

# All-PM Diode-pumped Mode-locked Holmium Fiber MOPA

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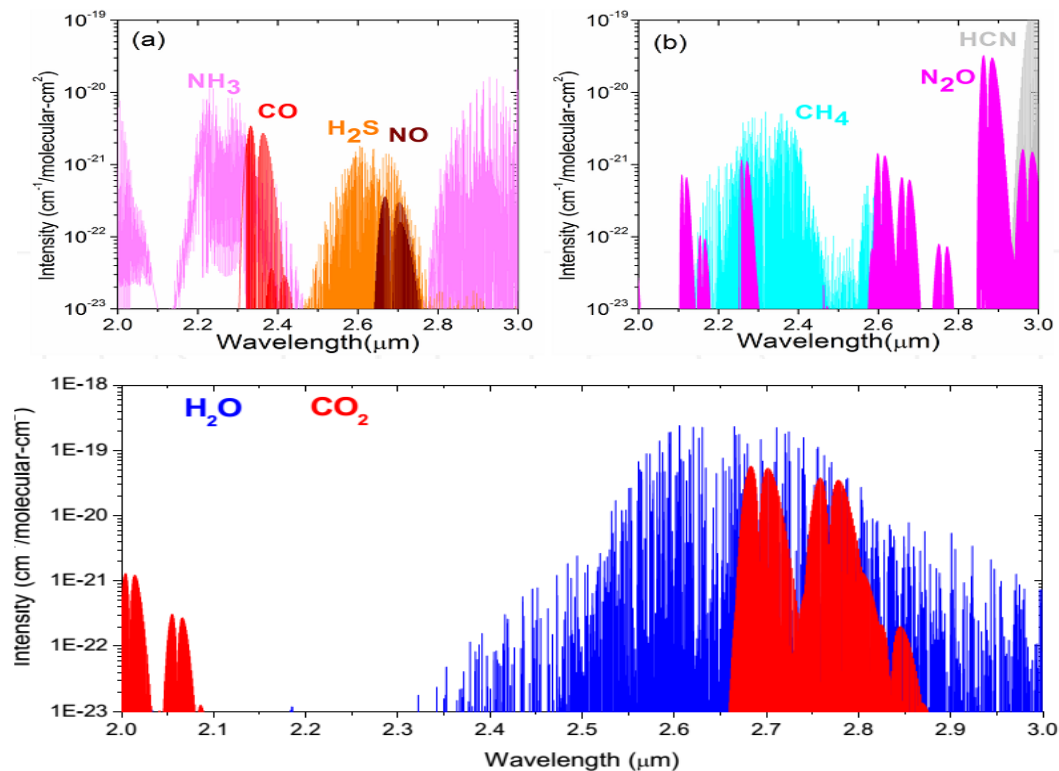
<sup>3</sup> Atla Lasers AS, Richard Birkelandsvei 2B, 7491 Trondheim Norway

## Acknowledgements

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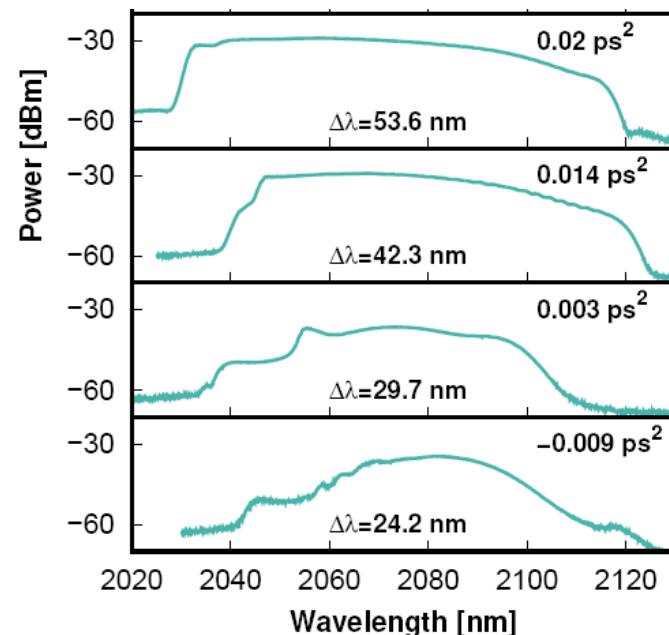
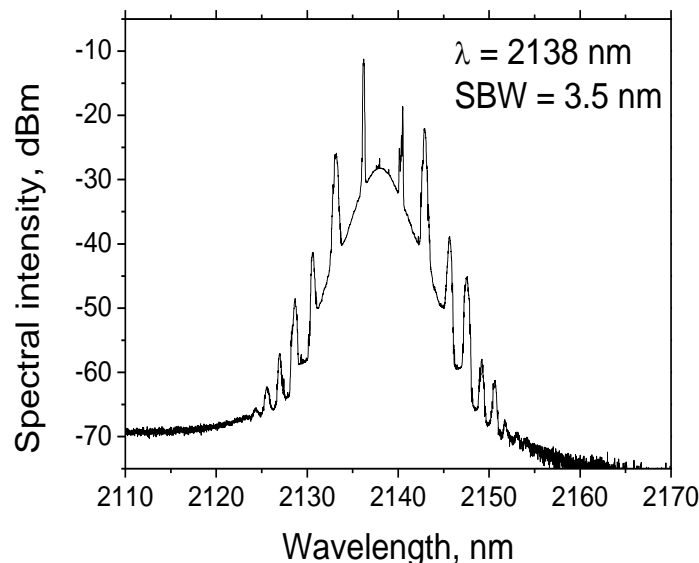
# Motivation

- Application of Holmium lasers:
- Medicine
  - Remote sensing;
  - Material processing;
  - Supercontinuum generation;

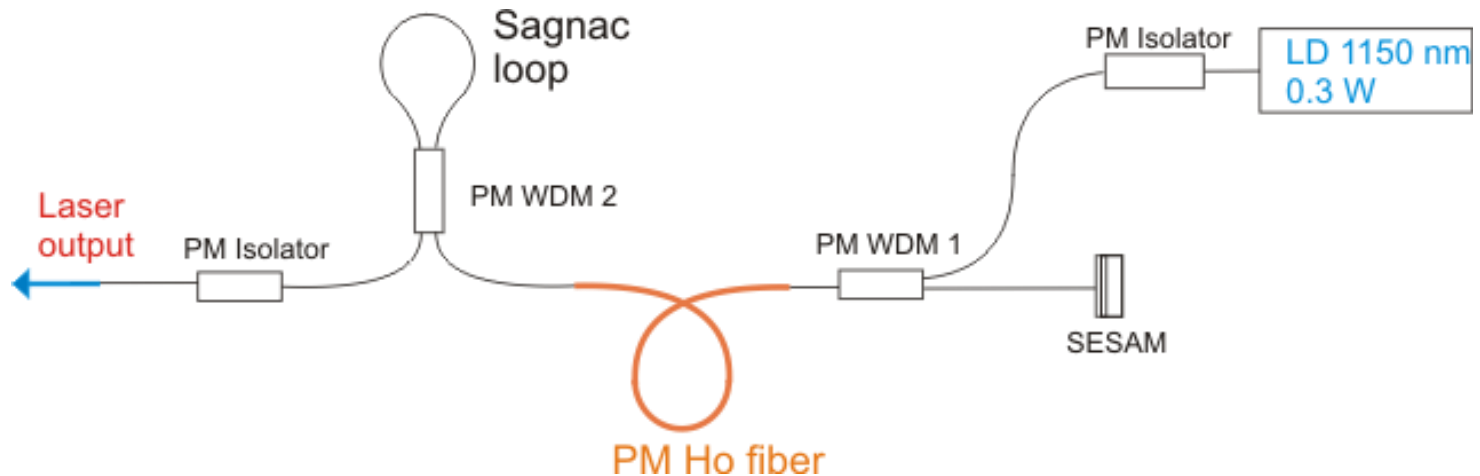


# State of the art of the mode-locked holmium fiber lasers

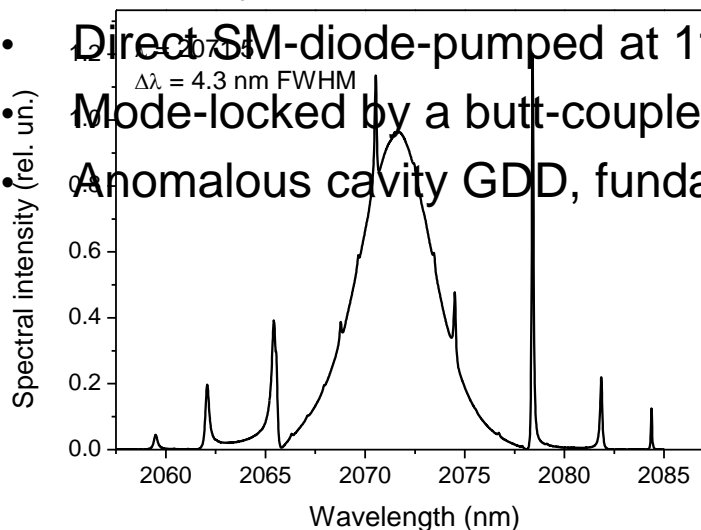
- Different mode-locking mechanisms (SESAM, graphene, CNT, nonlinear polarization evolution);
- Different pumping schemes (Tm fiber laser, laser diode, optically pumped semiconductor disc laser);
- Fundamental soliton and stretched pulse operation;
- Pulse duration below 160 fs;
- Emission wavelength up to 2139 nm;



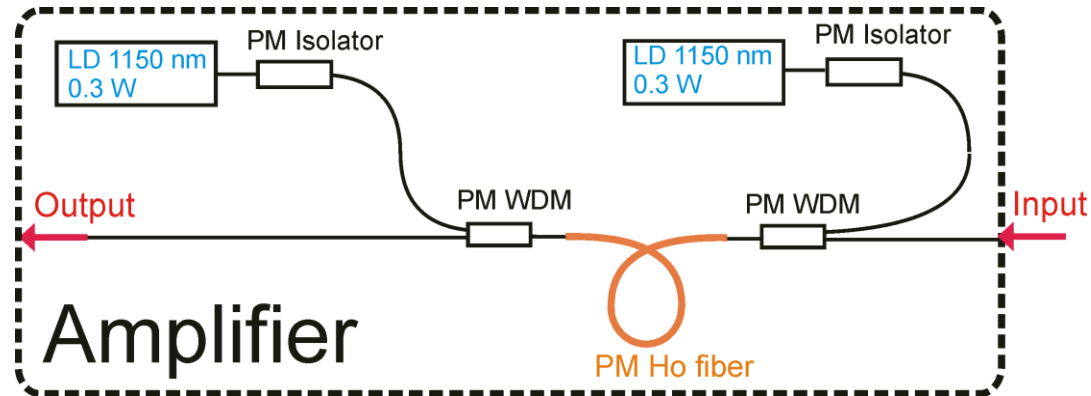
# All-PM all-fiber mode-locked holmium laser



- All cavity components are based on PM-fibers;
- Direct SM-diode-pumped at 1150 nm, Pump power  $\sim 230$  mW;
- Mode-locked by a butt-coupled SESAM, Output power  $\sim 1.7$  mW;
- Anomalous cavity GDD, fundamental soliton operation, Output coupler transmittance  $\sim 0.3$ ;
- Repetition rate 18 MHz;
- Pulse energy  $\sim 0.1$  nJ;
- PER  $\sim 15$  dB;

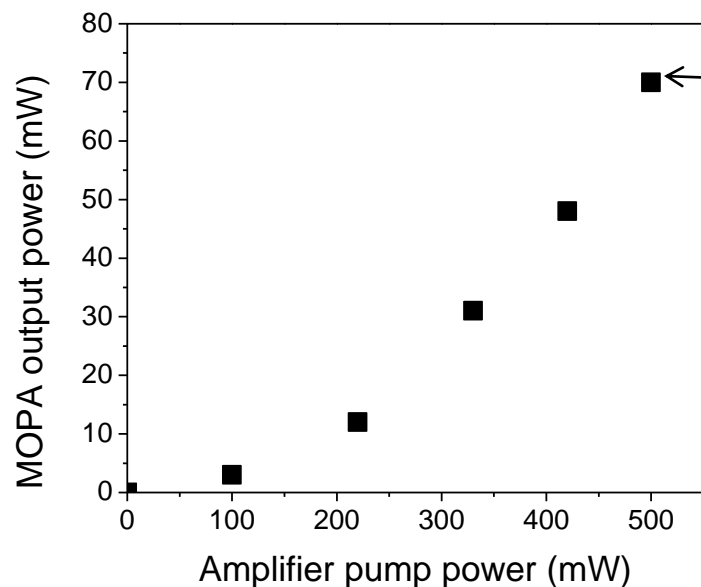
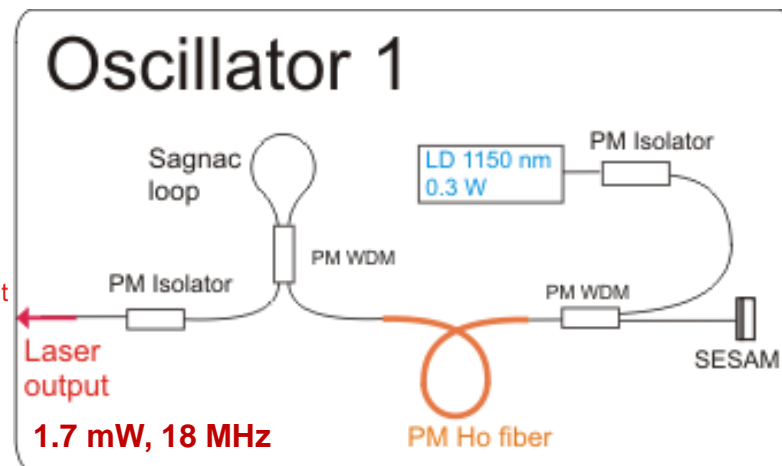
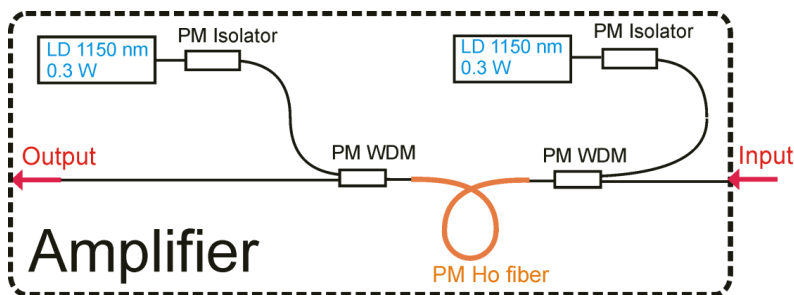


# All-PM diode-pumped holmium fiber amplifier

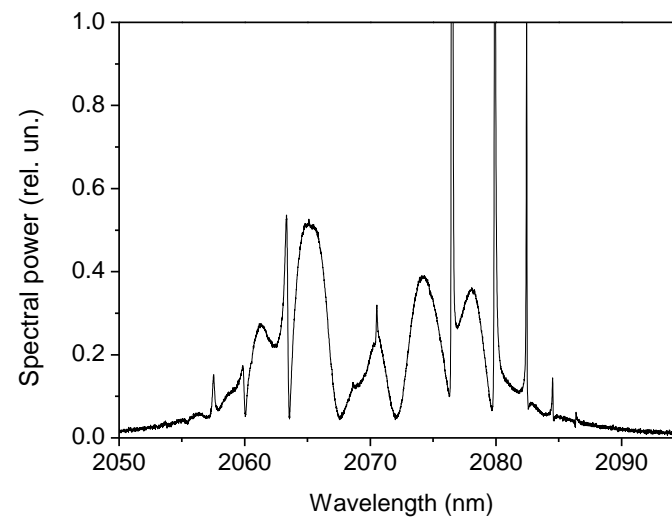


- Pump: 2 x single-mode laser diodes at 1150 nm, 300 mW each;
- PM holmium active fiber, 8  $\mu\text{m}$  core diameter (IxBue Photonics);
- All-PM passive fiber components;
- Potentially very compact system!

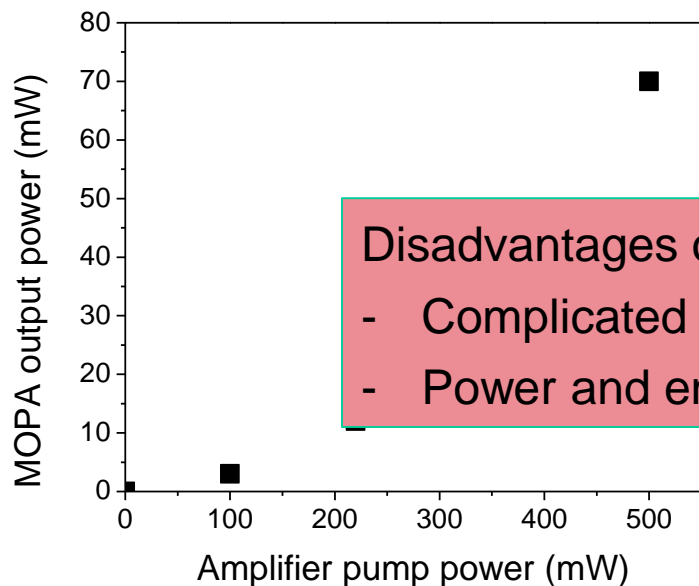
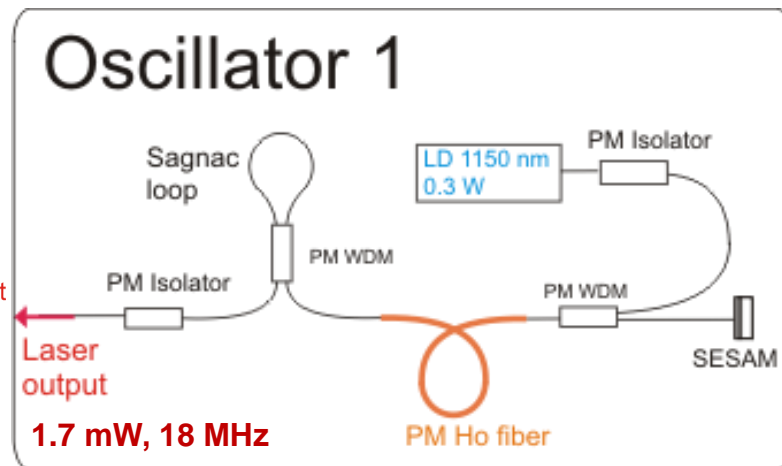
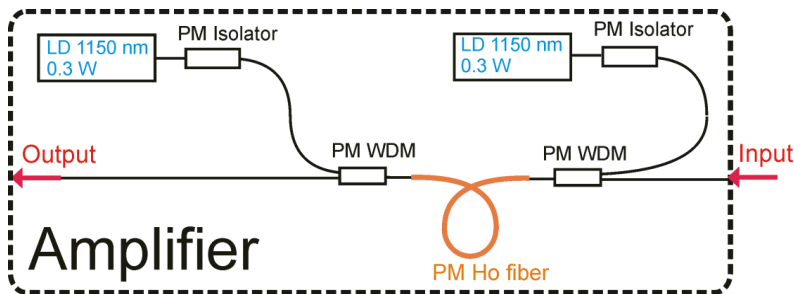
# All-PM diode-pumped holmium fiber MOPA (fundamental soliton operation)



- 70 mW output power;
- >16 dB amplification;



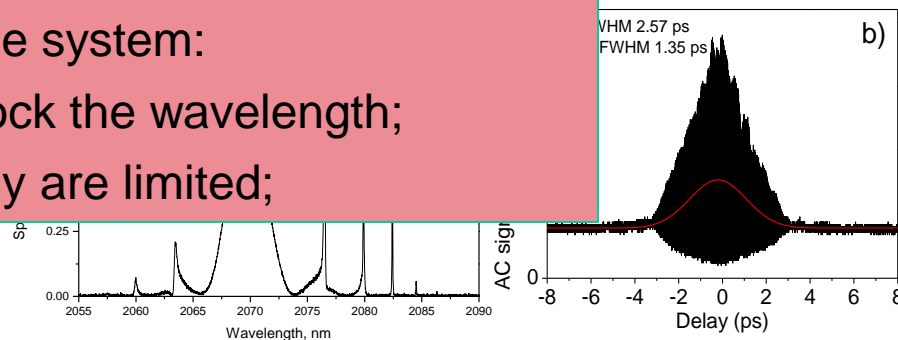
# All-PM diode-pumped holmium fiber MOPA (fundamental soliton operation)



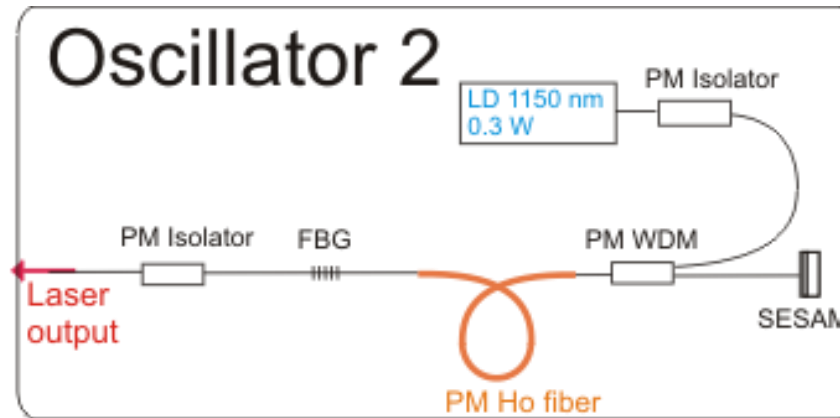
- 31 mW output power
- 1.8 nJ pulse energy

Disadvantages of the system:

- Complicated to lock the wavelength;
- Power and energy are limited;



# All-PM diode-pumped holmium fiber chirped pulse oscillator

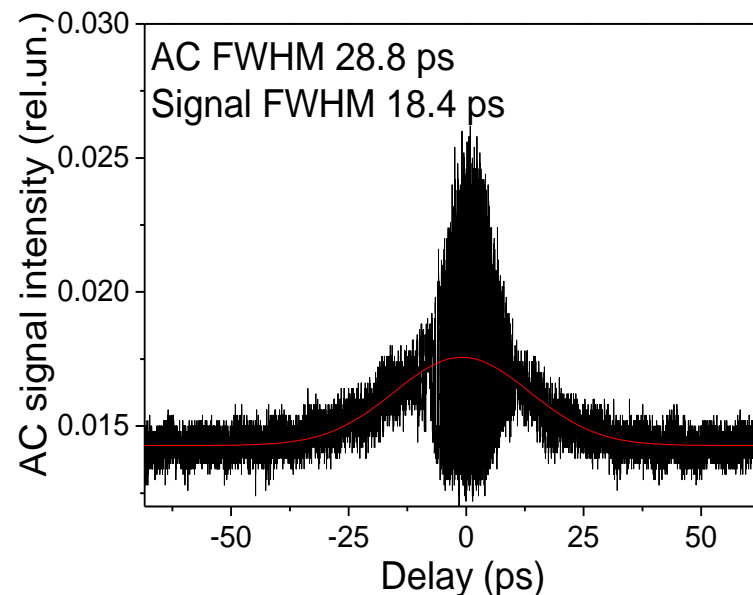
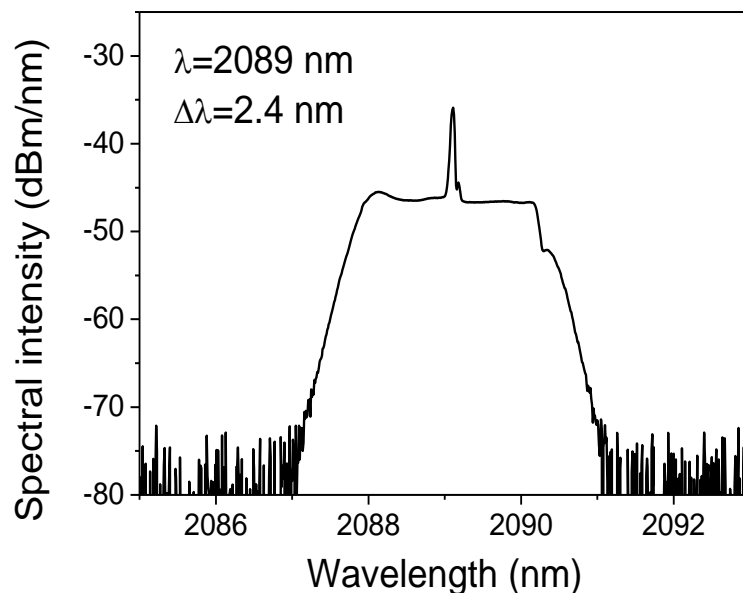


Chirped FBG with following parameters is used as an output coupler:

- Operation wavelength 2090 nm;
- Bandwidth about 5 nm;
- Reflectance about 30%;
- GDD around 2 ps<sup>2</sup>;
- Based on the PM fiber;

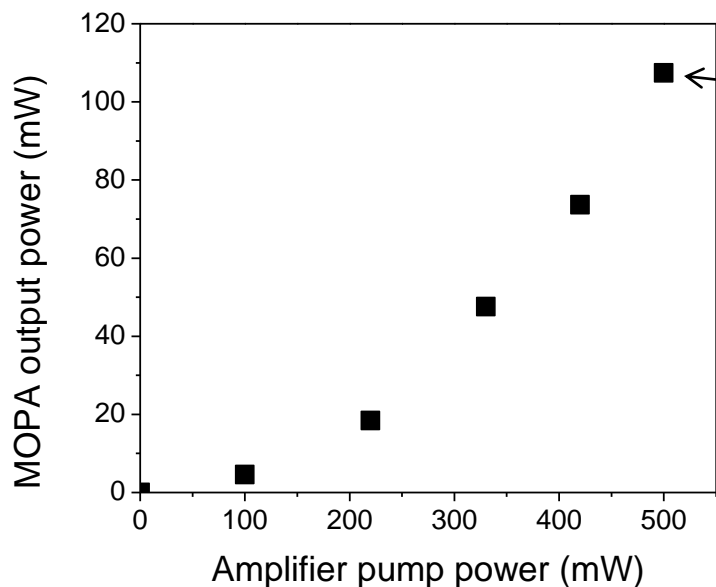
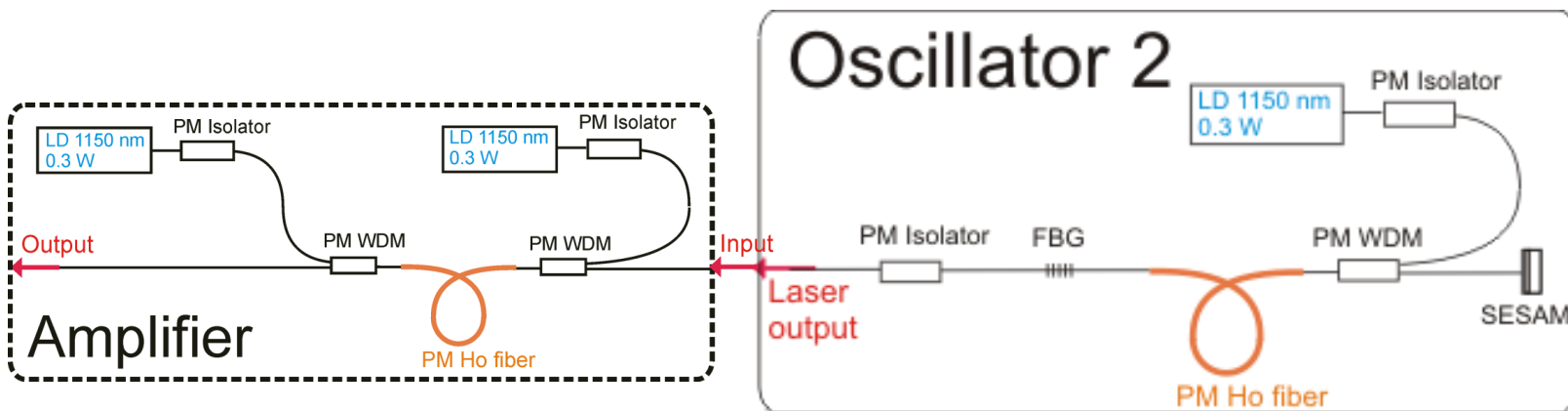


# All-PM diode-pumped holmium fiber chirped pulse oscillator

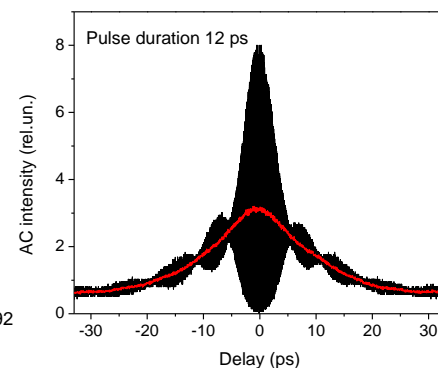
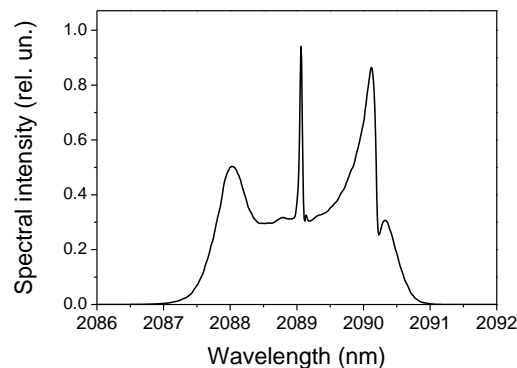


- 12 mW average output power
- 23 MHz repetition rate
- 0.52 nJ pulse energy
- Spectrum locked to Ho:YAG gain line

# All-PM diode-pumped holmium fiber MOPA (chirped pulse operation)



- 108 mW output power
- 4.7 nJ pulse energy



# Summary

- All-PM single-mode diode-pumped holmium fiber oscillators were demonstrated operating both in the fundamental soliton and chirped pulse regime;
- Ultracompact All-PM single-mode diode-pumped holmium fiber amplifier was developed with amplification up to 16 dB;
- Holmium fiber MOPA operated in the fundamental soliton regime provides 31 mW output power (1.8 nJ energy) before SPM distorts the pulse;
- Holmium fiber MOPA operated in the chirped pulse regime provides 108 mW output power (4.7 nJ energy) without spectral distortions;



# Outlook

- GDD optimization of the chirped pulse oscillator to obtain shorter pulses;
- Repetition rate optimization of the chirped pulse oscillator to extract higher pulse energies from the chirped pulse holmium MOPA;
- Seeding the solid-state Ho:YAG amplifier to obtain high-energy pulses promising for material processing;

