Ultra Wide band Light Emission from Bismuth and Erbium Doped Silica

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INTRODUCTION

In these days, a wideband optical fiber communication is capable of speed-up and large volume traffic in communicational network expecting the dramatic expansion of the internet system. In order to transfer optical signal efficiently, optical fiber amplifiers at 1.3-micron O-band are necessary, which can directly amplify weakened light, compatible to a low-loss and low-dispersion silica optical fiber.

It is known that silica-based optical fiber has a zero-dispersion at 1.3μm. A fluorescence peak of bismuth-doped silica glass (BiSG) is at 1.25μm and the full width at half maximum (FWHM) of the fluorescence spectra of BiSG is larger than 300nm, 53.3THz in the frequency region when it is pumped at 800nm. Here, the bandwidth in frequency region is converted by using a relation, \( \Delta \nu = c \times \Delta \lambda / (\lambda \sigma) \), where \( \Delta \lambda \) is the bandwidth in frequency region, \( \Delta \lambda \) is the gain bandwidth in wavelength, \( \lambda \) is the peak wavelength.

On the other hand, praseodymium-doped fluoride fiber amplifier (PDFFA) has a fluorescence peak at 1.32μm, and the FWHM of the fluorescence is 100nm (17.2THz). Erbium-doped fiber amplifier (EDFA) has a peak value of fluorescence spectrum at 1.53μm, and the FWHM of the fluorescence is 40nm (5.12THz). It is obvious that the bandwidth of BiSG is wider than PDFFA or EDFA.

In this study, we described that fabricated glass media have ultra wideband fluorescence spectrum and high optical quality by doping, Er2O3 to BiSG.

EXPERIMENTS

Bi-SG was fabricated as follows: Bismuth oxide (Bi2O3; purity, 99.9%), aluminum oxide (Al2O3; 99.99%), and silica powder (SiO2; 99.8%) were mixed and kneaded in a mortar. The mixture compound was put in a crucible made of aluminum oxide and then it was melted at 1750 °C in air. The sample was cut and polished at 1750 °C in air. 4) The sample was Bi2O3: 1.0 mol%, Al2O3: 7.0 mol%, SiO2: 92.9 mol%, and that of \( \alpha-\)BiSG was Bi2O3: 1.0 mol%, Al2O3: 7.0 mol%, SiO2: 92.0 mol%. The fabricating process of the Bi-ErSG sample was same as that of BiSG.

RESULTS & DISCUSSIONS

The fluorescence spectra of Bi-ErSG are shown in Fig. 1. Bi-ErSG shows broadband emission from 1.1μm to 1.6μm, so they cover both wavelength bands of 1.3μm and 1.5μm, which are well known as zero-dispersion and low-loss wavelength, respectively. Spectroscopic properties of wide band luminescent materials are listed in Table I which include the peak value of fluorescence, the FWHM of fluorescence, lifetime and cross-section of stimulated emission of Erbium-doped silica glass (ErSG), one of the BiSGs, Nd-glass, Cr-glass, Ti-sapphire, and Ti-sapphire. The composition of ErSG sample was Er2O3: 0.1 mol%, Al2O3: 7.0 mol%, SiO2: 92.9 mol%, and that of \( \alpha-\)BiSG was Bi2O3: 1.0 mol%, Al2O3: 7.0 mol%, SiO2: 92.0 mol%. The fabricating process of both samples was the same as that of Bi-ErSG. Since the fluorescence spectra of Bi-ErSG are not able to approximate to the Gaussian curve, FWHM of Bi-ErSG are shown as effective bandwidth calculated by integrating the fluorescence spectrum. The cross-section of stimulated emission is evaluated by the following form,

\[
\sigma_e = \frac{\lambda^2}{4\pi^2n^2(\Delta \nu)\tau_n}
\]

where \( \tau_n \) is the lifetime, \( n \) is the refraction index of the media, that of the silica glass is 1.46, \( \lambda \) is the peak wavelength. According to Table I, it is clear to say that the FWHM of Bi-ErSG became wider than that of ErSG or \( \alpha-\)BiSG by combining the both fluorescence characteristics. Since the calculated stimulated-emission cross sections (\( \sigma_e \)) of Bi-ErSG, \( \alpha-\)BiSG, and ErSG are almost same value, it is considered that the value of Bi-ErSG, 1.6×10^{-20} cm^2, is reasonable.

Table I. Spectroscopic properties of Bi-ErSG (pumped at 800nm) & other amplifiers

<table>
<thead>
<tr>
<th></th>
<th>Bi-ErSG</th>
<th>ErSG</th>
<th>( \alpha-)BiSG</th>
<th>Nd-glass</th>
<th>Cr-glass</th>
<th>Ti-sapphire</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \lambda_{\text{peak}} ) [μm]</td>
<td>1.29</td>
<td>1.53</td>
<td>1.26</td>
<td>1.06</td>
<td>0.85</td>
<td>0.79</td>
</tr>
<tr>
<td>( \Delta \nu ) [THz]</td>
<td>77.5</td>
<td>66.6</td>
<td>64.6</td>
<td>7.48</td>
<td>97.6</td>
<td>86.5</td>
</tr>
<tr>
<td>( \Delta \lambda ) [nm]</td>
<td>430</td>
<td>52</td>
<td>342</td>
<td>28</td>
<td>240</td>
<td>180</td>
</tr>
<tr>
<td>( \tau_n ) [ms]</td>
<td>0.22</td>
<td>3.0</td>
<td>0.19</td>
<td>0.34</td>
<td>0.018</td>
<td>0.0032</td>
</tr>
<tr>
<td>( \sigma_e [10^{-20} \text{cm}^2] )</td>
<td>1.6</td>
<td>2.1</td>
<td>2.3</td>
<td>2.9</td>
<td>7.2</td>
<td>34</td>
</tr>
</tbody>
</table>

\( \lambda_{\text{peak}} \): peak wavelength, \( \Delta \nu \): FWHM of fluorescence spectra, \( \Delta \lambda \): FWHM of fluorescence spectra, \( \tau_n \): lifetime, \( \sigma_e [10^{-20} \text{cm}^2] \): the cross-section of stimulated emission.
On the other hand, the lifetime of ErSG is one order of magnitude larger than that of α-BiSG, and therefore, it is considered that Bi-ErSG with wideband may work during the lifetime of α-BiSG rather than that of ErSG.

In order to find further wideband fluorescence of this Bi-ErSG, we checked the absorption spectrum again. Then, we found that there is another absorption band at nearly 970nm besides at 500, 700, 800nm. When the Bi-ErSG are pumped at 930nm and at 940nm the FWHM of the fluorescence spectra were nearly 540nm (92.8THz) and 470nm(81.9THz), respectively. When pumped at 940nm, there was interesting result that the fluorescence spectra had flat area from 1.25µm to 1.35µm. In other words, emission spectrum has a wide plateau over 100nm that is extremely effective for optical fiber amplifiers. This material, Bi-ErSG used as an optical fiber amplifier gives us a broaden bandwidth playing a big part for large volume communication transmittance.

Since the FWHM bandwidth of Bi-ErSG is extremely broad, it can be also applied to ultrashort pulse laser amplifier. There are some favorable characteristics of silica glass for laser amplifier; LD-pumping scheme is available, the thermal shock strength is high; the transmittance is high from vacuum ultraviolet region to near infrared region; it can be scalable to fabricate, finally the working wavelength is very near dispersion free range. The FWHM of Bi-ErSG is as comparably broad as that of Ti-sapphire shown in Table I. Since one of the absorption bands of Bi-ErSG is nearly 800nm that is popular wavelength of commercial diode lasers, it is easy to establish an amplification system. Bi-ErSG, however, has not oscillated as a laser yet, because there is some distortion in the glass medium, the thickness is less than 1cm and the cross-section of stimulated emission is not so large,0.9~1.6×10^(-20) cm^2. To solve these problems, we have to improve the optical quality of BiSG, for example by annealing BiSG with proper thermal process and/or by the special three-dimensional homogenizing treatment. BiSG will become a glass medium capable of laser oscillation.

CONCLUSION

We have fabricated glass medium which have ultra wideband fluorescence in the infrared region by doping Er2O3 to bismuth-doped silica glass. Fluorescence of this medium shows broadband emission from 1.1µm to 1.6µm, which cover the communicational bandwidth wholly, and there were emission planarization over 100nm from 1.25µm to 1.35µm. From the characteristics of the glass media listed above, the possibility for large volume communication traffic and the application for ultrashort pulse laser are expected.