ISSN 2229-5518

Ytterbium-doped Large-core Fiber Laser with 4.7Kw Continueous Wave Output Power

Tanvi, Neena gupta

Abstract— In the present simulation work laser made of ytterbium-doped fiber with large core double clad D-shaped generates 4.7kW of continuous-wave output power with very high efficiency at 1.1 µm and revealed no proof of roll-over even at the peak output power. The measured slope efficiency is 72.15%. The large core YDF laser is end-pumped with five diode stack sources through opposite ends of fiber (Three of them conjointly emits 3.3 kW while other two emit 3.0kW at 975 nm). This design of fiber which finished by simulation program can delivers much more output power which is restricted mostly by accessible pump power.

Index Terms— ytterbium (Yb), ytterbium-doped fiber (YDF), ytterbium-doped fiber laser (YDFL), ytterbium-doped fiber amplifier (YDFA), stimulated Raman scattering (SRS), stimulated Brillouin scattering (SBS), numerical aperture (NA)

1 Introduction

In the past few years onwards 1990s intense advancement has been seen in extraordinary high power fiber laser and amplifier technology. The optical fibers can be doped with any of rare earth elements such as Erbium(Er), ytterbium (Yb), Neodymium(Nd) or Praseodymium(Pr), Thulium(Tm) [1][2][3]. But silica-based ytterbium doped fiber are the foremost nominee for the cause that they have brilliant power conversion efficiency (>85%) which outcomes from the small quantum defect with the pump ranging between 910–980 nm and signal ranging in 1030–1100 nm wavelengths as the YDF energy structure is very simple, other reasons why YDF gaining lot of attention is that many unfavorable effects such as thermal effects, quenching, photo darkening effect and excited state absorption are extremely low [4][5]. In specific, the study on ytterbium doped fibers (YDFs) has been extreme because of their exceptional high efficiency, power-handling characteristics, and low budget of proprietorship for numerous scientific and industrial applications. These comprise photochemistry, spectroscopy, material treating, pattern design, medication, security, defense, remote sensing, range-finding, free-space communication, under water communication, display (when transformed into visible), lithography (when transformed into ultraviolet), bio-medical applications etc. [6][7]. Lasers and amplifier both can be power-scaled by ytterbium doped fiber. Laser formations are simple, flexible, and less costly as compared with amplifiers. So we worked on Power-scaling of Ytterbium-doped fiber laser. This rapid growth of power scaling is possible only due to pumping diode lasers of large power, diode stacks, fibers capacity to carry large amount of optical power, perfections in fiber design, and fabrication techniques. According to literature survey till now 13.3 kW output laser power in strict single mode and around 70.7kW in multimode configuration is achieved via multistage amplifiers or tandem-pumping schemes .But we stress on the easiness of a directly diode-pumped with large core double clad YDF configuration For achieving multi-kilowatt output power in contrast with supplementary arrangements. [8-15]. for further scaling of Output power small fiber length, large pump power larger inner cladding, and a larger core can be used. Reasons for the small fiber length, large core and large cladding help to lodge (absorb) the large pump power beams and also suppress non-linear scattering losses (SRS and SBS). In our work **VPI Photonics simulation software** is used for power scaling and up to 4.7kW is achieved by taking core diameter = 50µm with 0.05 numerical aperture, D-shaped inner cladding had a 900/950-µm diameter for the shorter longer/ axis with 0.48 numerical aperture, core to cladding area = .004, ytterbium-doped fiber length = 12m, pumping wavelength 975nm, total pumping power=6.3kW, temperature of fiber = 300°K, Yb overlap factor =0.95, Yb concentration =5.97×10^{25} m^{-3}(6000ppm), Yb life time = 0.8×10^{-3}sec are adjusted such that maximum output can be delivered.

2 Laser Phenomena

When a photon with certain energy is incident on an electron in a semiconductor at the ground state (lower energy level) the electron absorbs the energy and shifts to the higher energy level. After the absorption process the electrons at the higher energy level are in an excited state. In this case once the external photon strikes to this excited atom, this leaves its position from the higher energy level and & it will emit the photon. Thus we are getting 2 photons at the output, one which is striking on the atom and other coming out because of excited emission of two photons and the light amplification takes place. These two photons are in same phase and traveling in the same direction. For lasing action there should be more electrons at higher energy conduction band than at lower energy valence band. To create this high energy forward current is passed through small active area. Population inversion is necessary to create lasing effect because greater the number of excited electrons, greater is the no. of stimulated photons that can be radiated and hence higher emission intensity. The no. of Excited electrons determine gain. Reflecting mirror is used at ends for amplification of certain wavelengths, a process known as optical feedback [1-3].

3 ANALYSIS OF YDFL

In Figure 1 Simulation arrangement for an YDF laser is done with the help of VPI Photonics simulation software. The large core YDF laser is end-pumped with five diode stack sources through opposite ends of fiber three of them conjointly emits 3.3 kW from the left side while other two emit 3.0kW from the right side at 975 nm. The pump beams were combined into the YDF fiber of length 12m (which will act as gain media or named as a laser cavity) via twosome of dichroic mirrors which transmit at 975nm and reflect signal at 1100nm. Hence light beam moves forward and then backward in a loop so at the end when this iterations done 100 times a highly coherent, directional, energetic CW laser beam is produced at 1100nm. Attenuators are used to adjust coupling loss. In table1 we measured YDFL output power for different pump power values and figure 3 shows fiber laser output power versus launched pump power graph from which slope efficiency is measured that is 72.15%. In figure 2 YDF laser optical spectrum at maximum pump power (i.e. 6.3 kW) is shown and figure 4 give us YDF CW laser output power of 4.7 kW measured by YDF monitoring control and instrumentation.

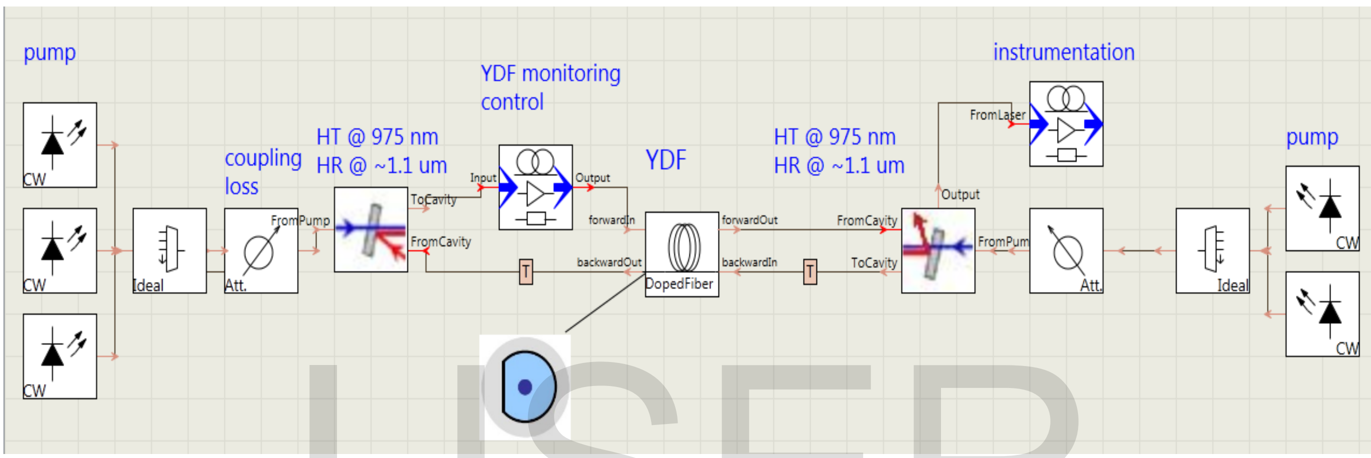

Fig1: Simulation arrangement for an YDF laser

4 RESULTS

TABLE1: Analysis of YDFL output power

S.no	PUMP POWER(kw)	OUTPUT POWER(kw)
1	1.8	1.4
2	2.2	1.8
3	2.5	2
4	3	2.3
5	3.5	2.7
6	4	3
7	4.5	3.4
8	5	3.8
9	5.2	3.9
10	6.3	4.7

ISSN 2229-5518

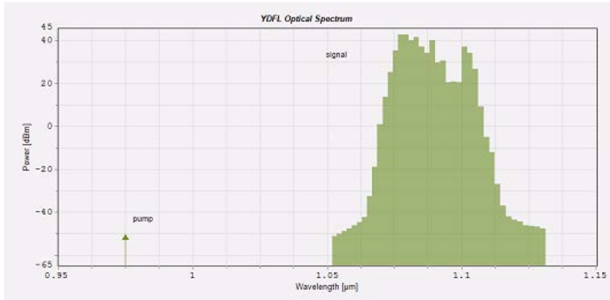

Fig2: YDF laser spectrum at 6.3 kW maximum pump power

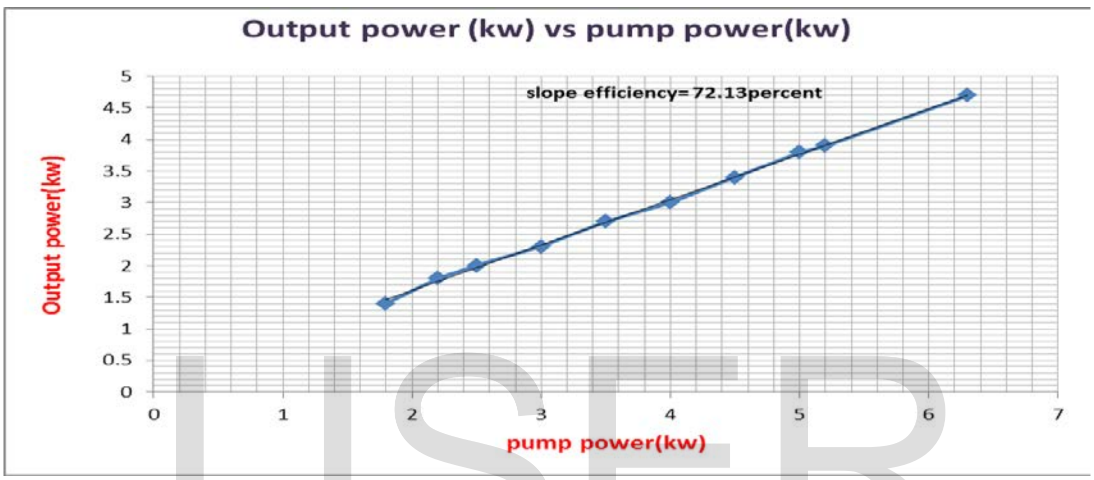

Fig3: Fiber laser output power vs. launched pump power

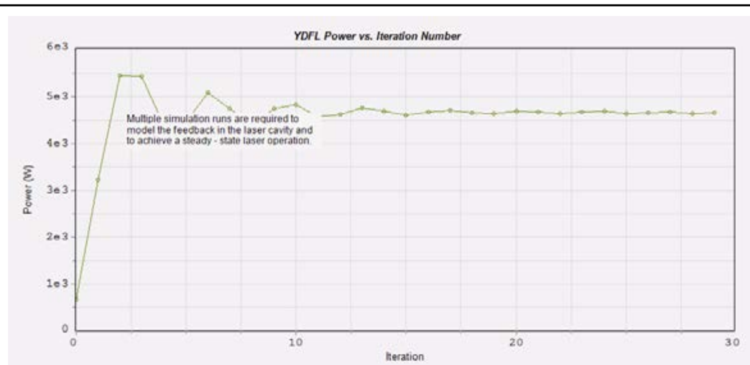

Fig4: YDF 4.7 kW CW laser output power at 6.3 kW maximum pump power

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5 CONCLUSION

By taking core diameter = 50µm with .05 numerical aperture, D-shaped inner cladding had a 900/950-µm diameter for the shorter longer/ axis with 0.48 numerical aperture, core to cladding area = .004, ytterbium-doped fiber length = 12m, pumping wavelength 975nm, total pumping power = 6.3kW, temperature of fiber = 300^{0}K, Yb overlap factor = 0.95, Yb concentration =5.97×10^{25} m^{-3}(6000ppm), Yb life time = 0.8×10^{-3}sec of ytterbium-doped fiber with large core double clad D-shaped generates 4.7kW of continuous-wave output power with very high efficiency at 1.1 µm and revealed no proof of roll-over even at the peak output power. The measured slope efficiency

ISSN 2229-5518

is =72.15%. Hence power scaling up to 4.7kW is achieved. For more high power scaling tandem-pumped ytterbium doped fiber lasers and amplifiers, MOPA, frequency dithering etc. techniques can be used, but these techniques are very complex as compared with above explained method which is simple, flexible and easily upgradable. Output power of this system is limited only by available pump power.

6 Future Scope

In future more power scaling can be done, it can go beyond megawatt. For this to make possible configuration, geometry and fabrication techniques of ytterbium doped fiber need to explore. Ytterbium doped fibers can be co-doped with some other material which can provide lasing action ranging in 1-1.1μm. Tandem pumped lasers and amplifiers, MOPA, frequency dithering etc. techniques can be used although they are complex but high power scaling can be done. Strong pump sources which can provide a high watt of power can be developed.

- *Tanvi is currently pursuing masters degree program in electronics and communication engineering inPEC University of Technology, India,E-mail: gargtanvi04@mail.com*
- *Neena Gupta is currently professor in electronics and communication engineering department inPEC University of Technology, india, E-mail: neenagupta@pec.ac.in*

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