Efficient silica-based Ho^{3+} fibre laser for 2µm spectral region pumped at 1.15µm

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For the first time an Ho^{3+} silica fibre laser has been realised using a Bragg grating as the input coupler and a fibre pump source at 1.15µm. The output power of 280mW at 2µm is to the authors' knowledge the highest value reported so far for Ho^{3+} silica fibre lasers.

Introduction: Fibre lasers for operation in the 2 µm spectral region can find a number of important applications in medicine, spectroscopy, eye-safe lidar, etc. Ho^{3+} ions have the $^5I_7 \rightarrow {}^5I_8$ transition which can be used to achieve laser emission at ~2µm [1]. Ho^{3+}-doped fibre lasers operate according to a three-level scheme, which means that it is necessary to have an efficient absorption of the pump power to obtain the population inversion in the active medium. The strongest absorption bands of Ho^{3+} ions are located in the visible range, therefore the first demonstrated holmium-doped silica-based fibre laser was pumped by argon-ion laser radiation at a wavelength of 457.9nm [2]. This laser had a relatively low slope efficiency of 1.7% and a maximum output power of 0.67mW at 85mW absorbed power.

It seems that the efficient practical utilisation of Ho-doped fibre lasers requires the use of semiconductor laser sources as the pump. Unfortunately currently available laser diode arrays have emission wavelengths longer than 750nm and cannot pump the visible absorption bands mentioned. One possible solution to this problem is to use Tm-Ho-doped fibres that can be pumped in a Tm-related intense absorption band located in the 800nm wavelength region with further energy transfer from the Tm ions to Ho ions. This scheme was demonstrated in [4], where a maximum output power of 71mW and slope efficiency of 17.5% were achieved. This result was obtained by pumping Tm:Ho-doped double-clad fibre with a Ti:sapphire laser at 786nm with a pump power of up to 1.2W. The weak point of this laser configuration is the strong competition between the Tm-to-Ho energy transfer and the processes of excited state absorption and the fluorescence of Tm^{3+} ions.

In addition, it should be mentioned that in all Ho-doped fibre lasers the laser cavities were formed by external mirrors, which resulted in additional coupling losses, thereby decreasing the laser efficiency.

In this Letter we present a new scheme for realising efficient Ho-doped fibre lasers, in which pumping is carried out in a strong absorption band of Ho ions centred at 1.15µm which corresponds to the $^5I_8 \rightarrow {}^5I_6$ transmission of a double-clad Yb-doped fibre laser. A fibre Bragg grating has been used to improve the laser efficiency and to stabilise the emission wavelength.

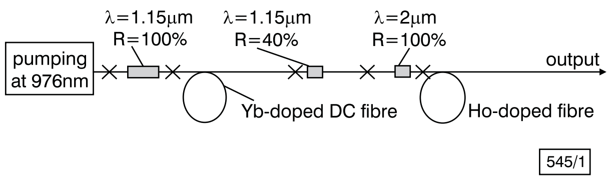

Fig. 1 *Schematic diagram of Ho-fibre laser pumped at 1.15µm*

Experiment: The laser scheme is shown in Fig. 1. An alumosilicate fibre co-doped with holmium using the solution doping technique was used as an active medium. The fibre had the following parameters: Ho^{3+} concentration of ~500ppm, numerical aperture of 0.1, cut-off wavelength of 1.5µm and core diameter of 12µm. The absorption level at 1.15µm in the fibre used was ~ 3dBm. The fibre was spliced with an SMF-28 fibre piece comprising a highly reflecting Bragg grating with a resonance wavelength of 2001nm and a bandwidth of ~1nm. The cleaved fibre end was used as an output coupler.

To pump Ho^{3+}-doped fibre in the core a high-power double-clad Yb^{3+}-doped fibre laser operating at 1.15µm was used. The Yb^{3+}-doped fibre laser was pumped by an OptoPower semiconductor diode array source at 976nm [5]. The maximum output power of the Yb^{3+}-doped fibre laser was ~ 3W with power from the semiconductor pump of 10W. To measure the output power of the Ho-doped fibre laser we rejected the unabsorbed radiation at 1.15µm by using an interference filter with –30dB transmission at this wavelength. To measure the output spectrum of the Ho laser a monochromator and PbS photodetector were used.

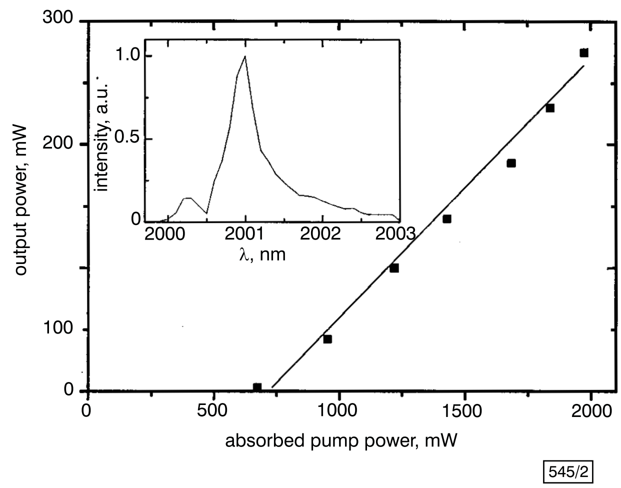

Fig. 2 *Dependence of output laser power against absorbed power at 1.15µm for laser length of 4.5m*

Inset: Output laser spectrum

Results and discussion: Fig. 2 illustrates the output laser power against absorbed power characteristic at 1.15µm for a laser length of 4.5m. It can be seen that a maximum output power of 280mW for 2W of absorbed pump power has been achieved. A slope efficiency as high as 20% has been calculated. The output laser spectrum measured to a resolution of 0.2nm is shown in the inset of Fig. 2. As seen, the spectral position of the laser wavelength is defined by the resonance wavelength of the Bragg grating. The laser linewidth was ~ 0.4nm.

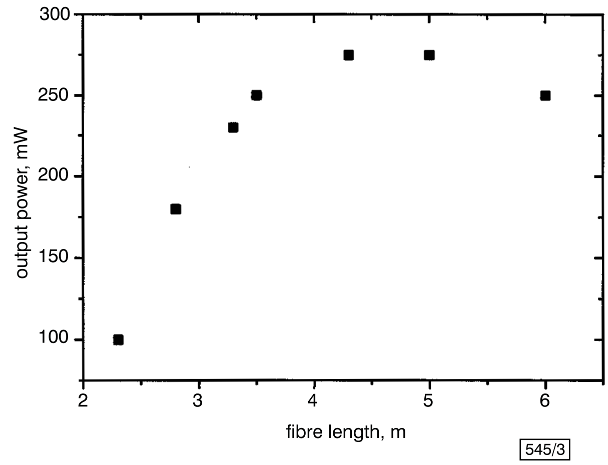

Fig. 3 *Dependence of output laser power on active fibre length*

Fig. 3 illustrates a dependence of the output laser power on the active fibre length. It is seen that the output power is maximised at 4–5m fibre length and tends to decrease with an increase of the laser length, indicating reabsorption of the laser radiation. Several methods for increasing the laser power could be suggested. First of all, a more powerful (20–30W) semiconductor laser could be used. This will increase the Yb-doped laser power up to 6–9W and a power at 2µm of ~ 700–1200mW could be achieved. Secondly, the pump wavelength used in our laser scheme (1.15µm) is rather far from the maximum of the gain curve for a Yb^{3+}-doped fibre laser, therefore it has a relatively low efficiency at this wavelength. To increase the output power at 1.15µm, a highly efficient Yb-doped fibre laser at 1.09µm with additional Raman conversion could be used. It can be estimated that use of this method would lead to an increase in the 1. 15µm laser efficiency up to 50%. Finally, the active fibre parameters should be optimised in order to minimise the material losses at 2µm, which was not carried out in our preliminary experiments. We expect that the improvements mentioned could lead to an increase in the output power of an Ho-doped fibre laser by at least one order of magnitude.

Conclusion: For the first time to the best of our knowledge an Ho^{3+}-doped silica-based fibre laser pumped by a 1.15µm Yb-doped fibre laser has been demonstrated. A photoinduced fibre Bragg grating was used as an input coupler. An output power as high as 280 mW at 2 μm has been achieved. It is noted that the output power could be further increased up to 2 W by appropriately optimising the parameters of an active fibre and pump source.

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