

Highly efficient cladding-pumped fibre laser based on an ytterbium-doped optical fibre and a fibre Bragg grating

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Abstract. Ytterbium-ion-doped double-clad optical fibres were developed. The differential quantum efficiency of a diode-pumped fibre laser, fabricated on the basis of such optical fibres with a fibre Bragg grating, was 90%.

1. Introduction

High-power fibre lasers, pumped by semiconductor laser diodes, may find the widest applications in optical communications, lidar systems, medicine, and materials processing. The principal element in such devices is a double-clad optical fibre with a single-mode core doped with a rare-earth element. After total internal reflection at the boundary with the outer polymer cladding, the pump radiation propagates along the inner quartz glass cladding. When crossing the core, the pumped radiation is absorbed by the rare-earth ions and lasing occurs in the single-mode core with a characteristic transverse size of 5–10 μm . Thus, a cladding-pumped fibre laser is a device which increases the radiation power density by 2–3 orders of magnitude.

The results of studies of the fabrication of a series of high-power fibre lasers based on optical fibres doped with Nd^{3+} [1, 2] and Yb^{3+} [3, 4] ions have now been published. The disadvantages of these lasers are a relatively low efficiency ($\sim 50\%$) of the conversion of the pump radiation and the use of bulky components such as interference mirrors.

The aim of the present investigation was development of ytterbium-doped double-clad optical fibres and the fabrication on their basis of a highly efficient diode-pumped all-fibre laser. The absence of absorption in the excited state and of cooperative effects, as well as the proximity of the absorption band (975 nm) to the luminescence region (1000–1200 nm), make Yb^{3+} in quartz glass the most promising medium for the attainment of a high lasing efficiency.

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Furthermore, high-power and reliable laser diodes, emitting in the range 960–980 nm, are available for pumping.

2. Laser design and parameters of the active optical fibre

The cavity of our fibre laser was formed by a fibre Bragg grating with the reflection coefficient $R = 99\%$ and a fibre end-face ensuring nonselective (4%) reflection (Fig. 1). The grating was 'written' in a section of a standard Flexcore-1060 optical fibre, which was then spliced to the active fibre. In order to increase the photosensitivity, the Flexcore-1060 fibre was subjected to a preliminary loading with hydrogen at a pressure of 150 bar. The grating was 'written' by a holographic method using frequency-doubled radiation of an argon laser [5]. The reflection spectrum of the grating had a maximum at a wavelength of 1067 nm and a half-width of 0.2 nm at the -3 dB level. The parameters of the active fibre were chosen taking into account the following conditions:

- the core size must be sufficiently large to ensure the absorption of the pump radiation propagating in the inner cladding over the fibre length, so that the excess losses of the pump radiation are still negligible;
- the size of the inner cladding must be minimal, but sufficient for effective coupling of the laser pump module to the fibre;
- the mode size in the Yb^{3+} -doped fibre must be close to the mode size in the fibre with the Bragg grating in order to minimise the optical losses in the cavity;
- the cut-off wavelength of the single-mode core must be less than the lasing wavelength.

The active fibre was fabricated by the MCVD method with impregnation of the porous core with a solution of salts of the active admixture [6]. Doping with GeO_2 and Al_2O_3 was used to form the refractive index profile of the core. The Al_2O_3 additive increased the solubility of ytterbium in quartz glass.

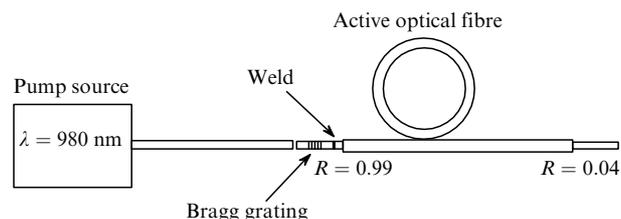


Figure 1. Schematic illustration of the fibre laser.

The difference between the refractive indices of the core and the cladding was 0.01, the core diameter was 5 μm , and the concentration of ytterbium ions was $7.5 \times 10^{19} \text{ cm}^{-3}$. To ensure full absorption of all the pump modes, the inner cladding of the waveguide had the form of a square [2, 7] with a 120 μm side. The absorption of the pump radiation propagating in the fibre cladding was 1.3 dB m^{-1} ; the pump radiation thus was fully absorbed over a 16-metre length of the fibre. The excess (nonresonant) optical losses were 10 dB km^{-1} in the core and 50 dB km^{-1} in the inner cladding.

Silicone rubber, the refractive index of which ensured a numerical input aperture of 0.38–0.4 for the pump radiation, served as the outer cladding of the active fibre. For the fibre parameters indicated above, the efficiency of injection of the radiation from the fibre pump module into the active fibre was $\sim 96\%$. At the lasing wavelength, the diameters of the mode profile for the active and passive fibres were 6.9 and 7.1 μm , respectively; the optical losses caused by splicing these fibres did not exceed 0.2 dB .

3. Laser characteristics

The power of the output radiation of the fibre laser was 3.1 W for a pump power of 4 W (Fig. 2). The pump source was an Opto Power laser diode, model OPC-D003-975-HB, with a fibre output. The maximum laser power density for a mode spot diameter of 6.9 μm reached 8.4 MW cm^{-2} . As can be seen from the emission spectrum (Fig. 3), the

suppression of the amplified spontaneous luminescence amounted to 55 dB . The slope efficiency of the laser reached 83%, which corresponds to a quantum efficiency of 90%.

4. Conclusions

An all-fibre laser was fabricated making use of the technologies for the fabrication of ytterbium-doped optical fibres, which have been developed, as well as of the technique for writing fibre Bragg gratings. The low level of additional optical losses in the ytterbium-doped fibre, the high reflection coefficient of the Bragg grating, and the low losses on splicing the active and photosensitive fibres made it possible to reach a 90% differential quantum efficiency of the laser.

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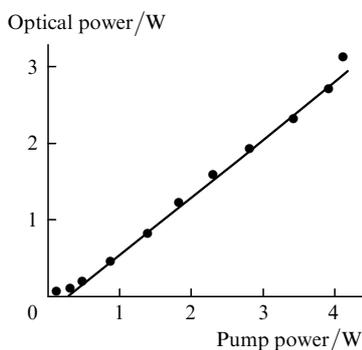


Figure 2. Dependence of the output power of the laser on the pump power.

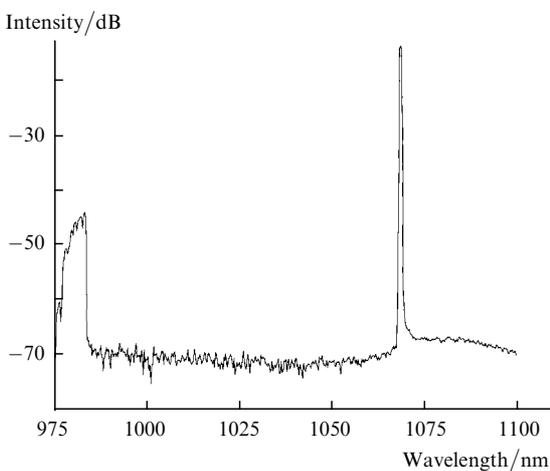


Figure 3. Emission spectrum of the laser (spectral resolution 1 nm).