High Power Pr^{3+}: ZBLAN and ALF_3 Fiber Laser

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Abstract

We present work on Pr^{3+} doped fluoride glass ZBLAN fibers pumped by GaN diode laser emitting at 444 nm. The continuous-wave laser oscillation at red wavelength (636 nm) is experimentally demonstrated by using 500 mW GaN Laser Diode. When pumped with 907 mW at a wavelength of 444 nm, the Pr^{3+}: ZBLAN laser emits 170 mW of output power at a wavelength of 636 nm. Threshold pump power and slope efficiency with respect to the absorbed pump power are determined to be 60 mW and 55%, respectively. In addition, GaN laser diode pumped Pr^{3+} doped AlF_3 fluoride glass fiber laser is experimentally demonstrated at red and green wavelength.

1. Introduction

Fiber lasers offer the advantages of spatial and temporal highly coherent behaviors and outstanding beam controllability at high average power. Efficiency factors are used to characterize the laser processes. Often, efficiency factors depend on energy transfer processes, quality of active medium, pump efficiency, absorption efficiency and on rather subtle parameters such as concentration quenching.

In this study we experimentally demonstrate the lasing operation of praseodymium doped fiber laser at red wavelength (636 nm) by combining two 500 mW orthogonally placed GaN laser diodes and polarizing beam splitter (PBS). We have focused on increasing the output power and slope efficiency. Also, the laser oscillation at red and green wavelength was experimentally demonstrated by using large core diameter size of Pr^{3+} doped AlF_3 fiber. The material composition of this series of fiber is different than that of ZBLAN series fiber. This AlF_3 fiber comes in a fixed ferrule, which is robust and easy to handle. This saves the hassle of handling the otherwise highly fragile fiber. The ferrule also eliminates the fiber cleaving problem. The emission spectrum of Pr^{3+} doped ZBLAN and AlF_3 is shown in Fig.1.

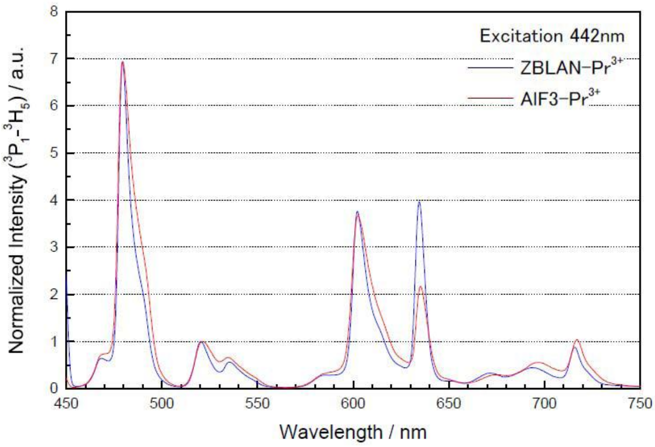

Fig.1. Emission spectrum of Pr^{3+} doped ZBLAN and AlF_3

The emission intensity for AlF_3 at 635 nm red wavelength is suppressed, making AlF_3 series fiber better for green oscillation while ZBLAN is better for red oscillation. It was experimentally confirmed that Pr:AlF_3 is attractive material for generating red and green laser oscillation.

2. Experimental Design

2.1 Pr^{3+}:ZBLAN Red Fiber Laser

Fig. 2 shows the experimental setup of Pr^{3+} doped ZBLAN fiber laser with polarizing beam splitter (PBS) as the main component. PBS combines the orthogonally polarized beams emitted from GaN laser diodes into a beam with single polarization state. A combination of two GaN Laser Diode from Nichia Corp. was used for end-pumping of ZBLAN fiber. End pumping is a useful arrangement here as it provides good transverse beam quality, higher efficiency, and output stability. The better beam quality is due to the strong overlap of the pump and resonator beam, while the high efficiency is dependent upon a good spatial match between the pump beam and the laser cavity mode, originally because the pump energy is not dissipated over pumping regions that are not used.

The fiber used in the experiment has a core diameter of 4.35 μm and a numerical aperture (N.A.) of 0.22. The Pr^{3+} doping concentration was 3000 ppm. The length of ZBLAN fiber was 100 mm.

In our study we have experimented by using combination of two 500 mW GaN laser diodes. The π-polarized GaN laser diode operates at 441 nm and σ-polarized GaN laser diode operates at 444 nm. Firstly the radiation from GaN laser diode was collimated by an aspheric lens with focal length of 3.1 mm. This collimated beam was then shaped with the help of cylindrical lens system with focal lengths of 50 mm and -20 mm respectively. The cylindrical lens pair has been specifically placed before the PBS on both sides to obtain the circular beam. After combining the pump lasers by a PBS, the π-polarized pump beam extended laterally whereas the σ-polarized beam extended longitudinally. Thus, those beams cannot be shaped into circular beam by using cylindrical lens pair individually before the PBS.

The distance from LD1 to collimating aspheric lens (f_1= 3.1 mm) was 3.1 mm, the distance from collimating aspheric lens to first cylindrical lens (f_2= 50 mm) was 80 mm, the distance between the cylindrical lens pair was 20 mm, the distance from second cylindrical lens (f_3= -20 mm) to focusing aspheric lens (f_4= 7.5 mm) was 250 mm.

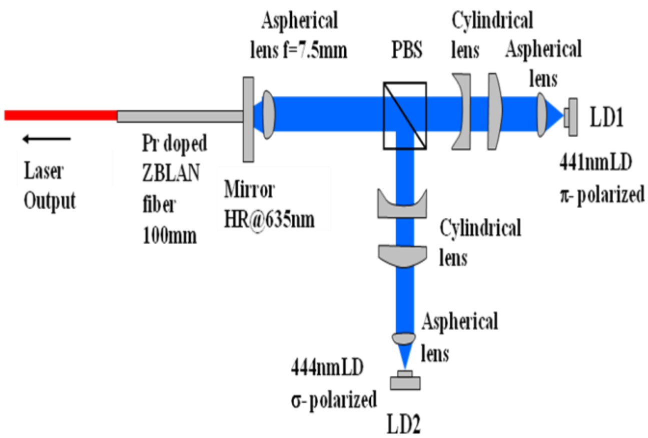

Fig.2. Experimental setup of Pr^{3+} doped ZBLAN fiber laser pumped by GaN laser diode

The circularly shaped beam was focused into the fiber core with the help of another aspheric lens with focal length of 7.5 mm. A mirror of thickness 5 mm with a high reflection (R> 99.5%) at the red wavelength of 635 nm and a high transmission at the pump wavelength was placed after the focusing aspheric lens and at the entrance facet of the ZBLAN fiber. The edge of the HT mirror and other end of the fiber acts as the cavity. The HT mirror placed at the input side acts as the total reflector for red light and reflects about 99% of the red light back into the fiber.

The laser output was obtained from the other end and measured by using a power meter. The beam profile was measured by using a CCD camera.

2.2 Pr^{3+}:ALF_3 Green Fiber Laser

Fiber laser oscillation experiment was carried out from the Pr^{3+} doped AlF_3 fiber at green wavelength pumped by a 1 W GaN laser diode. Fig.3 shows the experimental setup of Pr^{3+} doped AlF_3 fiber laser. 1 W GaN laser diode from Nichia Corp. was used for pumping the Pr:AlF_3 fiber. The fiber used in the experiment has a core diameter of 8 μm and a numerical aperture (N.A.) of 0.19. The Pr^{3+} doping concentration was 3000 ppm. The length of ZBLAN fiber was 40 mm.

Firstly the radiation from GaN laser diode was collimated by an aspheric lens with focal length of 3.1 mm. This collimated beam was then shaped with the help of cylindrical lens system with focal lengths of -20 mm and 100 mm respectively. The cylindrical lens pair has been used to obtain the circular beam. The distance from laser diode to collimating aspheric lens (f_1= 3.1 mm) was 3.1 mm, the distance from collimating aspheric lens to first cylindrical lens (f_2= -20 mm) was 41 mm, the distance between the cylindrical lens pair was 80 mm, the distance from second cylindrical lens (f_3= 100 mm) to focusing aspheric lens (f_4= 8 mm) was 250 mm.

The circularly shaped beam was focused into the fiber core with the help of another aspheric lens with focal length of 8 mm. The beam spot size calculated theoretically is well within the fiber core size so as to facilitate the full absorption of pump light by the fiber.

The mirrors used for green oscillation are coated on the fiber by the manufacturer.

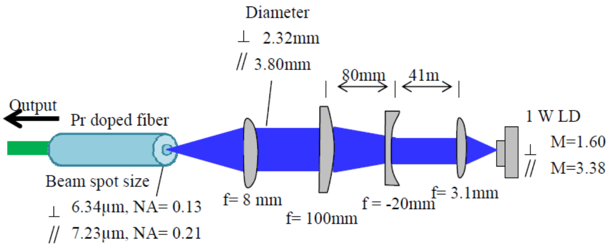

Fig.3. Experimental setup of Pr^{3+} doped AlF_3 fiber laser pumped by GaN laser diode

The entrance side of the fiber has a reflectivity greater than 99% at green wavelength. It has transmissivity greater than 95% at the pump wavelength and 20% at the red wavelength. Transmissivity of 20% at red oscillation is enough to exhibit the red oscillation at low pump power but it is suppressed at higher pump power and green oscillation becomes dominant. The exit side has reflectivity about 95% at the green wavelength.

2.3 Pr^{3+}:ALF_3 Red Fiber Laser

Similarly fiber laser oscillation experiment was carried out from the Pr^{3+} doped AlF_3 fiber at red wavelength pumped by 1 W GaN laser diode. The experimental setup of red fiber laser oscillation shown in fig. 4 is same as green fiber laser oscillation with the exception of a mirror of thickness 5 mm placed after the focusing aspheric lens and at the entrance facet of the AlF_3 fiber. It has a high reflection (R> 99.5%) at the red wavelength of 635 nm and a high transmission at the pump wavelength. The edge of the HR mirror and other end of the fiber acts as the cavity. The HR mirror placed at the input side acts as the total reflector for red light and reflects about 99% of the red light back into the fiber.

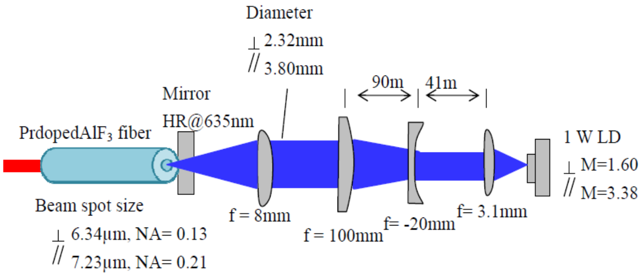

Fig.4 Experimental setup of Pr^{3+} doped AlF_3 fiber laser pumped by GaN laser diode

3. Experimental Results

3.1 Pr^{3+}:ZBLAN Red Fiber Laser

Fig. 5 shows the output characteristics of the 636 nm red laser oscillation using two 500 mW GaN laser diodes as pump source. When pumped with 907 mW, the Pr^{3+}: ZBLAN laser emitted 170 mW of output power at a wavelength of 636 nm. Threshold pump power and slope efficiency with respect to the absorbed pump power were determined to be 60 mW and 55%, respectively.

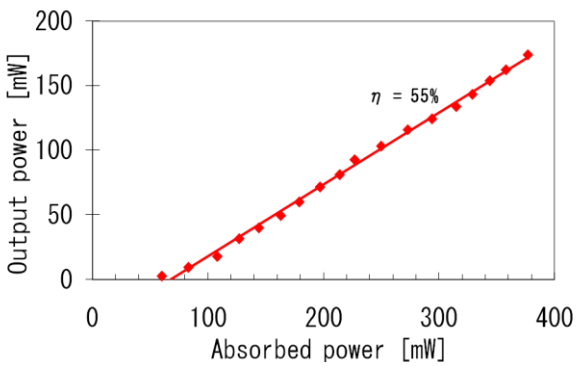

Fig.5. Output Power as a function of estimated absorbed pump power for Pr^{3+}: ZBLAN fiber laser

The coupling efficiency of 55% was measured by using silica fiber, which has same N.A. and core diameter as that of ZBLAN fiber.

Estimation of absorbed pump power:

It is essential for the power efficiency of a laser that the pump light is efficiently absorbed. For very small pump intensities, the degree of absorption can be simply calculated from the doping concentration N_{dop}, the length L of the gain medium, and the absorption cross section σ_{abs} at the pump wavelength.

The degree of power absorption is

$absL$

Very efficient pump absorption could in principle be obtained with a laser design based on a gain medium with a large length and a high doping concentration. The absorbed pump power is proportional to the incident pump power in a laser medium. Hence the absorbed pump power for this experiment was estimated as follows:

Absorbed pump power = Incident pump power x 0.43

The ultimate efficiency of Pr ion can be estimated based on the energy level scheme and transition radiation of the praseodymium doped ZBLAN. It can be calculated to be about 80% taking into account the losses by the stimulated emission and amplified spontaneous emission.

There is a gradual improvement from 40% to 55% in the slope efficiencies of fiber laser experiments. The reasons behind improvement can be attributed to many factors. In the case of 40% slope efficiency, only one 500 mW GaN laser diode was used for pumping. In the latter case of 55% slope efficiency, combination of two linearly polarized 500 mW GaN laser diode was used for the experiment which caused significant increase in the pump power. Also the position of HR mirror was changed to the input facet of the fiber, as both gain and intensity is high at that position. This is due to nonlinear optical phenomenon.

3.2 Pr^{3+}:ALF_3 Green Fiber Laser

Fig. 6 shows the output characteristics of the green laser oscillation using a 1 W GaN laser diode as pump source. The figure shows the incident pump power versus output power characteristics. When pumped with 750 mW, the Pr^{3+}: AlF_3 laser emitted 70 mW of output power. Threshold pump power was determined to be 250 mW. Coupling efficiency of about 75% is calculated by using the previously used formula. The slope efficiency was determined to be 8%. High threshold might be responsible for the low slope efficiency.

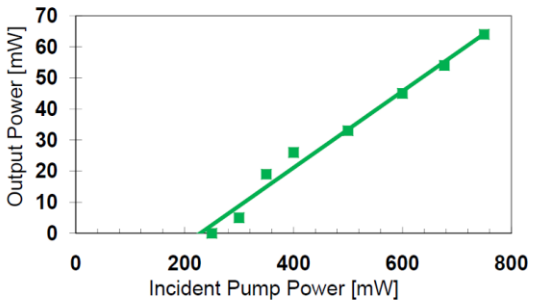

Fig.6 Output performance of Pr: AlF_3 green laser

Slope efficiency is an important property of laser defined as the slope of the curve obtained by plotting the laser output versus the incident or absorbed pump power. Above the lasing threshold, the resulting curve is usually close to linear. The slope efficiency is the slope of this line.

Coupling efficiency is the fraction of available output from a pump source that is coupled and transmitted by the fiber. It can be calculated by using the formulae,

$$\mathit{pump\ power}$$

The coupling efficiency is estimated to be 75% for 8 μm fiber.

Emission spectrum

The emission spectrum was measured at green laser threshold and at high pump power. There is some competition between intensity at green wavelength and amplified spontaneous emission (ASE) as the threshold for green laser is reached. The emission spectrum at both red and green wavelength can be easily seen in the emission spectrum figure. The emission spectrum at green threshold is shown in Fig.7(a). There can be a possibility if the laser oscillation occurs due to the transition competition between the two wavelengths. However at high pump power the amplified spontaneous emission (ASE) eventually dies out and emission at green wavelength becomes visibly dominant. The emission spectrum at high pump power is shown in Fig.7(b).

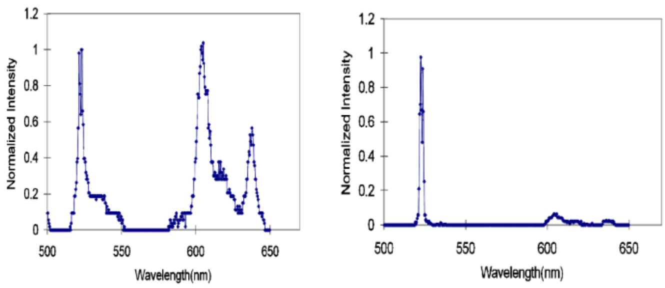

Fig.7(a). At green threshold 7(b). At high pump power

3.3 Pr^{3+}:ALF_3 Red Fiber Laser

Fig.8 shows the output characteristics of the red laser oscillation using a 1 W GaN laser diode as pump source. The figure shows the incident pump power versus output power characteristics. When pumped with 750 mW, the Pr^{3+}: AlF_3 laser emitted 40 mW of output power. Threshold pump power was determined to be 250 mW. The slope efficiency was determined to be 6%. Again in this case high threshold might be responsible for low slope efficiency.

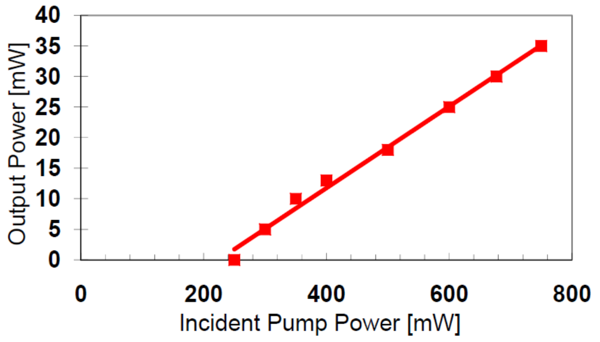

Fig.8 Output performance of Pr: AlF_3 red laser

The coupling efficiency is estimated to be 75% for 8 μm fiber.

4. Conclusion

We have experimentally demonstrated the laser operation of a Pr^{3+} doped ZBLAN fiber laser. The realized laser emitted in the red spectral range at 636 nm. The slope efficiency and output power of the Pr^{3+} doped ZBLAN laser were 55 % and 170 mW, respectively, with respect to the absorbed pump power using two 500 mW GaN laser diode.

The laser operation of a Pr^{3+} doped AlF_3 fiber pumped by 1 W GaN laser diode was experimentally demonstrated. The realized laser emitted in the red and green spectral range. Pr^{3+} doped AlF_3 fibers with core diameter of 8 μm and N.A. of 0.19 was used for the laser oscillation. The output power of the Pr^{3+} doped AlF_3 green fiber laser was 70 mW with respect to the incident pump power. The output power of the Pr^{3+} doped AlF_3 red fiber laser was 40 mW with respect to the incident pump power.

However the output performance using AlF_3 fibers is low as compared to ZBLAN fibers. There could be many reasons behind this. The main reason could be the core size diameter as we have used larger core size AlF_3 fibers as compared to ZBLAN fibers. Due to large core diameter, threshold becomes high and gain is low. The second possibility could be the material composition as the composition of AlF_3 fibers is completely different from ZBLAN fibers. In spite of these drawbacks it has been confirmed that Pr:AlF_3 is attractive material for generating red and green laser oscillation.

References

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