Er^{3+} doped glasses for laser and amplifier applications

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Introduction

The Er^{3+} emission at 1.5 μm is used in lasers and amplifiers operating in the second optical window of telecommunication systems. Recently, broad band amplifiers for wavelength-division-multiplexing technology are of great interest in order to enhance the capacity of glass fibers. Glasses with large emission cross section and large linwidth are required [1]. The Er^{3+} emission transitions in the visible spectral region are used in upconversion lasers [2].

Fluoride and phosphate based glasses are known to be attractive host materials for rare earth doped devices [3,4]. Recently, heavy metal oxide (HMO) glasses have received considerable attention because of their high refractive indices. In this paper, the properties of both glass systems have been analysed with regard to laser and amplifier applications. The search for Er^{3+} broad band amplifier at 1.5 μm is of special interest.

Experimentals

The glass compositions studied are given in Table 1. The glass samples were prepared by conventional melting technique. QX® is a commercial phosphate laser glass from Kigre Inc. The refractive indices were measured with a Pulfrich refractrometer. The absorption spectra in the range 200-3200 nm and the IR transmission spectra in the range 400-4000 cm^{-1} were recorded using commercial spectrometers. The Er^{3+} laser experiments and emission measurements at 1.5 μm were carried out by pumping with laser diodes at 940 and 980 nm, respectively. Laser performance tunability of Er^{3+},Yb^{3+} codoped samples was measured in a three mirror (HR) L-folded cavity with a brewster-cut fused silica prism inserted. Uncoated, 2 mm thick samples were placed directly behind the input coupling mirror. The laser was tuned by tilting the end mirror of the cavity. Output signal was aligned into a monochromator with a germanium diode attached, readout-voltage recorded.

Results and Discussion

Refractive index and transmission range of the host glasses are important properties in the design of laser and amplifier devices. The UV transmission edge shifts to higher wavelength in the order FP,P<ZBLAN<BiB<PBG (Fig. 1) due to increasing polarizability of the glass matrix. In the same order increases the refractive index (Tab. 1). In the HMO glasses, the highly polarizable Pb^{2+} and Bi^{3+} ions determine the UV cut-off. The broad band in the IR region at 2600-3800 cm^{-1} is caused by stretching vibrations of hydroxyl (OH) groups (Fig. 1). All the oxide glasses have a comparatively high OH content which decreases the IR transmission (Fig. 1). The IR transmission is further restricted by overtones of glass network vibrations. ZBLAN and PBG glasses have high IR transmission due to low energy of the Zr-F and Ga-O vibration. In the case of the FP03 glass, the overtone of the P-O vibration at about 2000 cm^{-1} is clearly observed beside the edge due to Al-F overtone. The high energy of B-O and P-O vibrations results in low transmission of BiB and P glasses.

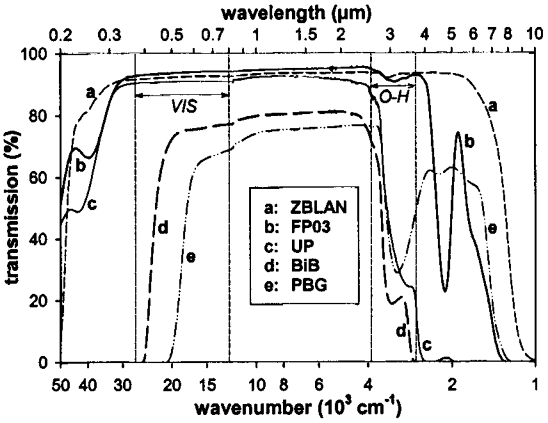

Figure 1: Transmission spectra of different glass samples having 2 mm thickness.

The lifetime and intensity of fluorescence transitions of rare earth ions is lowered by nonradiative multiphonon decay probability, which increases with growing maximum phonon energy of the glass network vibrations. As a result, the multiphonon decay rate of different host glasses increases in the order ZBLAN<PBG<FP<P,BiB.

Beside multiphonon decay, fluorescence quenching by OH groups shortens the observed lifetime with respect to the radiative lifetime. The ratio between both lifetimes reflects the quantum efficiency of the fluorescence transition. In ZBLAN, FP and PBG glass samples, the quantum efficiency of the Er^{3+} fluorescence at 1.5 μm is nearly 100% or greater (Tab. 1). Thus, non-radiative relaxations are negligible. In the P glass samples with higher OH content, fluorescence quenching by OH groups causes efficiencies <80%. In the UP sample with low Er^{3+} concentration ($<1\times10^{20}$ cm^{-3}) and with low OH content ($\alpha_{OH}<1$ cm^{-1}), OH quenching is negligible. The very low quantum efficiencies of the BiB glass samples are attributed to fast multiphonon decay due to high B-O vibration energy.

The F, FP and BiB glasses exhibit broad Er^{3+} emission band at 1.5 μm, whereas phosphate and PBG glasses show narrow bands. The emission cross section increases the higher the refractive index but decreases the higher the linewidth. Otherwise, the lifetime lowers with increasing refractive index. Thus, the HMO glasses have high emission cross sections but low lifetimes due to their high refractive indices. In the case of the BiB glass, the negative effect of the high linewidth on the emission cross section is compensated by the high refractive index. The UP glass has a high cross section, too, as a result of the very small linewidth. The FP20 glass demonstrates a quite high cross section together with a very high lifetime. In contrast, the ZBLAN glass has a very low emission cross section (Tab. 1).

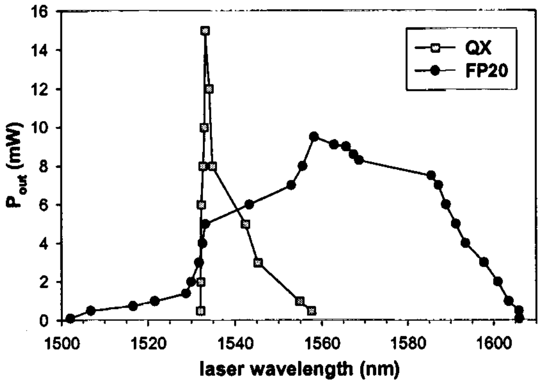

Figure 2: Laser tuning spectra of FP20 glass (5×10^{19} Er^{3+} cm^{-3}, 8×10^{20} Yb^{3+} cm^{-3}) and QX glass (1.4×10^{19} Er^{3+} cm^{-3}, 16×10^{20} Yb^{3+} cm^{-3}).

Laser experiments were carried out with FP20, UP and QX glass samples. Laser oscillation was observed for all three glass types. The laser tuning range was measured for the FP20 and the QX glass (Fig. 2). The FP20 glass demonstrates a very broad band ranging from 1505 to 1600 nm. The laser output is flattened between 1535 and 1585 nm. By contrast, the laser spectrum of the QX glass consists of a sharp peak ranging only from 1533 to 1555 nm. The lower output and higher threshold of the FP20 glass corresponds with the lower emission cross section at 1560 nm in the FP20 glass compared with the high peak emission cross section at 1533 nm in the QX glass. The UP samples show lower output and higher threshold than the QX glass due to low optical quality and occurrence of OH quenching.

In conclusion, the ZBLAN glass is appropriate for lasers in the VIS and mid-IR region because of wide transmission range and low phonon energy. However, it has low emission cross section and large tendency to crystallize. FP glasses are attractive photonic materials due to suitable combination of properties: wide transmission range, low nonlinear refractive index, low OH content, properties adjustable by the phosphate content, large linewidths. The broad and flattened laser tuning range connected with high laser output confirms that FP20 glass is very attractive for broad band amplifiers in telecommunication systems. Phosphate glasses show narrow linewidths, high emission cross sections and low nonlinear refractive indices, making them attractive for high power lasers. Special melting techniques for decreasing the OH content are required to obtain high quantum efficiency of Er^{3+} emission at 1.5 µm. The advantages of PBG glasses are their high emission cross sections combined with low phonon energy. But the high crystallisation tendency, low rare earth solubility and low transmission in the UV and VIS region are crucial points in the laser design. BiB glasses are promising candidates for broad band amplifiers due to high emission cross section and broad emission band. However, the shortening of the Er^{3+} lifetime at 1.5 µm may restrict their application.

References

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Table 1: Batch compositions and properties of the glasses studied: refractive indices, n_e, effective linewidth, $\Delta\lambda_{eff}$, stimulated emission cross section at the peak wavelength, $\sigma_{e,p}$, radiative and observed lifetimes, τ_{rad} and τ_{obs}, quantum efficiency, η, of Er^{3+} at 1.5 µm for samples with Er^{3+} concentration, N_{Er}, and OH content given as absorption coefficient, α_{OH}, of the OH band at about 3000 cm^{-1}.

type	glass	composition (mol%)	n_e	$\Delta\lambda_{eff}$ (nm)	$\sigma_{e,p}$ (10^{-21} cm^2)	τ_{rad} (ms)	N_{Er} (10^{19} cm^{-3})	α_{OH} (cm^{-1})	τ_{obs} (ms)	η (%)
F	ZBLAN	$53ZrF_4–20BaF_2–4LaF_3–3AlF_3–20NaF$	1.50	71	6.1	7.8	10	<0.01	10.0	128
FP	FP03	$3Sr(PO_3)_2–97[AlF_3,MF_2]$ {M=Mg,Ca,Sr}	1.42							
	FP20	$20Sr(PO_3)_2–80[AlF_3,MF_2]$ {M=Mg,Ca,Sr}	1.50	62	7.5	6.8	3	<0.01	9.8	144
P	KBaMP	$35KPO_3–40Ba(PO_3)_2–20Al(PO_3)_3–5BaF_2$	1.56	47	7.9	8.5	2	4.3	6.0	70
	QX®	$14(Li,K)_2O–14Al_2O_3–4(Er,Yb)_2O_3–67P_2O_5$	1.57	47	6.9		1.4	0.9	7.9	
	UP	$50M(PO_3)_2–14Al(PO_3)_3–36P_2O_5$	1.54	44	9.3	7.8	5	2.6	5.9	76
		{M=Mg,Ca,Ba,Zn}					7	0.8	8.7	111
HMO	BiB	$50Bi_2O_3–50B_2O_3$	2.11	72	9.3	2.6	3	3.8	0.80	31
	PBG	$57PbO–25Bi_2O_3–18Ga_2O_3$	2.40	60	9.7	2.1	3	3.2	2.3	111