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Ytterbium-doped fibre laser with a Bragg grating reflector written in a multimode fibre

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***Abstract*. An efficient cladding-pumped Yb-doped fibre laser with a Bragg grating written in a multimode graded-index fibre is fabricated for the first time. The laser emits one transverse mode with a slope efficiency of 60 %. The resonator design proposed in the paper can be used for the development of high-power fibre lasers with an increased fibre core diameter.**

Keywords: *fibre laser, Yb^{3+} ions, fibre Bragg grating, multimode fibre.*

High-power cladding-pumped Yb-doped fibre lasers find wide applications in fibreoptic communication systems, medicine, material processing, etc. It is expected that the scope of their applications will expand. As a rule, the resonator of such lasers is formed by fibre Bragg grating (FBG) [1] reflectors or dielectric mirrors [2]. The first method is preferable due to its simple scheme and a better spectral selectivity of FBGs. However, high-power cw fibre lasers emitting a few hundreds of watts and more use dielectric mirrors. This is explained by two reasons. First, FBGs introduce excess optical losses. Although these losses are small (according to our estimates, 0.1 – 0.2 dB), they can produce a significant heating of the FBG at high optical powers, which can result in the destruction of a fibre with the written FBG. Second, to reduce the power density and decrease the probability of fibre damage, high-power fibre lasers use, as a rule, fibres of increased diameter. This poses the problem of fabricating fibres with the required photosensitivity, which could be spliced with the active fibre without significant splicing losses.

In this paper, we propose a new design of a fibre laser with FBG reflectors written in multimode graded-index fibres. Our approach is based on the property of graded-index fibres to maintain the input mode distribution of radiation propagating in the fibre. Therefore, we can assume that the single-mode regime specified by the properties of the active fibre will be preserved during the propagation of radiation in the graded-index fibre with the written FBG. At the same time, the fundamental-mode field diameter in a multimode fibre considerably exceeds this diameter in a single-mode fibre. This allows one to reduce significantly the optical power density in the FBG, thereby decreasing the probability of its damage. Below, we present the experimental results of application of such 'multimode' FBGs in a single-mode fibre laser. Note that we demonstrated earlier a multimode fibre laser with a multimode FBG reflector [3].

Multimode FBGs. Gratings of this type were first demonstrated in [4]. In this paper, we used a multimode fibre with the index profile close to parabolic. The index profile was formed by changing the concentration of the GeO_2 dopant along the core radius. The maximum difference between the refractive indices of the fibre core and cladding was 0.015, the core diameter being 50 μm. The FBG was written by the holographic method by the second-harmonic radiation from an argon laser. The multimode fibre was preliminary hydrogen-loaded to increase its photosensitivity.

Figure 1 shows the typical transmission spectrum of a multimode FBG measured with a superluminescent fibre source. One can see that the spectrum consists of the bands corresponding to the groups of modes with different propagation constants. The width of the reflection spectrum for different modes is about 5 nm. This means that the maximum relative difference of the propagation constants of reflected modes is about 0.5 %. Note that a more detailed interpretation of this spectrum is complicated due to a great number of propagating modes and the possible inhomogeneity of the induced refractive index over the core section because of its large diameter.

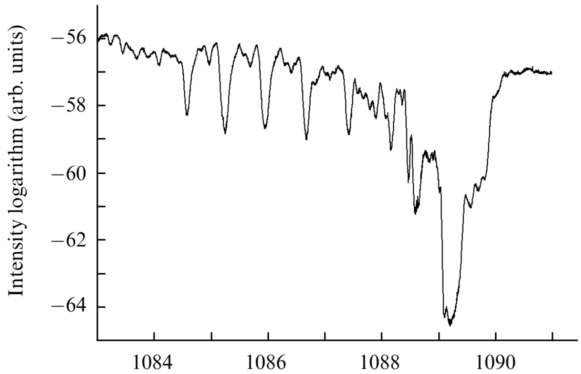

Figure 1. Transmission spectrum of a multimode FBG measured with a superluminescent fibre source.

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Laser characteristics. The scheme of the laser was very simple. The laser was pumped through a multimode fibre with a written FBG used as the input mirror. The multimode fibre was spliced with the active fibre whose exit end served as the output mirror. The multimode fibre had a polymer coating with a lower refractive index providing the transmission of pump radiation. The active fibre had a core of diameter of about 6 μm, and a cladding with a 120×120-μm square cross section. The active fibre length was 15 m. Pumping was performed by a 6-W diode laser array at 0.98 μm.

Figure 2 shows the dependence of the output power of the fibre laser on the pump power. The maximum output power achieved 3 W upon pumping by 5.4 W. The slope efficiency was 60 %. Although this value is lower than that reported, for example, in [1], it is nevertheless quite acceptable. The lower value can be explained by two reasons. First, the estimated diameter of the fundamental-mode field in the multimode fibre is 30 μm, which can introduce losses in the splicing of the two fibres used (we assume that these losses will decrease with increasing diameter of the active fibre core). Second, mode conversion can appear in the splicing and in the multimode fibre. This assumption requires the experimental verification.

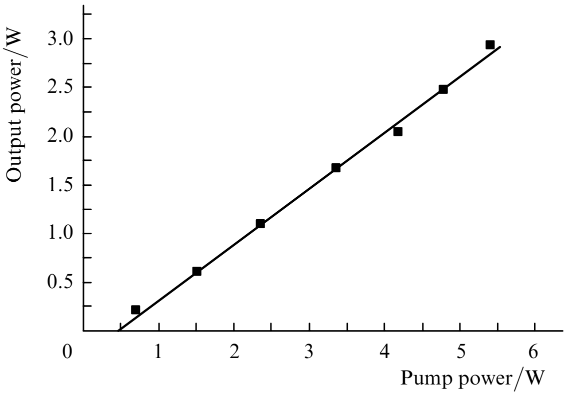

Figure 2. Dependence of the output power of the laser on the pump power.

Figure 3 shows the emission spectra of the laser for different pump powers. The emission spectrum broadens with increasing pump power and additional weak peaks appear in the wings of the spectrum. This effect can be explained by mode conversion, resulting in the appearance of reflection at resonance wavelengths corresponding to other modes of the multimode fibre. Nevertheless, the width of the emission spectrum measured at the 3-dB level did not exceed 0.3 nm. Note that, unlike the emission spectrum of a laser with a single-mode FBG, the emission spectrum of a laser with a multimode FBG is rather sensitive to the multimode FBG deformation. Therefore, to obtain a stable emission spectrum, the FBG should be reliably fixed.

Thus, we have shown that the cladding-pumped single-mode Yb-doped fibre laser can use multimode FBG reflectors. The slope efficiency of the laser is 60 %. An advantage of the laser design proposed in the paper is the possibility of splicing a multimode FBG with active fibres with different core diameters, which can be especially useful in the application of active fibres with increased core diameters in high-power fibre lasers. In addition, we assume

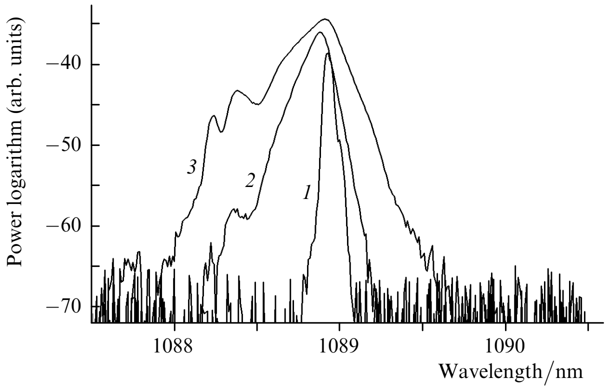

Figure 3. Emission spectra of the laser for pump powers 1 (*1*), 3 (*2*), and 5 W (*3*).

that the radiate resistance of multimode FBGs is higher than that of usual FBGs due to a lower radiation power density, which is also important for high-power fibre lasers.

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