Ytterbium Lasers Based on P_2O_5- and Al_2O_3-doped Fibers

M.A.Melkoumov, I.A.Bufetov, M.M.Bubnov, K.S.Kravtsov, S.L.Semjonov, A.V.Shubin, E.M.Dianov
Fiber Optics Research Centre at the GPI RAS, tel. (095)132 82 56, fax (095)135 8139, e-mail: iabuf@fo.gpi.ru,
38, Vavilov str., Moscow, 119991, Russia

Abstract *Starting from measured cross-sections of Yb ions in P_2O_5-doped and Al_2O_3-doped silica glass ranges of operating wavelengths of Yb-doped double-clad fiber lasers have been calculated. A number of 60W lasers on GTWave fibers have been realized.*

Introduction

The power of Yb-doped cladding-pumped fiber lasers progressively increases and have already exceeded 1 kW [1]. The main part of investigations in this field is directed towards increase of laser power but not to comparison of lasing parameters of different fibers. In particular there is not enough information about cross-sections of Yb ions in alumosilicate and phosphosilicate fibers available.

We present the results of measurements of absorption and emission cross-sections of Yb ions in Al-doped and P-doped glasses and possible ranges of lasing wavelengths of Yb-doped double-clad fiber lasers with cores based on these types of glasses. Using the results obtained we have developed a number of lasers based on double and triple GTWave fibers with the output power up to 60W.

Yb^{3+} emission and absorption cross-sections

All measurements were carried out using single-mode fibers. The fiber preforms were prepared by MCVD technology. Concentration of Yb and P in phosphosilicate fibers was in the range of 1÷8 and 4÷10 wt. % correspondingly. In Al-doped fibers we have achived concentration of Yb in the range of 1÷3 wt.% and about 1÷2 wt. % for Al.

To measure absorption and emission cross-section we have used different techniques including small signal absorption, saturation of luminescence and McCumber analysis. Measured lifetimes of the Yb^{3+} ions upper level were τ=0.83 ms in alumosilicate fibers and τ=1.45 ms in phosphosilicate fibers. The peak emission and absorption cross-sections have been found to be σ_e(974.5nm)=1.5 (pm^2), σ_a(974.5nm)=1.4 (pm^2) in P_2O_5-doped silica fibers and σ_e(976nm)=3.0 (pm^2), σ_a(976nm)=2.7 (pm^2) in Al_2O_3-doped.

The spectral dependencies of emission and absorption cross-sections in alumosilicate and phosphosilicate fibers are presented in Fig.1. The main difference between these hosts is not only in variation of absolute cross-section value but also in spectral properties, especially for main peak at 975nm. It is seen in the Inset of Fig. 1, that main absorption peak in Al_2O_3-doped silica fiber is nearly two times broader than one in P_2O_5-doped glass. Due to this fact Al-doped fibers are more tolerant to the wavelength shift or to the bandwidth of pump radiation when pumping at 975nm is used. This property of Al-doped fibers is important when pump units without temperature stabilization are used.

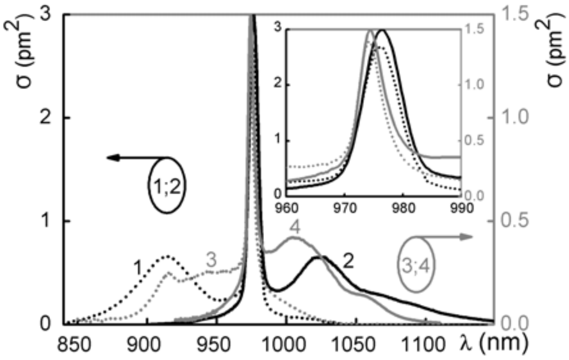

Fig. 1 Absorption and emission cross-sections in Al-doped glass – 1 and 2 correspondingly and in P-doped glass - 3 and 4 correspondingly. Inset – the main peak in more details

Laser design

On the basis of measured emission and absorption cross-sections for both types of glasses we have calculated possible lasing ranges of Yb-doped lasers based on simple double-clad and triple GTWave fibers.

GTWave fibers [2] can be effectively used in lasers [3] as well as in amplifiers [2]. GTWave fiber is an assembly of two or more fibers surrounded by shared low index polymer coating. One of the fibers (signal fiber) has Yb-doped core, whereas the rest are made of fused silica and serve for pump launching into the signal fiber. All the fibers in the assembly should be in tight optical contact along all their length to transfer pump radiation from the passive fibers to the signal fiber effectively.

The increase of number or the increase of size of passive fibers allows one to raise launched pump power. At the same time pump radiation is not launched into the signal fiber through its end face; thus, signal fiber can be spliced to another fiber at both ends. Additional advantage is that there is no need to induce asymmetry in the shape of signal fiber to provide effective pump absorption.

The scheme of the laser based on triple GTWave fiber is presented in Fig.2 A. Both ends of signal fiber are spliced to extra pieces of fiber with fiber Bragg gratings (FBG) which form laser cavity.

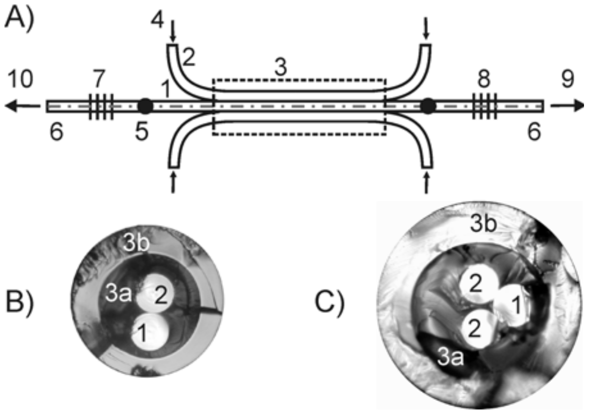

Fig. 2 A) Yb laser based on triple GTWave fiber: 1 – active fiber, 2 – passive fiber, 3 – shared polymer coating, 4 – pump radiation, 5 – splicing point, 6 – fiber with FBG, 7 – HR FBG, 8 – OC FBG, 9 – lasing radiation, 10 –radiation "leaking" behind HR FBG. B), C) – picture of double and triple GTWave fibers 1 – active fiber, 2 – passive fiber, 3a - polymer coating with low refractive index, 3b – protective polymer coating

The photographs of the cross-section of double and triple GTWave fiber is shown in Fig. 2 B) and C). The diameters of the signal fiber silica cladding and passive fiber were 125 μm. The diameter of the signal fiber core was in the range of 4.4÷11.5 μm. Pump radiation from fiber coupled laser diodes was launched into all four pump ports (4 in Fig.2) of the fiber.

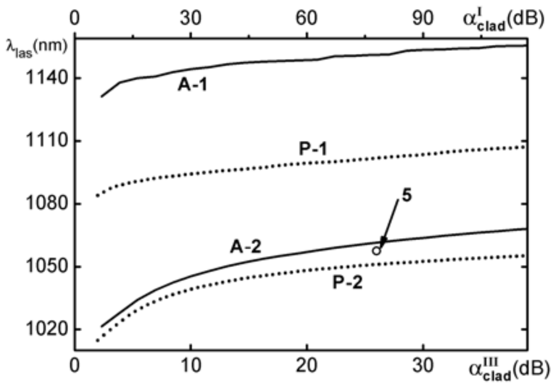

Fig. 3 Operating ranges of Yb-doped lasers based on P -doped (P1 - upper limit, P2 - lower limit) and Al-doped (A1 - upper limit, A2 - lower limit) silica fibers vs. total cladding absorption for triple GTWave fiber (α^{III}_{clad}) and single DC fiber (α^{I}_{clad}). 5 – experiment

Lasing ranges

Using measured cross-sections we have calculated possible lasing ranges of Yb-doped DC fiber lasers based on Al-doped and P-doped silica fibers in dependence on total (at full length) inner cladding pump absorption - α_{clad}. We carried out these calculations for lasers based on single DC fiber with inner cladding area to core area ratio K=300 as well as for lasers based on triple GTWave fiber with K=900. It is assumed that pump radiation wavelength coincides with absorption peak at 975 nm. We restrict our model to a case when total selective cavity loss (radiation wavelength coincides with resonance wavelength of FBGs) is equal to γ_r=10 dB and non-selective loss is γ_{nr}=49 dB. Corresponding dependencies are presented in Fig. 3. It is seen that lasing range of lasers based on Al-doped fibers extends up to 1155 nm, whereas for lasers based on P-doped fibers operating range is bounded by 1110 nm. In the short wavelengths region P-doped fibers have a small advantage in comparison with Al-doped. Thus, to realize Yb-doped laser based on triple GTWave fiber with lasing wavelength 1058 nm and with total inner cladding absorption α_{clad}=26 dB we could use only P-doped fiber (see 5 in Fig. 3).

Experimental results

In addition to laser at 1058 nm cited before we have realized a number of powerful cw single mode lasers based on P-doped and Al-doped double and triple GTWave fibers with output power up to 60 W.

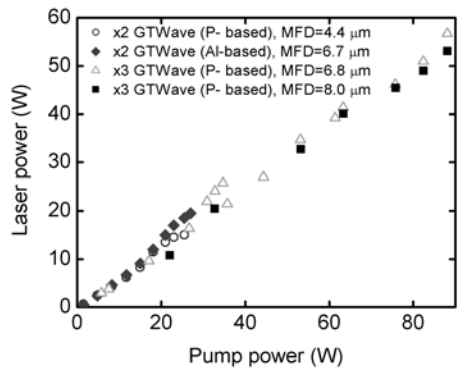

Fig. 4 Optical output power vs. launched pump power for different lasers

The dependencies of laser power on pump power for some of these lasers with different MFDs are shown in Fig.4. The lengths of the laser fibers ranged from 20 to 50 m. No evidence of roll-off in output power at the highest launched pump power for any of the lasers was observed. The only non-linear effect we observed was spectral broadening of laser radiation.

Conclusion

We have measured spectral dependencies of Yb ions emission and absorption cross sections in Al-doped and P-doped fibers. Starting from measured values of cross sections lasing ranges of Yb-doped DC lasers based on P_2O_5 and Al_2O_3 silica fibers have been calculated. A number of cw single mode GTWave fiber lasers with different lengths and mode field diameters ranging from 4.4 to 11.5 μm and with output power up to 60 W, and up to 70% efficiency have been realized.

References

1 Y. Jeong et al, *ASSP 2004* (Santa Fe, New Mexico, 2004)

2 A. B. Grudinin et. al. *ECOC'2002* (Copenhagen, Denmark, 2002, PD1.6)

3 S Norman et. al. *Photonics West 2004* (San Jose, Cal.)