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Norwegian University of Science and Technology

Recent progress in development of mode-locked holmium fiber laser

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Acknowledgements

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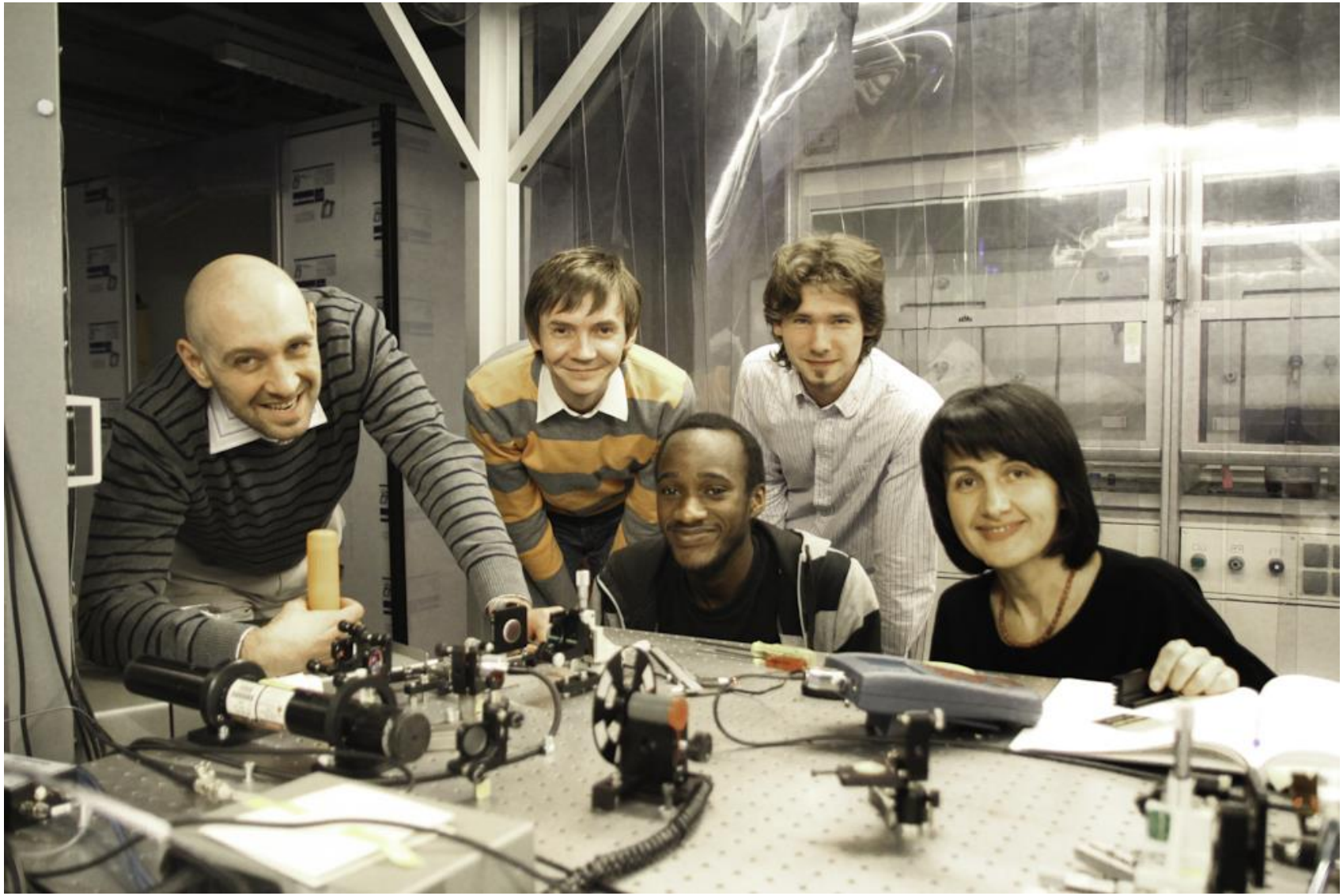
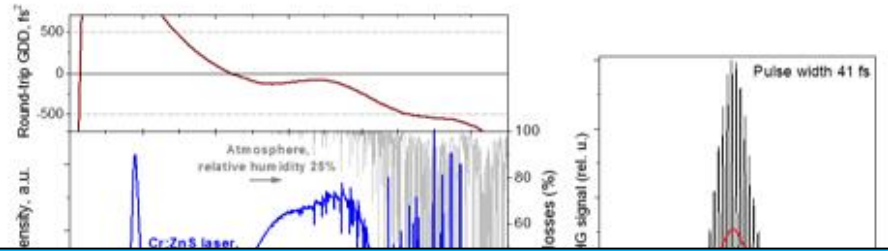
NTNU, ultrafast laser group



NTNU, ultrafast laser group

Key developments:

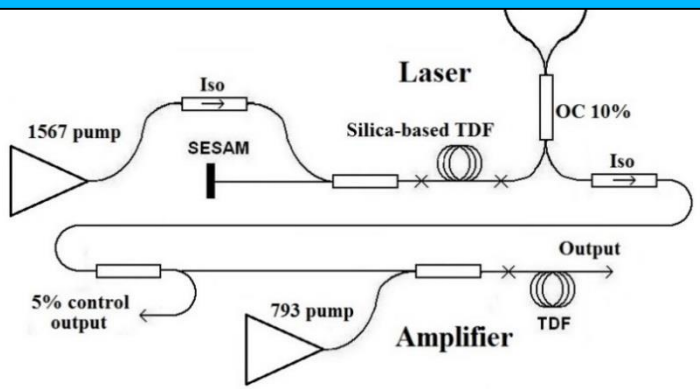
- Cr:ZnS ultrashort-pulse oscillator

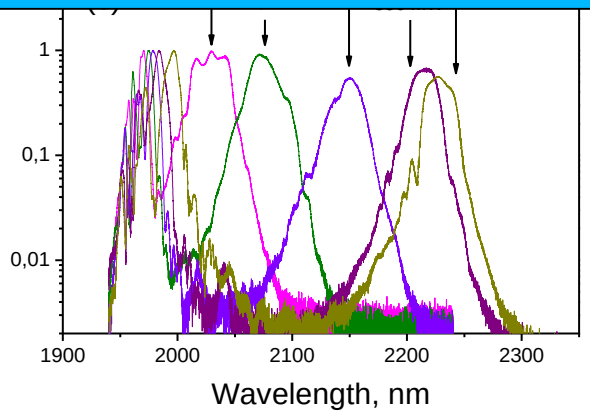


Review articles:

I. Sorokina et al., J. Sel. Topics in Quantum. Electron **20**, 0903412 (2014).

I. Sorokina et al., J. Sel. Topics in Quantum. Electron. **21**, 1601519 (2015)





2012: project proposal, laser source at 2.15 μm

Prof. Nathalie Vermeulen

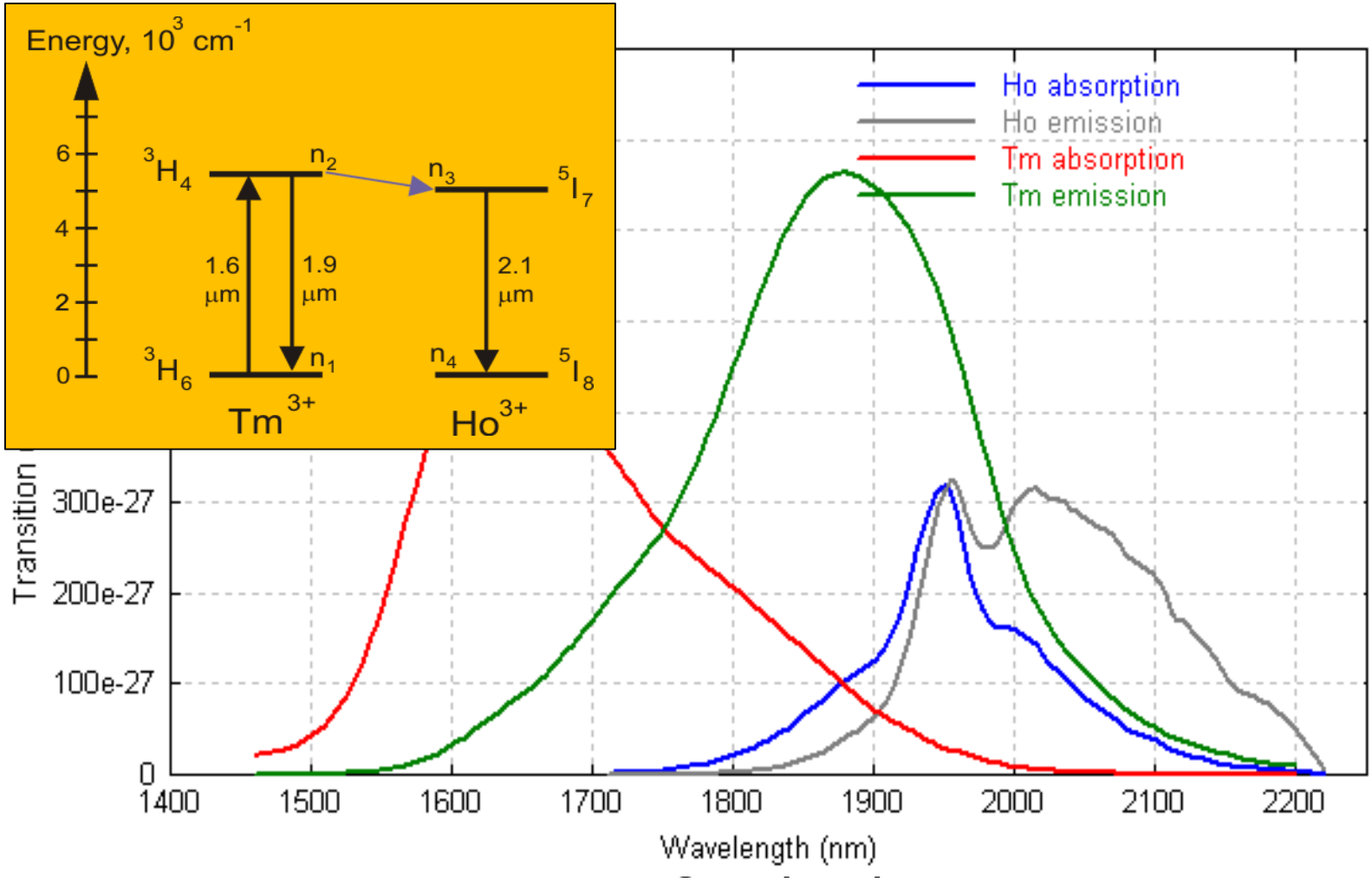
Vrije Universiteit Brussel

Project on optical waveguide requred a **laser source**:

- mode-locked fiber laser;
- emitting at 2.15 μm;
- Peak power > 200 W;
- Pulse duration 1 to 2 ps;
- compact, have a potential for mass production;

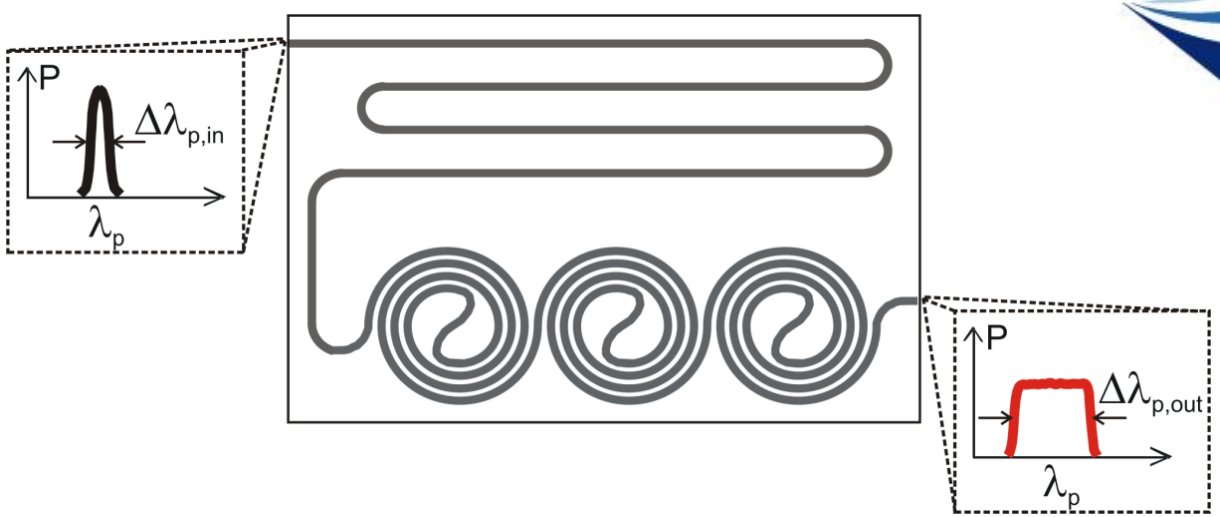
Well, 2.15 μm…

Cross-sections



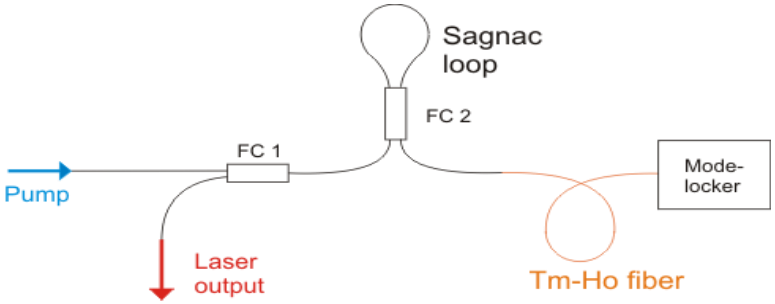
Graphenics project

EU-FET “Young explorers” project 618087 “GRAPHENICS”: development of a compact supercontinuum light source based on a **standard** silicon chip design.

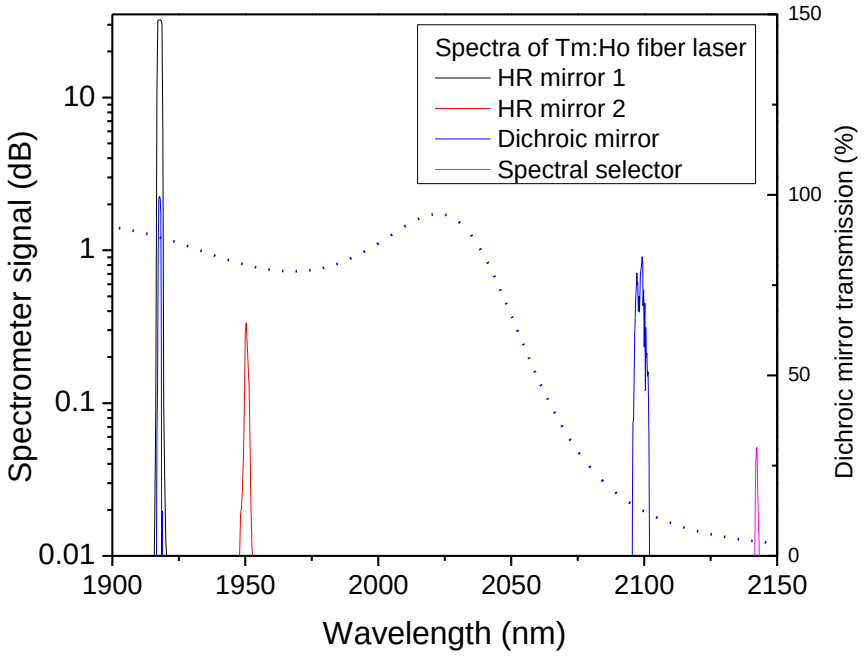


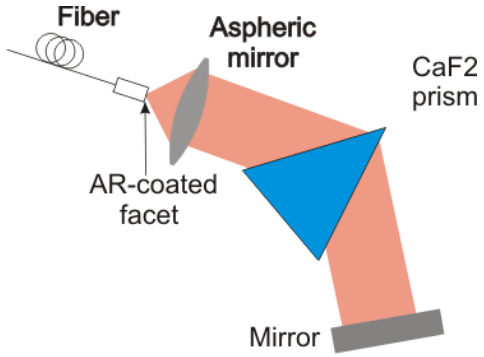
Pump laser is intended to **emit at 2.15 μm** in order for the supercontinuum to reach 2.41 μm required for further second harmonic generation. The laser should be compact and be ready for the mass production.

First attempt: Tm-Ho fiber laser



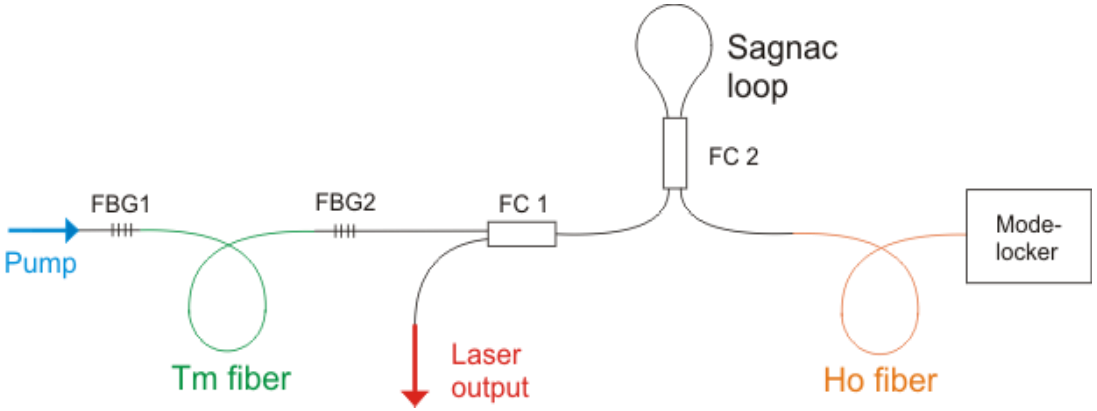
- Commercial Tm-Ho fiber (Coractive TH512);
- LD pumping at 1560 nm (300 mW, single mode);
- Sagnac loop as output coupler;



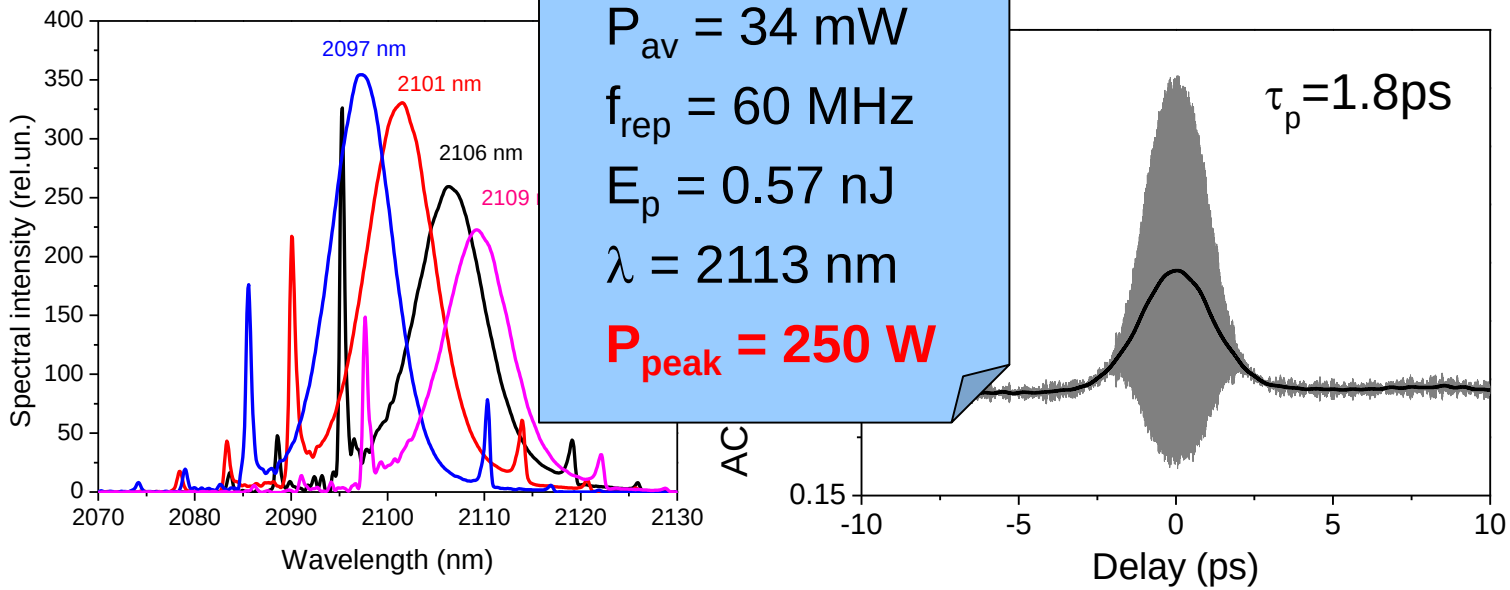


Resume: low Tm-Ho energy transfer efficiency for this particular fiber;

Back-up plan: holmium fiber laser



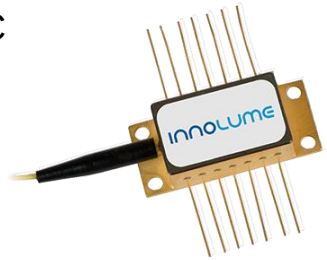
- Custom high-concentrated Ho fiber (FORC, RAN);
- laser pumping at 1850 nm (custom Tm fiber laser);
- Graphene mirror (GSAM) as a mode-locker;



Resume: Concept works, need to work further to deliver specific parameters;

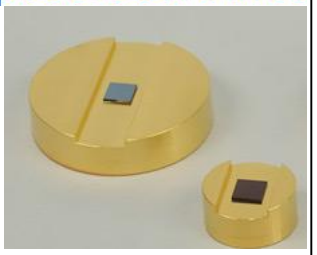
Improvements

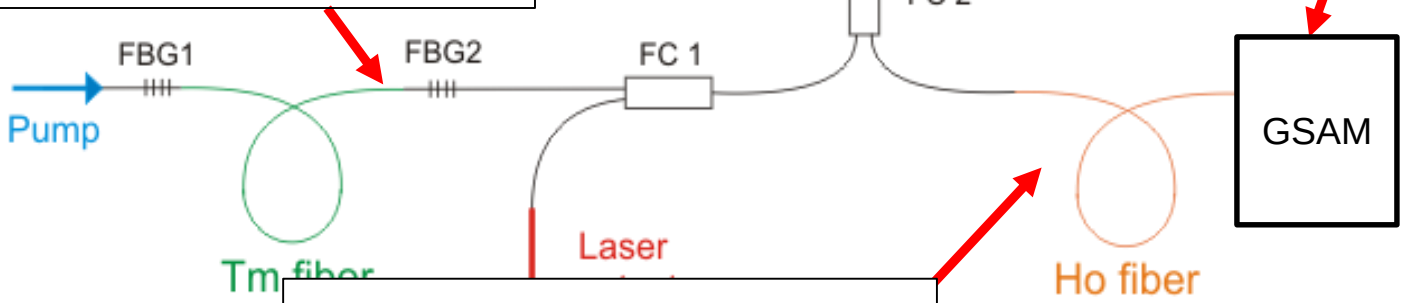
Two FBG-stabilized
SM LD at 1150 nm
combined in PBC
(1 W total power)



Commercial
SESAM
with 5%
modulation
depth

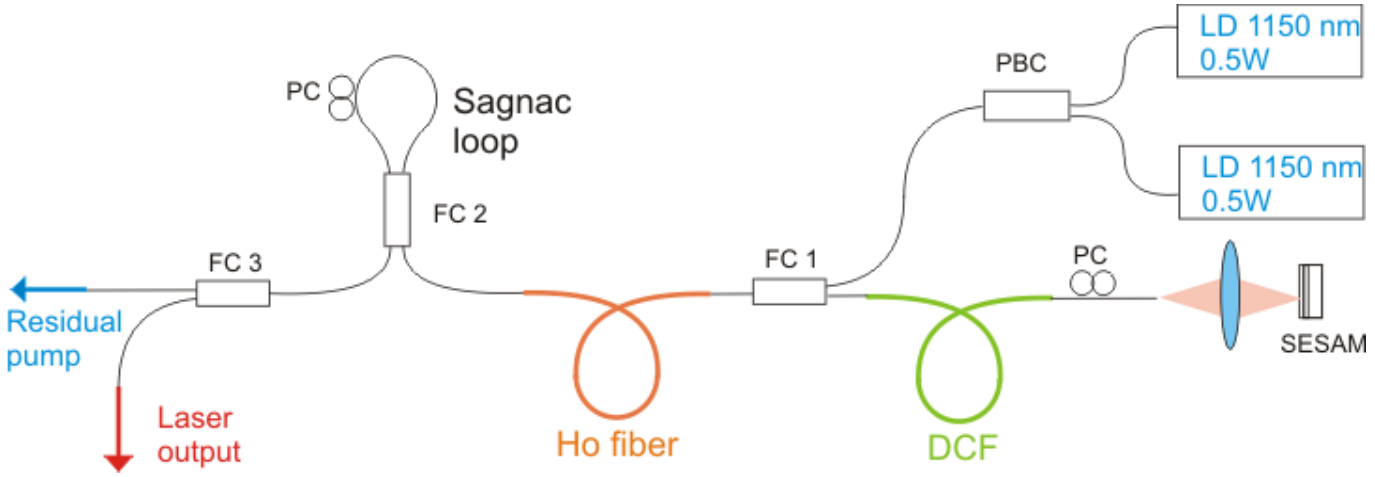
BATOP
optoelectronics

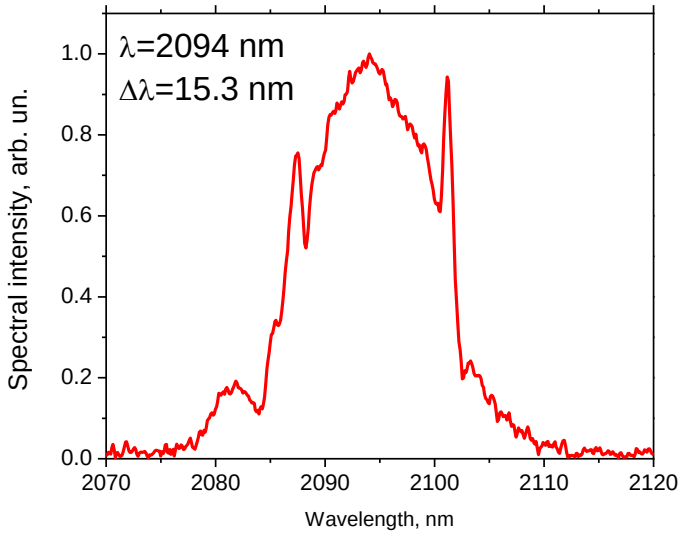


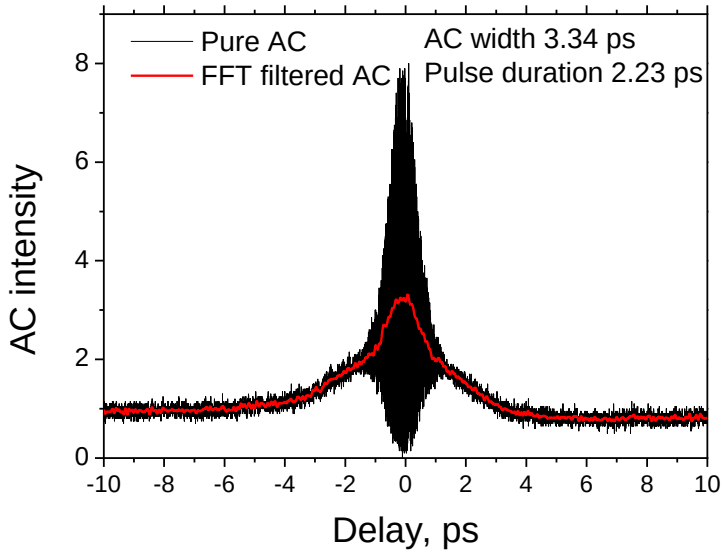


Commercial
Holmium fiber
(core absorption
70 db/m at 1950)

Dispersion-managed Holmium fiber laser

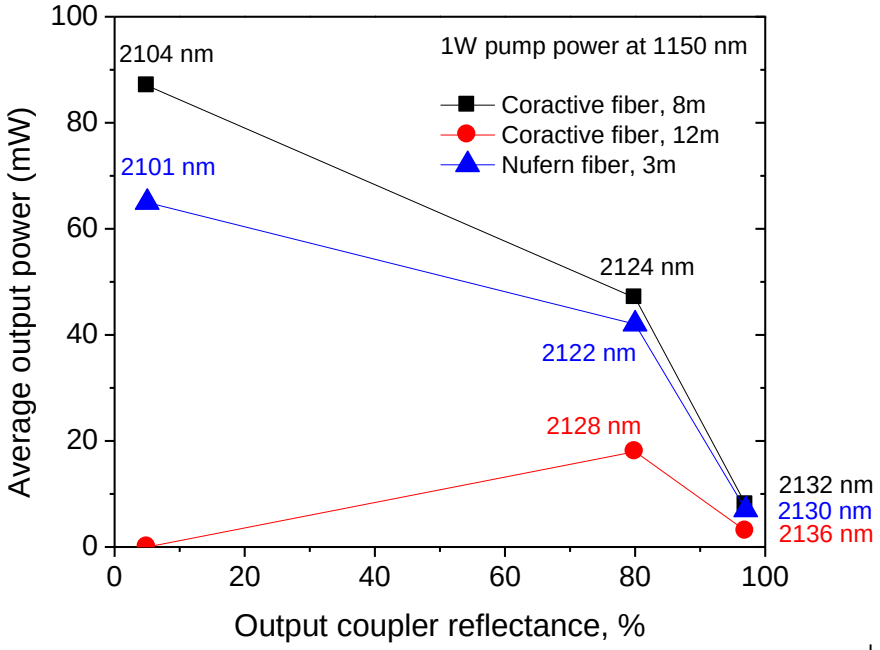


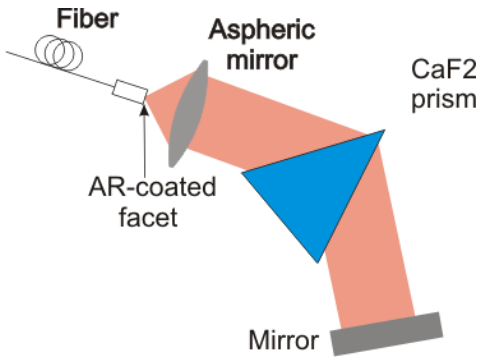


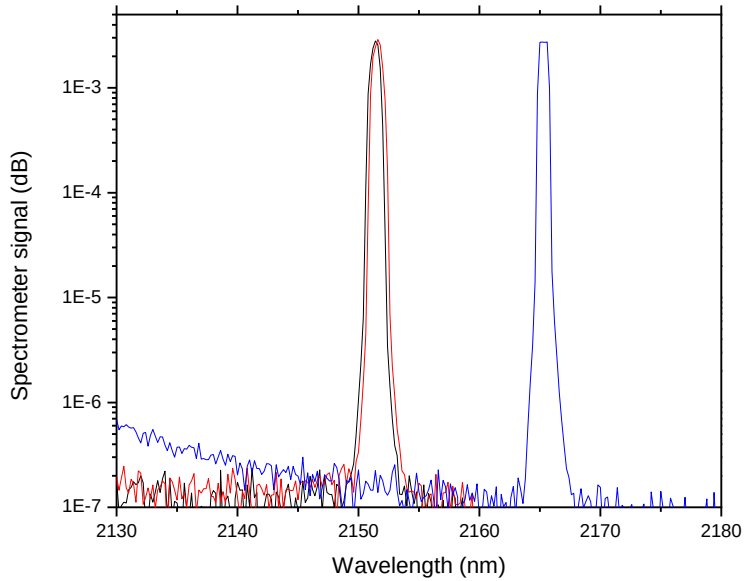


- Output power 28 mW, PRF 7.8 MHz, pulse energy 3.7 nJ
- Centered at 2094 nm, bandwidth 15.3 nm
- Chirped duration 2.3 ps, peak power 1.3 kW

Wavelength tuning in CW mode

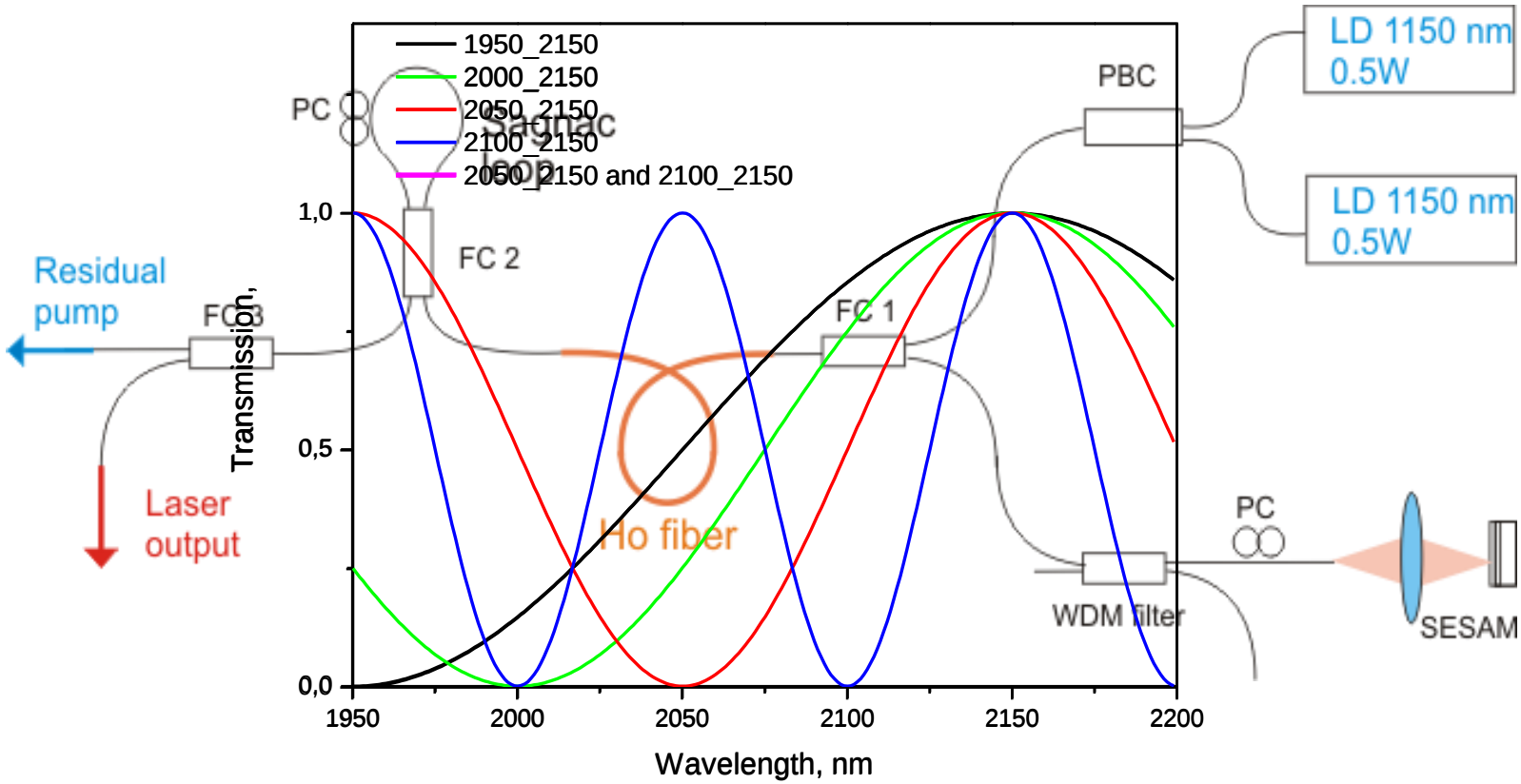




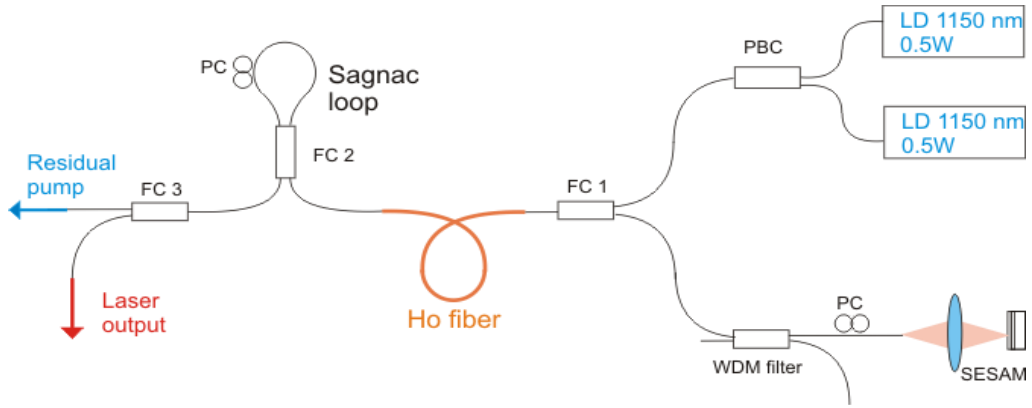


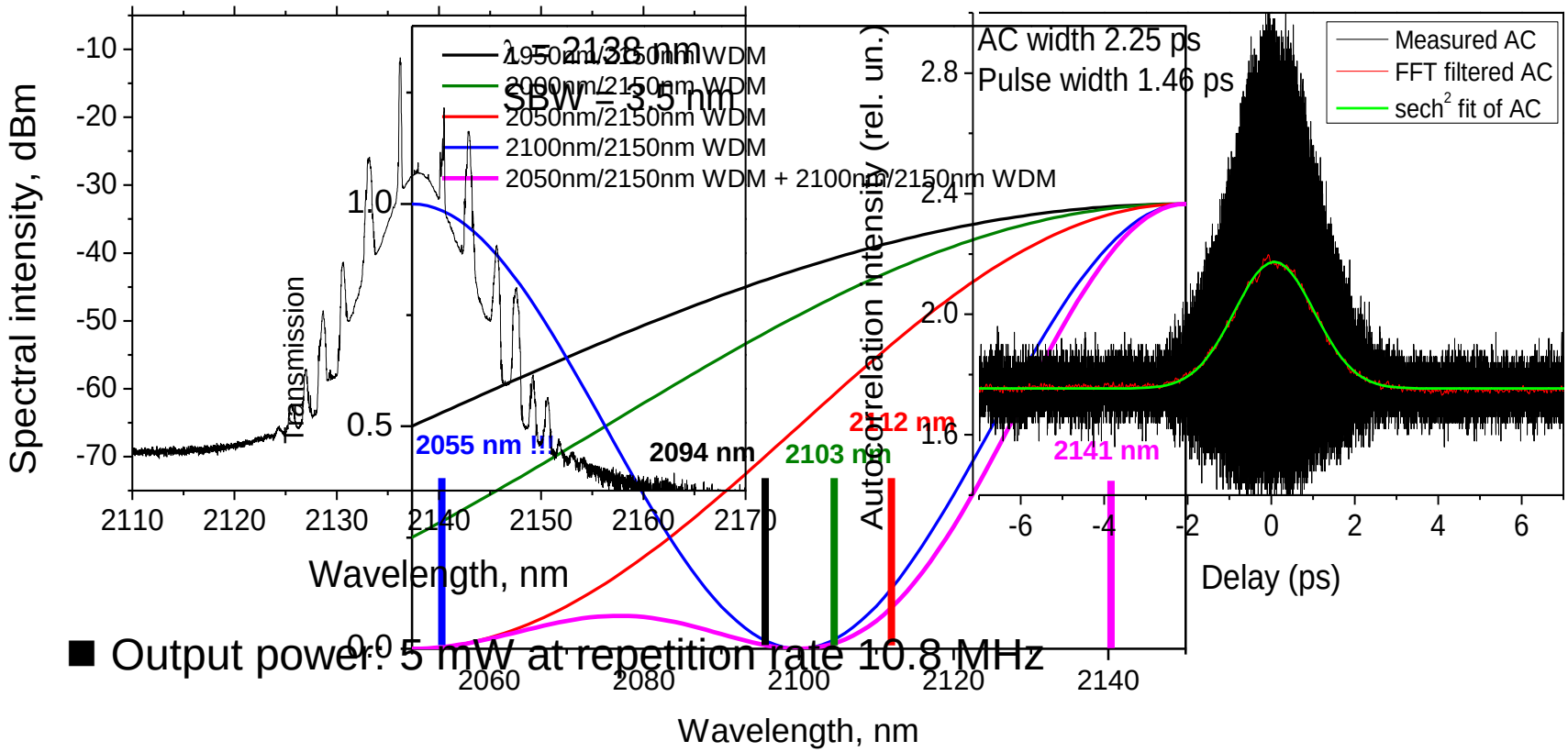
Wavelength tuning of a mode-locked fiber laser

- Tuning by active fiber length
- Temperature tuning;
- Fiber Bragg gratings;
- Dispersion-based prism/grating spectral selector;
- Wavelength-selective losses by WDM filter;



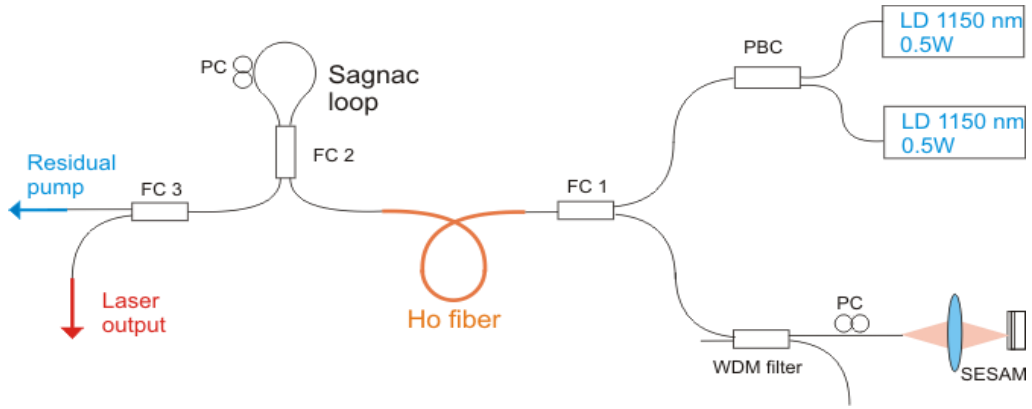
Wavelength tuning of a mode-locked Ho fiber laser

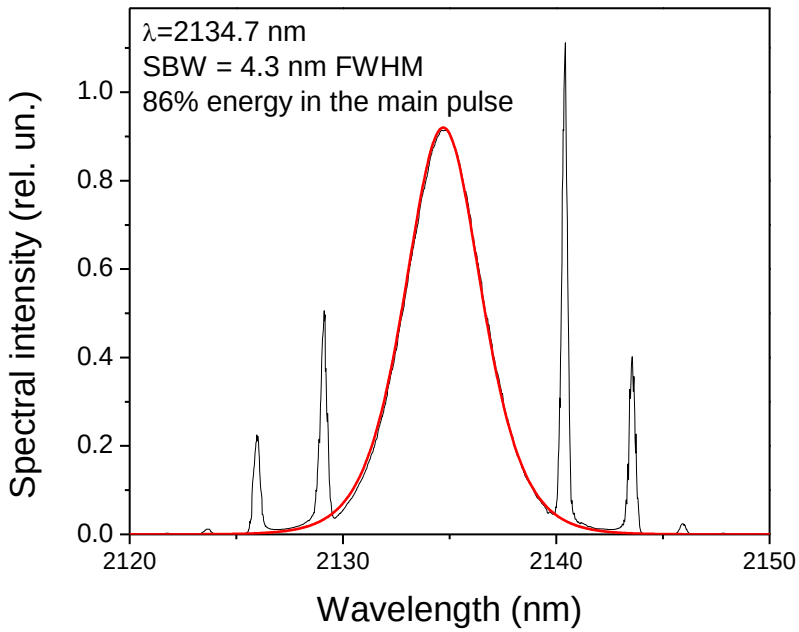


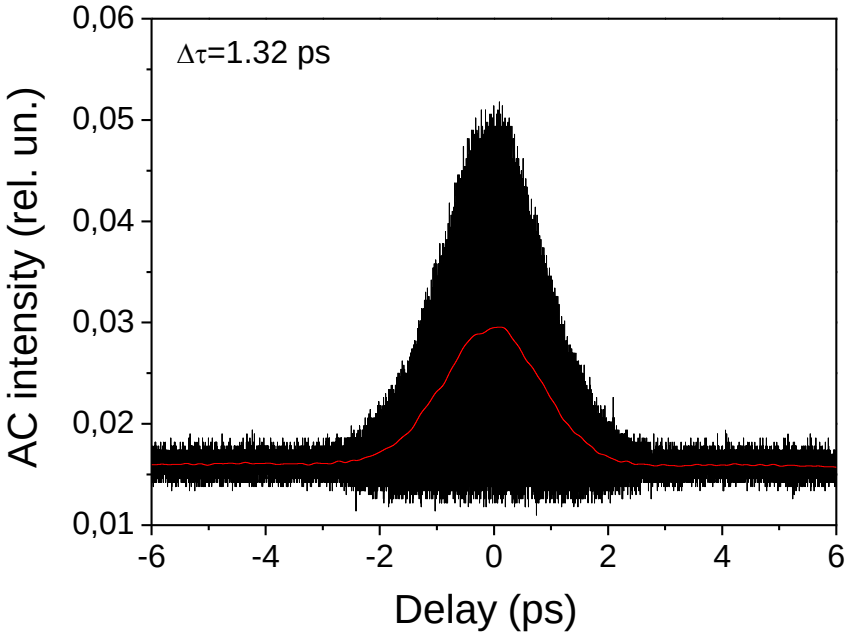


- Output power: 5 mW at repetition rate 10.8 MHz

Wavelength tuning of a mode-locked Ho fiber laser

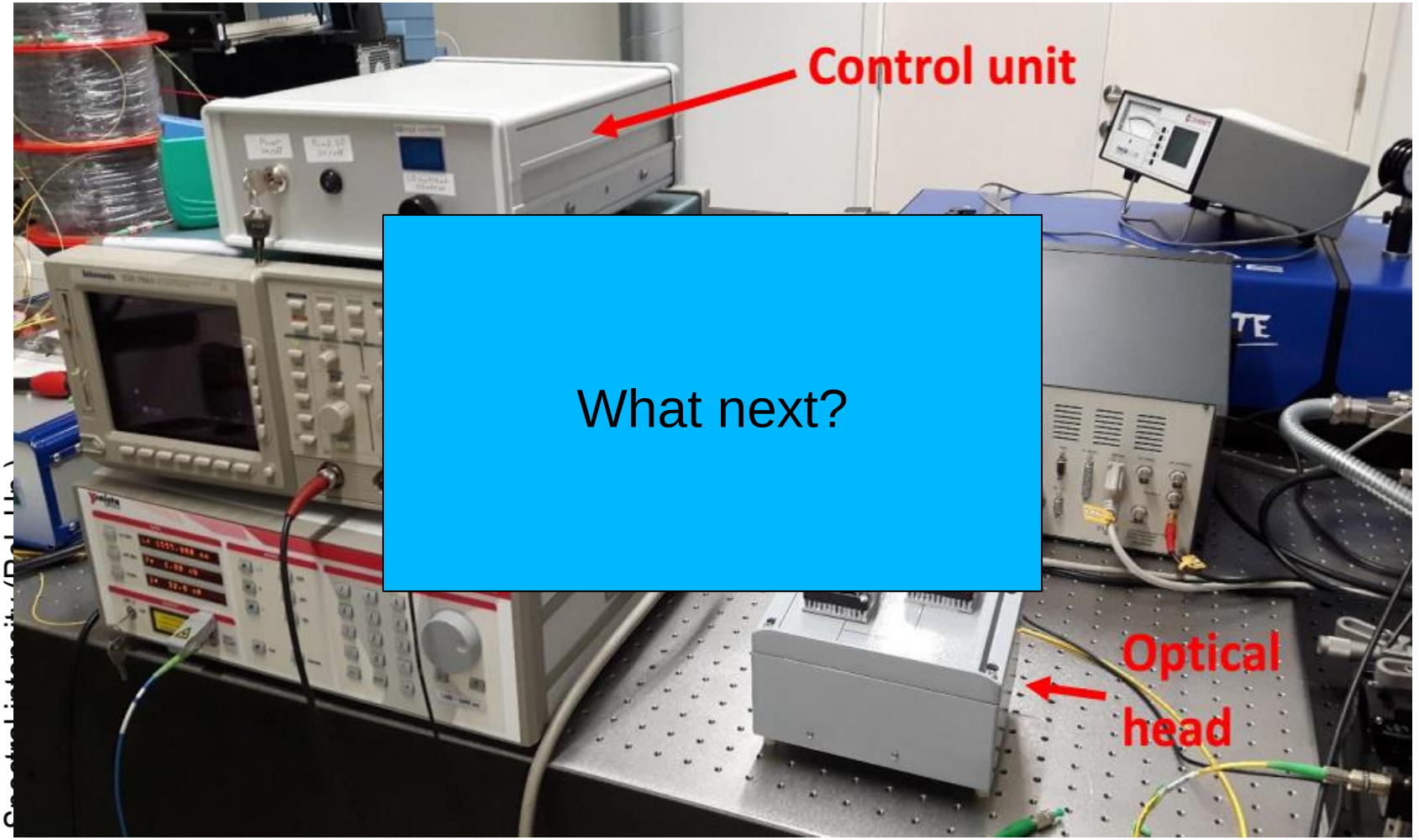






- Repetition rate 15.22 MHz, average output power 6.3 mW, pulse energy 0.42 nJ

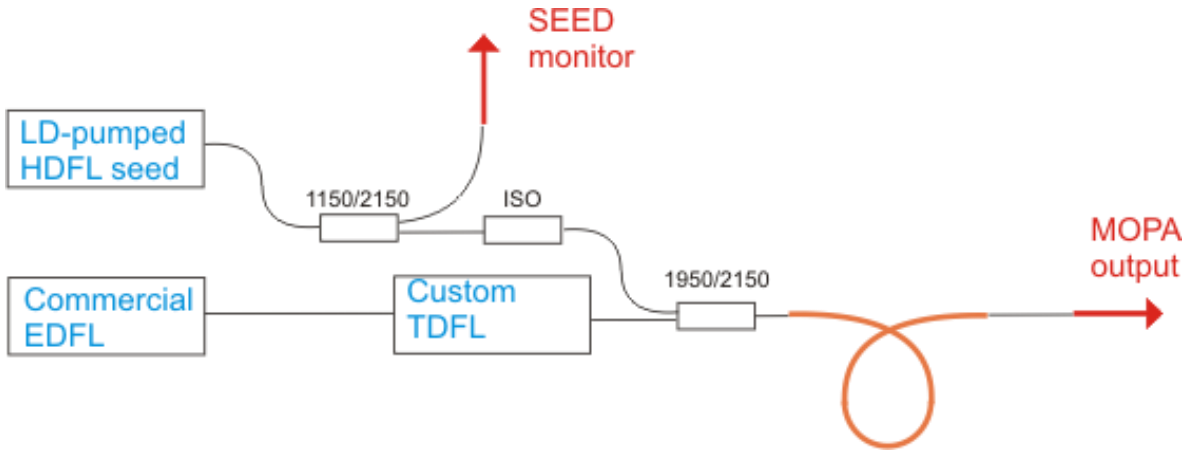
Packaging and installation

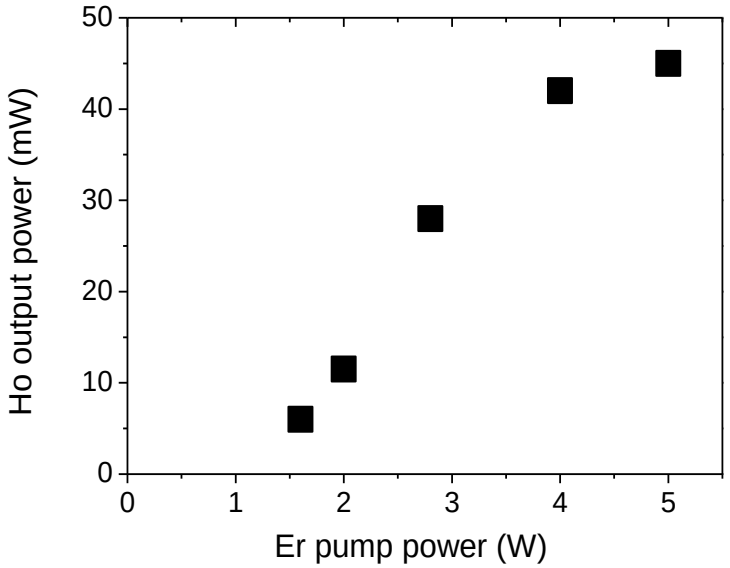


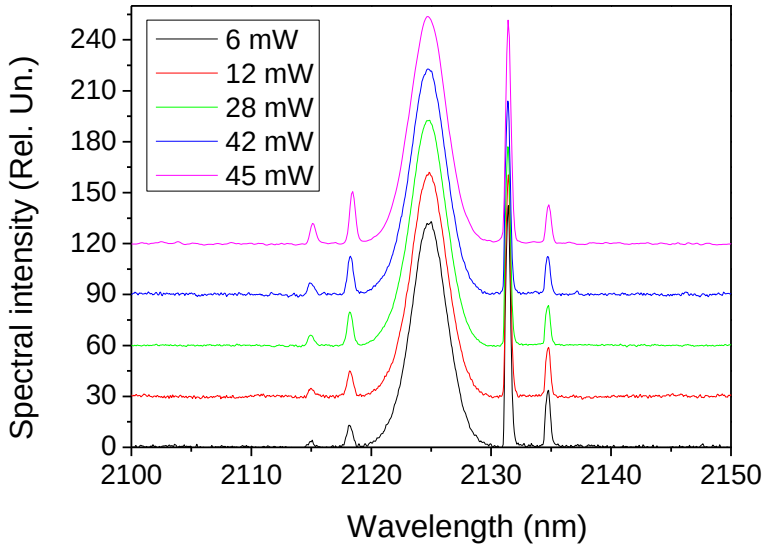
Installed at VUB (Brussels) in January 2017.

Works without maintenance since then.

Adding the amplifier stage

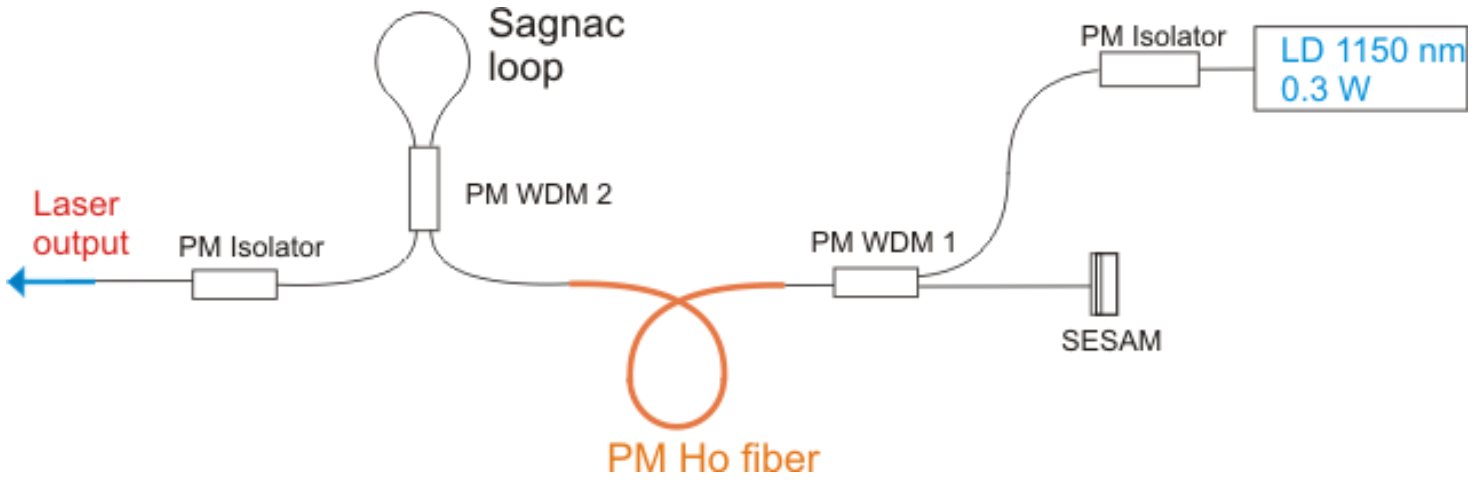






- Repetition rate 15.22 MHz, average output power 45 mW, pulse energy 3 nJ

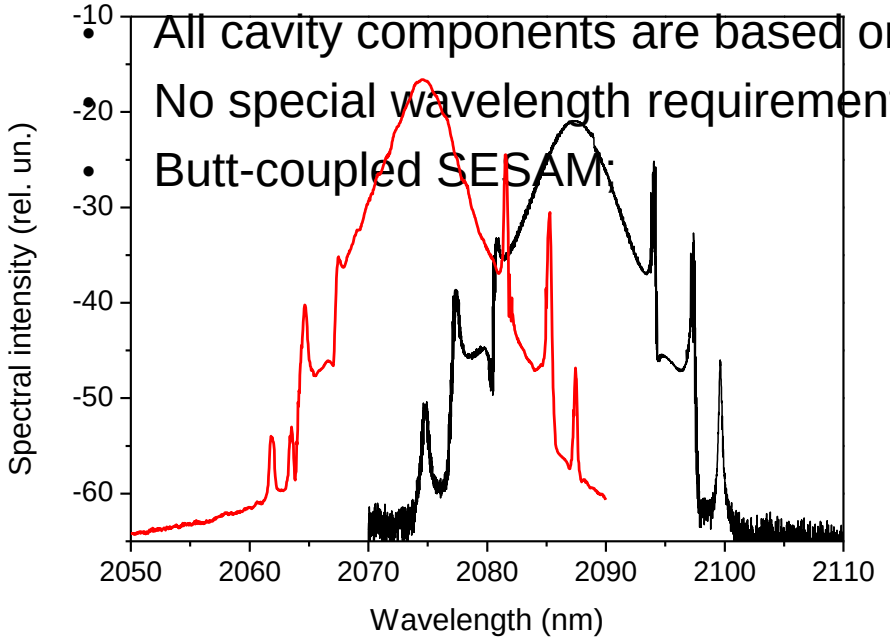
All-PM all-fiber mode-locked holmium laser



All cavity components are based on PM fibers;

No special wavelength requirements – single pump LD;

Butt-coupled SESAM;



Pump power ~ 230 mW;

Output power ~ 0.8 mW;

Output coupler transmittance ~ 0.2;

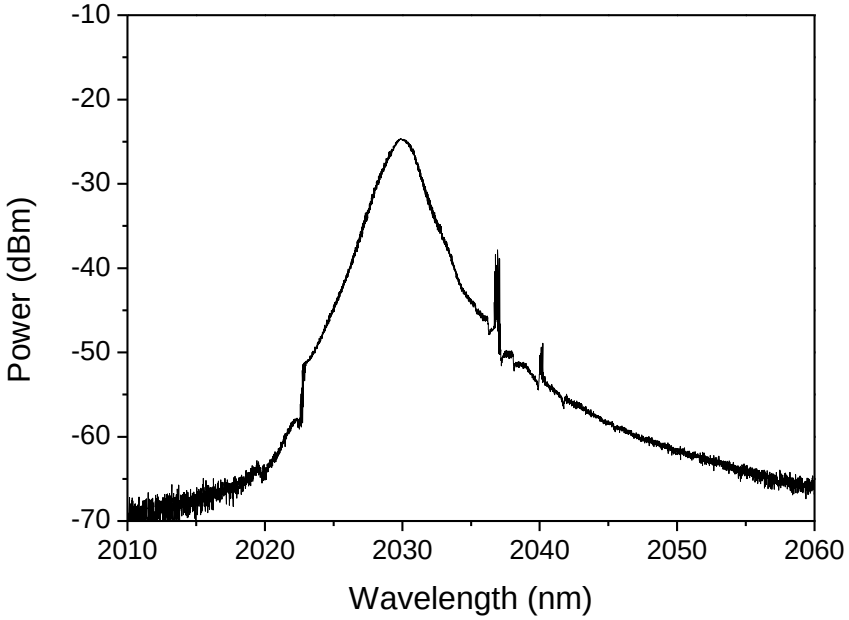
Repetition rate 18.5 MHz;

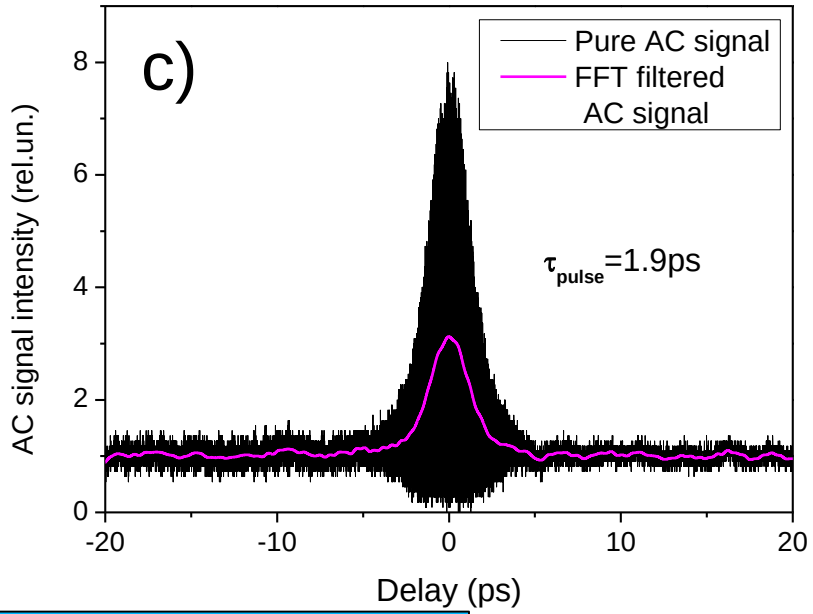
Pulse energy ~ 0.05 nJ;

SBW 3.7 nm;

PER ~15 dB;

All-PM all-fiber mode-locked holmium laser





Pump power

Output powe

Output coupl

Repetition ra

Pulse energy

SBW 2.3 nm

Pulse duratic

Time-bandwidth product ~ 0.32;

The first all-PM all-fiber mode-locked holmium laser

Next steps

- ring cavity configuration with PM circulator;
- Wavelength stabilization using chirped FBG;
- diode-pumped all-PM all-fiber preamplifier with ~10 dB amplification;
- power amplifier baser on either LMA fiber or solid-state crystal;

Summary

- Diode-pumped holmium all-fiber mode-locked oscillator reached longest emission wavelength of 2138 nm;
- Typical mode-locked pulse energy is in the range of 0.1 to 0.3 nJ with picosecond pulse duration;
- Chirped-pulse configuration (normal GDD) was demonstrated as an approach for pulse energy scaling up to 3.5 nJ;
- Laboratory prototype of the laser shows perfectly good stability in temperature-controlled lab environment;
- All-PM all-fiber holmium oscillator was demonstrated for the first time;