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Near-infrared emission from Pr-doped borophosphate glass for broadband telecommunication

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ABSTRACT

Broadband near-infrared emission from Pr-doped borophosphate glass was investigated. The emission band had three peaks centered at ~1040, 1163, and 1470 nm with full widths at half maximum of 108, 147, and 205 nm, respectively. These figures cover the entire spectrum of fiber-optic communication bands. The emission lifetimes at 1040, 1163, and 1470 nm were 68, 321, and 68 μs respectively. The product $\sigma\tau$ of stimulated emission cross-section (σ) and lifetime (τ) was 3.44×10^{-23} cm^2 s. These results indicate that the Pr-doped glass can be used as an amplification medium for tunable lasers and broadband optical amplifiers for wavelength division multiplexing transmission system applications.

1. Introduction

The development of wavelength division multiplexing (WDM) networks is increasingly becoming important in enhancing information traffic in telecommunication networks. Among the equipment for WDM optical communication systems, broadband amplifiers and tunable lasers are pivotal devices because of the number of channels that depend on the gain bandwidth of amplifiers and laser sources [1–6]. Numerous researchers have exerted considerable effort toward achieving broadband amplification; in such initiatives, scholars use rare-earth and transition metal-doped amplifiers, such as Er-doped fiber amplifiers [7–10], and Tm-doped fiber amplifiers [3,11,12], as well as Ti^{3+}:Al_2O_3 [13], Cr^{4+}:YAG [14], and Ni^{2+}-doped glass ceramics, for broadband tunable lasers [15].

Single rare-earth ions expand optical amplification bandwidths, however, this expansion is limited because the bandwidth of 4f–4f optical transition is narrow by nature, and these various amplifiers have a gain bandwidth of less than 100 nm [8,16–20]. Given that rare-earth ions easily exist in multivalent states, the valence state of rare-earth ions used in doping materials should be controlled [21]. Realizing broadband amplification with high gain efficiency via onefold wavelength pumping would mean revolutionary progress in WDM technology.

Pr ions exhibit short broadband emissions at approximately 1330 nm in glasses and glass ceramics with full widths at half maximum (FWHM) of less than 100 nm [22–24]. However, to the best of our knowledge, no comprehensive investigation on broadband emission from Pr-doped borophosphate glasses has been conducted. In this letter, we report the characteristics of broadband near-infrared emission from Pr-doped P_2O_5–B_2O_3–Al_2O_3–Y_2O_3 (PBAY) glass. We realized efficient broadband emission in the near-infrared region (880–1700 nm) at room temperature.

2. Experimental details

A PBAY glass system ($12Y_2O_3$–$8Al_2O_3$–$15B_2O_3$–$65P_2O_5$) was used as the host material of Pr ions. Analytical reagents of $NH_4H_2PO_4$, H_3BO_3, $Al(OH)_3$, and Y_2O_3 were used as raw materials. Glass samples were prepared by a conventional casting method. We tried 0.25, 0.5, 1.0, and 2.0 mol% Pr_2O_3 as dopant concentration and found that the optimum concentration of Pr_2O_3 used to dope the PBAY glass was 0.25 mol%. Raw materials of reagent grade were thoroughly mixed and melted in an alumina crucible in air atmosphere at 1400 °C for 2 h in an electric furnace. The melts were poured onto an annealed steel plate and then slowly cooled to room temperature. The sample was polished to optical quality before optical measurements were performed. The thickness of the samples was approximately 1 mm. Absorption spectra were recorded within a wavelength range of 400–2400 nm on a JASCO V-570 UV/VIS/IR spectrophotometer. The photoluminescence spectra were 850–1700 nm, as determined using a

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TRIAX550 spectrophotometer with a PbS detector and a 445 nm laser diode (LD) as the excitation source. Emission decay curves were obtained with an FLSP920 (Edinburgh Instruments Ltd., UK). The refractive indices of the glass were measured by a prism-coupling method. All measurements were carried out at room temperature.

3. Results and discussion

3.1. Optical absorption spectra

The optical absorption spectra of the glass samples in the 400–2400 nm region are shown in Fig. 1. The difference in spectrum of absorptions between the Pr-doped and undoped glasses is also shown in the figure. Two visible absorption bands at approximately 445 and 580 nm, as well as two broadband near-infrared absorption bands centered at 1500 and 1900 nm in the difference spectrum can be attributed to the $^3H_4 \rightarrow ^3P_2$ (445 nm), $^3H_4 \rightarrow ^1D_2$ (586 nm), $^3H_4 \rightarrow ^3F_3$ (1498 nm), and $^3H_4 \rightarrow ^3F_2$ (1905 nm) transitions of Pr^{3+} in the Pr-doped PBAY glass. All the transitions in the absorption spectra of Pr^{3+} started from the ground state $^3H_4$. These bands correspond to the $4f^2$-intra-configurational electric dipole transitions from the ground state $^3H_4$ to excited states $^3P_2$, $^1D_2$, and $^3F_{2,\ 3}$. The wavelengths of the absorption peaks matched with the results in previous reports on Pr-doped glasses [25–27]. The band widths are due to the combination of inhomogeneous broadening, site-to-site variations in crystal field strength and unresolved Stark splitting [28]. The intense absorption of the Pr-doped PBAY at 445 nm indicates that this glass can be more efficiently pumped using an LD at 445 nm.

The Judd–Ofelt (J–O) theory is commonly used to analyze the spectra of the rare earth doped matrix and the compositional dependence of the spectroscopic parameters. The calculated J–O intensity parameters of Pr-doped PBAY glass are compared with those of other hosts in Table 1. It is widely accepted that Ω_4/Ω_6 determines the spectroscopic quality of the host materials. From Table 1, the present glass has a relatively large Ω_4/Ω_6 value by comparison with other hosts. It indicates that the Pr-doped PBAY glass is a good matrix for broadband near infrared emission.

3.2. Emission spectra and energy level scheme

The emission spectra of the Pr-doped PBAY glass are illustrated in Fig. 2. Under an LD excitation of 445 nm, we observed three broad emission bands centered approximately at 1040, 1163, and 1470 nm with FWHM values of 108, 147, and 205 nm, respectively, covering nearly the entire range (830–1700 nm) of practical fiber-optic communication bands in the Pr-doped PBAY glass. Considering the application as optical gain media for telecommunication, an emission wavelength to cover from S-band ($\sim$1300 nm) to L-band ($\sim$1650 nm) is desirable [32]. In the experiment, we placed an 808 nm filter between the glass sample and detector. The fluorescence spectrum was not a single band; hence, the emission spectrum was fitted tentatively by multi-peak Gauss fitting [30]. Only the three-peak Gauss fitting was

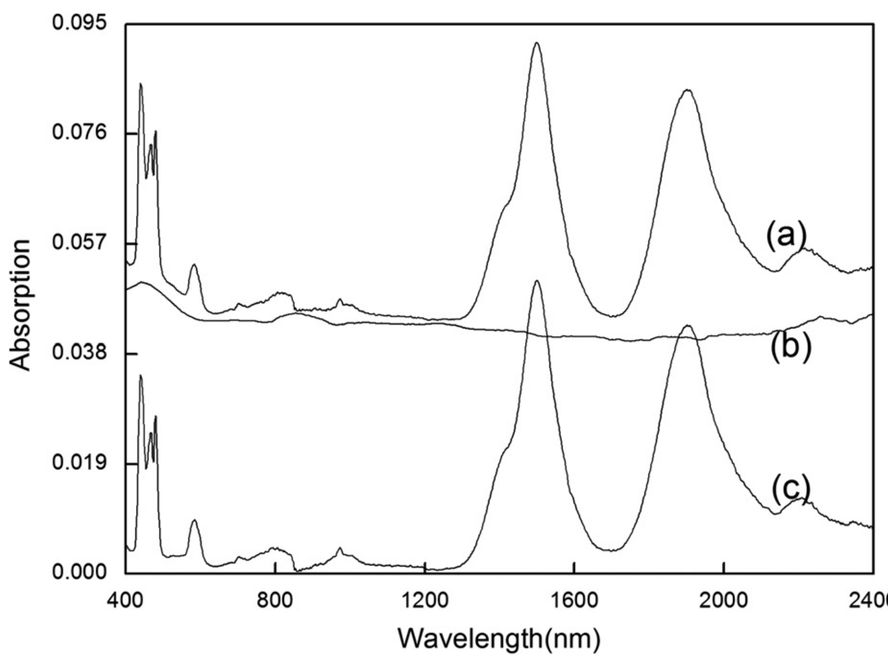

Fig. 1. Absorption spectra of the (a) Pr-doped glass, (b) undoped glass, and (c) their difference.

Table 1
Comparison of J–O parameters of Pr^{3+} ions in various glass hosts.

Glass	Ω_2 (10^{-20} cm^2)	Ω_4 (10^{-20} cm^2)	Ω_6 (10^{-20} cm^2)	Ω_4/Ω_6	Reference
Borophosphate	3.12	7.21	5.81	1.24	Present work
Fluorotellurite	3.57	6.60	5.18	1.27	[22]
Borate	0.77	3.84	3.58	1.07	[29]
Phosphate	4.26	4.33	6.27	0.69	[30]
Fluorozirconate	2.16	1.41	1.13	1.25	[31]