scattering of radiation upon random non-uniformities of the refractive index in a quartz waveguide [4]. At a cavity length of about 100 km, this distributed feedback may dominate over that provided by the cavity mirrors. Consequently, the laser's generation regime is fundamentally affected; the cavity becomes "mirrorless" and the inter-mode spacing, heretofore defined by the distance between the mirrors, changes. A discussion of the unique properties of ultra-long fibre lasers may be found here [5]. At shorter laser cavities (for example, 10 km and less), however, the inter-mode spacing (or the pulse repetition rate) is defined by the distance between the cavity mirrors. In pulsed operation, longer distances between the cavity mirrors lead to lower pulse repetition rates and, hence, to greater per-pulse energy (at a fixed pump power) [6]. This approach may be used for boosting the pulse energy, but it should be noted that as the cavity becomes longer, the type of pulses generated may change (conventional unstructured solitons may be transformed into noise-like pulses [7,8]). The initial type of the output pulses is retained up to the fibre laser cavity length of about 1 km [9].

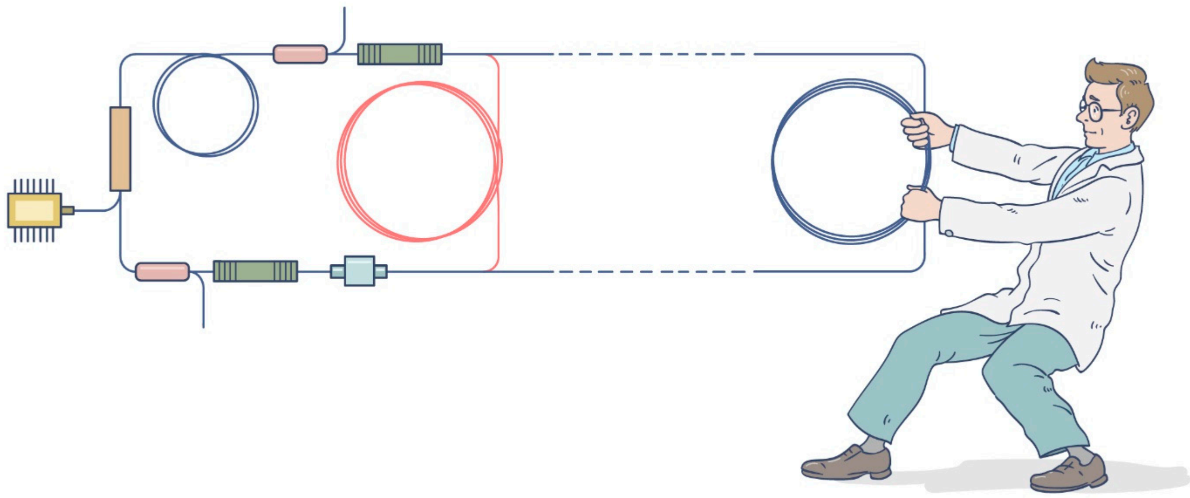

Figure 2. Use of optical fibre to form the laser cavity allows the significant elongation of the cavity length of such a laser (the fibre laser configuration shown in the figure is illustrative; any resemblance to actual components is purely coincidental).

Shortening of the fibre laser cavity may also present an advantage, but for CW generation as opposed to pulsed. Shorter cavity lengths result in larger inter-mode spacing. For example, shortening a laser cavity to 5 cm corresponds to a relatively large spacing of 3 GHz. However, even this is not sufficient for the selection of a single generation frequency (because the ~100 nm-broad spectral gain contour of a fibre laser at 1050/1550 nm corresponds to about 27,000/13,000 GHz). Nevertheless, a single narrow selector with a transmission peak width of 1–3 GHz and a free spectral range of 27,000/13,000 GHz is sufficient for single-frequency generation in a short-cavity fibre laser [10,11]. A Bragg grating with a π-shift in the centre that is written directly into the active fibre may perform effectively as such a narrow selector [12]. Such a grating is similar to an interferometer consisting of two gratings, therefore it has high spectral selectivity. Such π-phase-shifted fibre Bragg gratings have been shown to be not only efficient selectors for short-cavity single-frequency lasers, but also highly sensitive sensors [13–15].

The solutions mentioned above, which rely on short and long fibre laser cavities, allow better implementation of those generation regimes that are difficult (or inefficient) in cavities of medium length.

Another solution that can significantly expand the capabilities of fibre lasers is convenient control of their output wavelength.

3. Electronic Control of Wavelength Tuning in Wide Spectral Range

Electronically driven wavelength tuning is a desired option for many lasers. One of the most widely used laser wavelength selectors—the Lyot filter—combines a comparatively narrow transmission line with the possibility of its tuning over a broad spectral range and low optical losses. The adaptation of this filter to the "all-fibre" format [16] made it almost the sole choice of coarse wavelength selectors for all-fibre lasers. However, as one of the corollaries of this adaptation, it became impossible to rotate the filter "plates". This is why for electronically controllable spectral tuning, the primary method is adjustment of the "plate" temperature [17–19]. An interesting method of electro-mechanical wavelength tuning of a fibre-based Lyot filter was demonstrated in [20]. The PM fibre, playing the role of the Lyot filter "plate", is wound around a piezo-cylinder, whose diameter can be reduced or enlarged depending on the applied voltage. Properly tensioned winding produces stable elastic deformation of the fibre as the cylinder's diameter is changed. This elastic deformation induces a change in birefringence, which in turn results in a shift in the spectral position of the transmission peak of the Lyot filter. For stable long-term operation of this method, it is necessary to ensure the dense and well-fixed winding of the fibre around the piezo-cylinder and the maintenance of the diameter changes within a relatively narrow range in order to maintain elasticity of the fibre deformation. It is necessary to point out that electro-mechanical control of the output wavelength of a fibre laser relying on a piezo-cylinder is currently at the stage of laboratory prototypes and not found in any commercial products.

The commercially available electronically controlled tuneable filters mostly use, as broadly tuneable components, either volumetric Bragg gratings, thermally adjustable fibre-optical Bragg gratings, thin Fabry–Pérot interferometers, or acousto-optical devices (here, we do not consider lasers with frequency self-scanning [21]). The following examples may be mentioned. (1) The digital tuneable filter TF-100 produced by OZ Optics (OZ Optics, Ottawa, Canada) [22] using a thin Fabry–Pérot interferometer with tuneability across 1520–1570 nm (C-band), 1570–1620 nm (L-band), or 1470–1520 nm (S-band) nm, a transmission bandwidth of 1.1 nm, an insertion loss of 2.5 dB, and input power handling of 0.2 W; the principle of operation of the filter is conventional—rotation of a thin-film Fabry–Pérot interferometer in an open collimated beam of radiation between a fibre input/output. (2) An electrically tuneable grating-based fibre optic filter by Agiltron [23] that may be tuneable within the ranges of 1045–1075, 1480–1520, or 1980–2020 nm, having a transmission bandwidth of 0.25 nm, an insertion loss of 2.1 dB, and input power handling of 0.5 W; the principle of operation is similar to the one described above, except that it is the Bragg grating that is tilted.

The commercially available manually tuneable spectral filters designed for fibre lasers may be modified to be electronically operated. With an additional step motor drive, it is possible to tune these devices digitally. Among such devices that may be modified in this way, one may list (1) the tuneable filter XTM-50 by EXFO (EXFO, Quebec, Canada) by [24] that relies on a reflective Bragg grating with possible tuning over 1450–1650 nm, a transmission bandwidth adjustable from 32 pm to 5 nm, an insertion loss of ~5 dB, and input power handling of 1 W; (2) the tuneable filter TBF-1550-1.0 by Newport (Newport, Irvine, California, USA) [25] using a thin-film interference filter with tuneability over 1535–1565 nm, a transmission bandwidth of ~1 nm, an insertion loss of ~2.5 dB, and input power handling of 0.5 W.

We will now pass from the components that control the fibre laser output spectrum to the components that control the output polarisation.

4. Fibre-Optical Polarisation Controllers

Evolution of radiation polarisation in optical fibres without polarisation maintenance caused by mechanical action on the fibre (compression, torsion) [26] is broadly used in laboratory fibre lasers. Specially designed devices for such mechanical action have been named «fibre-optical radiation polarisation controllers». These devices enjoy broad popularity because they are compact, inexpensive, simple to operate, and compatible with the all-fibre format. For research purposes, fibre-optical polarisation controllers are an attractive solution. Their commercial applications, however, pose a number of problems. The main issue is the lack of a well-defined algorithm for tuning such a controller. This tuning depends upon the polarisation state outside of the controller, that is upon bending and twisting of the cavity fibre, and also upon the pressure applied to it and its temperature. For two visually identical fibre laser cavities, identical output parameters may be obtained at different settings of the polarisation controllers. Additionally, the settings of a fibre-optical polarisation controller are subject to drift related to both mechanical creep of the action members and plastic deformation of the fibre. Proper tuning of a polarisation controller requires live monitoring of the laser's output parameters, which means that specialised measurement equipment is necessary (spectrum analyser, autocorrelator, and so forth). Due to difficulties arising from the use of fibre-optical polarisation controllers, they are rarely adopted in commercial products but are often utilised in laboratories for research purposes. Therefore, this solution may be considered as promising in research tasks, but with little prospect in commercial products.

Nevertheless, commercial solutions emerge that stem from improvements of fibre-optical radiation polarisation controllers. Mostly, these improvements target electronic control of the state of radiation polarisation. Among the proposed solutions, one may mention the "Motorised fibre polarisation controller" from Thorlabs [27], in which the paddles are rotated by electric motors, and the "piezoelectric polarisation controller" from Agiltron [28], in which pressure is applied to the optical fibre by piezo-actuators positioned at 45 degrees from each other. In these and other similar cases, the question arises regarding the reproducibility of the controller tuning, which depends on the cavity configuration, bending and twisting of the fibre, its temperature, etc. The introduction of electrically driven fibre-optical polarisation controllers may speed up the tuning process, but it does not eliminate the essentially random character of the tuning process and parameter creep.

Electronic control is being attempted not only for the components that determine the radiation spectrum and polarisation but also for saturable absorbers.

5. Electronic Control of Saturable Absorber Properties

Electronically controlled variation in the properties of saturable absorbers has been primarily developed in fibre lasers (Figure 3). This is partially due to rather limited possibilities of electrical control over the output parameters of these lasers, especially in all-fibre configurations. Controlled variation in the properties of saturable absorbers allows the adjustment of some output radiation parameters, thus providing greater freedom of control over a laser. Electronically controlled variation in absorber properties is applied both to material-based and artificial types [29].

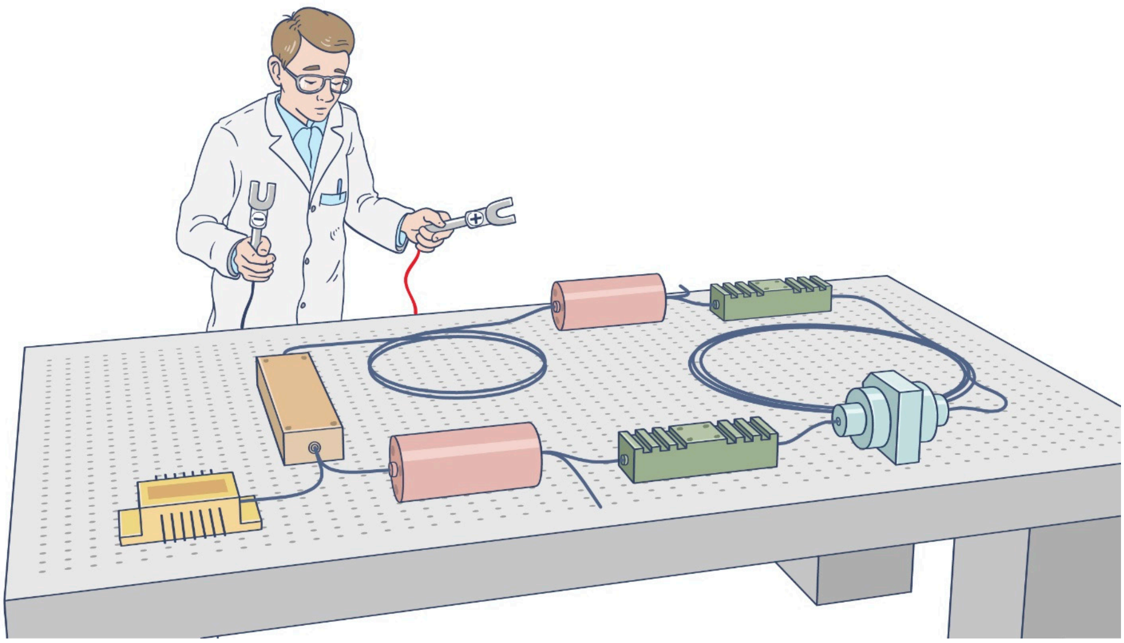

Figure 3. Electrical control of the fibre laser output parameters is, undoubtedly, very desirable, but such methods are still insufficiently developed (the fibre laser configuration shown in the figure is illustrative; any resemblance to actual components is purely coincidental).

5.1. Electronic Control of the Properties of Material-Based Saturable Absorbers

Variation in the properties of material-based saturable absorbers may lead not only to respective changes in radiation parameters within a given generation regime, but also to switching between different regimes. Depending on the combination of the pump radiation power (or the injection current of the pump diode) and the control parameter of the material-based saturable absorber, the generation regime of a fibre laser and its output radiation parameters within a given regime may be varied [30]. Such a control parameter may be either voltage applied to an ionic liquid contacting with a carbon-nanotube-based saturable absorber [31–33] or the incident power of a separate optical radiation beam [34]. It should be noted that in spite of the novelty and originality of these solutions, they are unlikely to enjoy a substantial prospect of being adopted in commercial products. The principal culprit is the inherently short lifetime of material-based saturable absorbers (several thousand hours at best).

5.2. Electronic Control of the Properties of Artificial Saturable Absorbers

Non-linear amplifying loop mirrors (NALM) became a convenient artificial saturable absorber for electronic control. The addition of such a mirror of a second independently pumped active medium to the loop allows more flexible variation in generation parameters (for example, independent control of the duration and peak power of the generated pulses) [35–38]. The idea of an additional independently pumped active medium for better electronic control of the output parameters was adopted not only in NALM, but also in other configurations of fibre lasers [39–42]. It is necessary to note that the inclusion, for instance, of two independently pumped active media makes it possible to characterise a laser with a map of generation regimes [39], in which various generation regimes of the laser are plotted as a function of the ratio of the pumping powers of different active media.

Methods of electronic control can certainly be considered promising, but innovative solutions are not limited to these methods.

6. Splicing PM Fibres at an Angle Between Their Slow/Fast Axes of 45°

A piece of PM fibre connected to other PM fibres at an angle of 45° between the slow axis of this PM fibre piece and slow axes of the input and output PM fibres plays the role of a birefringent plate in a Lyot filter [43], whereas the input and output PM fibres play the corresponding roles of polarisation analysers [44]. Three pieces of PM fibre may be used to implement a polarisation spectral filter, but its tuning possibilities are limited since the simplest way of changing the birefringence of the central PM fibre is by variation in its temperature. Thermal adjustment of the PM fibre birefringence provides relatively slow spectral tuning of the generation line, but the tuning range may be as large as tens of nanometres [45]. A salient feature of this solution is that such a spectral filter does not require all of the fibre cavity to be made of PM fibre. Most of the cavity may contain non-PM fibre and the filter segments may be connected to the rest of the cavity through fibre-optical polarisation controllers [46]. However, as was demonstrated earlier, this solution is only appropriate for laboratory lasers.

We will now transition from a discussion of macro-level solutions to fibre component miniaturisation.

7. Chip-Scale Fibre Devices

Fibre-optical technology provides new possibilities of more compact fibre-optical devices, including fabrication of optical elements with a 3D printer [47] and implementing lasers as photonic integrated circuits [48]. The integration of high-precision laser sources on a chip has long attracted developers [49] because it promises more advanced technologies and applications. Combining the concepts of fibre-optical technology and photonic integrated circuits [50] opens up broad new opportunities for light-wave technologies. Similarity, fibre and waveguide technologies allow the rapid implementation of fibre-optical configurations in photonic integrated circuits. Additionally, this simplifies the problem of connecting a fibre to a photonic integrated circuit, which is already being solved in various ways [51–53]. The key problems of photonic integrated circuits are not only related to the complexity of implementing various optical elements in a chip-scale form factor [54], but also to minimisation of the loss introduced by the input/output connections between waveguides and fibres [55,56].

The transfer of fibre laser technology onto the photonic integrated circuit platform not only opens up new applications of ultra-compact laser sources with competitive output parameters but also allows the consideration of such laser sources as a new type: all-waveguide lasers. Earlier on, the term 'waveguide lasers' was used to refer to volumetric lasers, in whose active media an artificial waveguide was created with femtosecond radiation [57–60]. However, in most implementations, this waveguide was only created in the laser's active medium. Its presence improved generation efficiency but did not change the general volumetric configuration of the laser. Implementation of all the laser elements as waveguide components will lead to development of an all-waveguide laser, best adapted to the chip-scale platform.

8. Modification of Quartz Refraction Index by Femtosecond Pulses

Another solution, specific to fibre lasers and holding great promise, is the creation of optical elements in fibre through the modification of its material's refractive index. Most frequently, this is used to introduce Bragg gratings [61] and mirrors (also essentially gratings). Both gratings and mirrors may be chirped [62], thus simultaneously playing the role of dispersion management elements. Gratings and mirrors may be used to make interferometers [63,64]. Local refractive index modification in the fibre core material (fused silica with various additives) is achieved either by UV exposure [65], by irradiation with ultra-short pulses [66–68], or by mechanical stress [69]. Tilted fibre Bragg gratings may be used as polarisers in lasers [70,71] and as high-precision sensors [72,73]. Other methods of interaction with the fibre core may be through an evanescent field [74], V-groove [75], or through a micro-channel [76]. The effect of longitudinal micro-channels parallel to the core will be discussed later. The approached to interaction with the fibre core mentioned so far are mostly aimed at sensor applications and the development of better fibre-optical sensors. The suitability of these approaches for the improvement of laser parameters is usually limited to research labs.

Modification of the refractive index of quartz by femtosecond pulses is used to create special fibres, whereas many methods for extending the working spectral range through non-linear optical techniques can be based on standard fibres.

9. Non-Linear Effects for Expansion of the Working Spectral Range

In this section, we will talk about such non-linear effects as Raman conversion, supercontinuum and harmonic generation, soliton self-frequency shift, and parametric generation.

Broadening of the working spectral range on the basis of non-linear optical methods is conventionally used in various types of lasers. The difference in fibre lasers consists of the fact that many of these methods may be implemented inside the optical fibre and, consequently, are compatible with the all-fibre format inside or outside of the laser cavity. For such methods as Raman conversion [77–79], supercontinuum generation [80–83], and soliton self-frequency shift [84,85], no special crystalline fibre or photonic crystal fibre is needed. They may be used even with standard fibre [86–88]. However, harmonic and parametric generation usually need non-linear crystal media, therefore their implementation with non-linear crystals violates the all-fibre concept. It is necessary to remark that not all of the above-mentioned methods are equally popular. Spectral shift in a radiation line arising from the effect of self-frequency shift only works in short-pulsed generation, and the energy of tuneable pulses is too variable over the tuning spectrum (the shift depends on the pump radiation power) [89]. In supercontinuum generation, the spectral power density of the output radiation is significantly reduced [90]. As drawbacks of the Raqman approach, one may point out the conversion losses of radiation (they may be relatively low, not exceeding ~20% [91]) and a fixed spectral shift that depends on the material used for conversion [92]. In spite of that, the main advantages of Raman conversion are the possibility of using it both inside and outside of the laser cavity (in the former case, it may be just a Raman laser emitting in the shifted longer-wavelength range [93]); spectral tuning over the shifted range by tuning the fundamental radiation wavelength [94]; and the possibility of conversion both in pulsed- and continuous-wave generation [92].

It is important to note that such non-linear effects as Raman conversion, supercontinuum generation, and harmonic generation are actively utilised in the development of new fibre lasers [93–104]. While Raman fibre lasers and super-continuum fibre generators have been known for a long time [95,96], generators of the second harmonic from fibre laser radiation have seen significant advancements recently, as their output power reached increasingly higher levels. For instance, in the green field of the spectrum, CW output power can reach tens [104] and hundreds [102,103] of watts, making these frequency-doubling fibre lasers a promising pump source, including for Ti:Sapphire and dye lasers [105].

10. Expansion of the Working Spectral Range with New Active Fibres

Expansion of the working spectral range is also possible through active fibres that support generation in spectral regions outside the traditional ones, in which optical gain is provided by Yb-doped, Bi-doped, Er-doped (or Er/Yb-doped), Tm-doped, and Ho-doped (Ho/Tm-doped) silica fibres. Non-linear methods of expansion have limitations either related to comparatively low spectral power density, or to the dependence of the spectral conversion strength on the radiation power, or to the need to use additional radiation or non-linear crystals, while the use of new active media overcomes these limitations. First and foremost, we should mention Dy3+-doped fluoride glass optical fibre, which provides generation in the yellow spectral region (~565–590 nm) [106]. Another promising fibre active medium with gain in the visible spectral region (orange, red and deep red) is Pr3+:WPFG (waterproof fluoride glass) [107]. Reviews on visible-range fibre lasers are given in [108–110]. In the other direction of the spectrum (mid-IR), there is also development, with new active media supporting generation in the 2.5–5 μm region [111,112].

It should be noted that the new spectral regions are still poorly supported by other (apart from active media) fibre components. In this regard, the expansion of fibre lasers into new spectral regions is progressing relatively slowly.

We will now turn to the use of laser and fibre technologies in sensor applications. The application of these technologies in sensor systems, especially for monitoring extended objects, is not entirely straightforward. Typically, their immunity to electromagnetic interference and chemical inertness is presented as the advantages of these systems. However, they have significant drawbacks, which will be discussed in the next section.

11. Sensing Applications of Fibre-Optical and Fibre-Laser Technologies

The high sensitivity of light passing through an optical fibre to the ambient conditions, especially in such cases when this sensitivity is enhanced by appropriate measures, makes it possible to use fibre-optical and fibre-laser technologies in sensing applications. It was especially hoped that fibre-optical sensor systems would be advantageous for the monitoring of extended objects (border control, pipelines, bridges, and so on). It turned out, however, that although the high sensitivity of long fibre-optical sensing systems may be achieved by using unprotected optical fibre (without metal or other sheath [113]), such unprotected fibre becomes easily damaged by underground wildlife. Installing similar optical fibre above the ground exposes it to damage by animals or birds. In cases where optical fibre is embedded into structural elements (for example, in concrete), it may be destroyed, according to the author, due to the difference in thermal expansion coefficients of the fibre and the surrounding material. Thus, unprotected optical fibre is practically unusable in applications related to the monitoring of extended objects and adding protection to the fibre substantially reduces the sensitivity of such a system. For example, additional fibre protection in the form of an external metal sheath or using a fibre strand within a fibre-optic cable significantly reduces the fibre's sensitivity to vibrational, thermal, and other perturbations compared to the sensitivity of conventional unprotected fibres typically used in laboratory experiments. This is why many extended fibre-optical sensing systems are not feasible in practice. Conversely, applications of fibre-optical sensors in situations that require local measurement are more widely adopted [114].

Fibres with special geometric parameters/designs may enable unique generation regimes; however, the greater the departure of the parameters/designs from the standard, the more challenging it is to use such fibres. The input and extraction of radiation from such fibres require special adaptor devices, which are not always available commercially.

12. Microstructured Fibres: Hollow Microresonators

Using fibre-optical medium for the propagation of optical radiation provides the possibility of variation in the medium properties in order to obtain the desired radiation parameters while preserving wave-guide propagation. These variations may include changes both to the wave-guide material (for instance, the composition and amount of dopants, and so on [115]) and to the wave-guide structure (wave-guides with the core surrounded by micro-channels—micro-structured fibres [116,117]—or wave-guides with air-filled core [118], or enlarged/multi-mode core [119,120], or using high-Q micro-ring cavities [121]).

Wave-guides of different composition and structure are used in order to achieve desired generation regimes with the required output parameters. Unlike many other solid-state lasers, where intra-cavity radiation is mostly passing through atmospheric air, fibre lasers are subject to variability of their parameters caused by change in the parameters of the radiation propagation medium.

Specialty fibres [122] (of special design or made of special material) used in fibre laser cavities may affect the generation characteristics. However, in most cases it is difficult to predict the result of this influence. This result also depends on the resonator configuration, the pump radiation power, the generation mode, etc. Therefore, solutions related to the use of special fibres remain predominantly limited to the research area.

Multimode fibres are more common which differ from standard single-mode ones by having a thicker core and a stepped refractive index profile or a thicker core with a smoothed refractive index profile (graded-index (GRIN) multimode fibre [123]). Let us consider these fibres in more detail.

13. Multimode Fibres

Multimode fibres [124] are more accessible than the fibres discussed in the previous section. Due to their larger core area, these fibres can support higher power or pulse energy of radiation [125–127], but this advantage applies to only a small number of fibre lasers.

A significantly larger number of fibre lasers are affected by the fact that, again due to the larger core area, the threshold of non-linear effects in multimode fibres is higher than in single-mode fibres, so the use of multimode fibres enables non-linear effects to be removed or significantly reduced.

The downside of a higher non-linear effect threshold (which is positive for many applications) is deterioration of the beam quality at the output of the multimode fibre. However, under certain conditions (short-pulse generation, graded-index fibre), the Kerr effect can lead to a spatially clean output beam, i.e., non-linear beam reshaping into the TEM00 mode (beam self-cleaning) can be achieved [128,129]. That is, despite the multimode nature of the fibre, single-mode propagation of the radiation may be maintained.

Undoubtedly, the identification of a way of obtaining a high-quality radiation beam at the output of a multimode fibre is one of the prominent and promising discoveries of recent years in the field of fibre optics.

14. Conclusions

Analysis of promising solutions demonstrates the complexity of the dilemma related to controlling the output parameters of fibre lasers. On the one hand, a major advantage of these lasers is a cavity isolated from the environment and alignment-free operation. On the other hand, such isolation rules out many proven methods of control successfully used in open free-space cavities of conventional solid-state lasers. In essence, fibre lasers adhering to the all-fibre format require the development of novel control methods. Some of them have already been introduced and are discussed in the present work.

Development of these methods is linked to improved functionality of the optical fibre used in the cavity elements of all-fibre lasers (due to Bragg grating (s) recorded in such fibre, due to changes in the material or structure of the fibre, and so forth). Enabling additional (spectral, spatial, and other) functions of optical fibre is one of the pressing problems in the development of new methods of output parameter control in all-fibre lasers

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