CLEO 2005 poster
Fiber Laser Design

Motivation

- Fiber lasers have become very attractive laser sources due to their excellent beam quality even at high powers or energies and their ease of cooling. In particular, Ytterbium doped fibers offer a very low quantum defect and a very broad emission between 1 and 1.1 μm.
- Triggered by the progress in high-brightness pump diodes and the availability of large-mode-area (LMA) gain fibers, several fiber lasers with output powers in the 1kW range from a single fiber have been reported [1-3].
- While these demonstrations typically employ a length of gain fiber pumped via free-space coupling and free space optics as the high reflector, there are fewer reports of integrated all-fiber laser cavities, e.g. [4]. However, the availability of high-power fiber-optic components and the assembly thereof is crucial for making this technology available for a variety of applications [5].

Multi-Mode Combiners and Fiber transitions

- The figure below shows a 6+1 fiber bundle and a double clad fiber (DCF). Through a fusion process,both can be matched such that the pump light as well as the signal light couple into their respective cores with low losses (typically 0.3dB and 0.7dB). The resulting (6+1)x1 Multi-Mode Combiner (MMC) combines pump and signal light into a single DCF.
- For efficient operation as well as high quality beam output (low M^2), the signal light has to stay in the fundamental mode LP_{01} in fiber transition regions. The measured intensity profile displays the quasi-singlemode operation within a multimode core. The same principle in employed in Mode Field Adapters (MFA) providing an adiabatic transition of the signal mode from one signal fiber to the next.

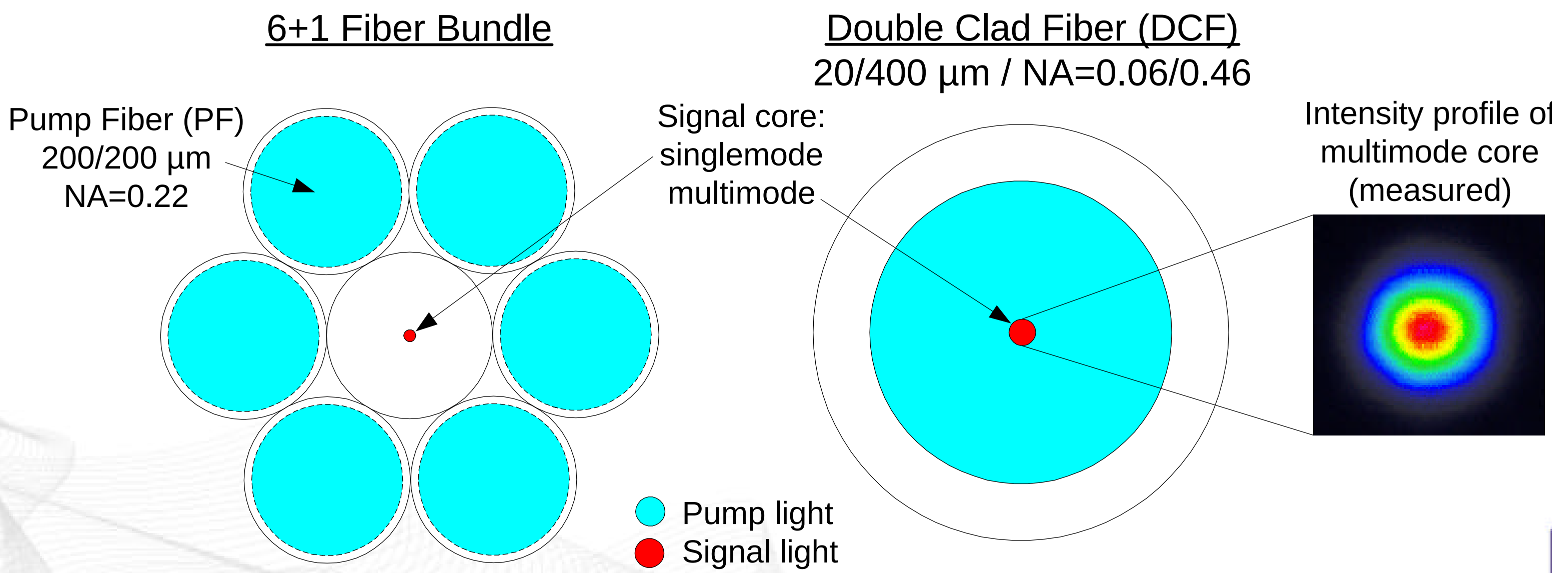

Fig. 1 Multi-Mode Combiner

Investigated cavity designs

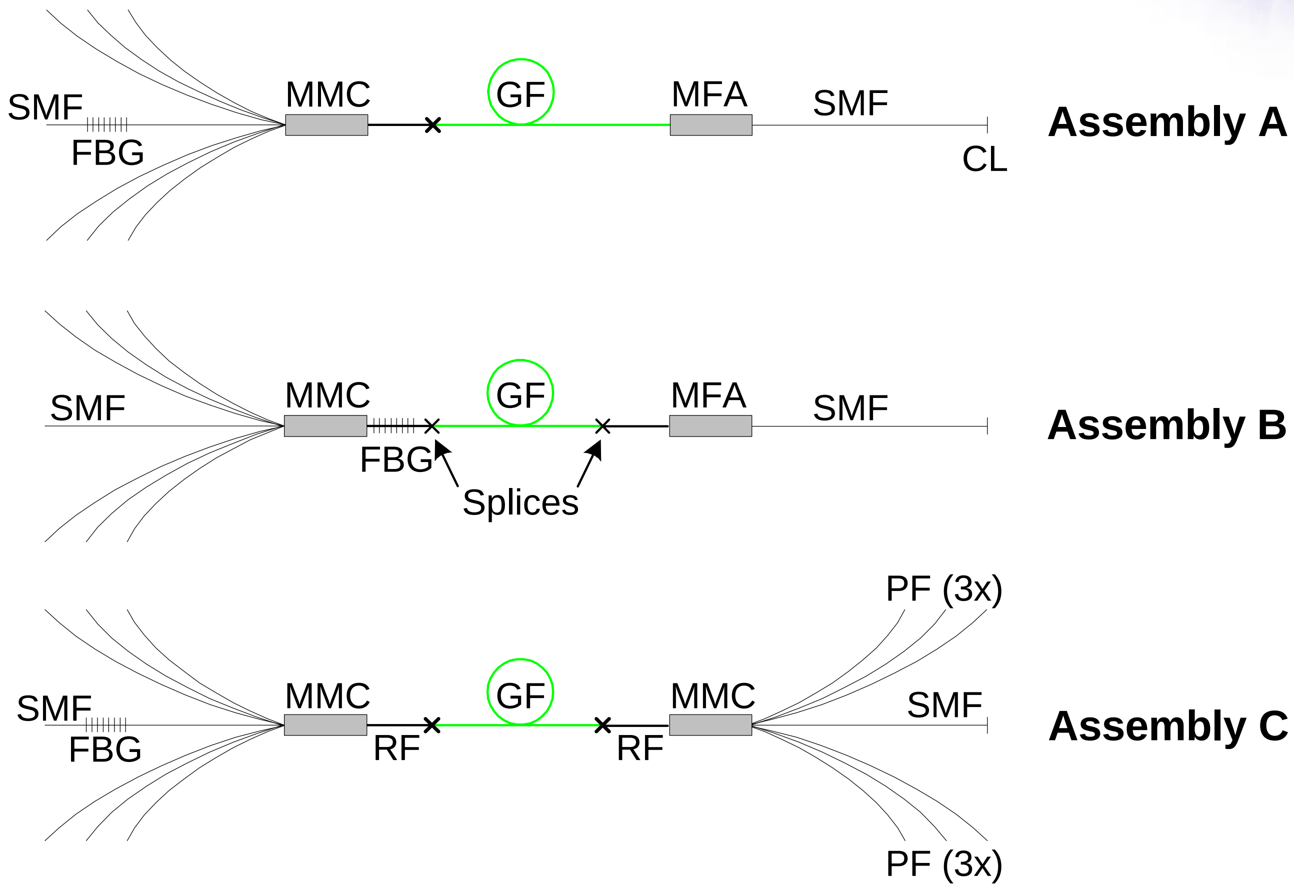

Fig.2 Laser assembly schematics: MMC – multi-mode combiner, MFA – mode field adapter, FBG – fiber Bragg grating, SMF – single mode fiber, GF – gain fiber (Yb doped DCF), RF – relay fiber (DCF), PF – pump fiber, CL – straight cleave,

Laser module details

Three different configurations of fiber lasers were investigated (Fig. 2):

- In all cases, a **Multi-Mode pump and signal Combiner** (MMC) was used to couple the pump light into a double clad fiber (Fig. 1). Assemblies A & B employ **Mode Field Adapters** (MFA) to provide a low-loss transition of the fundamental mode LP_{01} from the DCF signal core to the single-mode fiber.
- On the output side and high reflector side, single mode operation is enforced through the use of **single mode fiber**.
- The **double clad** relay fiber is spliced to an Ytterbium doped gain fiber (GF, Nufern LMA-YDF-20/400) of similar geometry and a length L>8m. Because the 20 μm core supports more than one mode, the gain fiber is coiled with a radius of 5cm to suppress the lasing action of higher order modes [6].
- For each assembly, the **laser cavity** is formed between a fiber Bragg grating (FBG) as the high reflector and a straight cleave of the single mode fiber as the output coupler. In assemblies A & C, a chirped grating with a reflectivity R>99% and a bandwidth of 5 nm was written into a Corning HI-1060 fiber. Assembly B employed a grating in the relay fiber (20/400) core with a reflectivity of 89% and a 0.14nm bandwidth.

Measurement setup

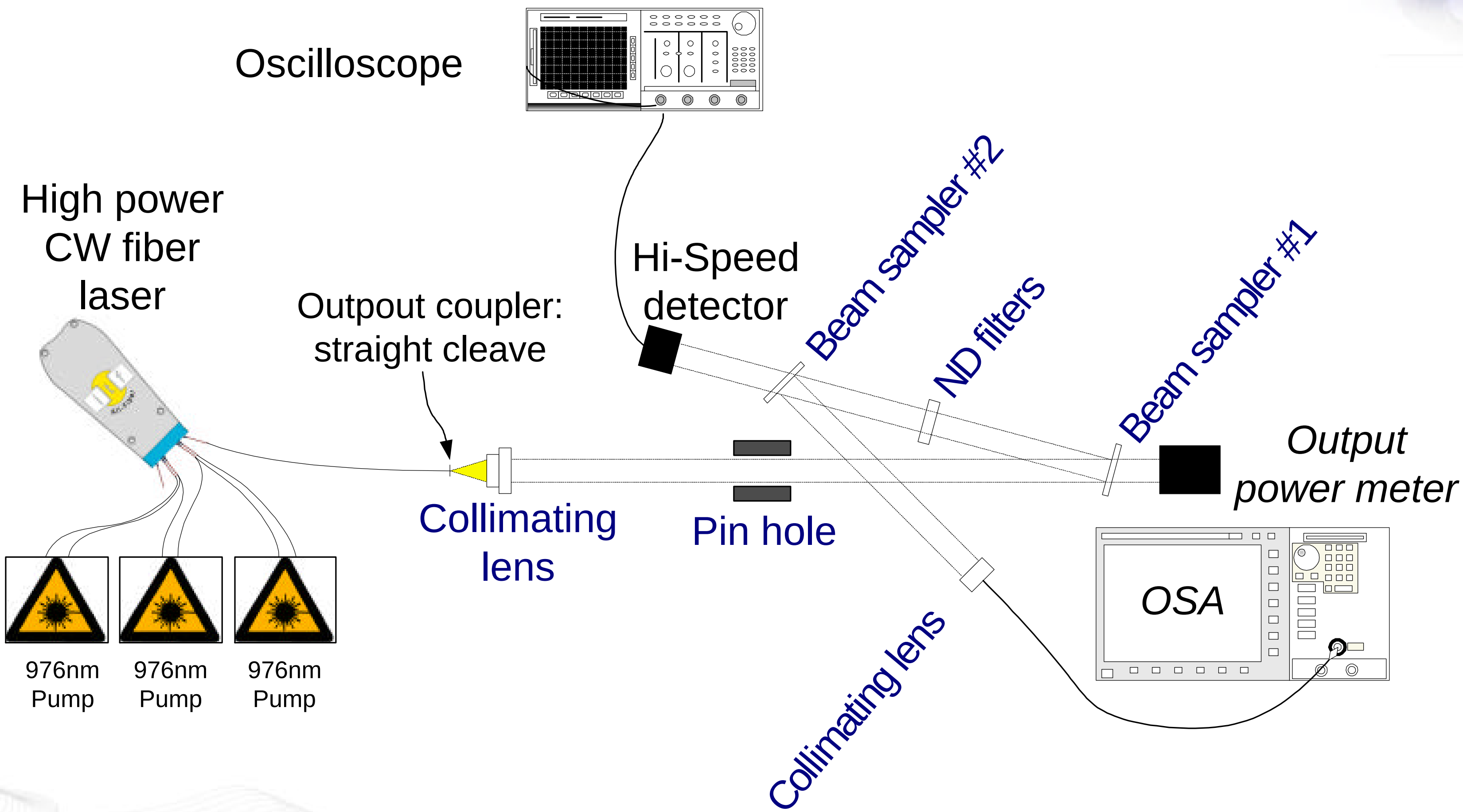

Fig. 3 Experimental setup

Laser: Experimental Results 1

- The fiber assemblies were tested using three fiber-coupled pump diode modules at a wavelength of 976nm (Jenoptik Laserdiode GmbH). Each module delivers a total power of ~45W in two fibers, yielding a **total pump power of 138W** in six fibers. The diode modules were simply spliced to the fiber laser assemblies without the use of isolators.
- The laser output power was measured using a 300W **thermal detector** (Fig.3). A portion of the laser was coupled out of the beam to allow further characterization. Using the **fast detector** (1GHz) and a 500-MHz **oscilloscope**, the intensity noise was monitored. Finally, an **Optical Spectrum Analyzer** (OSA) was used to monitor the spectral quality of the laser output.
- All fiber laser assemblies exhibited a low threshold pump power around 1 W. Fig. 4 summarizes the achieved **output powers**, which are **91W, 83W, and 84W** for assemblies A, B, and C, respectively. All curves show a very linear behavior without roll-off. Assembly A had the highest **slope efficiency of 66.5%**, which is based on the pump power in the pump fibers. Therefore the slope efficiencies contain the coupling loss from the pump fibers to the gain fiber (typically 0.3 dB).

Laser Performance: Efficiency

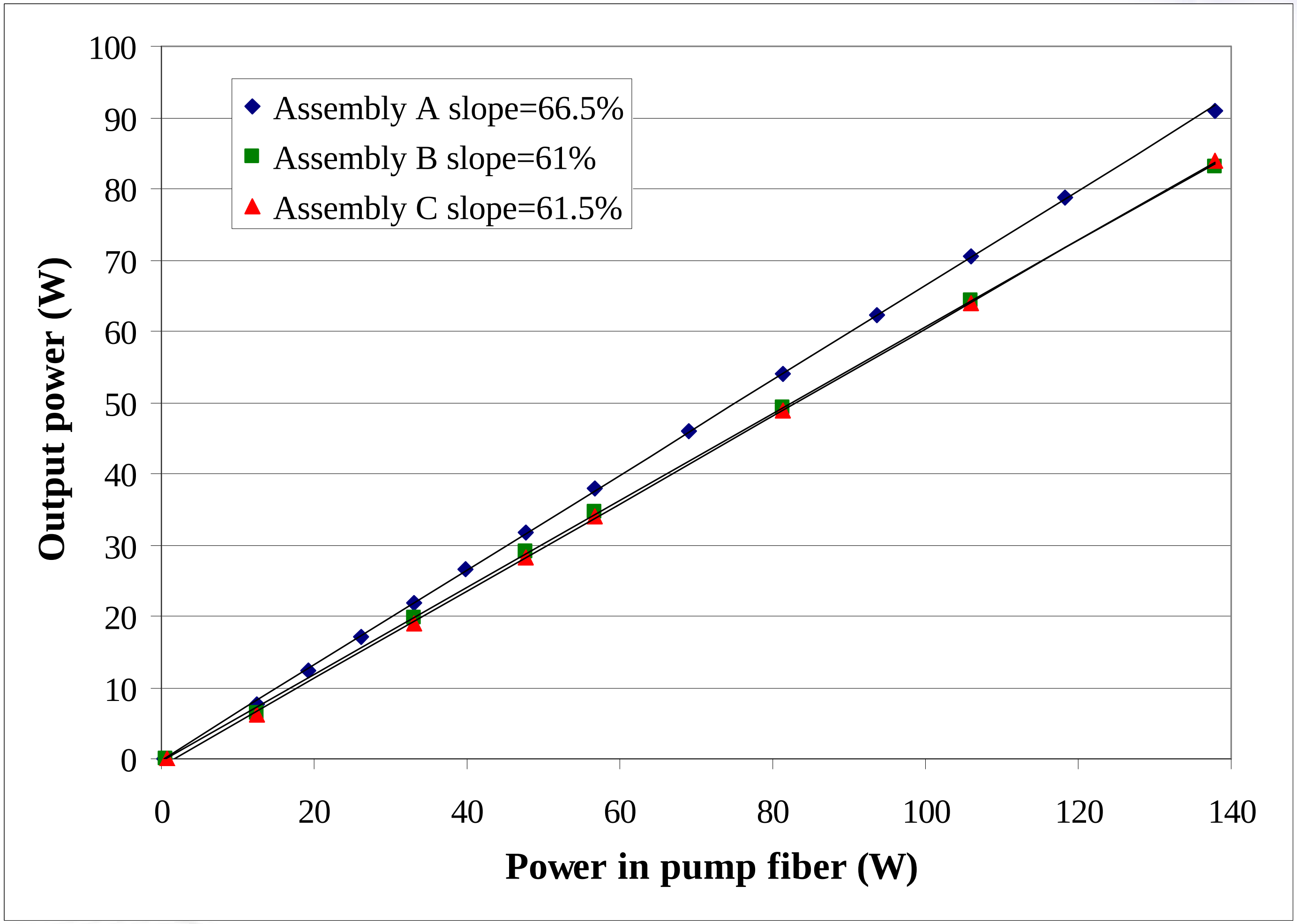

Fig.4 Laser efficiency of the three modules

Laser: Experimental Results 2

- The **output spectra** were measured using an optical spectrum analyzer (OSA), and exhibited a good agreement with the measured reflection spectra of the fiber Bragg gratings. Assembly A was emitting at a wavelength of 1075nm and the others at 1080nm. At high power, there was slight evidence of four-wave mixing as shown in Fig. 5. At 83 W of output power, the Full-Width-Half-Maximum (FWHM) of the optical spectrum widens by about 50% as compared to low powers.
- There was **no stimulated Raman scattering** present for any of the configurations.
- The measurement of the **intensity noise** of assembly C indicated very stable operation with a standard deviation of **1%.**

Broadening of Laser Spectrum

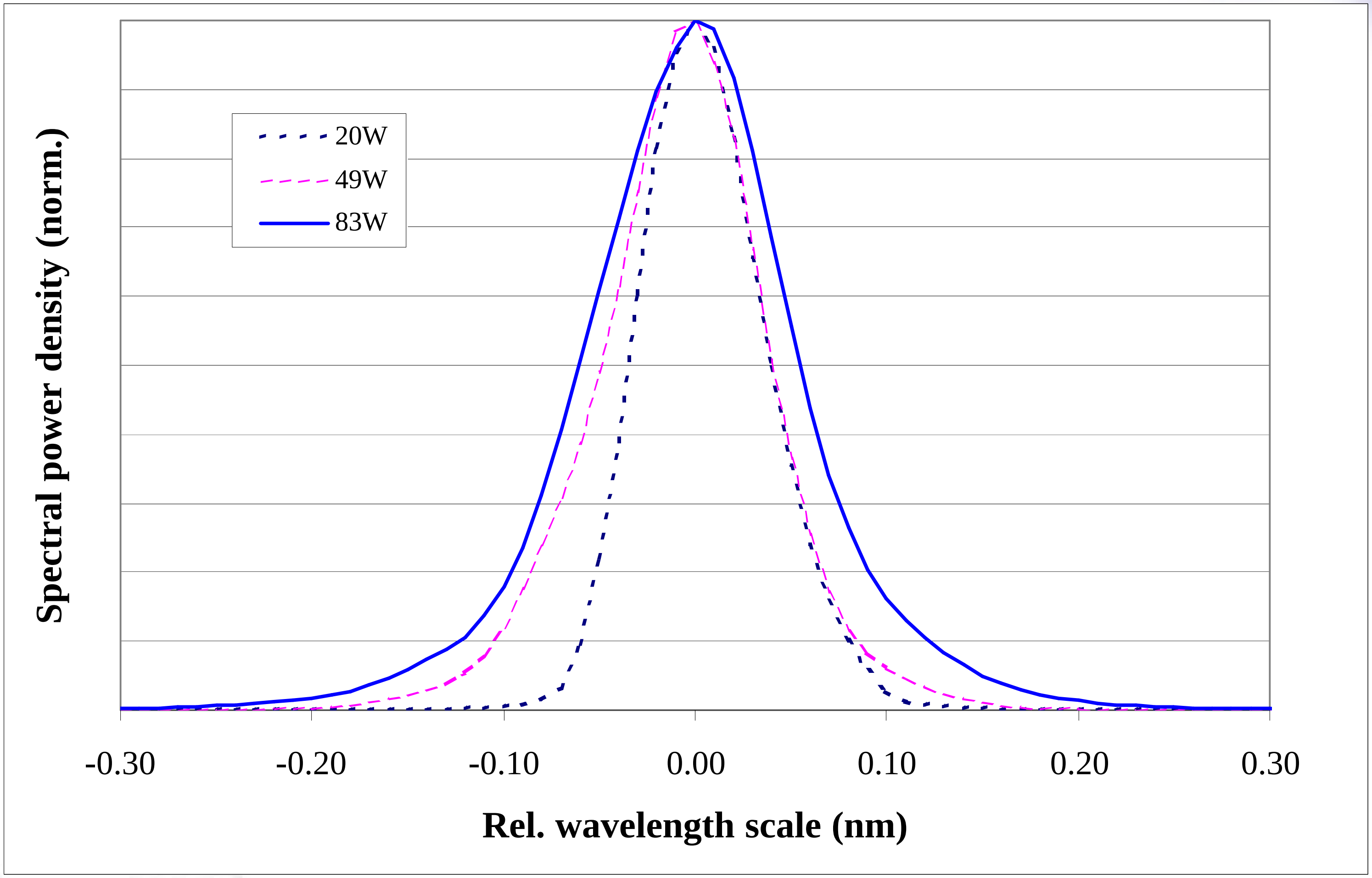

Fig. 5 Emission spectrum of assembly B for various output power levels. The broadening is attributed to four-wave mixing.

Amplifier module: See it at booth 2034!

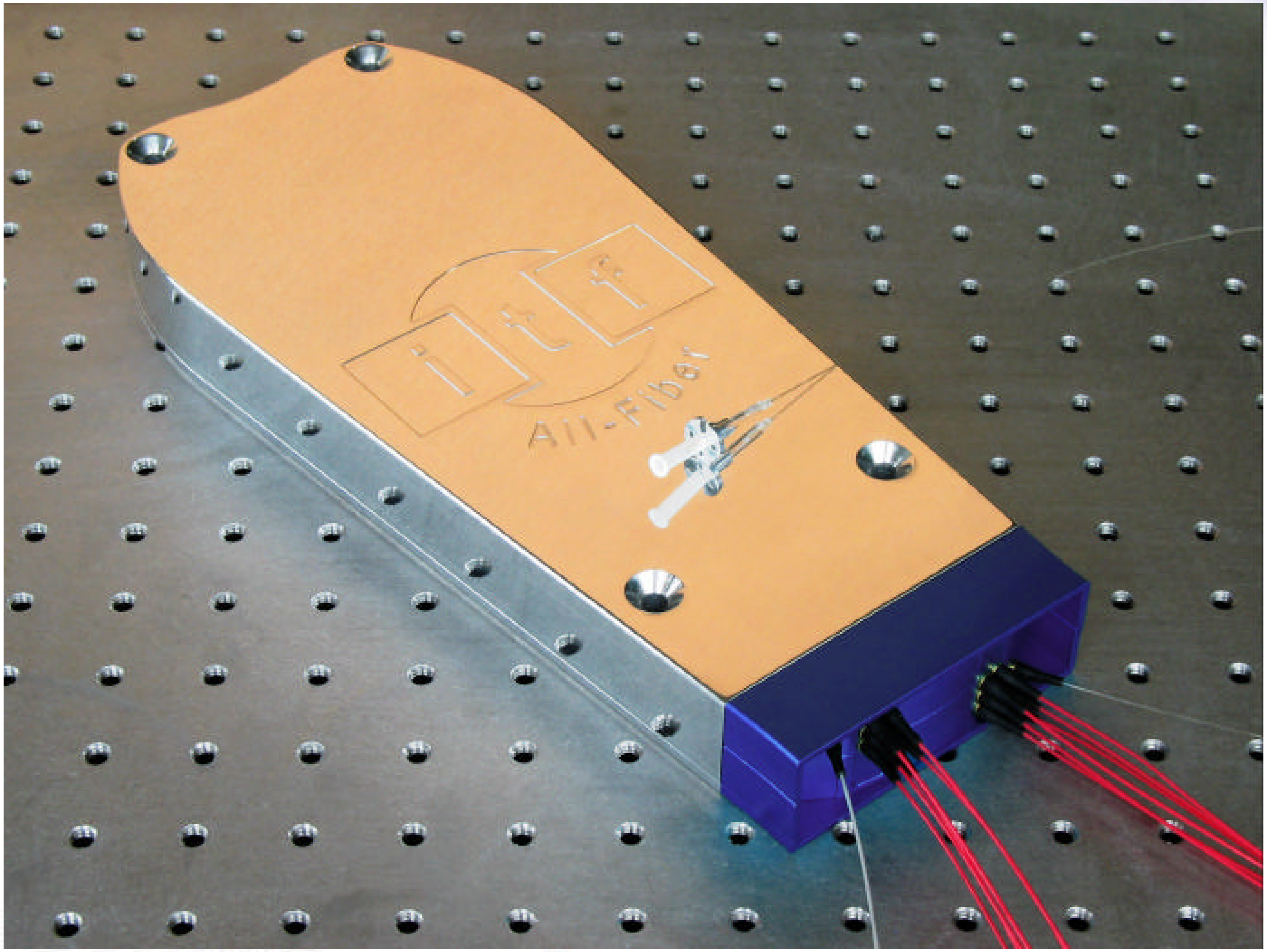

Fig. 6 Picture of the amplifier module

Amplifier Experiments

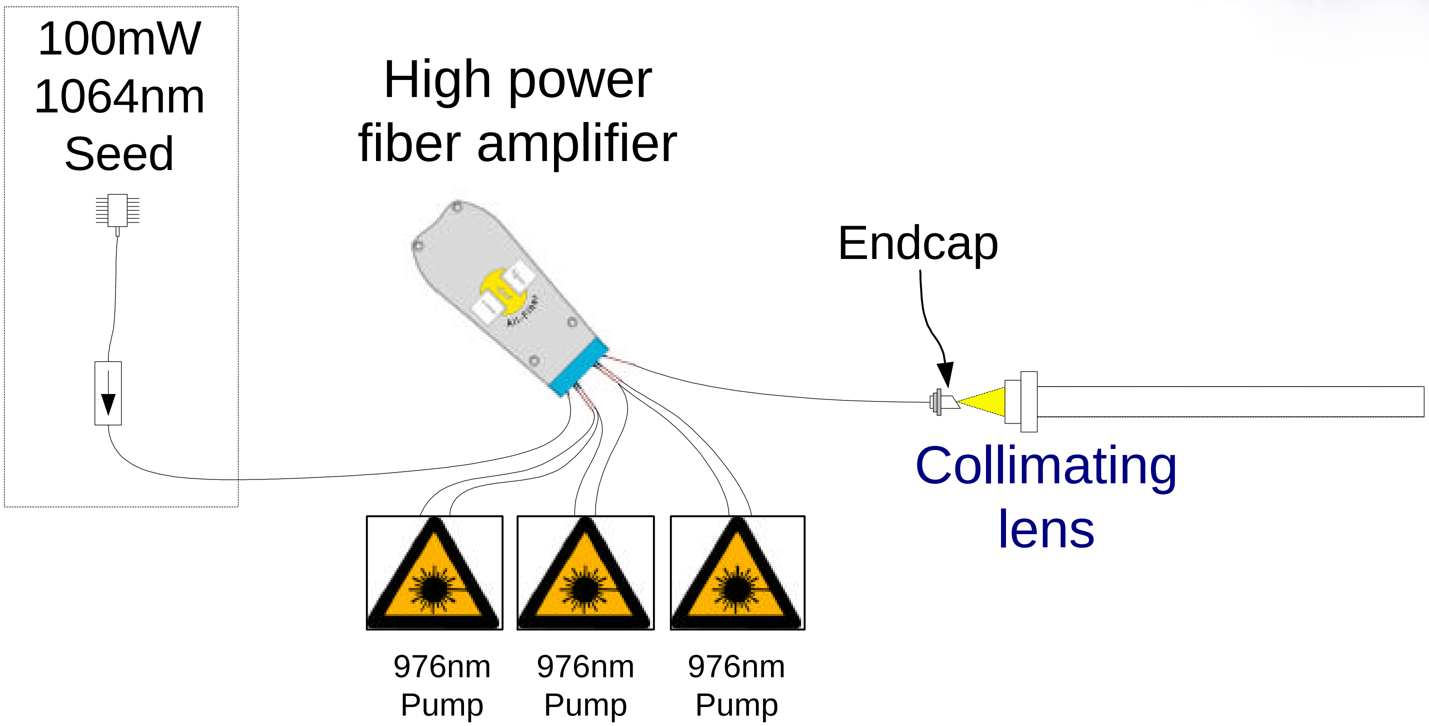

Fig. 7 Module B was also tested as an amplifier by seeding it with a 100mW laser. The signal seed was injected in the direction counter-propagating to the pump light. The angled end cap avoids reflections back into the amplifier as well as surface damage due to high peak intensity. The slope efficiency and the gain vs. pump power are summarized in Fig. 8 & 9.

Amplifier Performance: Efficiency

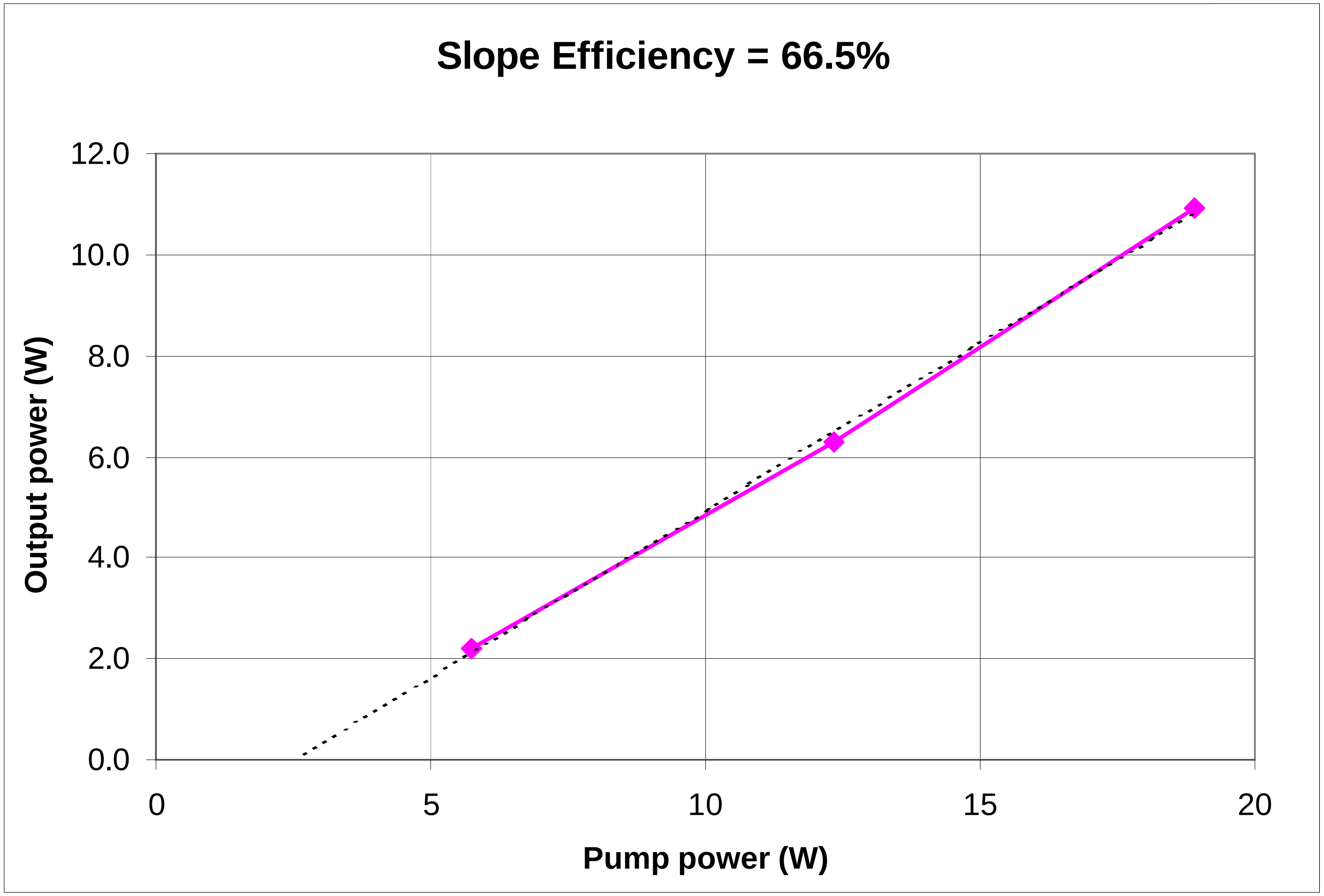

Fig. 8 Amplifier output power for a CW seed power of 95 mW.

Amplifier Performance: Gain

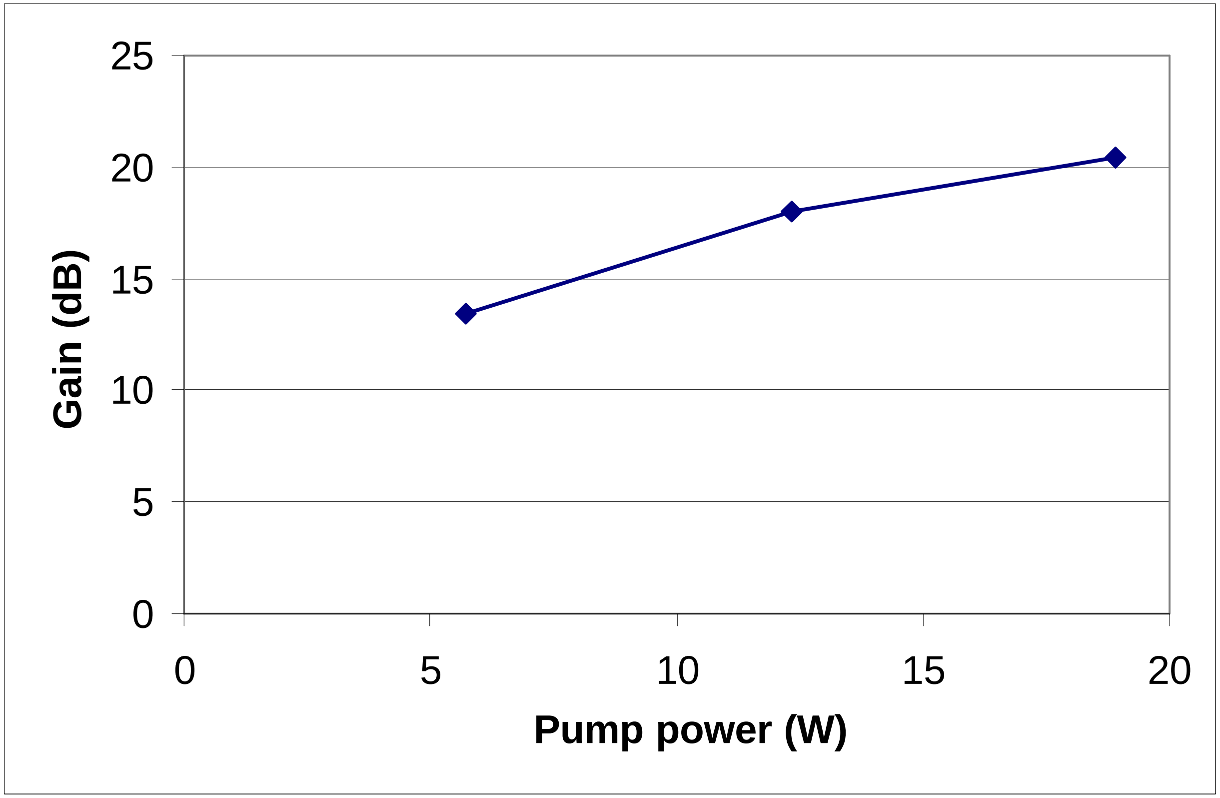

Fig. 9 CW gain vs. pump power with 95 mW of seed power.
Higher pump powers are easily achievable with a stronger seed.

Component Reliability: High Power Test at 123W

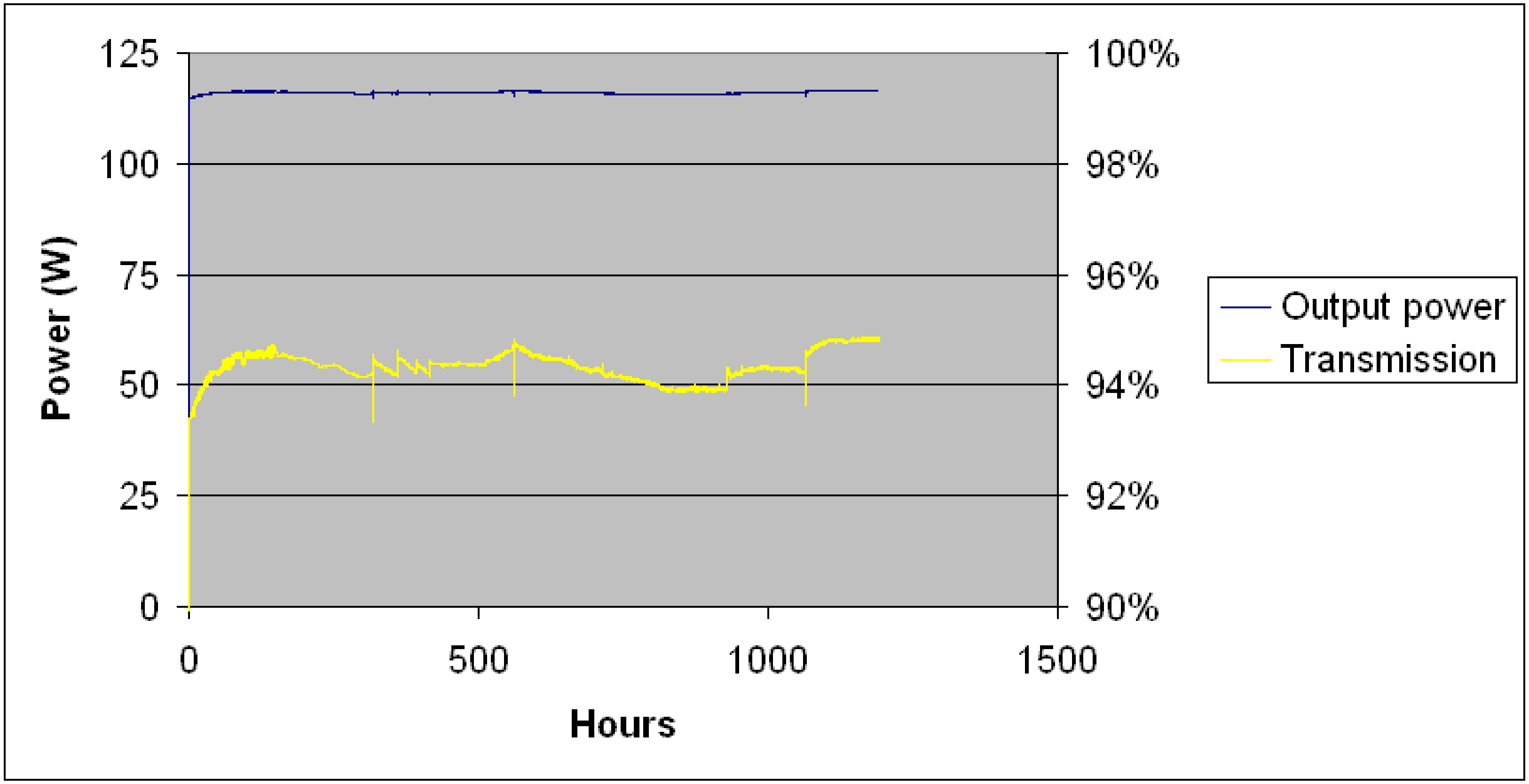

Fig. 10 Output power and Transmission of a Multi-Mode Combiner during a high power test at 123W

ITF's All-Fiber® technologies

Pump Sources

- **End pumping**
  - Nx1 for combining N pumps into one output fiber
  - (N+1)x1 for combining N pump fibers and one signal fiber is into one output double clad fiber
- **Output splitting**
  - 1xN for splitting pump power or output laser power
- **High power - large core splices**
- **Large core fiber couplers**
- **Large core fiber Bragg gratings**
- **Mode field adaptors**
- **High Reliability Packaging**

Active Fiber

Conclusions

- In conclusion, we have demonstrated up to 91W from single-stage, single-mode fiber lasers in three different configurations. The slope efficiencies are up to 66.5% with threshold pump powers around 1W.
- There was no evidence of stimulated Raman or Brillouin scattering and only a small amount of Four-Wave Mixing. One of the modules has also been tested as a CW amplifier exhibiting a similar slope efficiency.
- When testing the assembly in an amplifier configuration similar slope efficiencies were obtained.
- Further output power scaling can be obtained for Assembly C, because only half of the pump ports are used. Potential issues with the high power density at the output cleave (HI-1060 mode field diameter=6.2μm) can be overcome through the use of end caps. Alternatively, large mode area fibers can be employed, which further suppress nonlinear effects.
- Future work includes the characterization of the pulsed performance as well as the use of other gain media (e.g. Erbium-Ytterbium at 1550nm).

References:

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