High Power Fiber Lasers & Amplifiers

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Company Overview

- Private Company
- Located in Montreal, Quebec
- Founded in 1997
- 8 patents & 16 patents pending
- Approx. 80 employees
- 60,000 sq/ft facilities
- 16,000 sq/ft class 10,000 clean room
- 2,200 sq/ft for high reliability qualification
- ISO 9001 certified
- Highly automated for volume production

All-Fiber® Technology…

- **All-Fiber® technology uses optical fiber as the constituent medium**
- **Components optical properties are obtained by fusing, tapering and UV writing of optical fibers**

Filter Coupler M-Z Bragg Multimode Star Coupler

- **Optical structures are bonded to a substrate and packaged for protection and long term reliability**
- **Advantages**
  - **Superior optical performance**
  - **High power handling**
  - **Low loss**
  - **Ruggedness and low maintenance**
  - **Athermal packaging design**
  - **Flexible manufacturing processes**

Advantages of Fiber Lasers

- Excellent beam quality even at high powers or energies: Enhance the brightness by 4 or 5 orders of magnitude over the those of the pump diodes
- Ease of cooling: No thermal lensing
- Excellent overlap of pump absorption and signal mode
- Very wide gain spectrum: e.g.
  - Yb 1 - 1.15 μm
  - Er 1.5 – 1.6 μm
  - Tm 2 μm, 2.3 μm
- Very high gain achievable
- Very low quantum defect (Yb) resulting in high slope efficiency
- Light is already in the fiber and can be easily guided to the location where it is needed.
- 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 over 1kW from a single fiber have been reported.

Limitations of Fiber Lasers and Amplifiers

Fibers have a very tight confinement and long interaction lengths!

- Nonlinear optical effects scale with fiber length / (mode field diameter)^2

  Stimulated Brillouin Scattering (SBS)

  Stimulated Raman Scattering (SRS)

  Self-Phase Modulation (SPM)

  Four-Wave Mixing (FWM)

- Power damage threshold scales with (mode field diameter)^2
- Most of the high-power “fiber” laser demonstrations employed a free space cavity and a free space pump coupling setup, i.e. there is a need to go to All-Fiber solutions to fully realize the potential of fiber lasers and amplifiers.

There is a need for reliable all-fiber components & modules combining

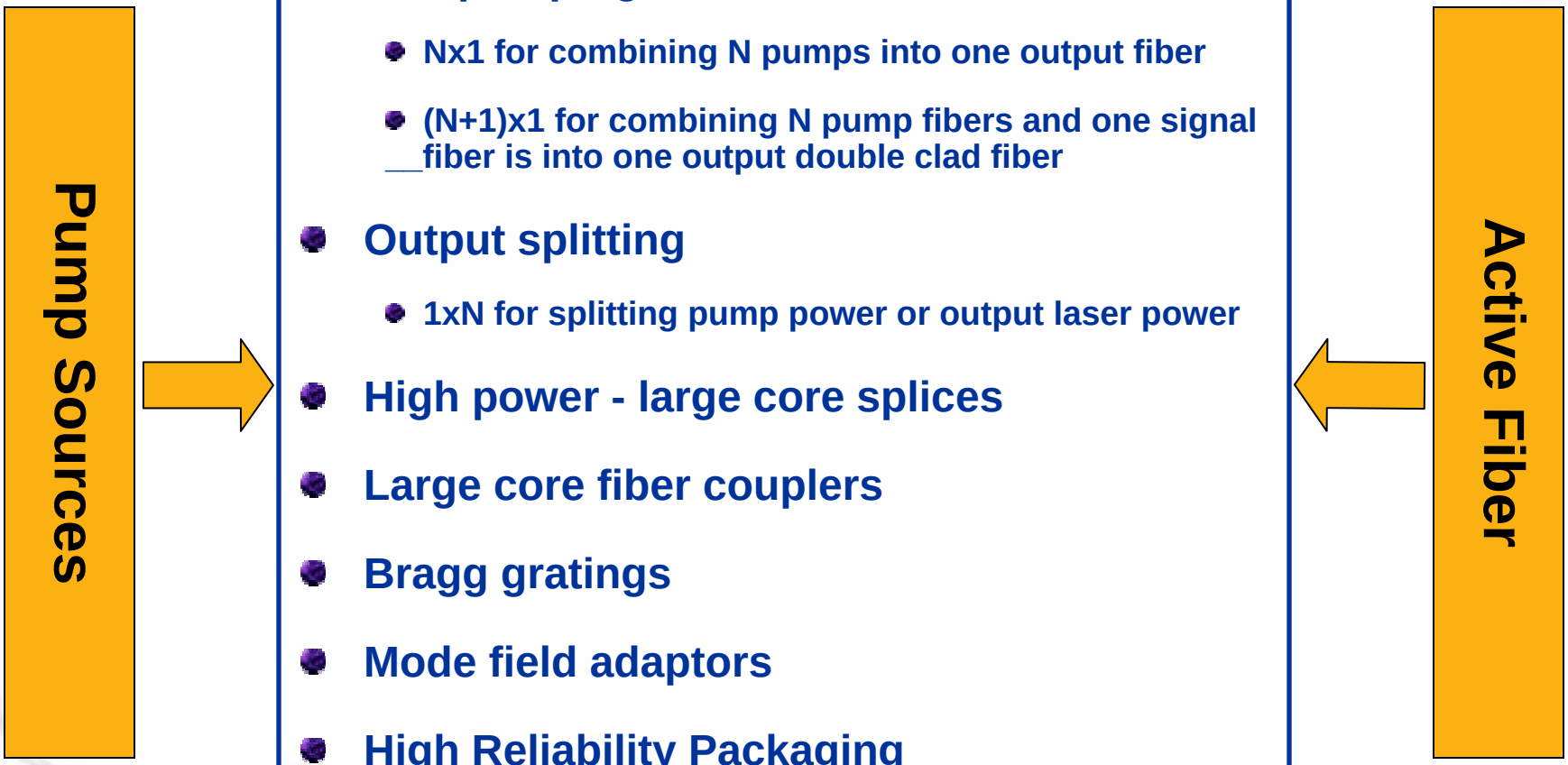
- **large mode area fibers (i.e. multi-mode fibers) with**
- **excellent modal control (i.e. quasi single-mode operation)**

Double Clad Fiber Lasers and Amplifiers

Example Fiber Laser:

Example Fiber Amplifier:

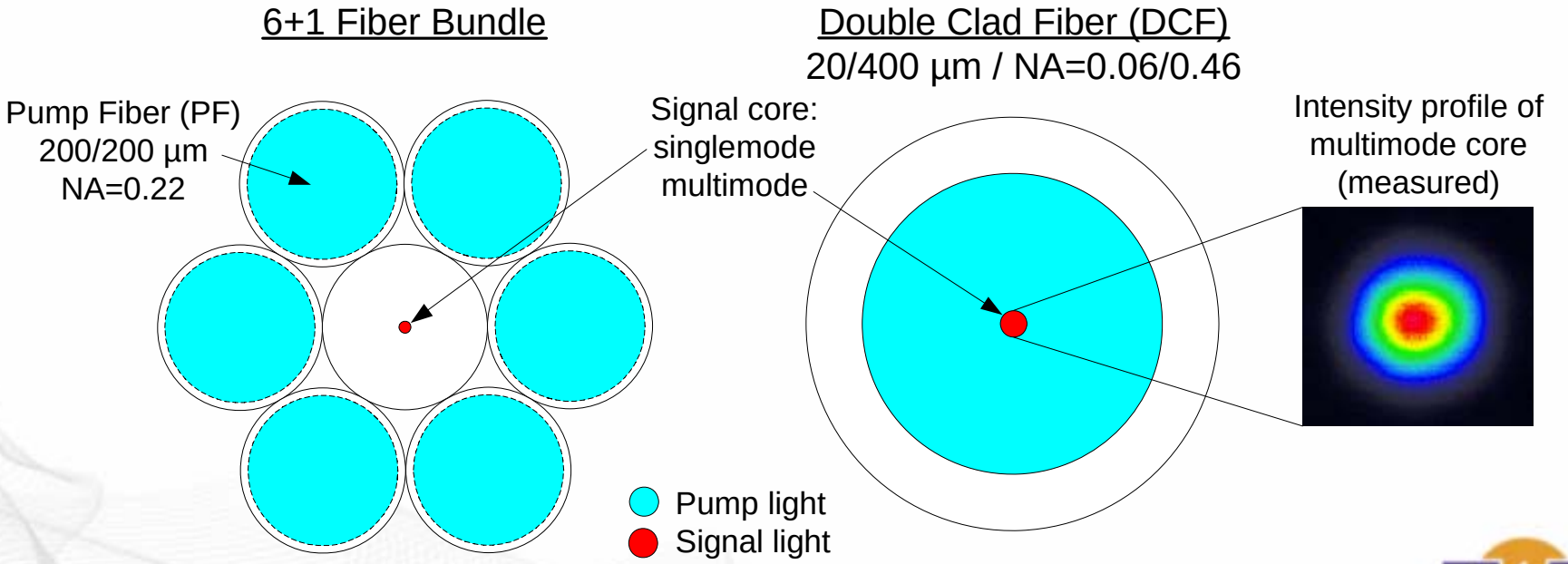
ITF's All-Fiber® technologies



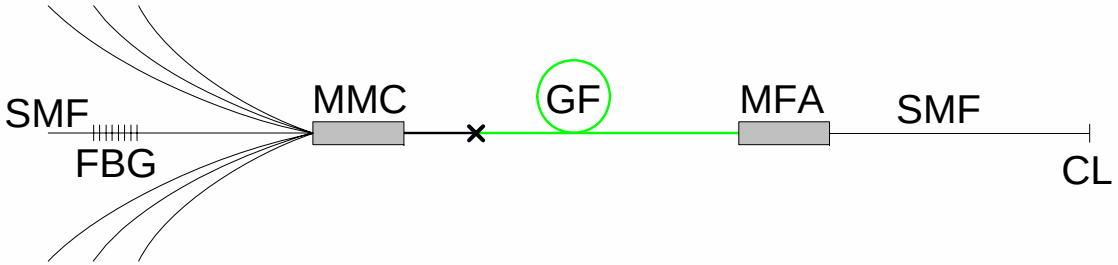
Multi-Mode Combiners and Fiber transitions

Example of a (6+1)x1 signal and pump combiner:

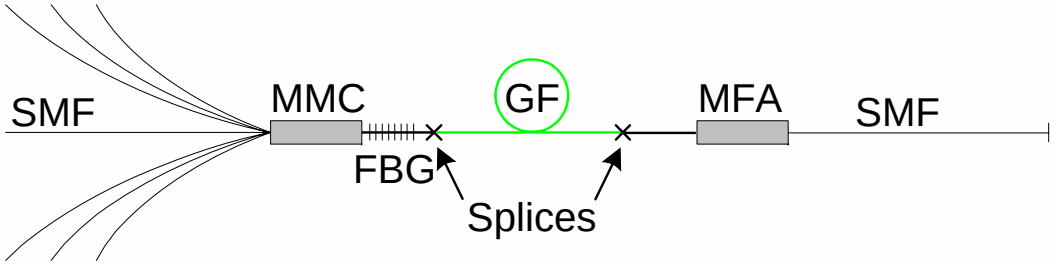
- For efficient operation as well as high quality beam output (low M^2), the signal light has to stay in the fundamental mode LP_{01} in fiber transition regions. The signal core of the Double-Clad Fiber (DCF) is multi-moded!
- The same principle in employed in Mode Field Adapters (MFA) providing an adiabatic transition of the signal mode from one signal fiber to the next.



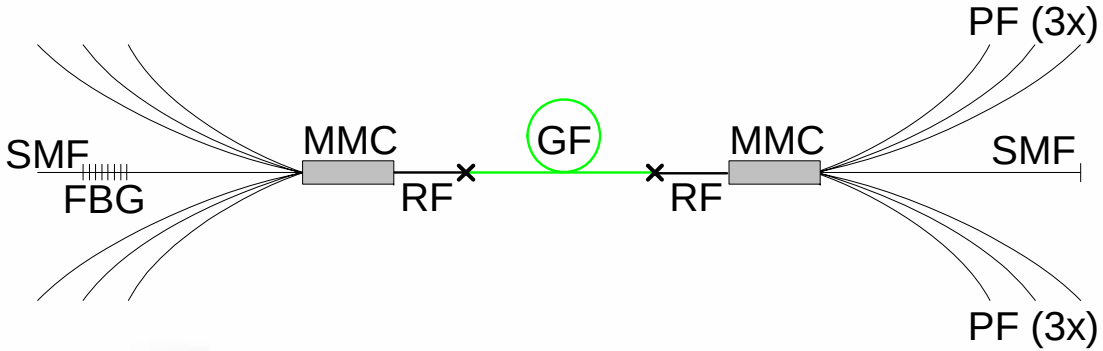
Investigated cavity designs



Assembly A



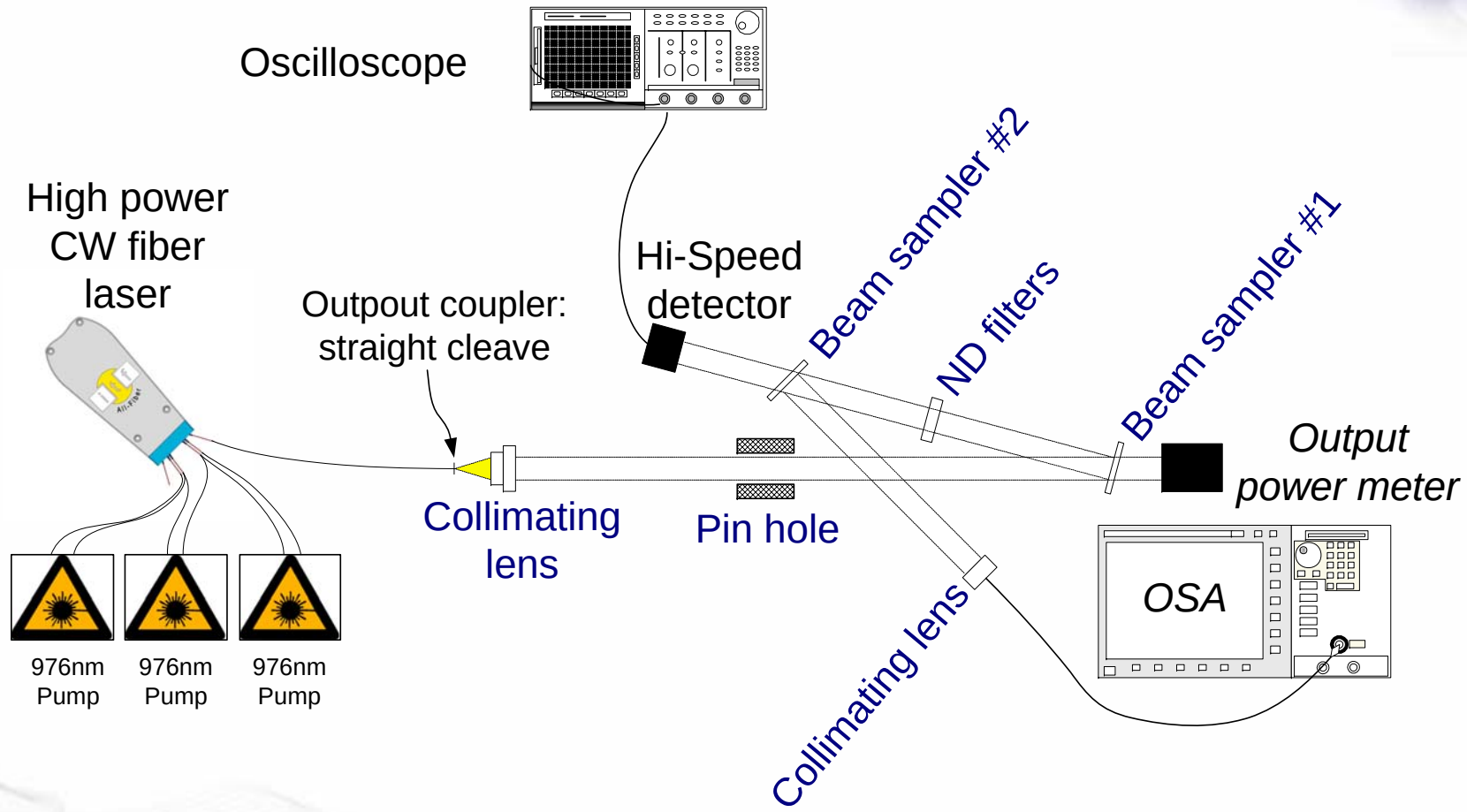
Assembly B



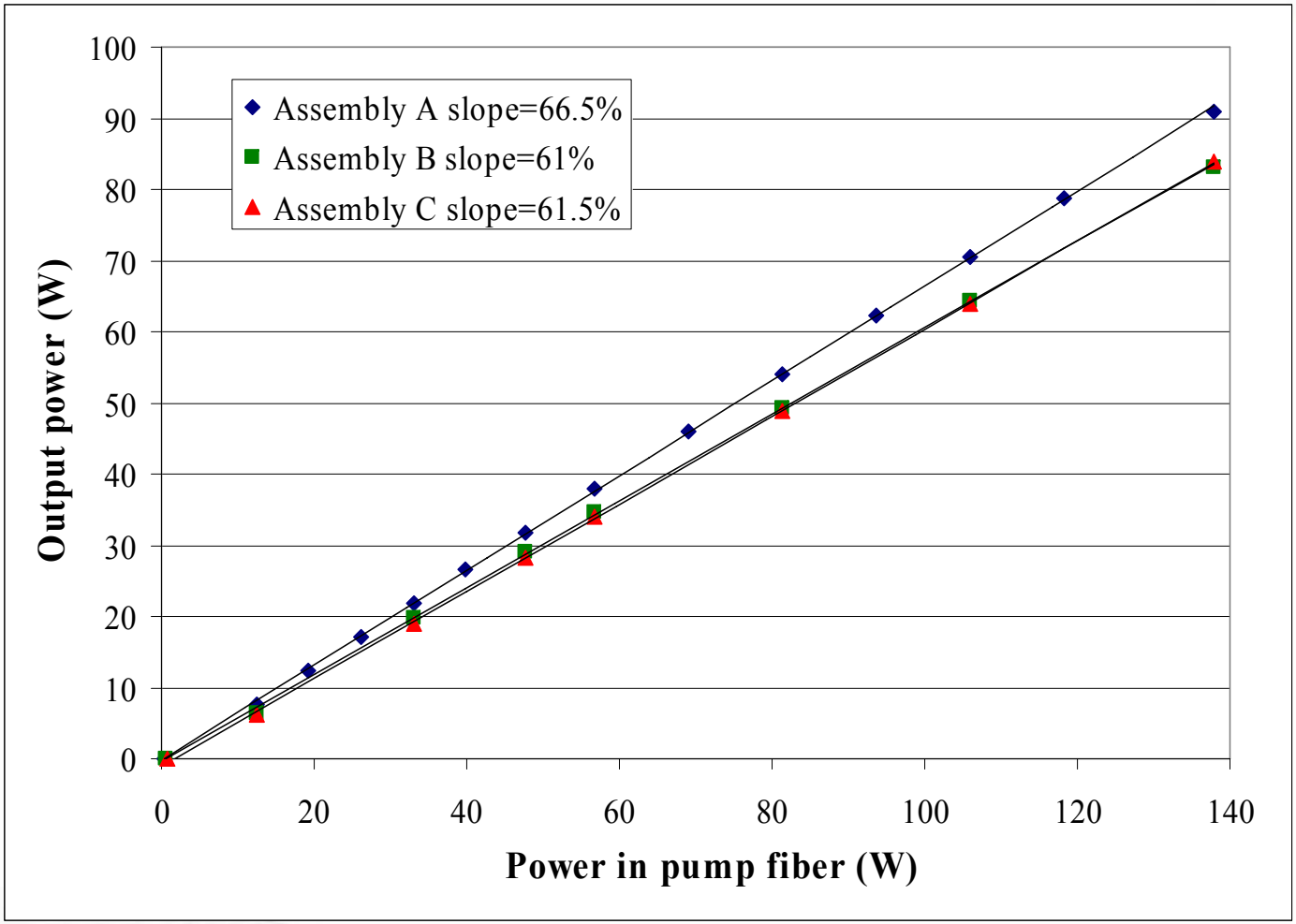
Assembly C

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,

Measurement setup



Laser Performance: Efficiency

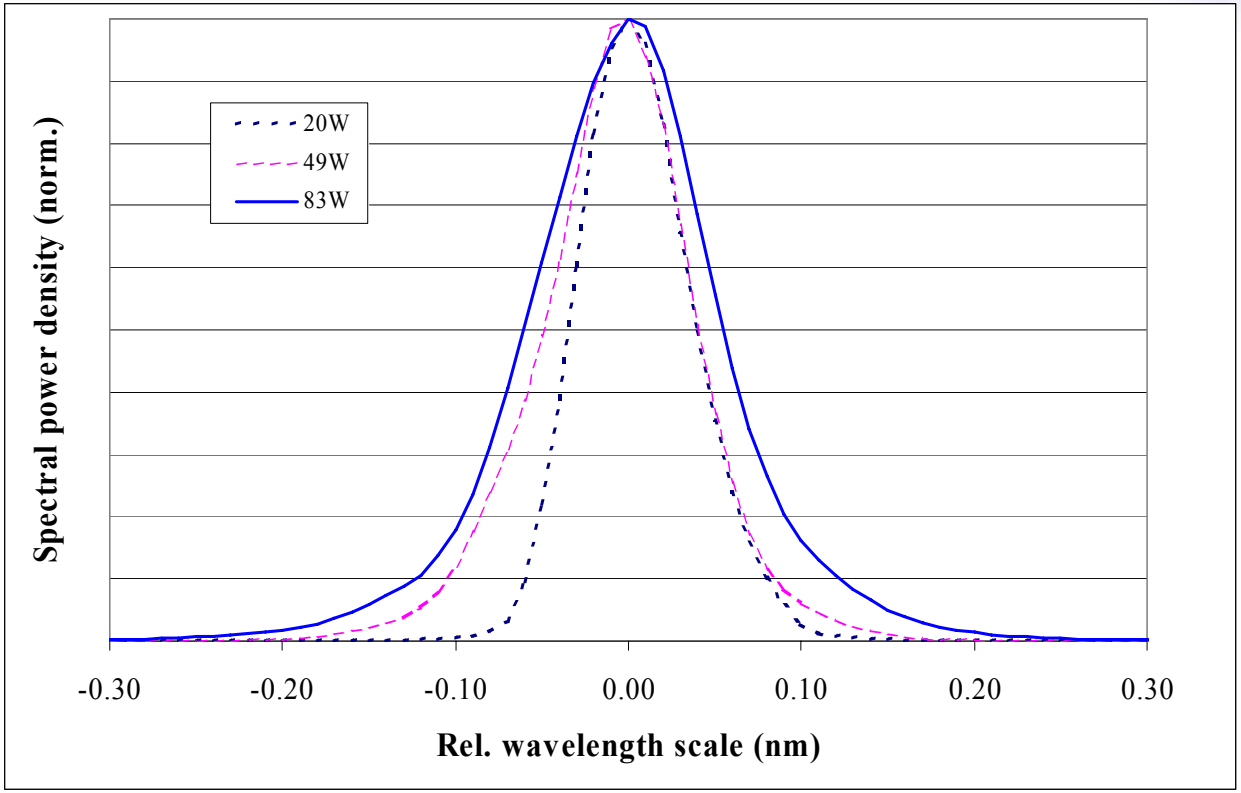


Laser: Experimental Results

- The achieved **output power** was:
  - 91W Assembly A
  - 83W Assembly B
  - 84W Assembly C

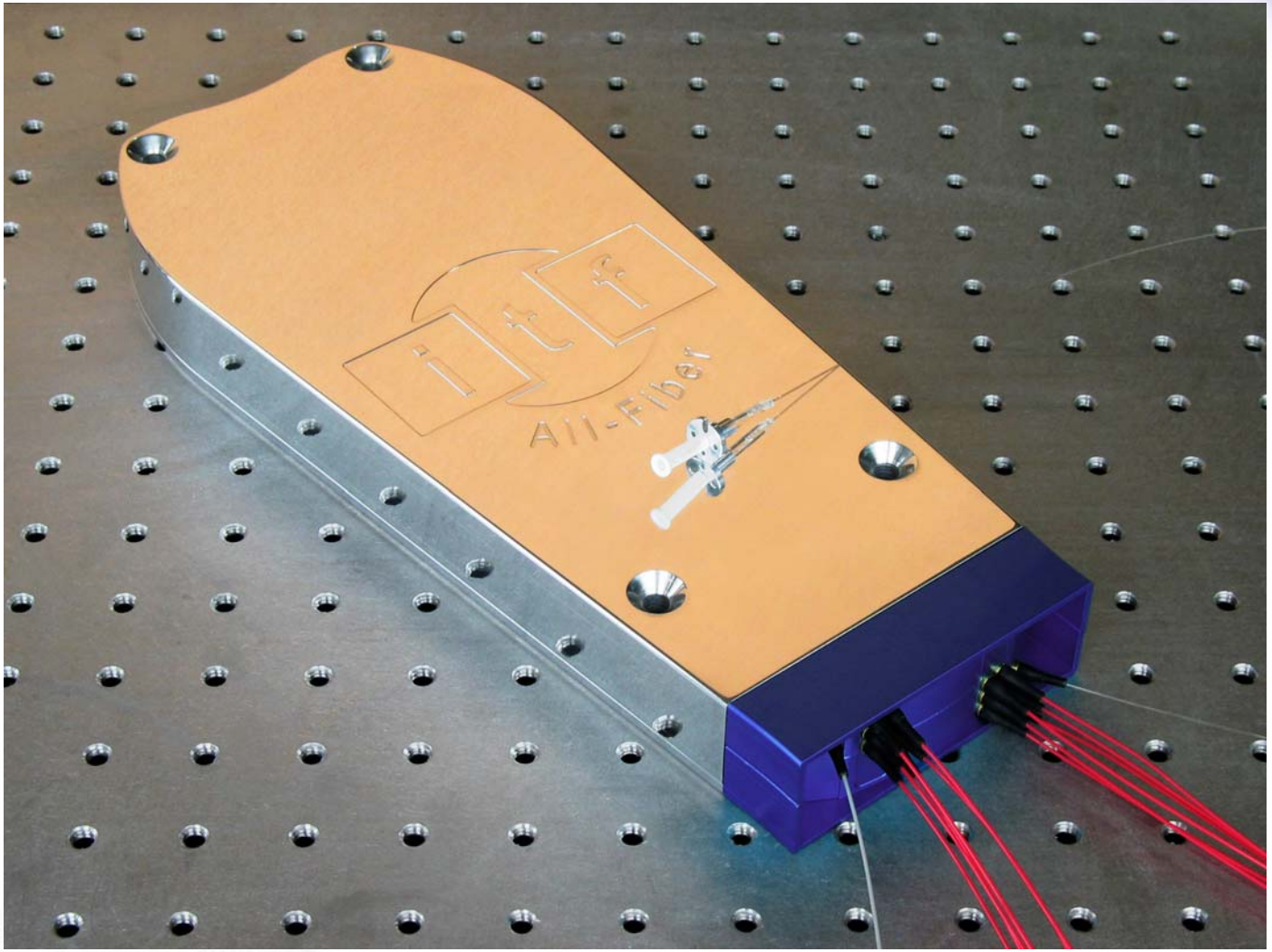
  using a total pump power output of 138W from the pump modules.
- All curves show a very linear behavior without roll-off with **slope efficiencies** up to 66.5% and a **threshold** of less than 1W.
- The signal **beam quality** is “perfect”, because the output fiber is truly single-mode.
- There was **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

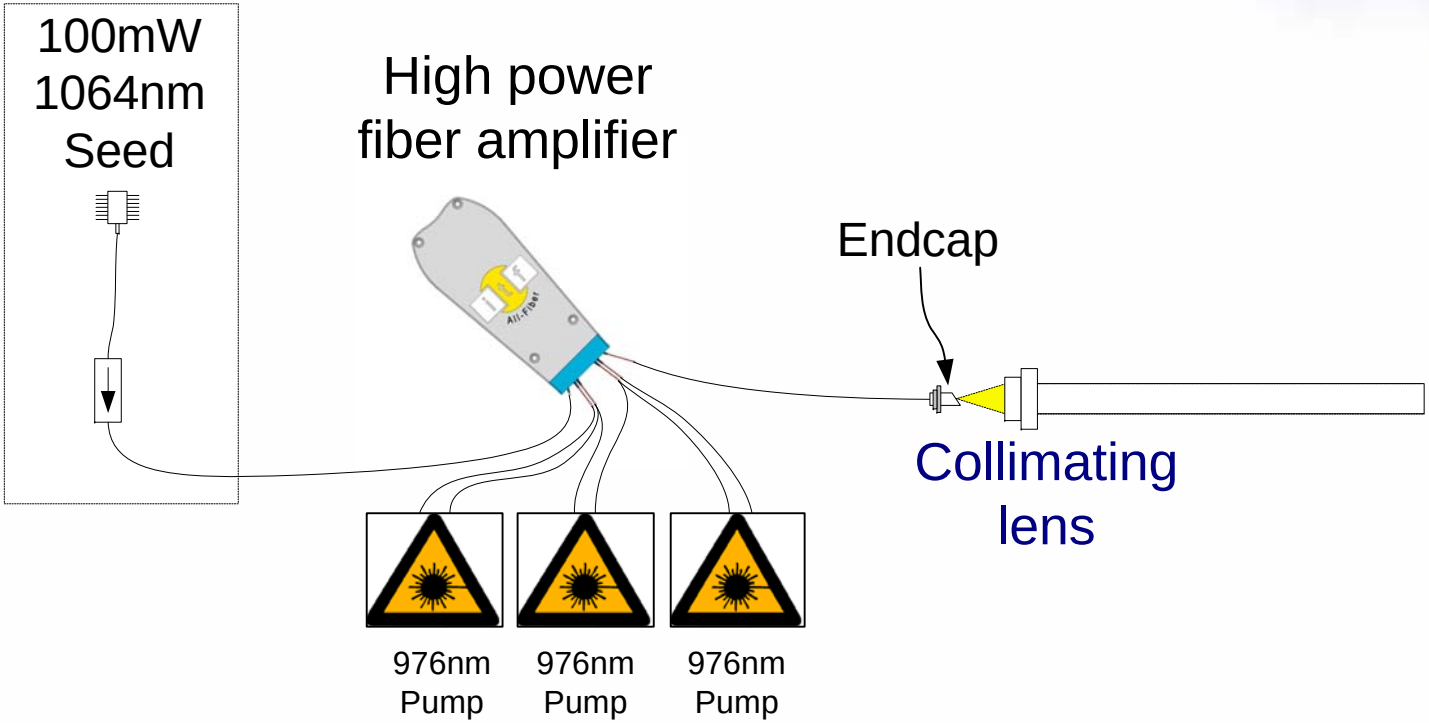


- At full power (83W), the optical emission spectrum of assembly B widens by about 50% as compared to low powers.The broadening is attributed to four-wave mixing. At 20W, the Full-Width-Half-Maximum (FWHM) of the spectrum corresponds to that of the Bragg reflector.

Design of amplifier module

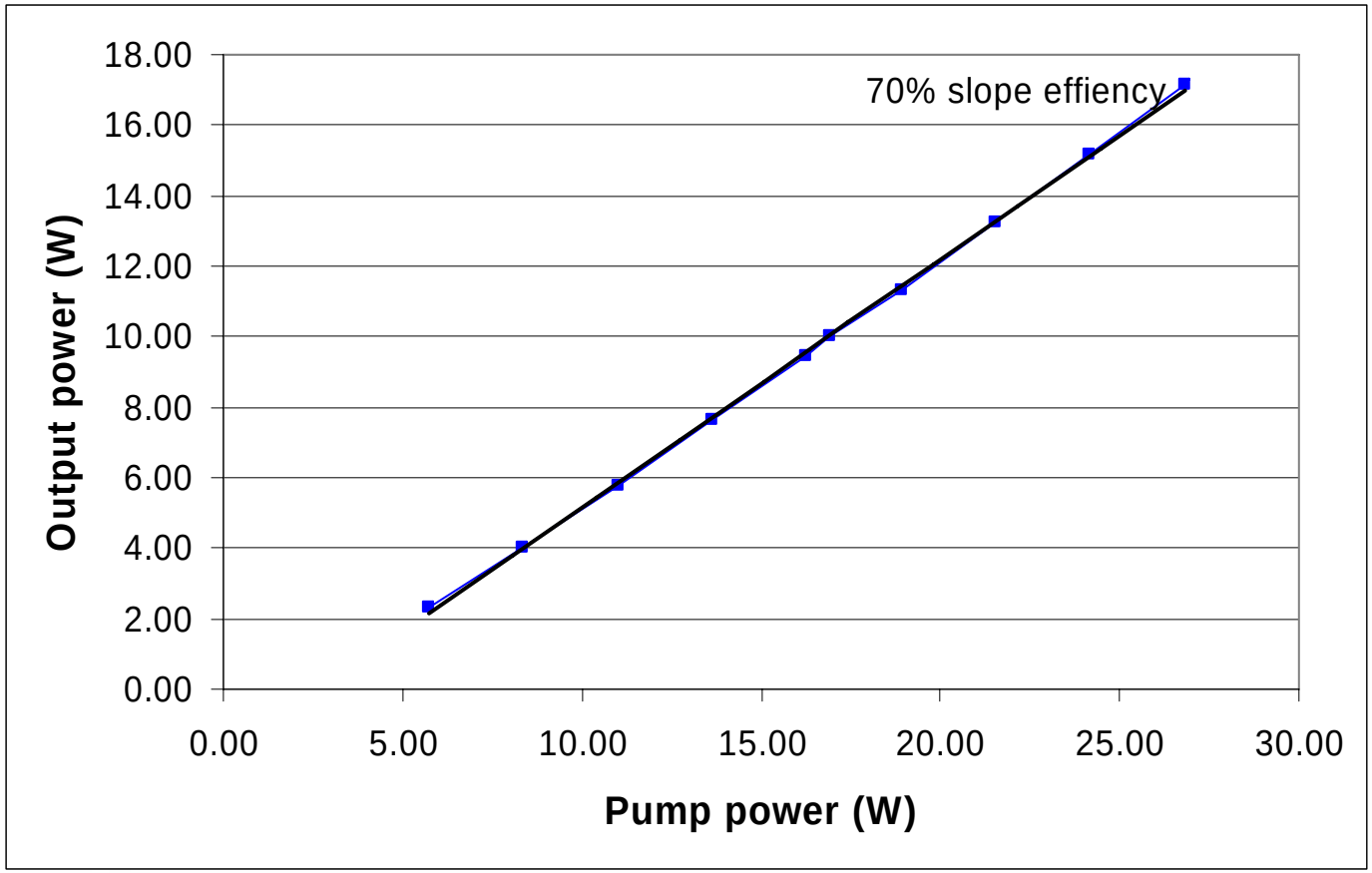


Amplifier Experiments

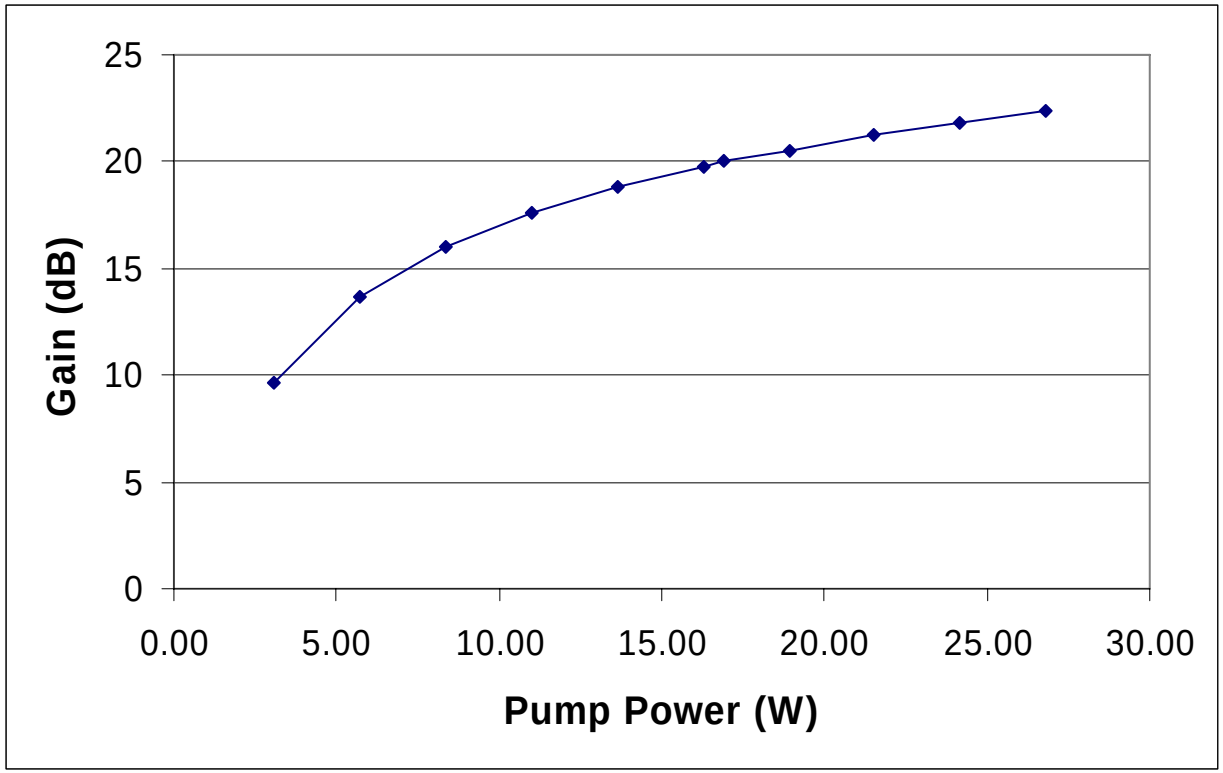


- The 100mW signal seed was injected in the direction counter-propagating to the pump light.
- The angled end cap avoids reflections back into the amplifier as well as surface damage due to high peak intensity.
- The output fiber is now multi-mode (20/400 μm fiber).

Amplifier Performance: Efficiency

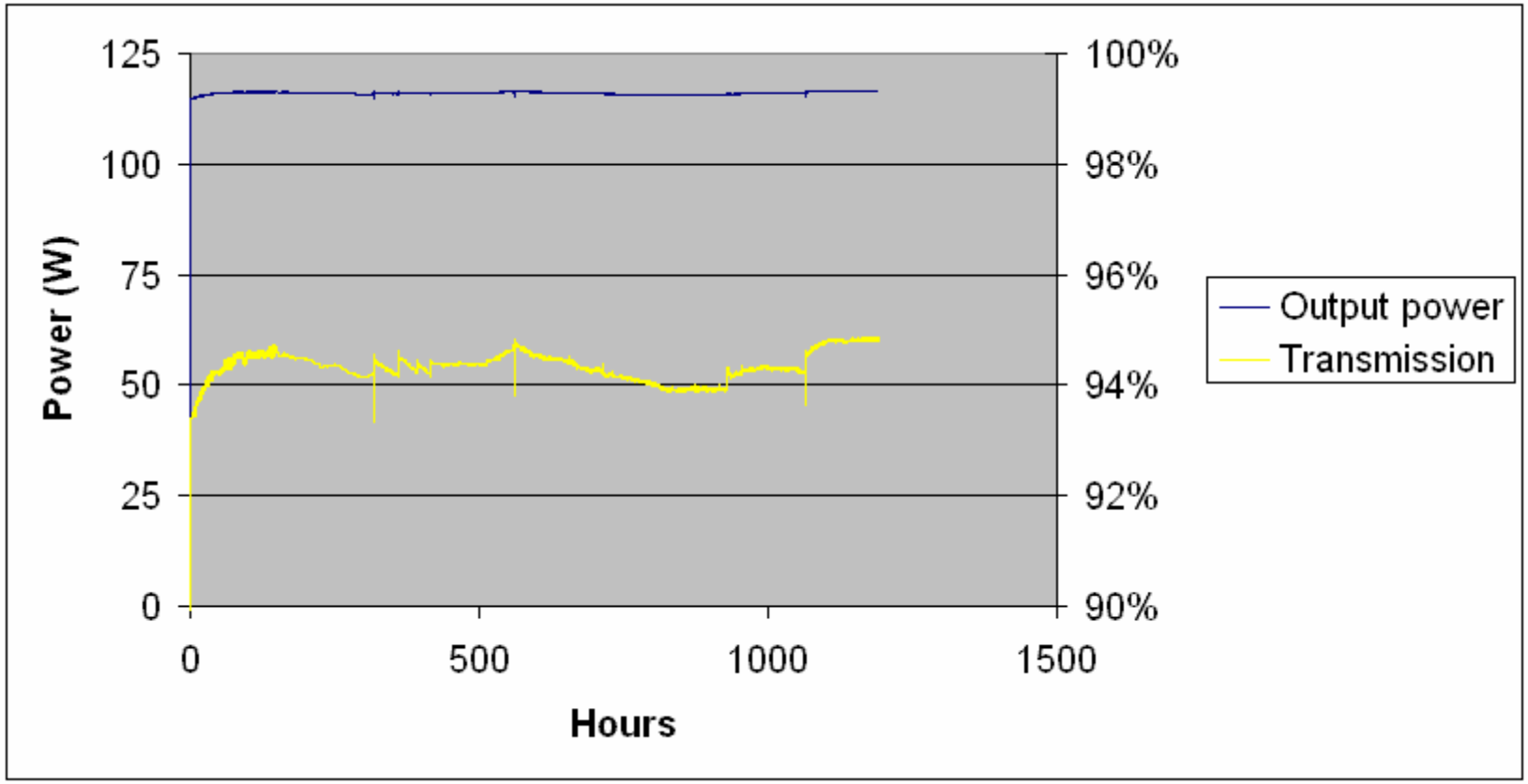


Amplifier Performance: Gain



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



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

Conclusions

Laser tests

- 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.

Amplifier tests

- Over 70% slope efficiency were obtained using a similar gain module with a CW gain of 22dB.
- The beam quality from the multimode output fiber was still very good: $M^2 = 1.2$

Outlook: Where do we go from here?

- **Power scaling:**
  - Use all pump ports and/or higher brightness pumps
  - Use larger core fibers (HI-1060 mode field diameter=6.2μm)
- **Extend wavelength to 1.55 μm range (Er-Yb)**
- **Explore pulsed performance: Target specifications are**
  - 5mJ at 1060 nm / 10ns (500kW)
  - 140 μJ at 1550nm / 10ns (14kW)