Fabrication of Multicore Fibers for High Power Lasers, Sensing and Communications

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Abstract: Many fiber applications require novel fiber concepts to overcome existing limitations. The advantages of multicore fibers as a promising fiber concept for fiber lasers, sensing and communications are discussed. Different fabrication technologies are presented.

1. Applications for Multicore fibers

Today, fibers can be found in a wide range of applications. They are used for light transport, as sensors or as amplification media, e.g. in lasers or for nonlinear frequency conversion. To achieve the best possible performance, fibers are often operated up to their physical limits. To push these further, novel fiber concepts are necessary.

In the field of telecommunications, the demands on transmission capacity are constantly increasing. There is currently no end in sight to this trend. Various multiplexing concepts have been developed. In the past, e.g. wavelength division multiplexing succeeded in increasing capacity by more than three orders of magnitude [1]. However, this concept has reached the nonlinear Shannon limit. Another promising concept that can be combined with the other multiplexing approaches is spatial multiplexing. Here, the use of multicore fibers is a line-guiding approach. The idea is to integrate several independent or coupled cores into a common fiber cladding. The capacity increase achieved in this way scales with the number of cores and the number of modes guided in each individual core.

In the field of sensing, multicore fibers can be used for multidimensional data acquisition. One example is the use of a multicore fiber as a shape sensor [2]. Due to the different positions, each core of a multicore fiber experiences a different strain when the fiber is moved. By additionally inscribing many different Fiber Bragg Grating along the fiber, this transverse information can be supplemented with longitudinal information. Accordingly, it is thus possible to infer the shape of the bent fiber from the position-resolved strain. This can be used in various fields, e.g. for medical applications, system control or navigation.

The rapidly increasing output power of fiber laser systems in the past has stagnated for several years. Further power increase is limited by nonlinear effects and the occurrence of thermally induced mode instabilities leading to beam quality degradation. These limitations can be shifted by, among other things, the use of special fiber designs. Nonlinear effects, for example, are reduced by fibers with larger mode field areas and short application lengths. To realize extremely large mode field diameters (>30µm) with excellent beam quality at the same time, special fibers with air hole structures in the glass cladding are required. A concept that circumvents both limitations at the same time is the multi-channel amplifier concept, in which the light amplification takes place in several channels in parallel. The individual beams are then combined to form a signal beam. In this case, the existing limitations apply to the individual channel. The achievable total output power scales with the number of channels. For this purpose, concepts have already been implemented in the past in which several parallel amplifier fibers were used [3,4]. A major disadvantage of this concept is the space requirement and expense, which increases with the number of channels. A very elegant and compact solution is offered here by the use of multicore fibers [5]. In multicore fibers, several signal cores are arranged in a common pump core. It has already been demonstrated that the power limitation in each core is comparable to single-core fibers. The realization of multicore fibers also requires preform structuring to place multiple cores in one fiber.

2. Manufacturing of Multicore fibers

Figure 1 (left) outlines the fiber manufacturing process chain for structured fibers. The final structure of the fiber is already realized in a macroscopic copy of the fiber - the preform. This glass preform is heated in a fiber drawing process so that the material becomes viscous and can be drawn into the fiber. One of the greatest challenges in the production of structured fibers is the structuring of the preform. Two technologies are available at Fraunhofer IOF for this purpose: Deep hole drilling involves drilling holes in a glass cylinder, which are then filled with differently doped glass rods (Figure 1, bottom right). While deep-hole drilling is a subtractive process, the alternative stack process is an additive procedure. In this process, glass rods and tubes are first stretched to suitable dimensions, which are then used to stack the fiber preform together (Figure 1, top right).

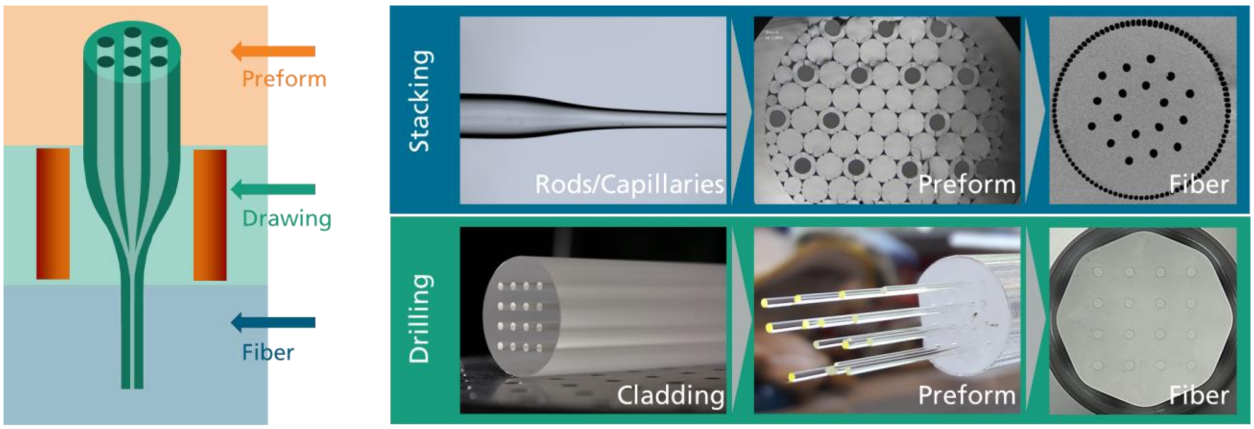

Figure 1: Left: Sketch of fiber production; top right: Images of the process steps of deep hole drilling for preform production; bottom right: Images of the process steps of stacking for preform production.

In Figure 2 different realizations of multicore fibers (bottom row) with the corresponding preforms (top row) are shown. Both technologies (drilling and stacking) allow flexible core arrangement. Square arranged as well as circularly arranged cores have been realized. Circularly arranged 12-core fibers for sensing applications with comparable geometry could be demonstrated for both fabrication techniques. The number of circularly arranged cores can easily be adopted to the requirements of a specific application. Additionally, a couple of square arranged core fibers are shown again demonstrating the flexibility of number and arrangement of cores.

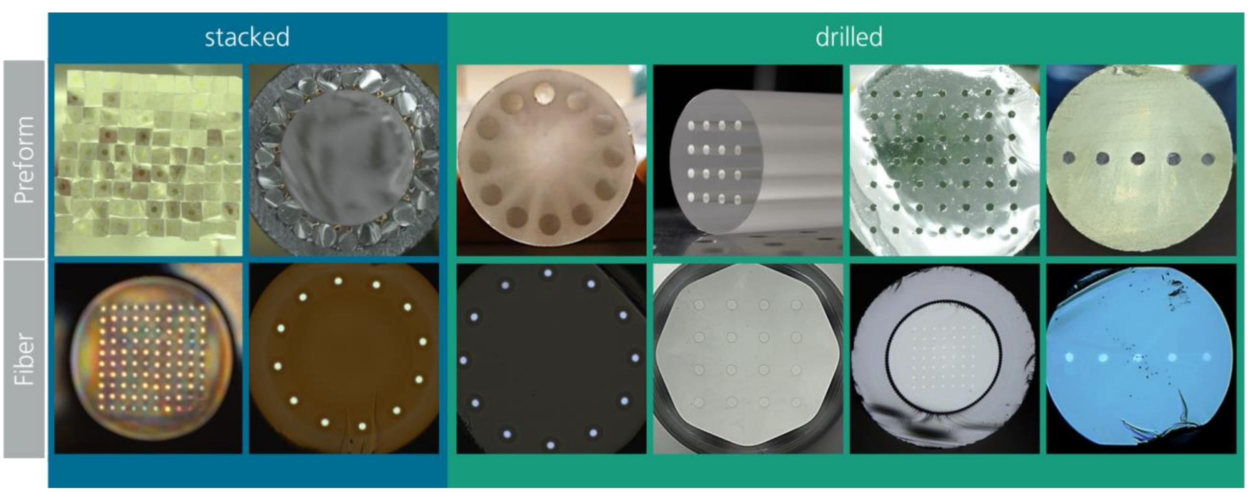

Figure 2: Pictures of different Multicore fiber Preforms (top raw) and resulting fibers (bottom raw) realized by stacking (blue shaded) and drilling (green shaded).

Both presented the manufacturing technologies (drilling and stacking) have advantages and disadvantages depending on the application. Stacking is ideal for manufacturing complex, delicate structures from many elements. It is a technology that can be implemented manually and can be readjusted at any time during the preform buildup. Accordingly, the risk of complete failure of the preform is reduced. A disadvantage is the huge surfaces that are present in the stack and need to be fused without defects during fiber drawing. Here, there is an increased risk of defects being introduced. This manual technology is not suitable for automated volume production. Deep hole drilling technology on the other hand offers a high degree of geometry flexibility with high positioning accuracy. The deep-hole drilling process is fully automated, making it suitable for high-volume production. Avoiding breakthroughs between adjacent holes requires a minimum spacing. In addition, the effort and risk of complete destruction of the preform scales with the number of drilled holes. Accordingly, deep-hole drilling is particularly suitable for realizing few, well-separated element structures.

The advantages of both technologies can be combined in a combined concept as follows. In addition to these different manufacturing concepts, a combination of deep-hole drilling of a unit cell, its square outer shaping and subsequent stacking of the preform is also feasible. This procedure has been successfully demonstrated with the production of a 7x7 core fiber (see Figure 3).

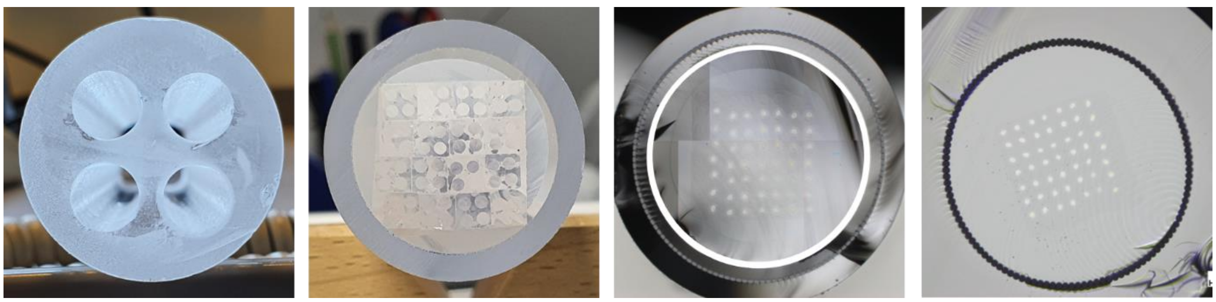

Figure 3: Starting from a drilled 2x2 structure, this was brought into square outer geometry, stretched and loaded with core material. The cane, realized by fusing and stretching, was overlaid with an airclad and warped into fiber.

3. Acknowledgement

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2. References

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