High average power, 20 ps pulses at 1 GHz repetition rate from a fiber-amplified gain-switched 1.06 μm Fabry-Perot laser diode

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SPI

Introduction

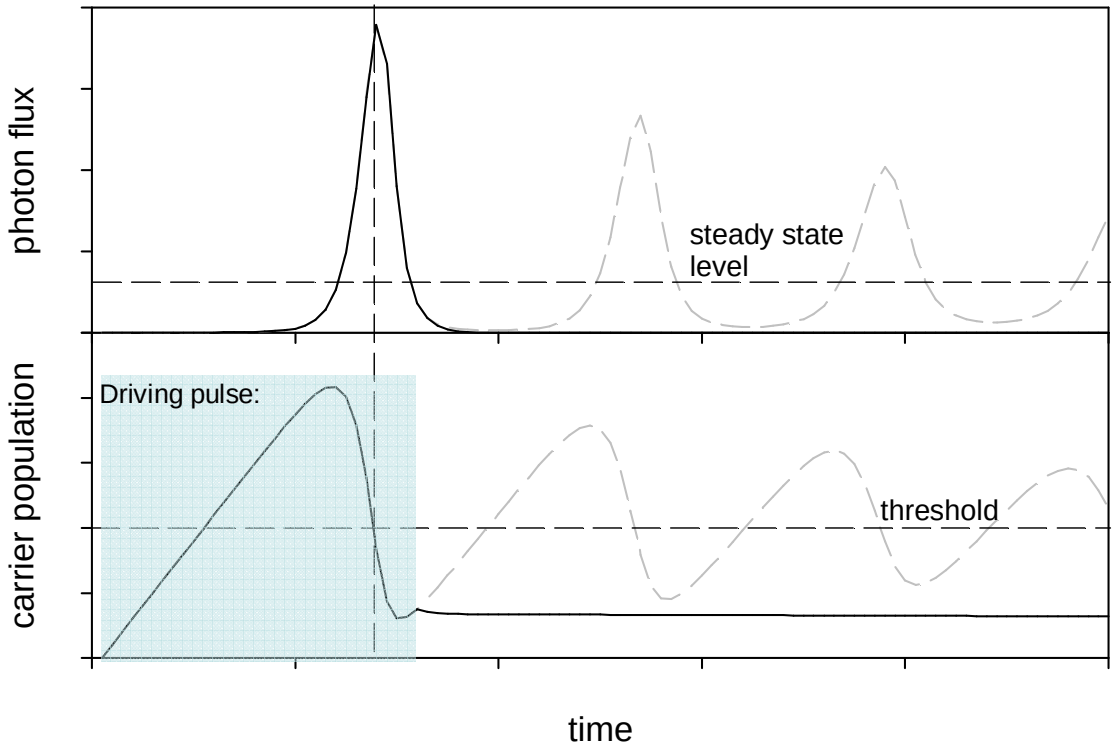
- Motivations
  - Micro-machining
  - Nonlinear frequency conversion

- Attractions
  - High-speed optoelectronic components developed for telecom applications
  - Fiber MOPAs provide a flexible and efficient way to high powers via high-gain amplification of low-power seeds
  - Electrically variable repetition rate
  - Good output spatial and spectral quality
  - “quasi-cw”

Previous work at ORC, Southampton:

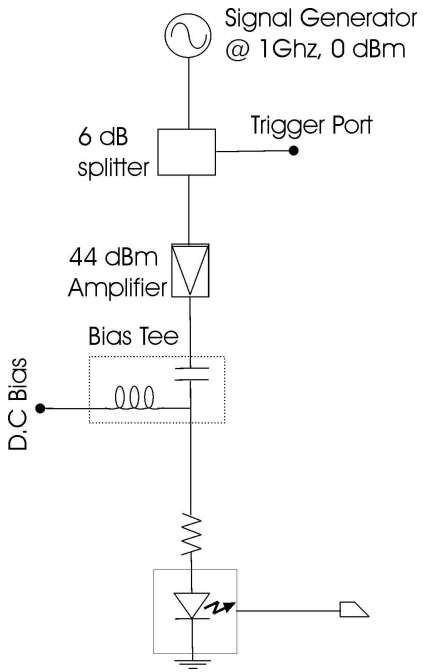
B. C. Thomsen, et.al., “60 W 10 GHz 4.5 ps pulse source at 1.5 μm,” CLEO/IQEC 2004, paper CMAA (2004).

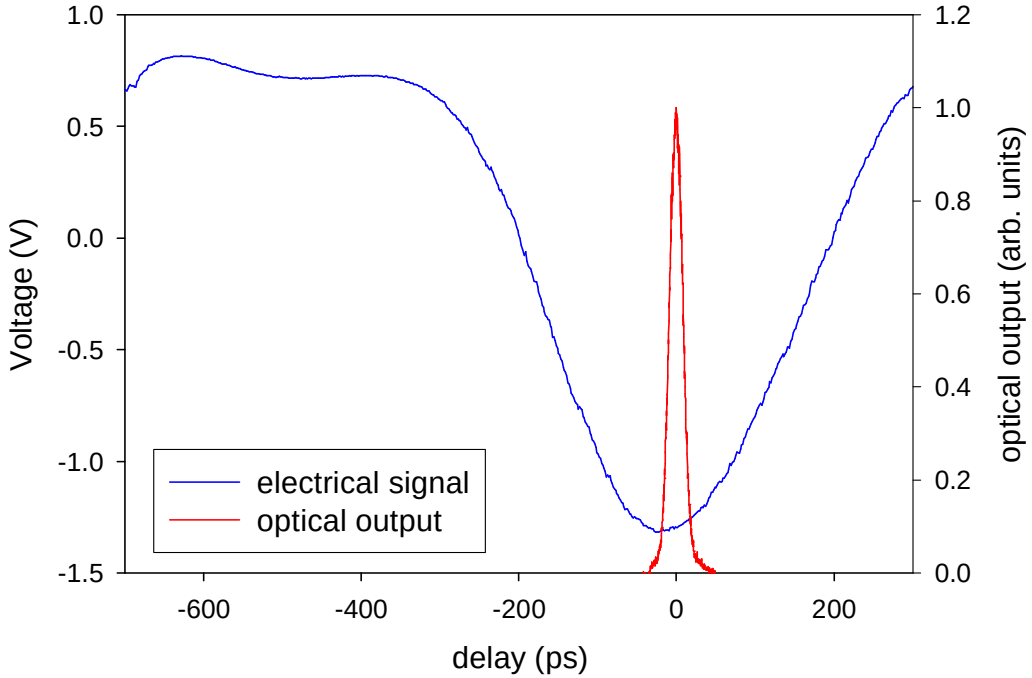
Gain-switching



- Short electrical pulses injected into device
- Leading edge of electrical pulse initiates a series of relaxation oscillations in optical output
- Terminating electrical pulse before second relaxation oscillation results in an optical pulse much shorter than the driving electrical pulse

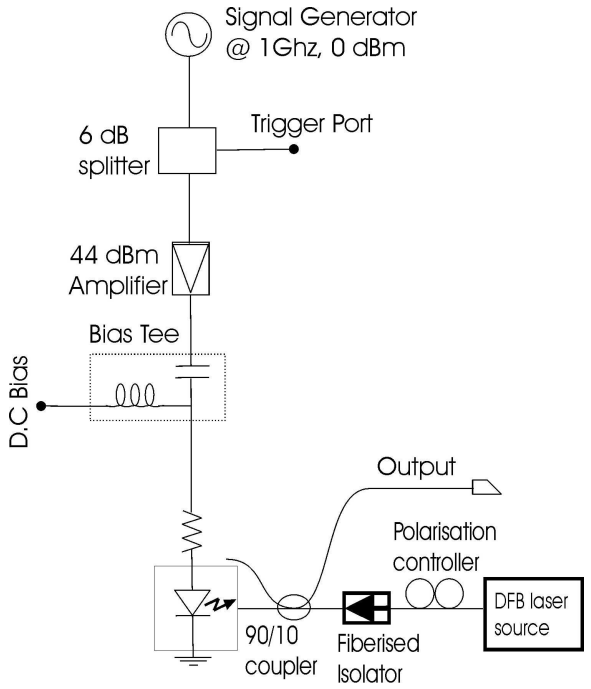
Gain switched diode laser

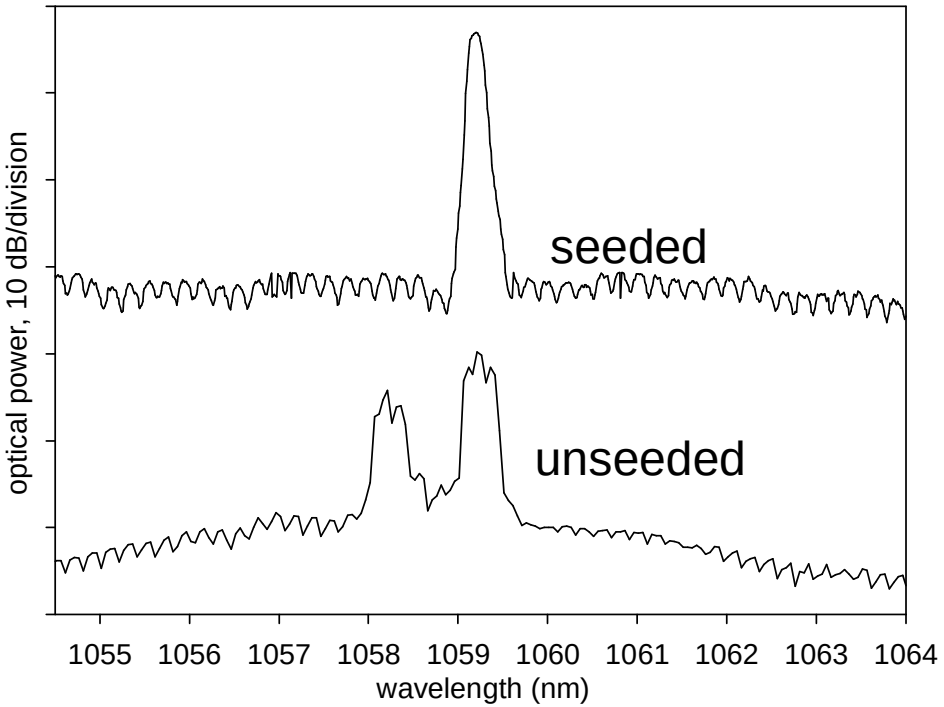




- Fiber pigtailed telecoms grade diode operating at 1060nm
- Pulse duration: 55-85 ps
- Repetition rate: 1 GHZ
- Peak power: 115 mW
- Average power: 7 mW

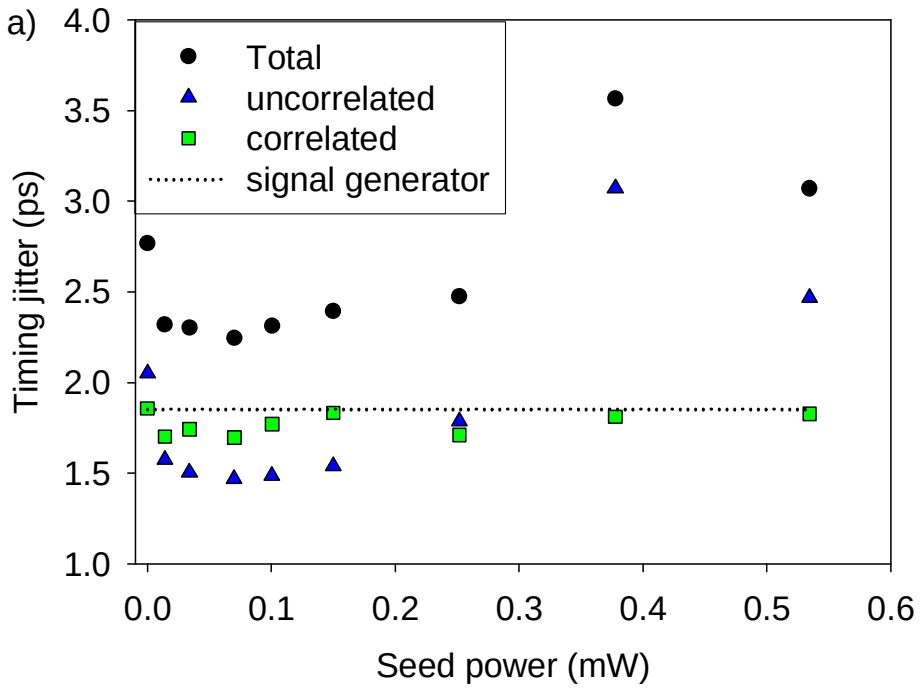
Seeding to induce single longitudinal mode operation

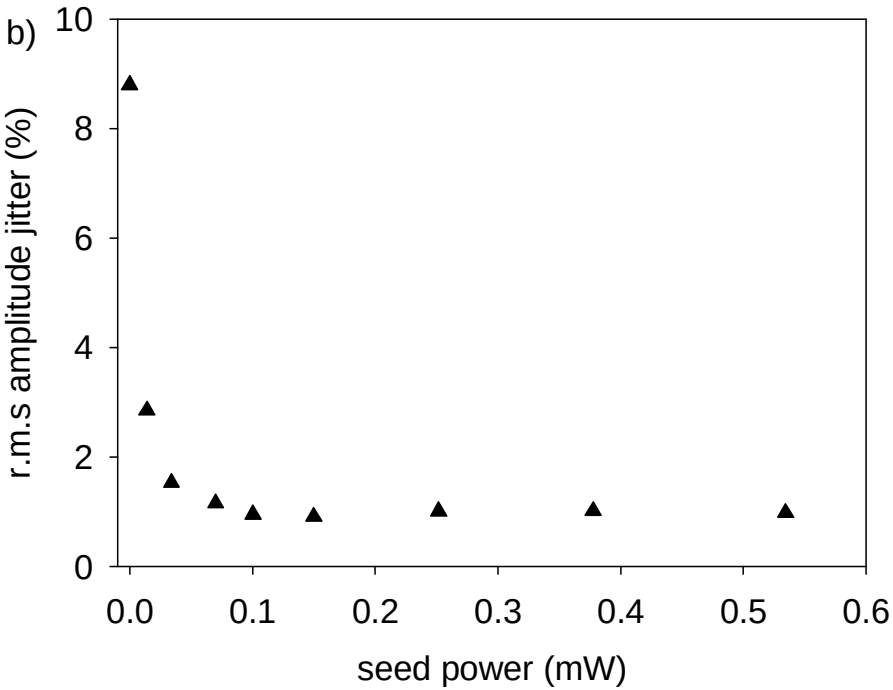




- Without external seeding, the diode lases on several longitudinal modes, and the spectrum is unstable over time
- narrow linewidth (<100 KHz) CW DFB fiber laser at 1059.94 nm
- SMSR: up to 40 dB
  - can be controlled by power and wavelength detuning of c.w. seed and by bias current on diode

Timing and amplitude jitter

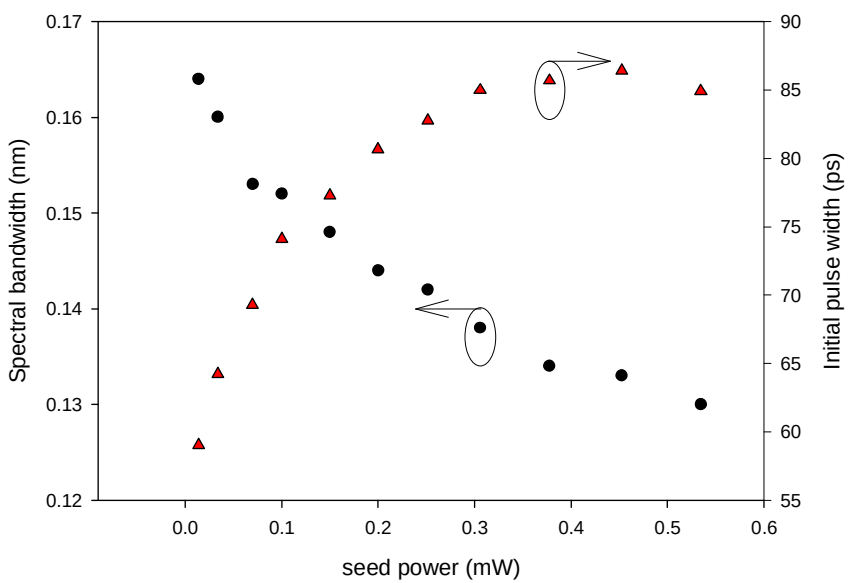


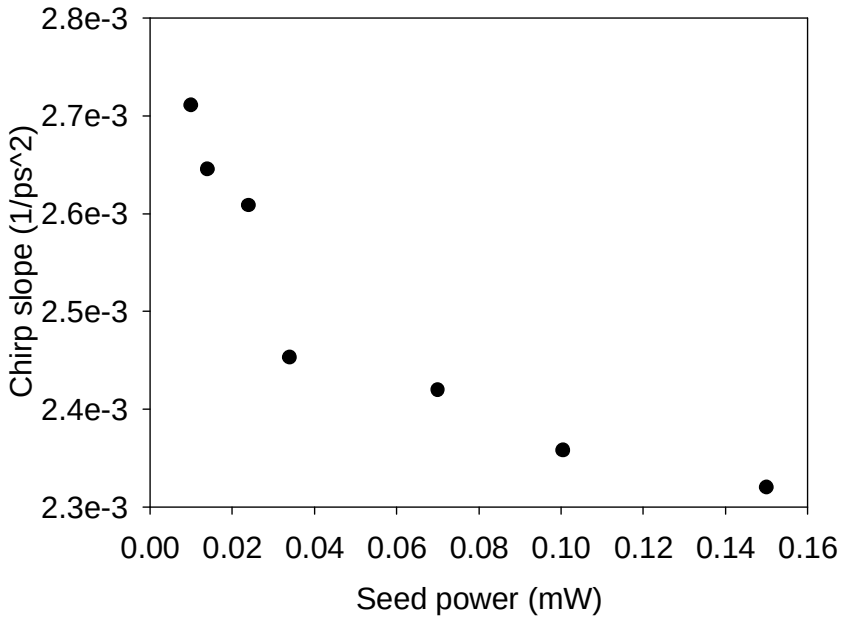


- Timing jitter ~2.5 ps (<< pulse duration)
- Largest component is correlated jitter: due to drive electronics
- Amplitude jitter ~1%

Bandwidth and Chirp

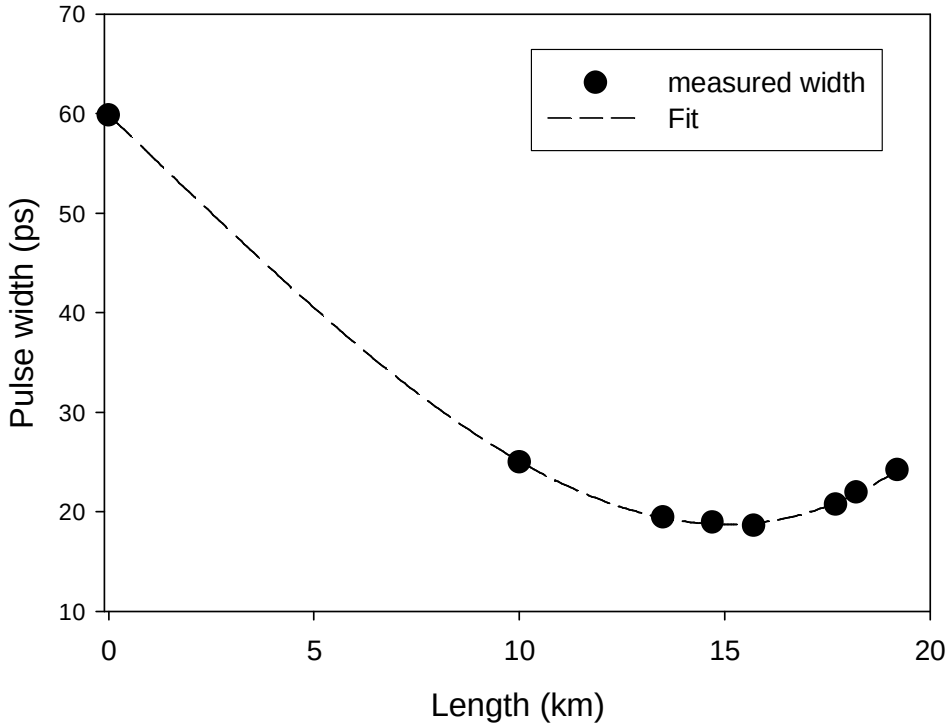
Injected seed power (mW) with spectral width (nm) and initial pulse width (ps)

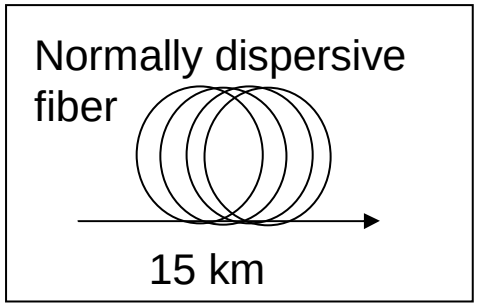


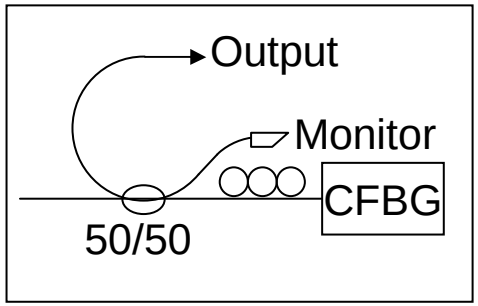


- Emitted pulse is strongly chirped
  - Carrier density drops during optical emission
  - Refractive index has dependence on carrier density
- Chirp, bandwidth and duration are dependent on c.w. seed power
- TBW product: 2.6 - 3

Chirp compensation

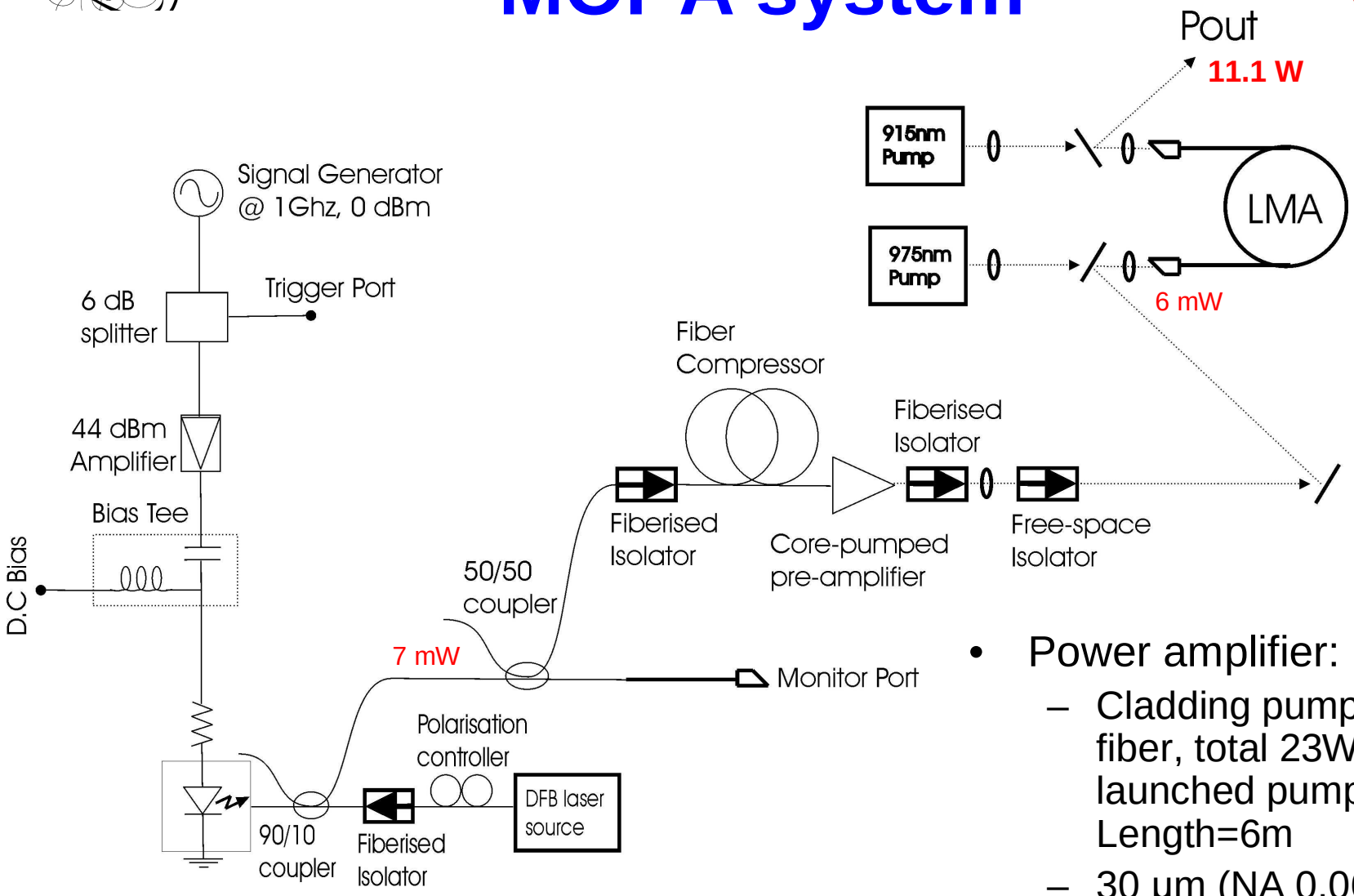






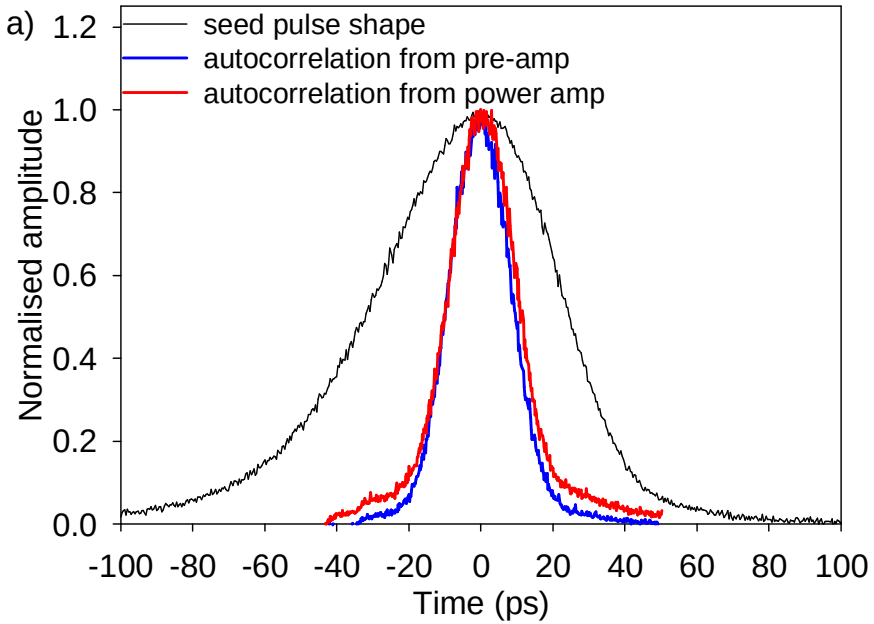
- Initial experiments: pulses were compressed in 1.55 μm single mode fiber (SMF 28).
  - Multimode at 1 μm, splicing to single mode output gives ~13dB loss
- minimum pulse duration 18.6 ps (TBW ~ 0.8)
- Later experiments used a Chirped Fibre Bragg Grating
  - more chirp control, compact, lower loss

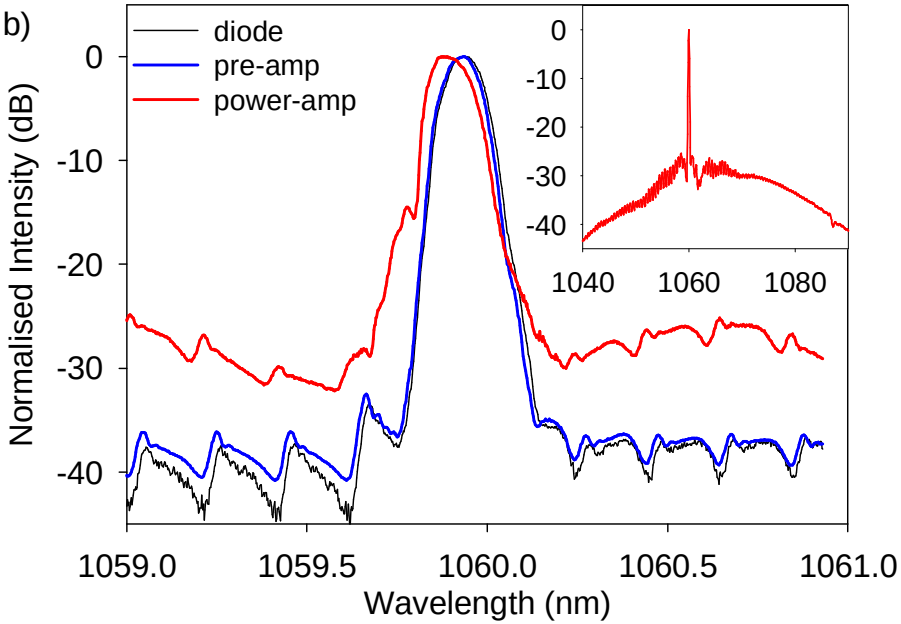
MOPA system



- Power amplifier:
  - Cladding pumped LMA fiber, total 23W launched pump, Length=6m
  - 30 µm (NA 0.06) core, 300 µm cladding, M^2=1.1

Amplified pulses



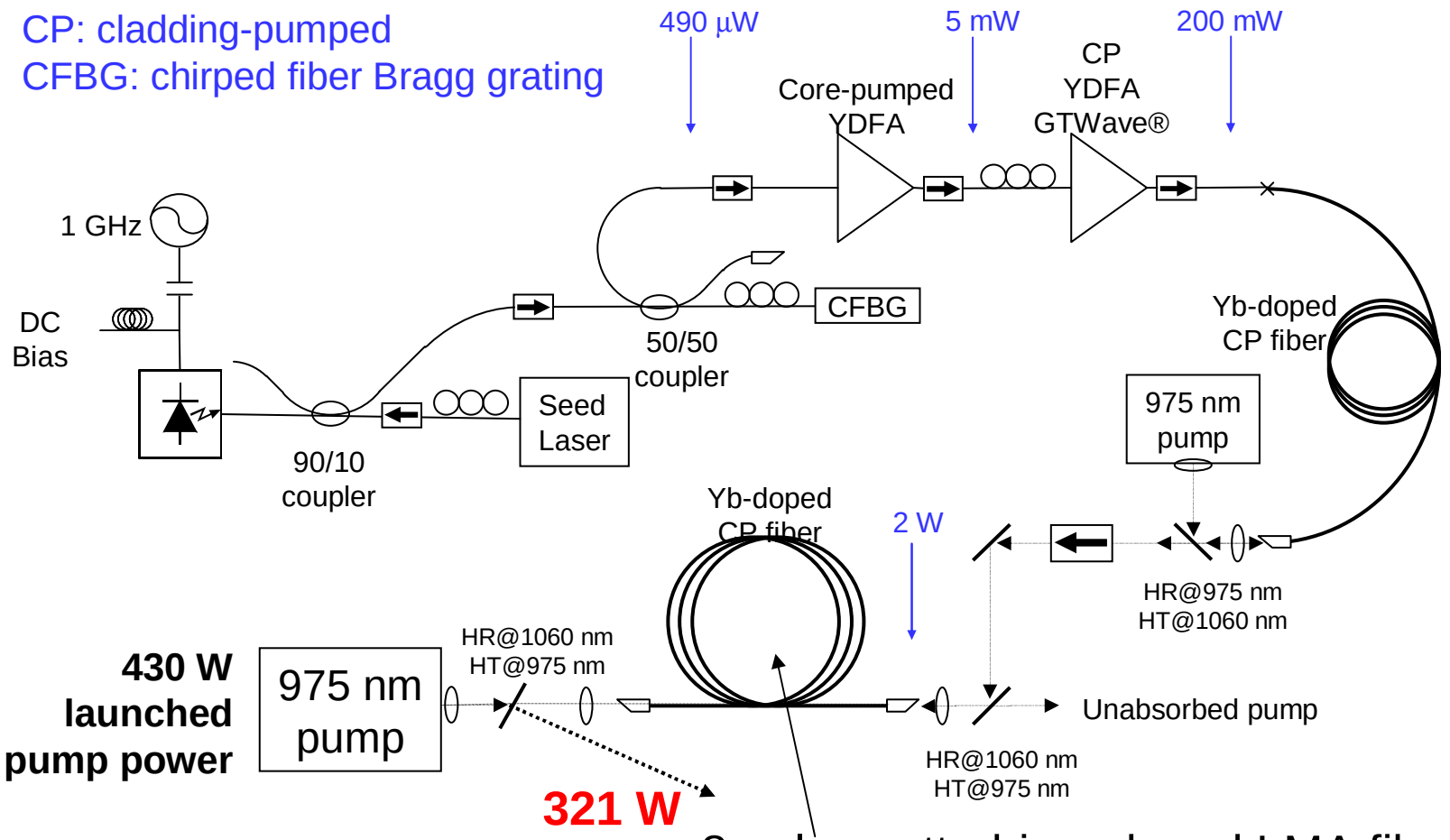


- Average power= 11.1W
- Pulse duration= 20 ps
- Bandwidth=0.2nm

- SMSR=28dB
- Peak power =0.56 kW
- M^2=1.1

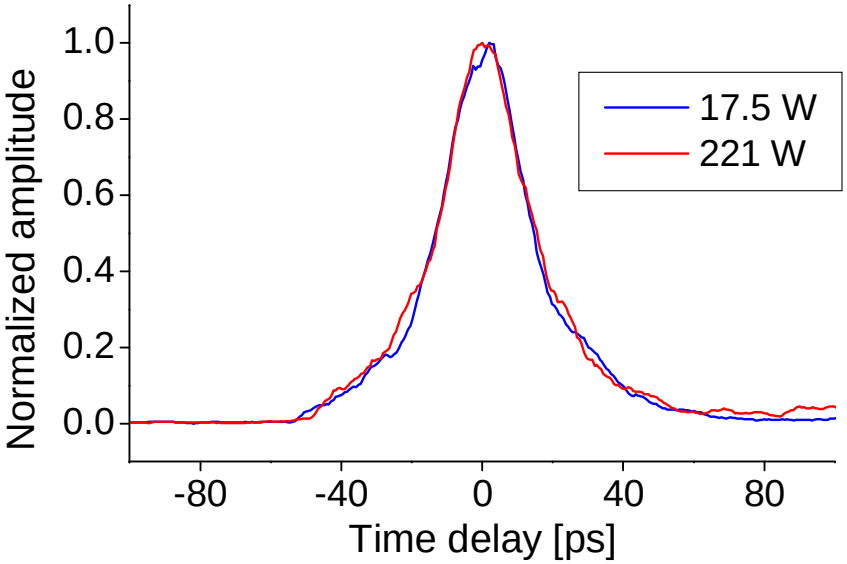
High Power System

CP: cladding-pumped
CFBG: chirped fiber Bragg grating

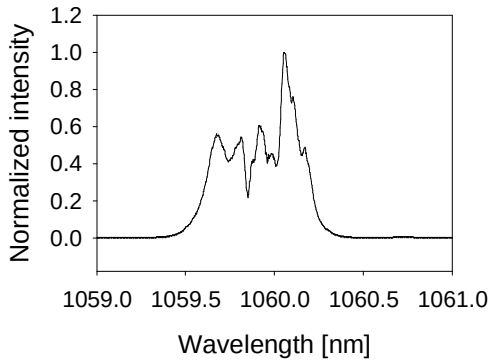


8 m long ytterbium doped LMA fiber:
Core: 43 µm diameter, NA ~ 0.09
Cladding: 650/600 µm D-shaped, NA ~ 0.48
3 dB/m absorption

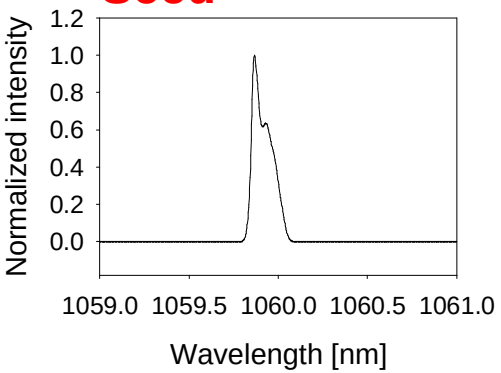
High Power System



321 W



Seed



- Repetition rate=1 GHz
- Pulse duration= 20 ps
- Bandwidth=0.5nm (broadened by SPM)
- Peak power =13 kW (Energy ~260nJ)
- Average Power = 321W
- Conversion efficiency = 74% @max output

OFC 2005 (Postdeadline):

P.Dupriez, et.al., "321 W average power 1 GHz 20 ps 1060nm pulsed fiber MOPA source"

Conclusions

- Performance:
  - 20 ps, 1 GHz repetition rate
  - 11W system: M^2=1.1, BW<0.2nm (near transform limited)
  - 321W system: M^2=2.4, BW=0.5nm
  - Highest reported average power reached with a short pulse fiber laser

- Further work:
  - All-fiberized beam-path
  - Increasing average power to 1 kW relatively straightforward (allready achieved c.w.)
  - Further power scaling feasible:
    - Stimulated Raman scattering & spectral broadening via SPM are concerns at higher peak powers
    - Increasing rep. rate is an option