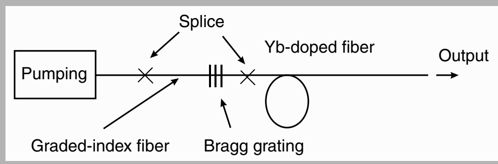
Abstract: We have realized a set of multimode lasers based on a double-clad Yb-doped fiber and Bragg gratings written on a graded-index multimode fiber. Efficient laser operation in the spectral range of 1.03-1.09 μm has been observed. Spectral characteristics of the laser emission have been investigated.



The multimode laser scheme

Multimode fiber lasers based on Bragg gratings and double-clad Yb-doped fibers

A.S. Kurkov, [1,*] *D.A. Grukh,* [1] *O.I. Medvedkov,* [1] *V.M. Paramonov,* [1] *E.M. Dianov,* [1] *M.V. Yashkov,* [2] *N.I. Vechkanov,* [2] *and A.N. Guryanov* [2]

[1] Fiber Optics Research Center at the General Physics Institute of the Russian Academy of Sciences, 38 Vavilov Str., Moscow 117756, Russia

[2] Institute of Chemistry of High Purity Substances of the Russian Academy of Sciences, 49 Tropinin St., Nizhny Novgorod 603600, Russia

Received: 20 May 2004, Accepted: 26 May 2004
Published online: 11 August 2004

Key words: fiber laser; Bragg grating

PACS: 42.55.Wd, 42.79.Dj

1. Introduction

At present, double-clad Yb-doped fiber lasers with an output power in the range of 1 W-1 kW find a lot of various applications which can be divided into different groups. Telecommunication applications, such as pumping of Raman converter for amplifiers or wireless communication, require emission in one transversal mode [1]. At the same time, some applications in medicine and material processing don't require the single-mode operation. Moreover, increasing the core diameter of active fibers decreases the probability of fiber optical damage allowing one to achieve a higher output power as compared to single-mode active fibers. Therefore, the creation of multimode high power laser appears to be useful for various applications.

The main problem of fabrication of a compact multimode fiber laser consists in choice of the selective reflectors. The application of dichromatic mirrors [2] complicates the laser scheme and cannot provide the same laser characteristics as in the case of using fiber Bragg gratings. At the same time, there is a possibility to fabricate multimode Bragg gratings in multimode fibers. In this case, it is preferable to use graded-index fibers providing compensation of the mode propagation constants. For the first time, this type of the Bragg gratings was described in paper [4]. Thus, the application of multimode gratings as the reflectors of multimode lasers is attractive. Earlier we have demonstrated a fiber laser with multimode Bragg grating reflectors emitting in several transversal modes [5]. The laser was based on an active fiber with a small size of the inner cladding. Also, in this case glasses with different compositions created a waveguide structure for the pump emission. Now we present multimode fiber lasers based on a double-clad active fiber coated with low-index polymer and with an increased core diameter.

2. Experiment

Bragg gratings were photoinscripted in a graded-index fiber with a core diameter of 50 μm and a maximum core-cladding index difference of 0.015. Germanium co-doping formed the refractive index profile of the core. To fabricate gratings we used the holographic method with UV-source

* Corresponding author: e-mail: kurkov@fo.gpi.ac.ru

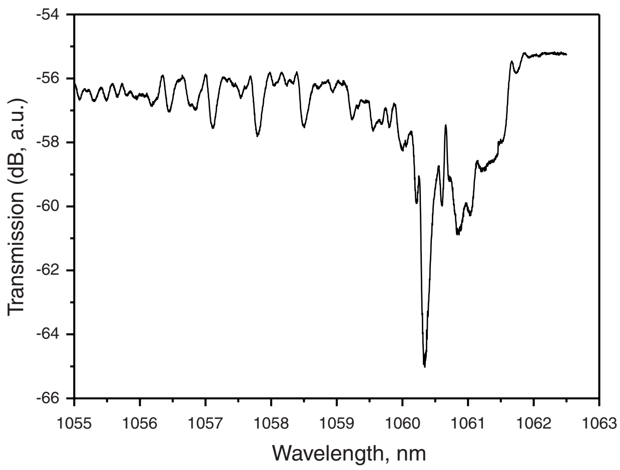


Figure 1 Transmission spectrum of the multimode grating

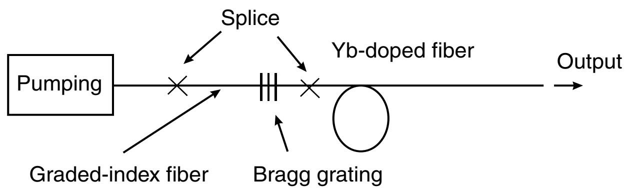


Figure 2 The multimode laser scheme

emitting at 244 nm. The graded-index fiber was H_2-loaded before the grating fabrication. Fig. 1 illustrates a typical transmission spectrum of the multimode grating measured with use of a fiber superfluorescence source. One can see that the reflection spectrum consists of a set of bands in accordance with propagation constants of separate modes. The spectral range of the reflection for different modes is approximately 5 nm. This means that the relative difference of the mode propagation constants is 0.5%. It should be noted that the interpretation of the reflection spectrum is difficult because of a large number of the modes. Also, we can suppose that a large fiber diameter leads to some non-uniformity of the UV-irradiation inside the core. The obtained fiber Bragg gratings were spliced with an active fiber.

As an active medium of the laser we have used a fiber with an Yb-doped core having a diameter of 30 μm. The refractive index profile had a step shape with a maximum index difference of 0.01. The fiber had a square shape of the inner cladding with a size of 120×120 μm. The fiber was coated with low-index polymer, which provided a numerical aperture for the pump emission of 0.38. It should be noted that the same polymer was used to coat the graded-index fiber applied for the grating fabrication. That simplified a connection of a pump source and a fiber laser.

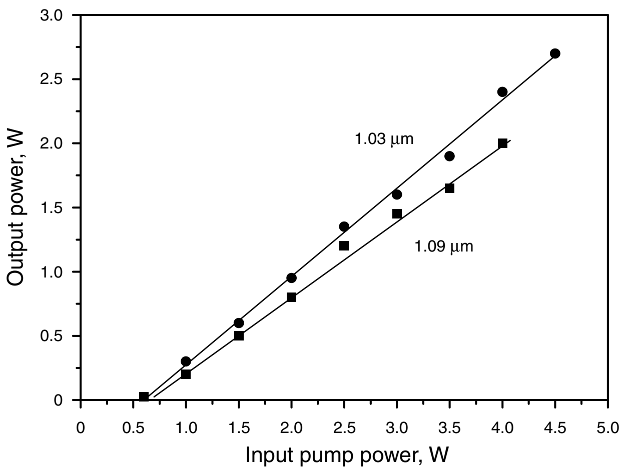


Figure 3 Power characteristics for the lasers emitting at 1.03 and 1.09 μm

The laser scheme is shown in Fig. 2. The multimode grating spliced with the active fiber was used as the input reflector and the cleaved end of the active fiber as the output reflector. The length of the cavity was approximately 1 m. We used the end pump scheme with a semiconductor source emitting in the range of 0.98 μm with a maximum power of 6 W. This source was produced by Laser-Melon (Russia). We investigated several lasers with gratings having the resonance wavelength in the spectral range of 1.03-1.09 μm.

3. Results and discussion

We have fabricated and tested 6 fiber lasers emitting in the range of 1.03-1.09 μm. For all samples the efficiency slope of 0.55-0.65 with regard to the input pump power was observed. The power characteristics for lasers emitting at 1.03 and 1.09 μm are shown in Fig. 3. It should be noted that the maximum efficiency (0.65) was observed in a fiber laser emitting at the wavelength of 1.03 μm, which corresponds to the second maximum of the fluorescence intensity of Yb-ions in silica glass. The near-field picture of the output emission constitutes a speckle image with a diameter of approximately 30 μm. That means that a laser emission fills all core diameter of the active fiber.

Fig. 4 illustrates a typical emission spectrum of the multimode laser for different values of the output power. One can see that the output spectra consist of several peaks determined by reflection of different groups of modes. The number of the peaks increases with a pump power. Nevertheless, the total width of the emission spectrum is less than 1 nm. Comparison with the grating transmission spectrum (Fig. 1) shows that lasing occurs for mode groups having the largest reflection. A complicate structure of the emission spectrum was observed for all lasers. Therefore, it was interesting to investigate the spatial dependence of

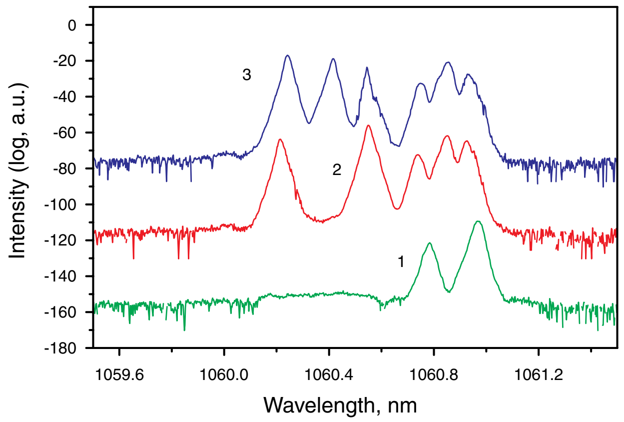


Figure 4 (online color at www.lphys.org) A typical emission spectrum of the multimode laser for different values of the output power – 0.1 W (1), 0.7 W (2), 1.5 W (3)

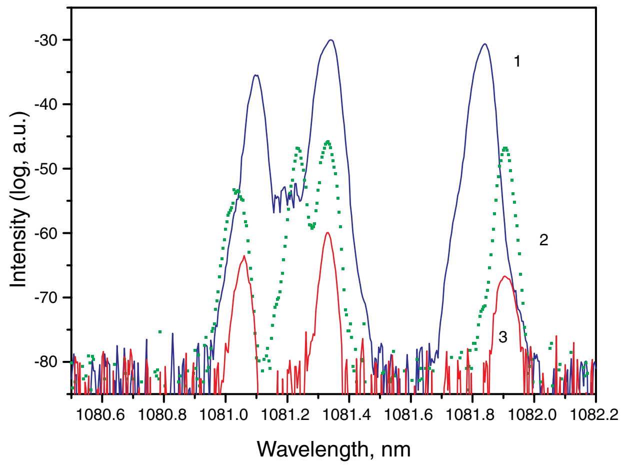


Figure 5 (online color at www.lphys.org) Emission spectra measured in the different points of the output cross-section of the laser. 1 - an emission spectrum in the center of the active fiber cross-section, 2–5 μm, 3–10 μm away from the center

the output spectrum. Fig. 5 shows results of the measurement in the different points of the output cross-section of the active multimode fiber obtained with the help of a single-mode fiber connected with the laser output. Curve 1 corresponds to an emission spectrum in the center of the active fiber cross-section. Curves 2 and 3 correspond to measurements at points 5 and 10 μm away from the center, respectively. One can see that spatial variations of the emission spectra are not so strong. This can be explained by strong mode conversion in the active fiber.

We have tested the temperature sensitivity of the emission spectrum for one of the fabricated lasers. The temperature shift of the emission wavelength of approximately 0.05 nm per degree was measured. This value coincides with that for conventional single-mode Bragg gratings. The shape of the emission spectrum practically doesn't depend on the temperature variation in the range of 20-100°C. On the other hand, the output spectrum is quite sensitive to deformation of the grating. This means that the multimode Bragg grating should be fixed to get a stable emission spectrum.

4. Resume

Thus we have realized and investigated multimode double-clad fiber lasers. The proposed laser configuration is based on a multimode Yb-doped fiber and Bragg gratings photoinscripted in a multimode graded-index fiber. An efficiency slope of 0.55-0.85 was observed for lasers emitted in the spectral range of 1.03-1.09 μm. A width of the emission spectrum less than 1 nm was measured. The suggested approach can be applied to the fabrication of the compact high-power multimode lasers.

References

[1] A.S. Kurkov, A.Yu. Laptev, E.M. Dianov, et al., Proc. SPIE **4083**, 118 (2000).
[2] V. Dominic, S. MacCormack, R. Waarts., et al., Electron. Lett. **35**, 1158 (1999).
[3] A.S. Kurkov, V.I. Karpov, A.Yu. Laptev, et al., Quantum Electron. **27**, 239 (1999).
[4] T. Mizunami, S. Gupta, T. Yamao, and T. Shimomura, Proceedings of the 23-rd European Conference on Optical Communications, 22-25 September 1997, Edinburgh, UK, pp. 182-185.
[5] A.S. Kurkov, O.I. Medvedkov, S.A.Vasiliev, et al., Technical Digest of International Quantum Electronics Conference (IQEC/LAT-2002), LSuD4, 22-28 June 2002, Moscow, Russia.