Multimode-Pumped Monolithic Amplifier Arrays Based in Erbium-Doped Phosphate Glass

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Abstract: We demonstrate the first monolithic optical amplifier array based on high gain per unit length erbium-doped phosphate glass. The 7-cm long chip, pumped by one multimode diode laser, delivers 28 dB gain at each of three-ports.

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1. Introduction

The integration of high performance optical amplifier devices into low-cost, compact packages will be necessary for deployment into the metro, access and fiber-to-the home markets. At present, erbium fiber amplifiers consisting of erbium-doped silica fibers more than one meter long achieve greater than 20 dB gain near the 1.54 μm range. More commonly, the length of the erbium doped silica fiber is approximately 10 to 20 meters. However, it is clear that the fiber management associated with such lengths is not practical for assembly into integrated optical components. This difficulty is motivating research and development into other technologies such as semiconductor optical amplifiers (SOA) and erbium doped waveguide amplifiers (EDWA). Although compact in size, SOAs have inherently large noise figures, typically greater than 8 dB. This makes them unattractive in usual network applications where a series of amplifiers are required. EDWA have better noise figure performance, but typically suffer from polarization dependence and internal loss due to coiling tens of centimeters of an erbium-doped waveguide on the planar chip.

In this paper, we demonstrate the first monolithic optical amplifier array based on high gain per unit length erbium-doped phosphate glass. Phosphate glass fibers allow doping with high Er^{3+} concentration without the deleterious effects of ion clustering, making possible erbium-doped fiber amplifiers using very short (a few cm) fiber lengths. In our previous work we demonstrated phosphate glass fiber amplifiers with a high gain per unit length pumped with single mode 980 nm diode lasers [1,2] as well as with multimode broad area pump lasers [3]. Importantly, the gain achieved is comparable to typical silica fiber amplifiers containing several meters of fiber.

Here, we use the high gain per unit length core glass to draw a multi-core fiber amplifier array structure in a method analogous to optical fiber drawing – producing a 3-element array of highly doped cores embedded in a lower index cladding layer. The fact that our short-length array structure can be fabricated in a manner similar to how optical fibers are produced is tremendously significant in terms of realizing low cost devices. In addition, we use one multimode pump laser to simultaneously energize the entire gain array. This approach results in a massive, scalable, and highly cost-effective sharing of one pump laser over many amplifying cores.

2. Glass and Fiber

The core phosphate glass contains high erbium and ytterbium concentrations suitable for highly absorbing the 975 nm pump light and producing high gain per unit length. We produced the multi-core array structure in a method analogous to our usual optical fiber drawing for a single core. We take a cladding glass pre-form and mechanically drill 3 cylindrical holes instead of the usual one. Core glass is machined into rods and placed in cylindrical pre-forms made of the same cladding glass. The 3 core sections are placed in the 3 holes, and the entire structure is pulled much like single core optical fibers – resulting in monolithic amplifier arrays with active core elements containing very high erbium and ytterbium doping concentrations, and circular cross sections. The numerical aperture of the cores is designed to match the numerical aperture of the single mode fibers that carry the input signals. The cores are placed on a 30-μm pitch with a rectangular shaped outer cladding that is 112-μm by 68-μm. Figure 1 shows a cross-sectional image of the cleaved surface.

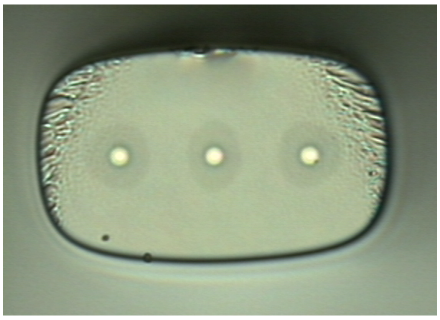

Fig. 1. Cross sectional image of the 3-core gain array structure. Cores are spaced on a 30-µm pitch. Outer cladding dimension is 112-µm x 68-µm. Roughness at the edges is due to cleaving and does not reflect the quality of the structure.

3. Amplifier Array Chip

We fabricated a gain array chip that allows efficient injection of multimode pump light into the pump-confining layer. Figure 2 shows a schematic representation of the amplifier array chip. We use the all-glass structure, discussed earlier and shown in Fig. 1. Since it is similar to a conventional fiber in its shape and handling, we simply cut the desired length of amplifying material to be used in the experiment – in this case between 3-cm and 7-cm. A low index epoxy – index-matched to fused silica – is used to bond a stack of 3-core array structures – essentially producing several layers of active core arrays one on top of the other. The bonded chip is mechanically polished on both end facets to facilitate low-loss coupling to the standard silica fibers carrying the optical signals. We attach a dielectric mirror to one end of the chip – to allow signals to pass twice through the amplifying cores.

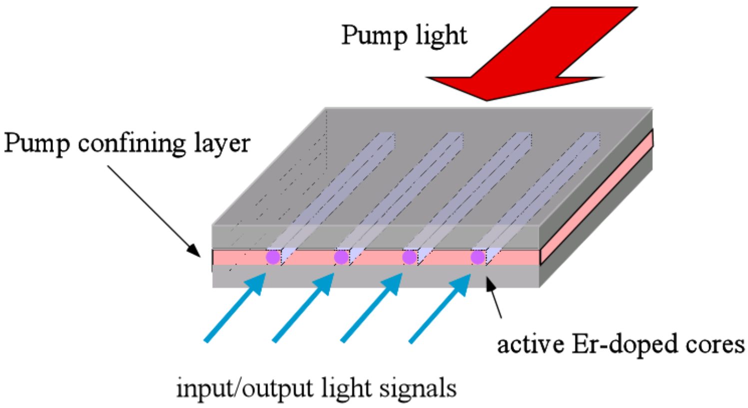

Fig. 2. Schematic representation of geometry for end-coupled multimode pumping of monolithic amplifier array to demonstrate pump-sharing of active cores.

4. Amplifier Characterization

We characterize the gain array chip in a double pass geometry using standard single mode fibers to carry light signals into each one of the 3 active cores. To evaluate the optical performance of the gain array using a pump sharing approach, we end-coupled one 1.5 W multimode pump laser from one side of the gain array chip. The pump passes through a dielectric coating, which reflects C-band signals in the cores but passes the 975 nm pump light. The pump uniformly energizes the array. Figure 3 shows the gain spectra for all three active cores energized by the one pump for a 7-cm long gain array chip. It is notable that the gain spectra for each of the active cores are nearly identical. The internal gain across the entire telecommunication C-band (1530 nm to 1565 nm) is above 10 dB, with peak gain greater than 28 dB in each of the three ports. It is significant that the same pump power is effectively shared among 3 cores – reducing the power requirement per core by a factor of approximately 3. Despite any inhomogeneities in the input pump beam profile from the multimode diode source, the small variation of the peak gain across the 3 cores is clear evidence for a powerful scrambling effect in the active multimode array waveguide. This demonstrates and validates the concept of pump sharing of multimode power across arrays of active cores.

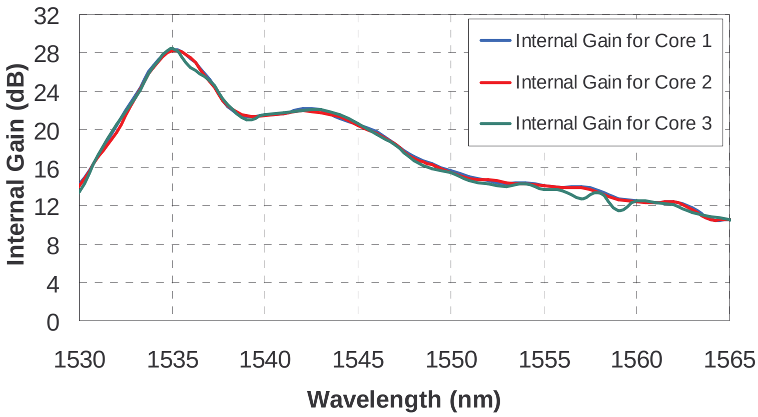

Fig. 3. Double pass gain spectra in the 3-core amplifier array (L=7 cm) with end-coupled multimode pumping power of 1.5- W shared among 3 active cores. Core 2 is the central core.

5. Summary

We have successfully demonstrated the "erbium-doped monolithic gain array", initiating a new class of optical amplifier technology, which combines the high performance features of standard erbium-doped fiber amplifiers with the compactness and integration capabilities of semiconductor-based amplifiers. The gain array is a compact glass chip a few centimeters in length currently providing greater than 28 dB of peak optical gain at each of 3 ports. Using multimode pump lasers to energize the array offers a 5-10x reduction in pump laser cost in comparison to currently deployed single mode pump lasers. Because of the pump-sharing approach using multimode semiconductor lasers and the fiber drawing fabrication methods for the array, we expect to drive down the cost of optical amplification to a point where many optical functional devices can afford to have their insertion losses compensated by our amplifier arrays. This dramatic cost reduction in compact, high performance amplifiers will make a large impact on the design philosophy and implementation of metro and access optical networks. It is for this reason we believe the monolithic gain chip will be an optical engine easily deployed throughout the network – driving all-optical data transport and all-optical signal processing.

6. References

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