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Low pump power photonic crystal fiber amplifiers

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Abstract: We present designs of low pump power optical amplifiers, based on photonic crystal fibers. We demonstrate that such amplifiers may deliver gains of more than 15dB at 1550nm with less than 1mW of optical pump power.

OCIS codes: (060.2280) Fiber design and Fabrication

1. Introduction

As optical networks evolve from point-to-point nature into more advanced network topologies, the need for small scale optical amplification will increase. We examine the use of erbium-doped photonic crystal fibers (PCFs) [1] as fiber amplifiers. PCFs used as active fibers were first reported by Wadsworth et al. [2], and offer several advantages compared to standard fibers [3]. In this paper, we focus on the design of erbium-doped photonic crystal fiber amplifiers, operated at very low pump powers.

2. Modeling of photonic crystal fiber amplifiers

The results presented here are based on numerical investigations. We calculate the electromagnetic field distribution in the photonic crystal fibers, using the freely available MIT Photonic Bands program [4]. The resulting field distributions are then used as input in the amplifier calculations, where we solve the population rate equations [5]. We consider index-guiding PCFs with a triangular structure of air holes (see inset in Fig. 1). The core (the center silica rod) is erbium doped. The fiber performance is characterized by calculating the minimum pump power required to obtain a specific gain, for a given fiber.

3. Fiber amplifier performance

In Fig. 1 the pump power required to achieve 15dB gain is shown, as a function of the PCF pitch (interhole distance), for 4 different hole sizes. We observe that large air holes results in lower pump powers. This is a consequence of the larger index contrast, which allows for tighter confinement of the pump and signal light. The pump power depends strongly on the pitch of the fiber. For large pitches, the mode field diameter (MFD) increases, resulting in the need for more pump power, because the pump light intensity drops. For small pitches, the structure becomes too small to effectively confine the signal light. The signal light then spreads out, resulting in a poor overlap with the erbium distribution and thus an increase in the required pump power. For a normalized hole size of 0.8, we see that the minimum required pump power to achieve 15 dB gain is only 0.69mW. To compare these PCF values with what can be obtained using standard fiber technology, we calculate the same minimum pump value for a step-index fiber amplifier. In Figure 2, the minimum pump value is shown for varying core radii and three different refractive index steps. For a large index contrast of 0.03, the minimum pump value to achieve 15dB gain is 3.5mW, which is 5 times higher than that required in the PCF case. The improved performance of the PCFs is primarily a result of the smaller MFDs obtainable in PCFs.

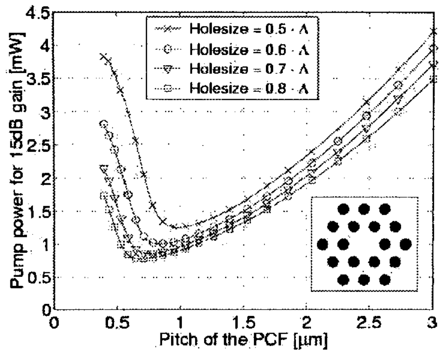

Fig. 1. Minimum pump power in a PCF for 15dB gain, as a function of the pitch, for d ifferent normalized hole sizes.

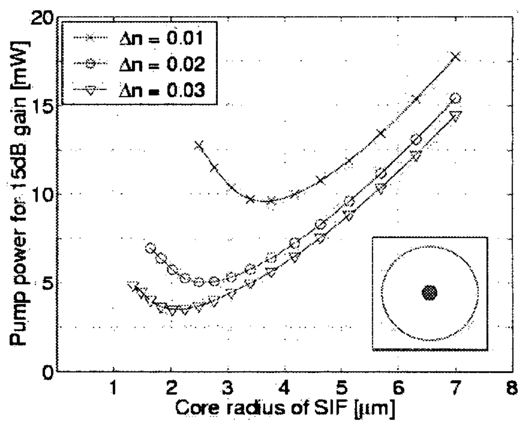

Figure 2. Minimum pump power to achieve 15 dB gain in a step-index fiber as a function of core size, for three different index contrasts.

We then investigate the PCF performance as a function of the desired gain. The results are shown in Figure 3, where we see the minimum pump power, the amplifier noise figure, and the optimum pitch as a function of the desired gain. The values are calculated for a PCF with a normalized hole size of 0.8. The minimum pump power naturally increases with the gain. 10dB gain may be obtained with less than 0.3mW of optical pump power while 2.2mW is needed for 20dB gain. The noise figure only increases slightly for larger gains from about 4dB to 4.5dB. An interesting observation is that the optimum pitch is almost constant for gains between 10dB and 16dB, indicating that the same fiber may be used at optimum for different gain values, by only changing the length of the fiber. For larger gains, it is important to design the fiber for the specific application.

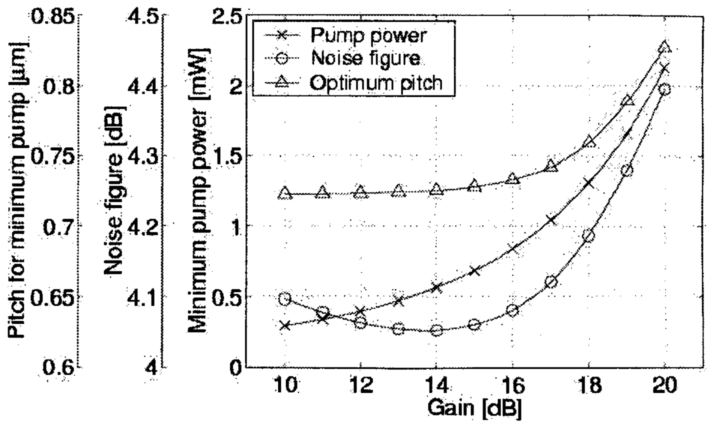

Figure 4. Noise figure, pump power and optimum pitch as a function of the desired gain.

3. Conclusion

We have demonstrated the design of fiber amplifiers based on photonic crystal fibers. By using PCFs with very large air holes, it is possible to design amplifiers with very small mode field diameters, and as a consequence, obtain gain in these fibers with very low pump powers. 15dB gain may be obtained with less than 0.7mW of optical pump power. The designs help to illustrate that the flexibility of PCF technology allow us to design PCF amplifiers for specific applications, which may outperform amplifiers based on standard fibers.

4. References

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