Deliverable 4.6:
End-capped PMC module for beam delivery:

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Declaration: Any work or result described therein is genuinely a result of the Hiperdias project. Any other source will be properly referenced where and when relevant.

1 Scope and objectives

The deliverable D4.6 is part of the task 4.5. The task objective is to provide a more integrated PMC module (or BDS) than the current state-of-the-art, for more flexible fiber handling and integration with system integrator machines. The work consists of end-capping the tips of the fiber with tailored glass optics or optical mechanical part. This end-cap will then be an integral part of the BDS module.

Here we recall the description of the task as it was proposed for the project. The termination will be designed and fabricated so to allow gas loading and handling. The termination will comprise coupling and collimating lenses with tailored dimensions for the following requirements: 1) dispersion management and compensation; 2) ultra-high power handling; and 3) mode-matching with the HC-PCF guided mode. The task will be divided into parts. First, we develop a process for output tip termination with integrated collimated lens. The resulting PMC module will be tested by characterizing the output beam quality and pulse duration, and by assessing the power handling. Second, and based on the developed process, we will develop input fiber glass termination with integrated coupling lens. Care will be taken for optimum integration with the laser system.

Role of partners involved: As per task 4.4, AMP role is to test and qualify the different PMC modules for beam delivery using their laser. AMP will provide GLO with the necessary feedback for redefining the module specifications for optimum performance and ease-of-use. XLIM will provide the necessary scientific and technical skills in designing and characterizing the HC-PCF and its dispersion properties for distortion free pulse delivery.

2 Design and fabrication of hollow core PCF end-cap for BDS

Following the examination of several possibilities on how to end-cap the HCPCF (see e.g. MS28), two main options were studied. The first one is based on fusing an end-cap capillary on the HCPCF end-tip. The second is a hermetically sealed mechanical cell. Given the stringent requirements on the high power and high energy, glass-based end-capping solution has been eliminated. This is more so because the glass-based end-capping would cause difficulty in gas handling. The results show that keeping the gas inside the HCPCF under a controlled pressure is paramount for USP beam delivery with no spectral-temporal distortion due to the optical nonlinearities. Consequently, we have chosen an end-capping based on an optical-mechanical cell. We have chosen to have a specific design for each of the HCPCF ends (input and output). We have chosen to keep the design modular so to keep sufficient margin of control over the final and most effective design.

2.1 Injection/input end-capping cells.

Several Optical-mechanical based end-capped HCPCF have been developed. The injection head of all BDS system are now equipped with end-capped cell. The latter ensures (1) high power handling with AR window, (2) Gas hermeticity for gas control, (3) gas-connectors. An upgraded version of the cell has a water-cooling option for high average power handling. The BDS output system is also equipped with an opto-mechanical cell. The latter is designed so to be easily integrated into the machines.

The power handling tests of the output cell indicate that the cooling option is not required for average power less than 200 W if the laser beam profile quality and pointing stability are good enough (i.e. M2 <1.1 and angle jitter <1µrad). In order to ensure a larger range of laser beam delivery, especially for the ultimate Hiperdias project laser, GLO developed a water-cooled output cell. Today, the end-capped PMC is now a common part of the BDS system.

Figure 1 illustrates the opto-mechanical end-capping cells for both the fiber input (Fig.1A) and output (Fig. 1B) ends respectively, along with a photograph of the assembled PMC based BDS (Figs. 1C and 1D).

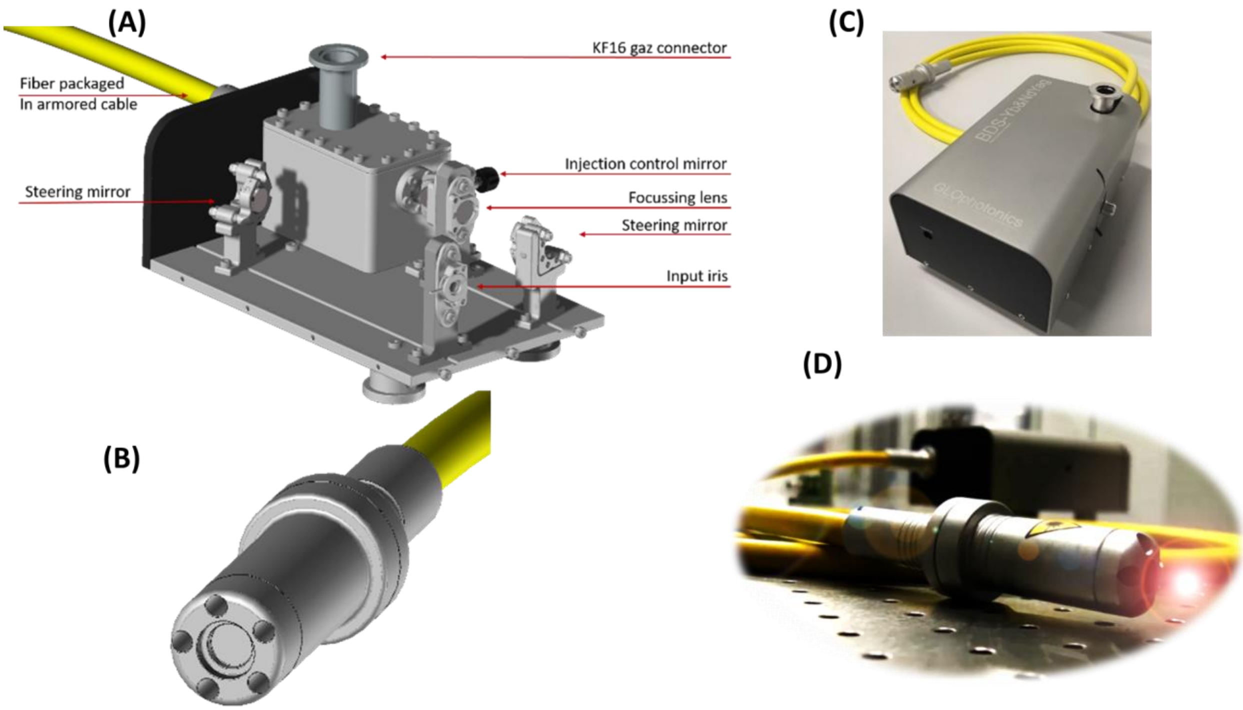

Figure 1. Inside view of the injection head of a BDS (A). The injection head includes the end-capping cell along with the alignment and collimation/coupling optics. The output end-capping cell (B). Photography of the BDS (c). Close-up Photography of the output cell.

Figure 2 shows three cells among the different designs that have been considered for the injection head end-capping cells. All the considered cells comprise a housing v-groove plate for the fiber tip stable holding and alignment. The cell comprises a high power and anti-reflection window for laser beam launching. At the end facet of the cell is attached a hermetically sealed fiber holder. The holder also can accommodate a cable to ruggedize the BDS. The gas/vacuum management is ensured with a cell top equipped with gas/vacuum connectors. Fig. 2A shows the cell that has been selected to equip the first versions of the BDS (we call low power laser BDS). Several BDS have been developed and tested with such cell. The results show a satisfactory vacuum handling (the measured gas leakage rate was found to be typically around 0.1 µbar/sec. liter).

Fig. 2B and 2C shows the cell designs for the high average power version of the BDS. In this design the v-groove plate is water cooled. Several cells have been fabricated, and one was integrated in the high power BDS version. Fig. 3 shows how the cell sits in the BDS injection head. The cell of Fig.2B was integrated in this BDS and has been tested by USTUTT and XLIM. The results in USTUTT were based on the USP laser (delivering up to 500W at a repetition rate of 1.28MHz and a pulse duration of ~300fs) that is developed for the project. They show power handling of up to 180 W. The results indicate that the limit is set by several possible sources: (1) the beam pointing instability, (2) beam quality degradation induced by a beam-expander, (3) fiber evacuation is not sufficient. These are under investigation to improve the performance of the BDS. The power handling was also tested by XLIM using CW lasers. Results shows a power handling up to 400 W, which is the limit of the laser output. In conclusion the injection end-capping cell is adequate for high power USP (i.e. ~500 W -1kW), however this requires appropriate beam launching optics (beam expander, etc.…) to minimize the degradation of the beam quality.

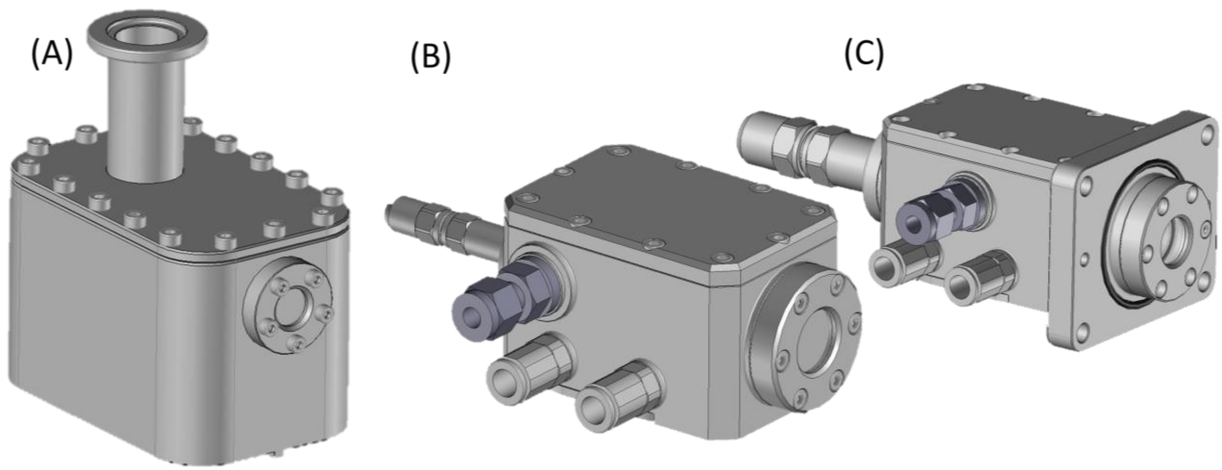

Figure 2: Injection head end-capping cells. Version 1 cell (B). BDS High power water cooled end-capping cell (C). Bespoke-interface water cooled end-capping cell (C).

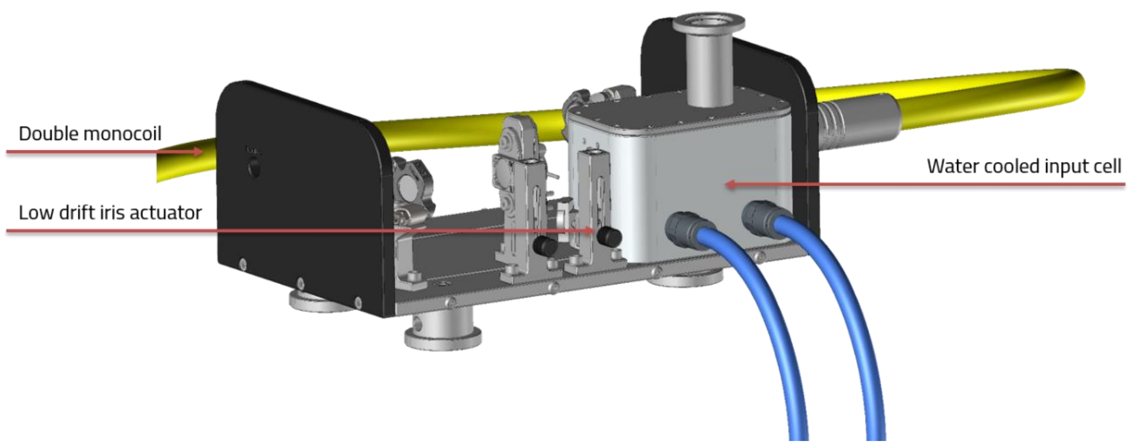

Figure 3: Overview of the BDS injection head with the water-cooled end-capping cell.

2.2 Output end-capping cells

GLO considered several out-cell end-capping cells. The requirements for the output cell are less stringent than the input cell in term of the power handling. However, the geometrical shape has to be at least compatible with the machines to which they will be connected

As a first step, GLO developed a modular out-put cell (Fig. 4A). This cell has a tubular shape and can be fixed to a simple mechanical holder to attach to the machine and align it appropriately with the work-piece. The cell comprises a sealed fiber holder and anti-reflection output window. The cell is designed to accommodate collimation and beam expansion optics. Fig. 4B shows a photography of two BDS with a close-up on the output cells. All the BDS versions developed for the project are equipped with this out-put end-capping cells.

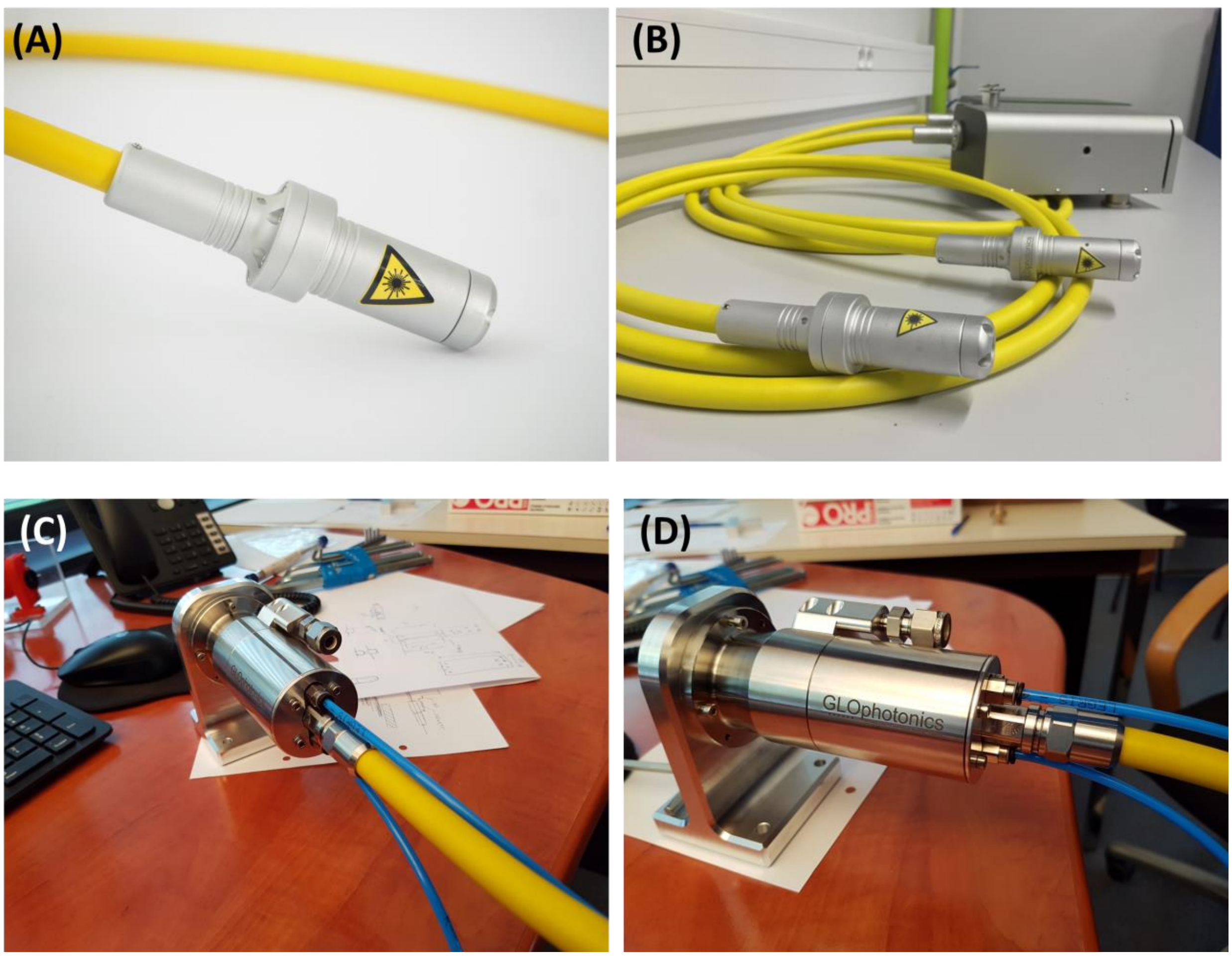

Figure 4

Fig. 4C and 4D shows photos of another type of output end-capping cells. This cell is under test. The development of this cell is motivated by the fact that some laser machines use standardized connection (LLK). This type of cell accommodates both gas handling and water cooling options. Even though it won’t impact the machines of the project partners, it can be assessed for the appropriateness of LLK standard with USP based machines.

3 Conclusions

Several end-capping cell designs were developed and their specifications defined. Opto-mechanical based end-capping was chosen for the BDS. Several injection head end-capping PMC cell were developed, integrated in the BDS and tested. Similarly, output end-capping cells were developed. In both cases, water cooling and gas handling options were integrated.