Laser Development for SSMB EUV Light Source at THU

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On behalf of the THU SSMB Laser Group

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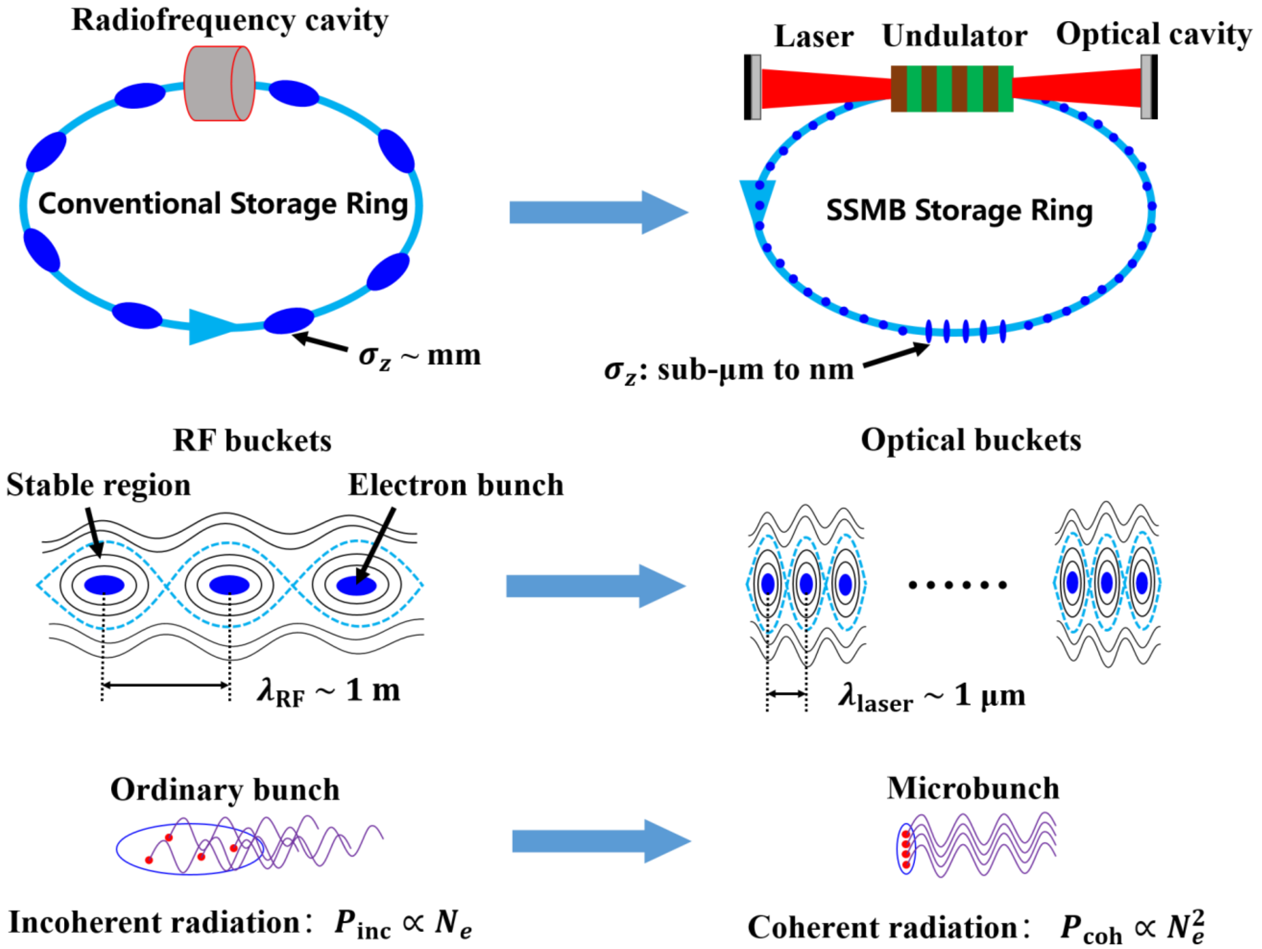
outline

- Motivations
- High power laser for SSMB PoP experiment
- Laser OEC development for SSMB EUV source
- Summary

Lasers acting as modulators are very important for SSMB EUV light source development

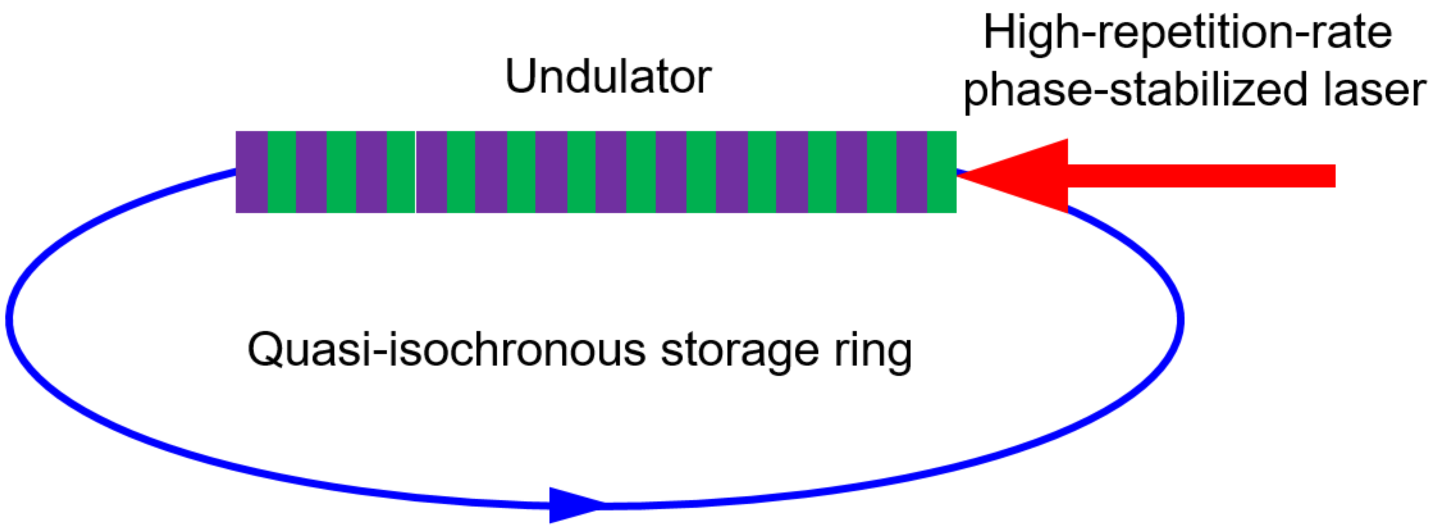
- It replaces the conventional RF cavity in an electron storage ring by high power laser optical cavity for beam focusing.
- For PoP experiments, high power laser is applied for beam energy modulation to demonstrate SSMB mechanism.
- For these purposes, we' re developing the related laser technologies at THU.

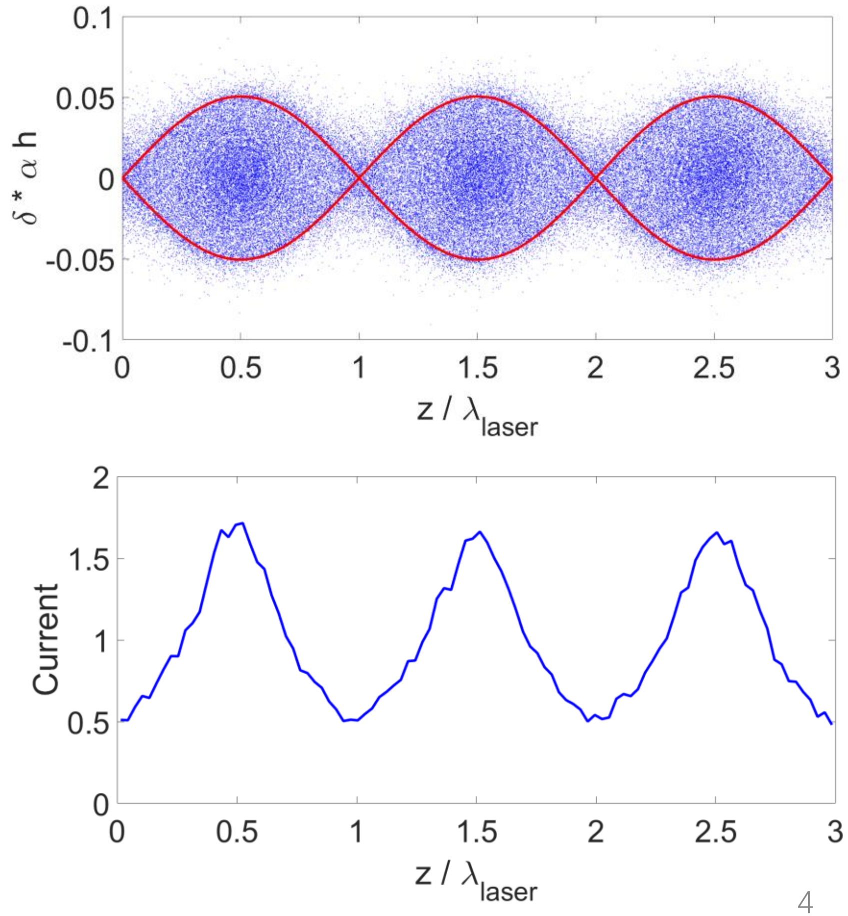
Six orders of magnitude extrapolation



Following phase I, PoP Phase II planned at the MLS

- With the laser-electron phase locked on a turn-by-turn basis, we' ll try to to establish stable microbuckets and maintaining of such microbunching for multiple turns.





- It is to be accomplished by using a high-repetition-rate phase-stabilized laser to interact with the electron beam in phase turn by turn.

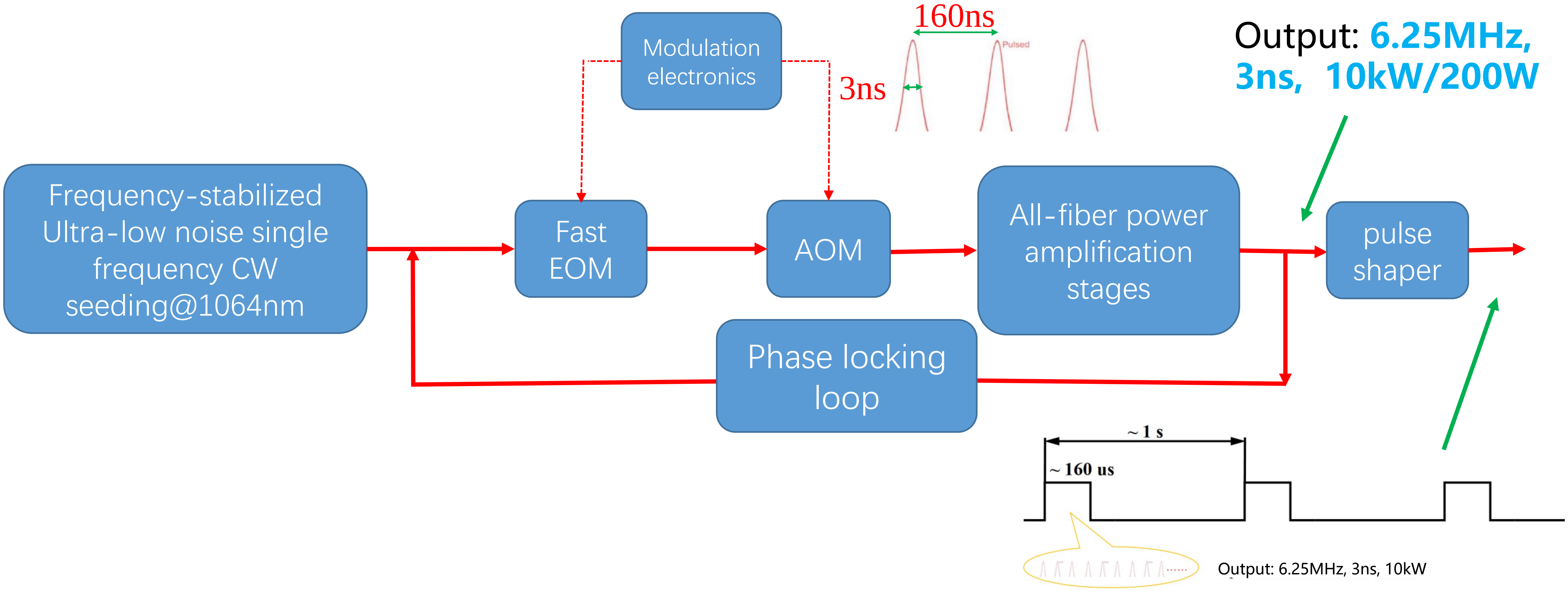
Laser requirements

- After technical and engineering design, a fiber laser with following parameters has been proposed and customized:

  - **Wavelength:** **1.064μm**(most mature for high rep-rate amplification by Yb-doped fibers)
  - **Spectral Linewidth:** **< 20kHz** (for longer coherence length)
  - **Pulse Repetition Rate:** **6.25MHz / 3.125MHz** (determined by the electron ring)
  - **Pulse Width:** **≤ 3ns** (for suppression of SBS, and to avoid timing jitter influence)
  - **Peak Power:** **≥ 10kW** (higher preferred, but limited by SBS / SPM)
  - **Average Power:** **≥ 200W** (pulse energy * PRR)
  - **Macro pulse length:** **160μs** (for 1000 collisions, tunable)
  - **Phase Jitter:** **≤ 1/20 λ** (With Phase-Locking Loop between amps and CW seeding)
  - **Polarization:** **Linearly** (for effective laser-electron interaction in the undulator)
  - **Beam Quality:** **≤ 1.3** (to control the transversal mode purity)

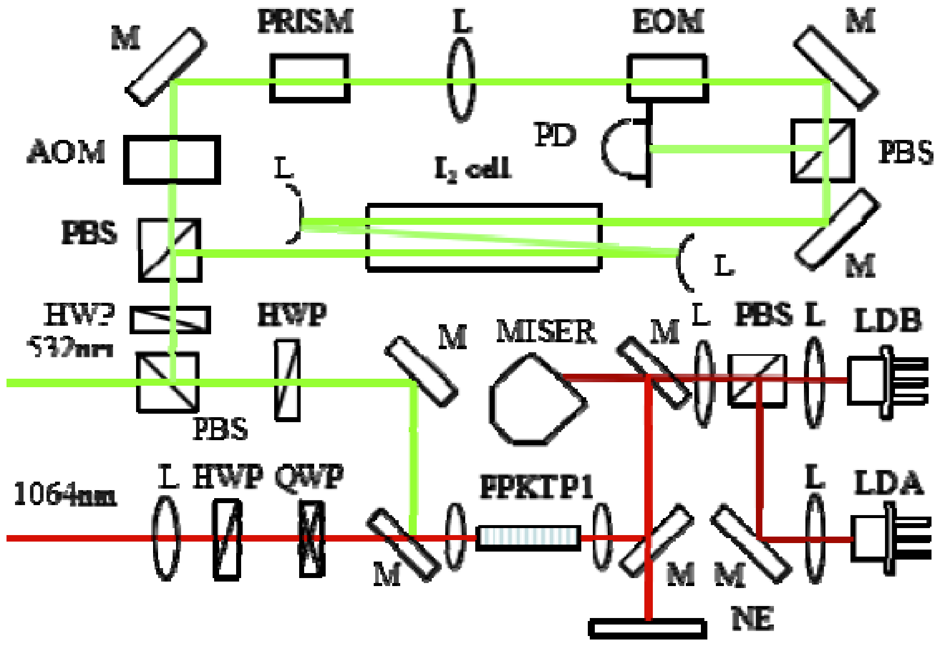
Schematic design of the laser

- Strategy: Frequency stabilized CW seeding + MOPA pulsed fiber amplifiers + phase locking + pulse shaper

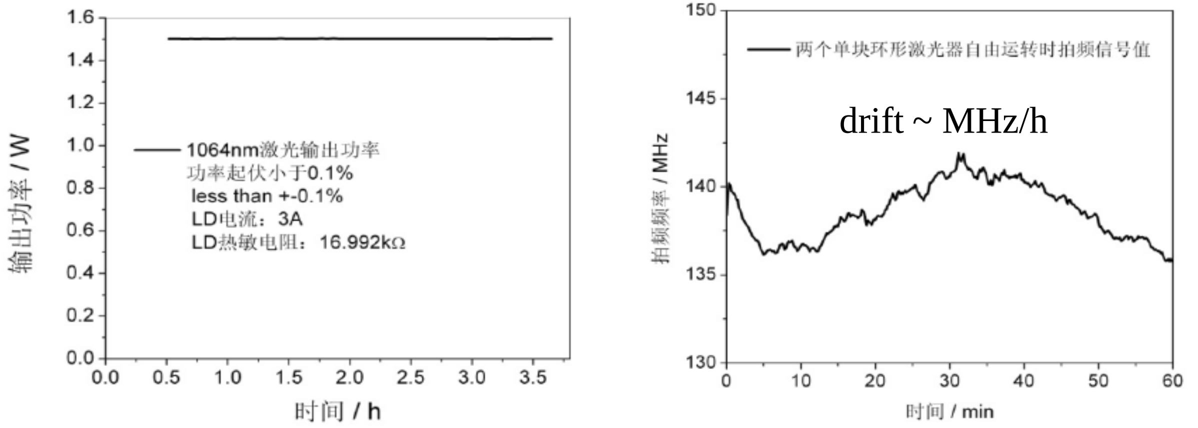


Solid CW seeding laser

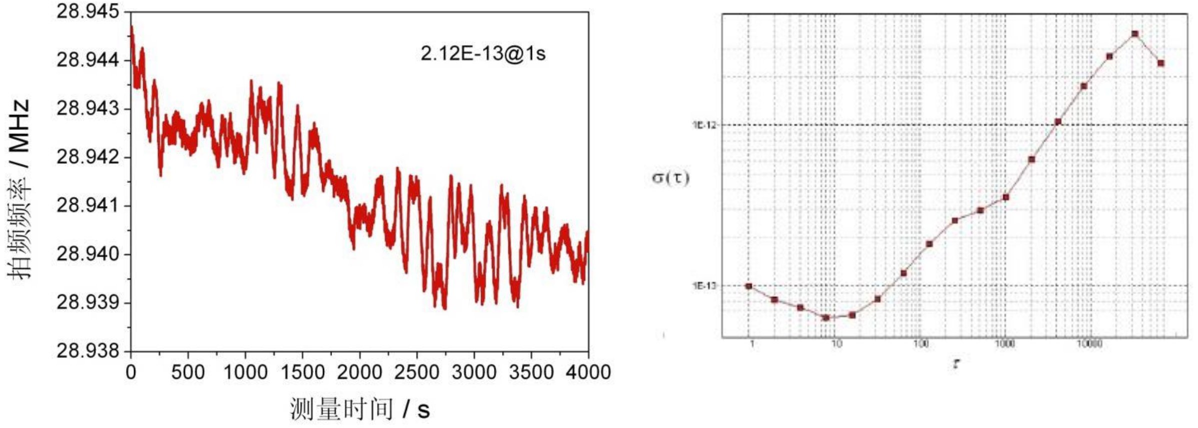
- For its robustness and compactness, we choose a special designed iodine-frequency-stabilized CW solid laser as the seeding.



➢ Schematic of the compact iodine stabilized CW seeding laser: SH of MISER output is locked to one of spectral line of iodine molecules to stabilize the laser fundamental frequency to high precision.



➢ For open loop, the stability of power and frequency



➢ After locked with iodine cell, the frequency stability improved to ~10^{-12}~10^{-13}

Frequency-stabilized monolithic crystal seeding laser

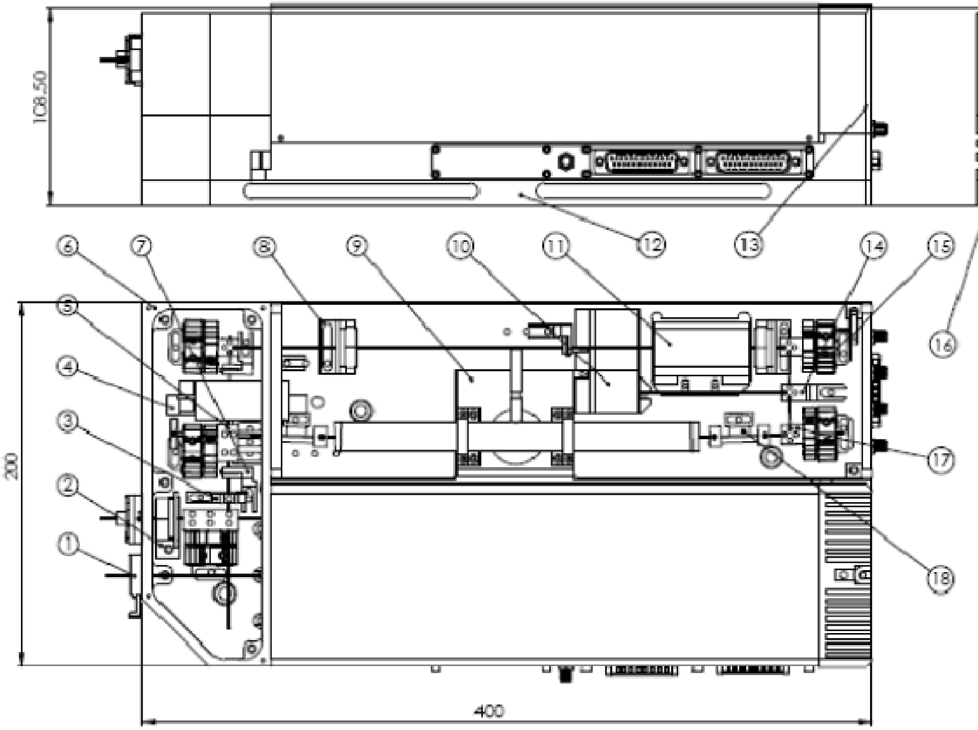


图 21 小型化碘稳频激光器设计结构图

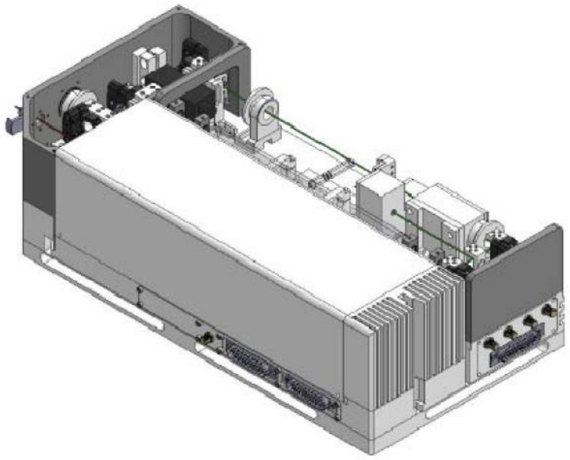


图 22 小型化碘稳频激光器设计效果图

Picture of the laser head

Units of electronics for the seeding laser

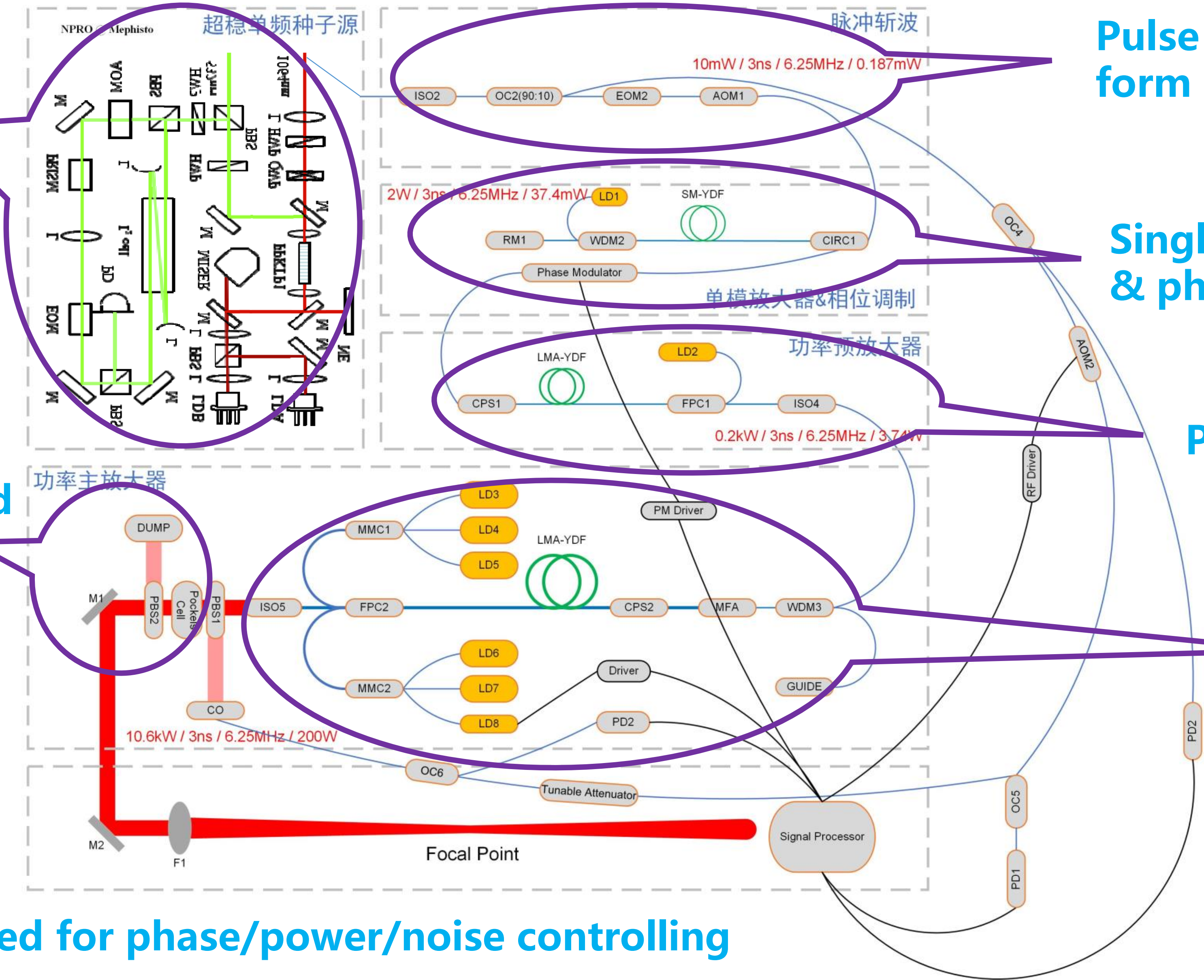
Developed by National Institute of Metrology, China

dimensions of the laser (optical part): 40cm*20cm*11cm

MOPA all-Fiber amplifiers

Iodine-locked single frequency CW seeding

Pulse shaper for required macro time structure



Pulse modulator to form ns seeding pulse

Single mode fiber AMP & phase modulator

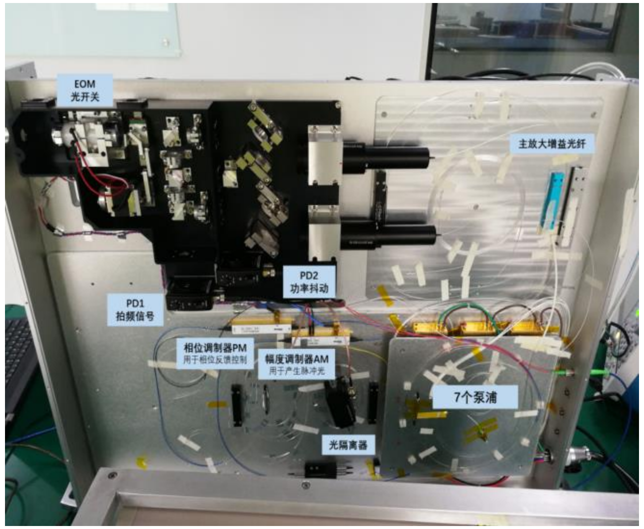
Pre-AMP

Main-AMP

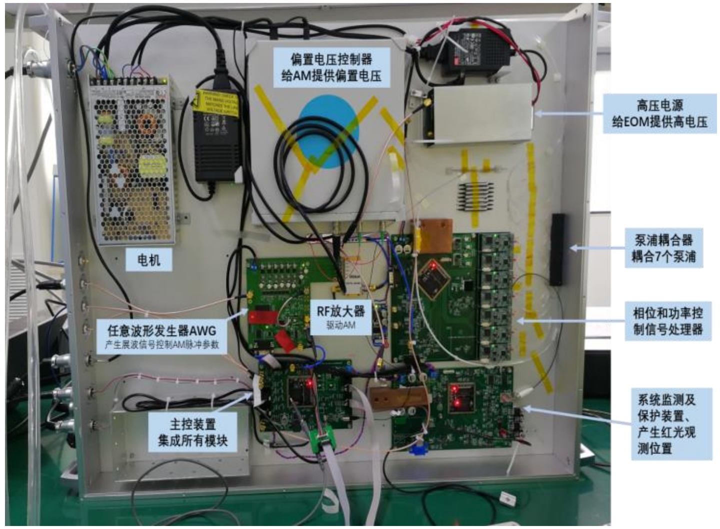
dimensions: $60*100*16.5cm^3$

4 feedback loops designed for phase/power/noise controlling

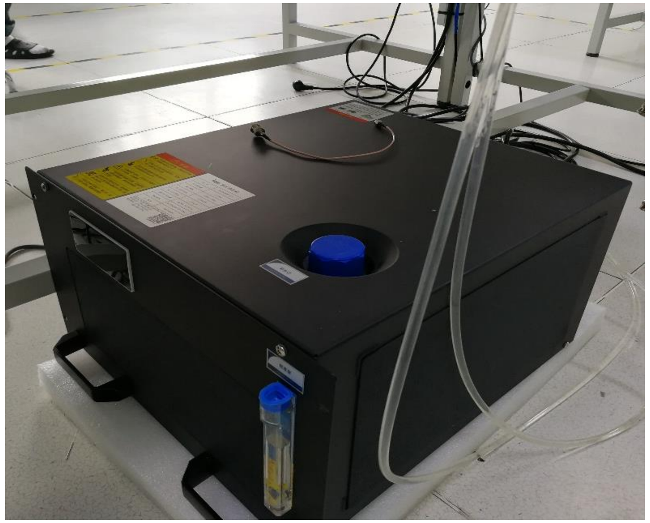
Laser manufacturing finished and under testing



Optical layout



Controlling electronics



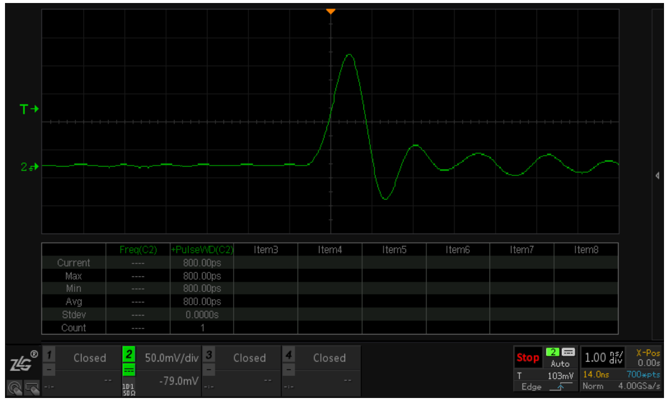
Chiller

Signal and Power Supply

Test parameters of the laser system

- The laser pulse width is **tunable in the range of 0.8ns to 3ns**. The peak power can **reach 22kW** with a pulse width of 0.8ns and a repetition rate of 3.125MHz.

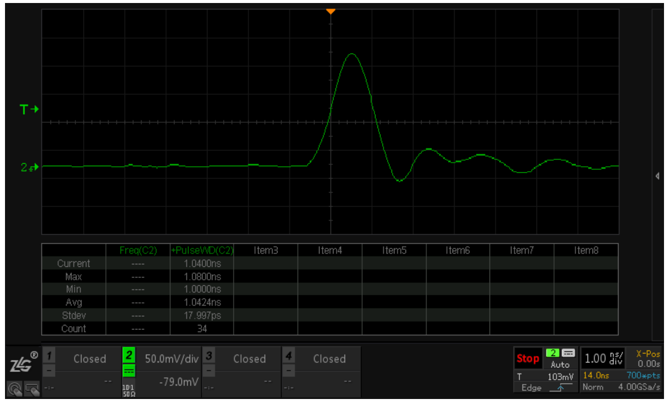
Pulse sequence with
a repetition rate of 3.125MHz



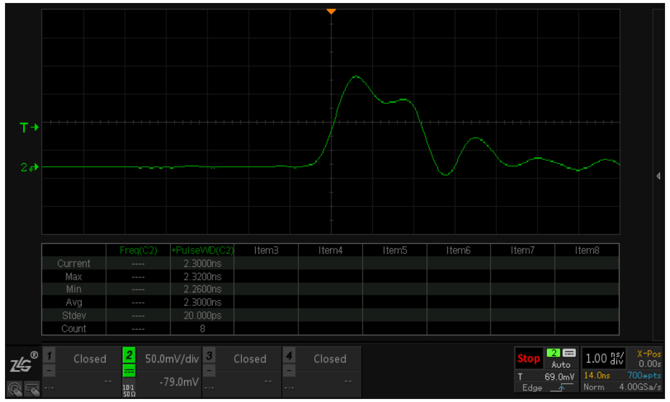
Amplified pulse waveform @0.8ns

Percentage/%	Power/W	Backscattered power/uW	Peak power/ kW
0	2.3	0.1	0.9
10	6.6	1	2.6
15	12.7	3.8	5.1
20	19.6	9.7	7.8
25	26	16.9	10.4
30	35.8	26.9	14.3
35	41	42.3	16.4
42	55.2	65	22

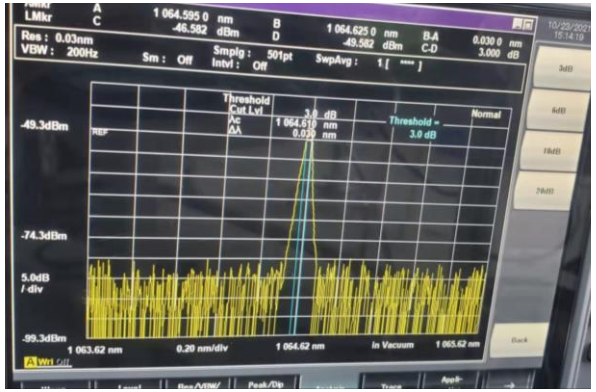
Peak power 22kw @0.8ns, 3.125MHz



Amplified pulse waveform @1ns



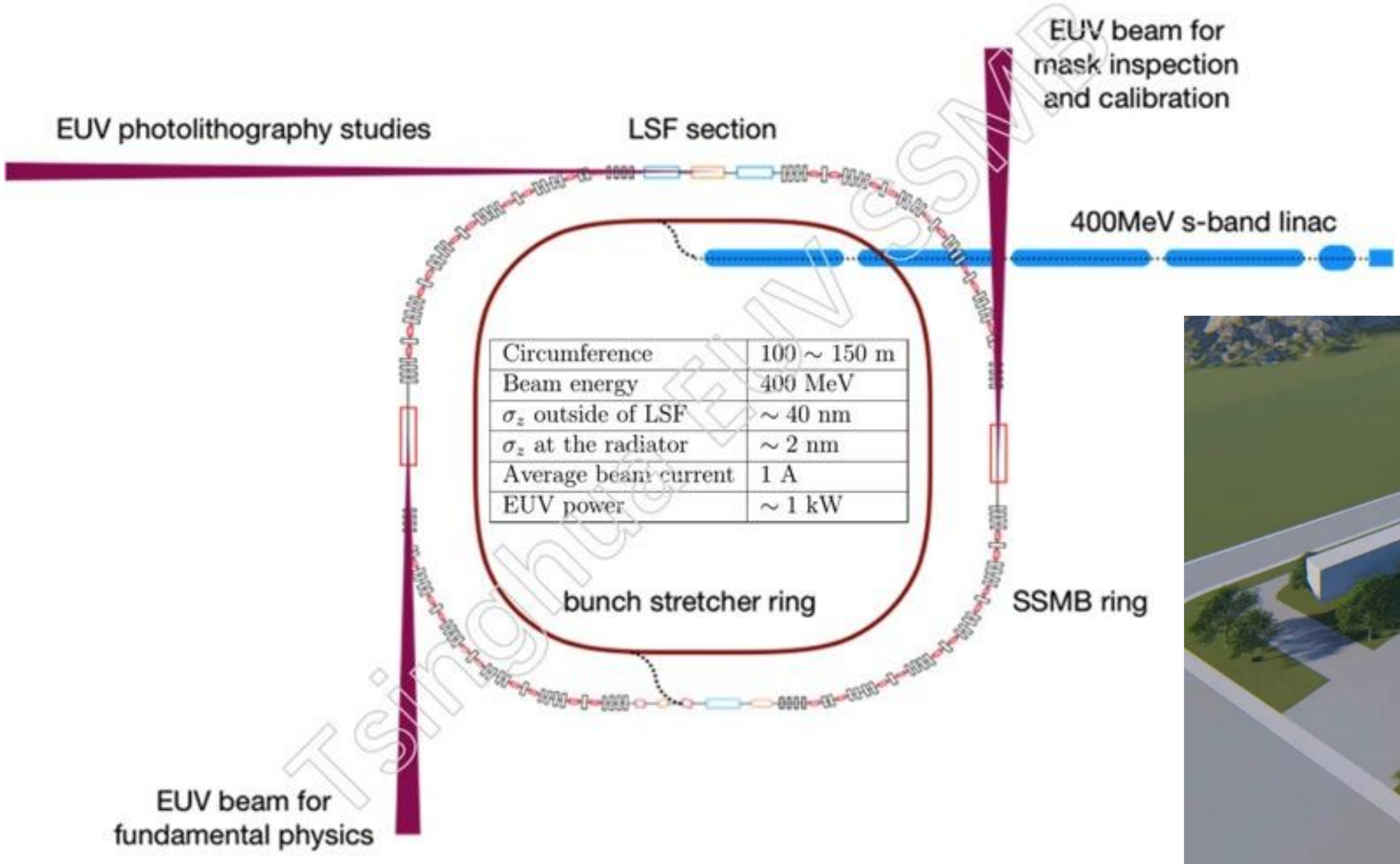
Amplified pulse waveform @2.3ns



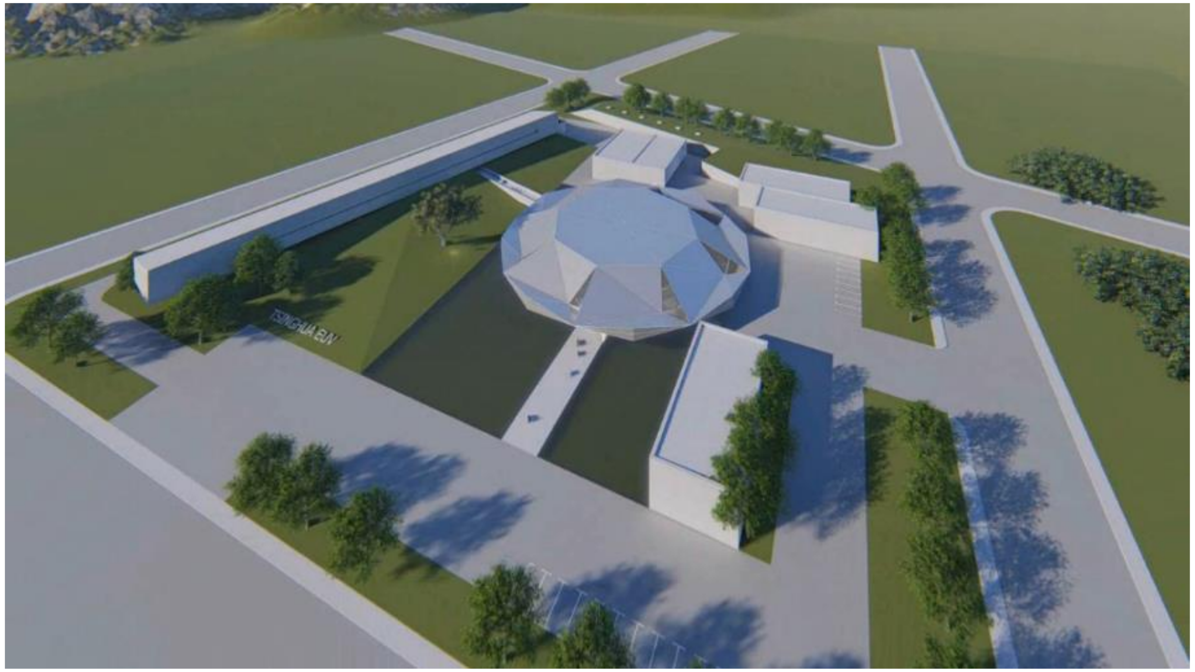
Amplifier output spectrum@1064.6nm

Optical Enhancement Cavity for SSMB

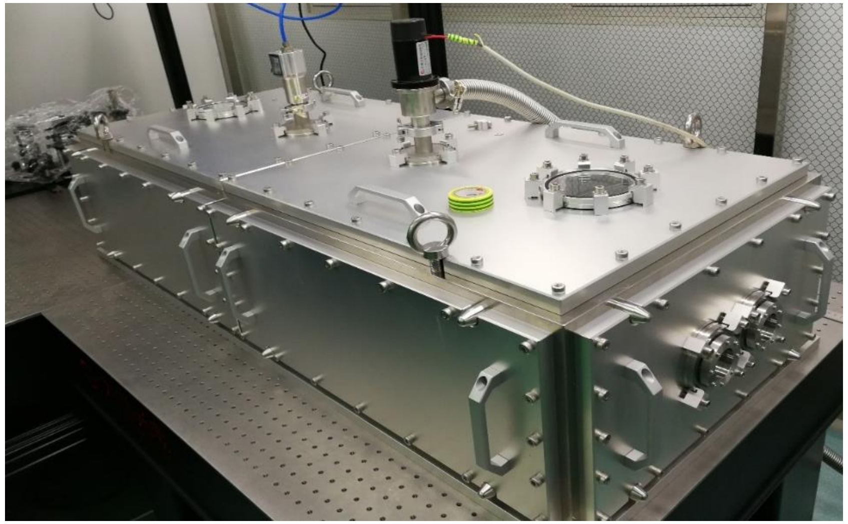
- Envisioned Tsinghua EUV SSMB storage ring:



MW CW laser is necessary for electron beam modulation in the ring. We’ re now dedicated to developing high power OEC at THU.

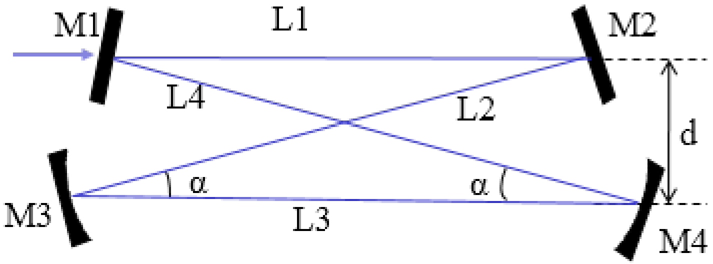


T-Box for OEC technology development



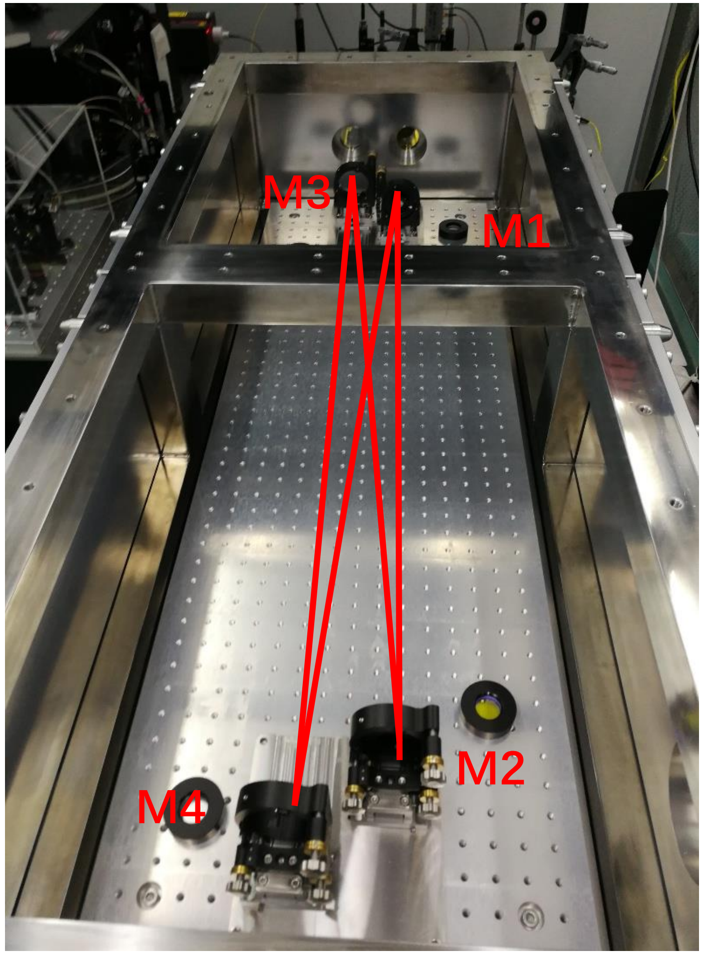
T-Box cavity

FSR=79.3MHz, Lcav=3.783m



Planar 4M bow-tie cavity

Cavity Design Parameters	
Finesse	2093
Gain	667
Round-trip length	3.78275 m
Resonance FWHM	37.8596 kHz
Decay time	4.20382 μs



Setup inside OEC

L1 (mm)	**L2(mm)**	**L3(mm)**	**L4(mm)**	**d(mm)**	**ρ(mm)**	**α (degree)**
882.12	947.44	1006	947.44	80	1000	4.844°

Status of prototype cavity T-Box

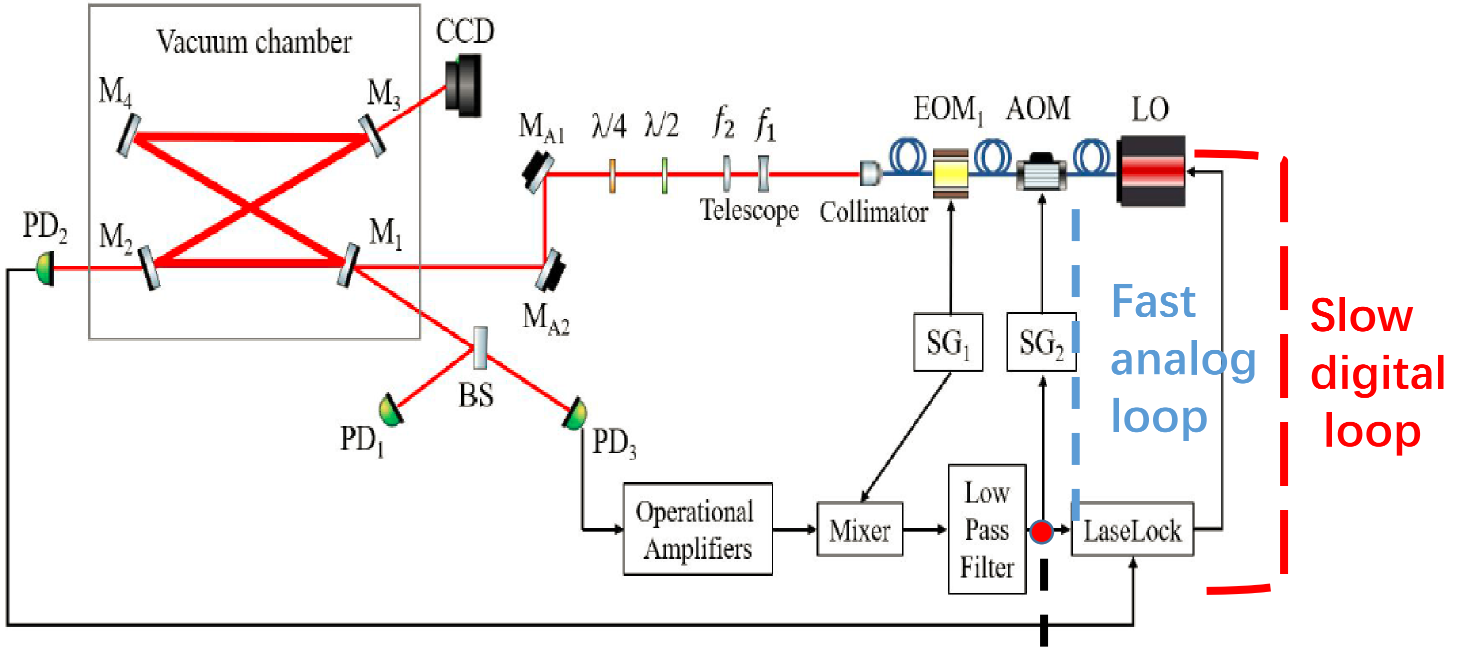
Two closed loops designed for feedback systems (PDH):

- **Fast analog loop (AOM)**

  In order to obtain a good lock, AOM is used to compensate the high-frequency noise. The cavity can be lock for several ms.

- **Slow digital loop (PZT)**

  Compensate the low-frequency noise.



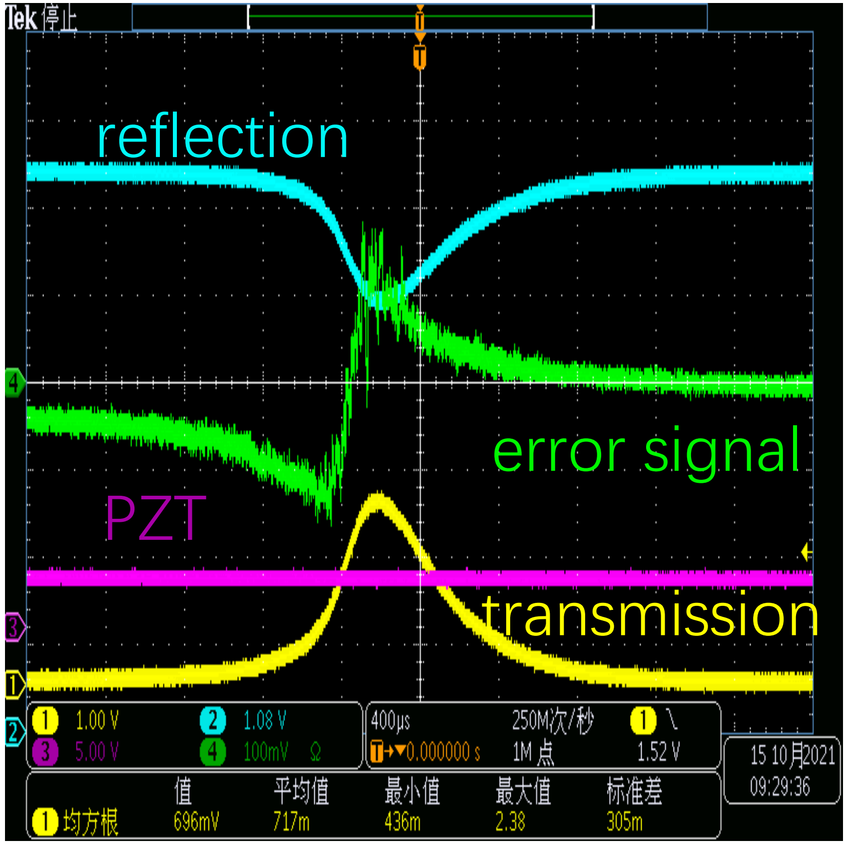
Schematic of T-Box cavity

Error signal

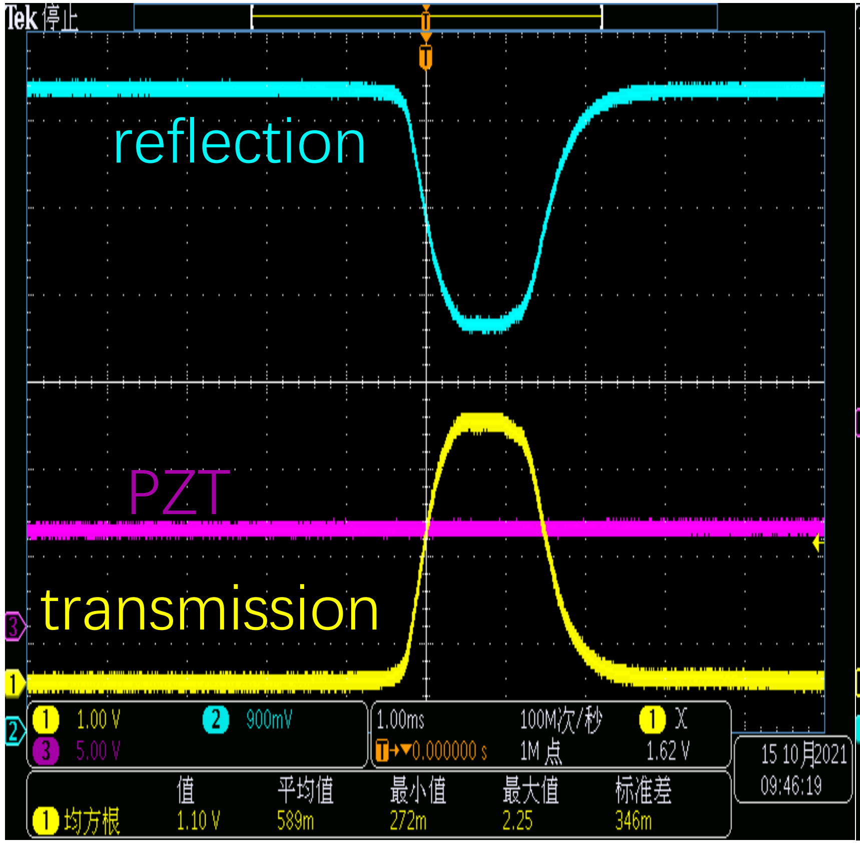
Stable locking of OEC achieved

Locking results:

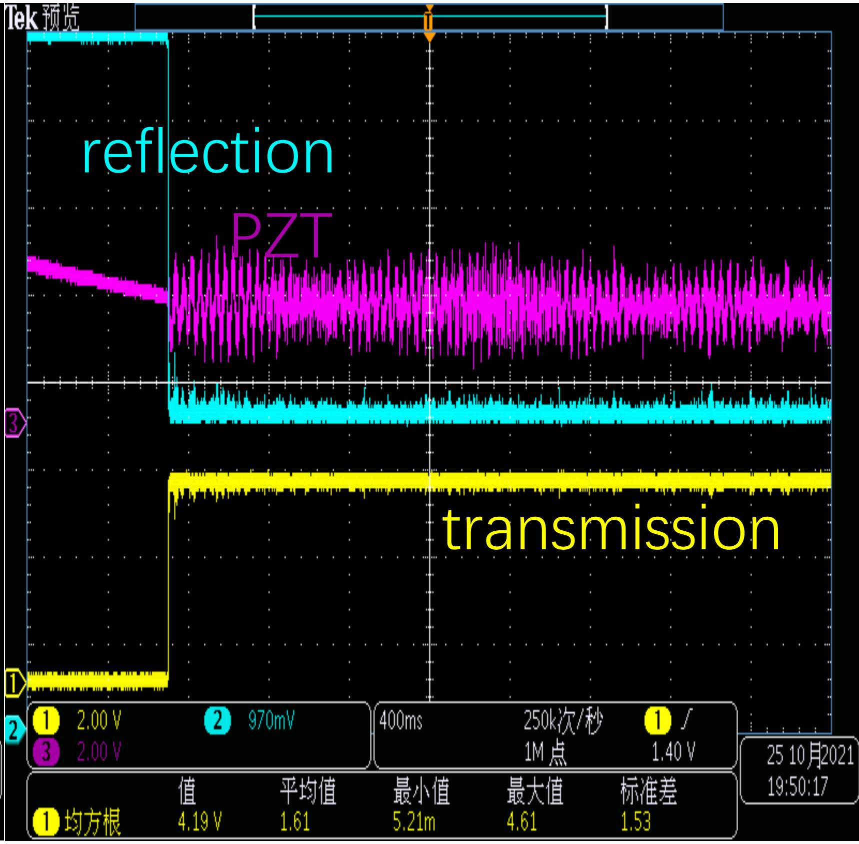
In open loop



With fast analog feedback



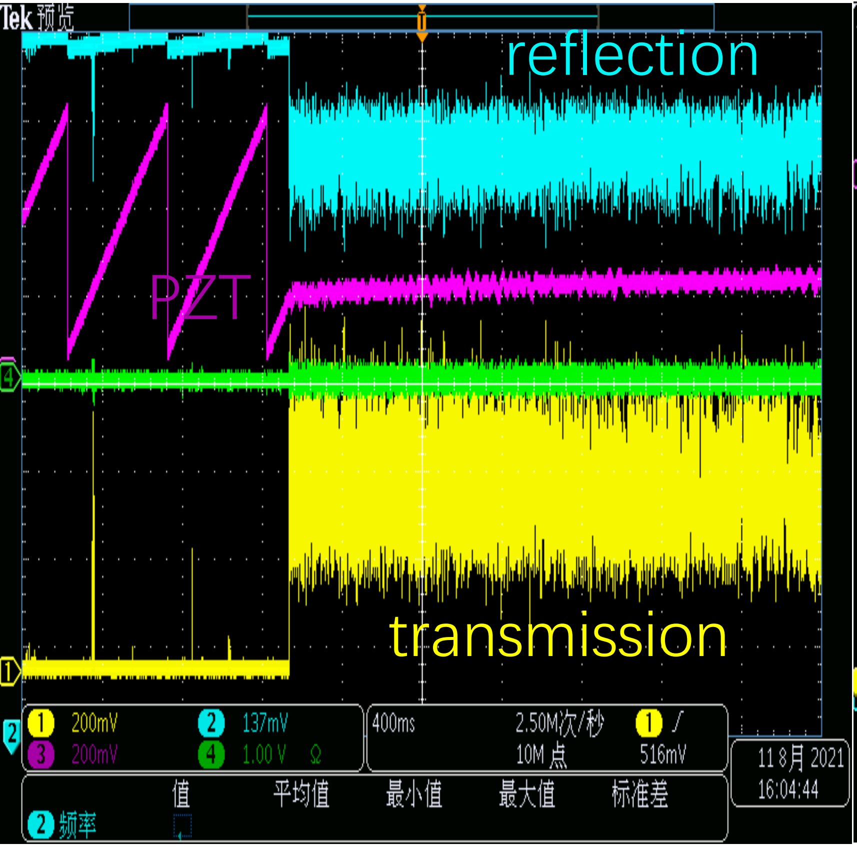
With two closed loop



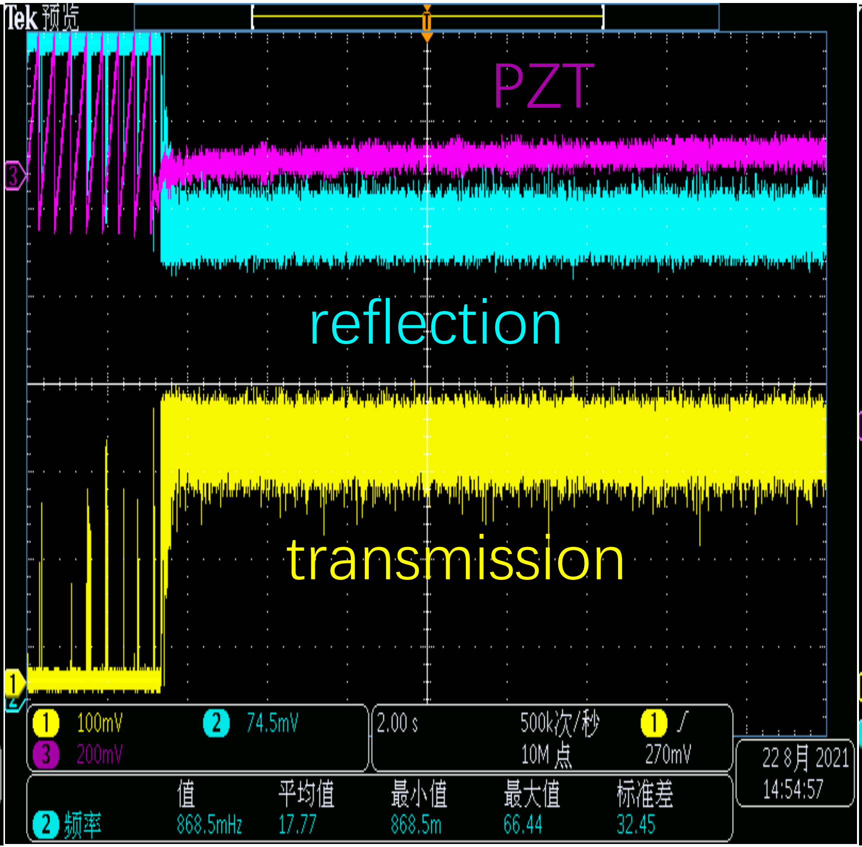
The lock is kept around several ms thanks to the fast analog feedback. Stable locking for more than four hours has been realized with two locking loops running.

Stable locking of OEC achieved

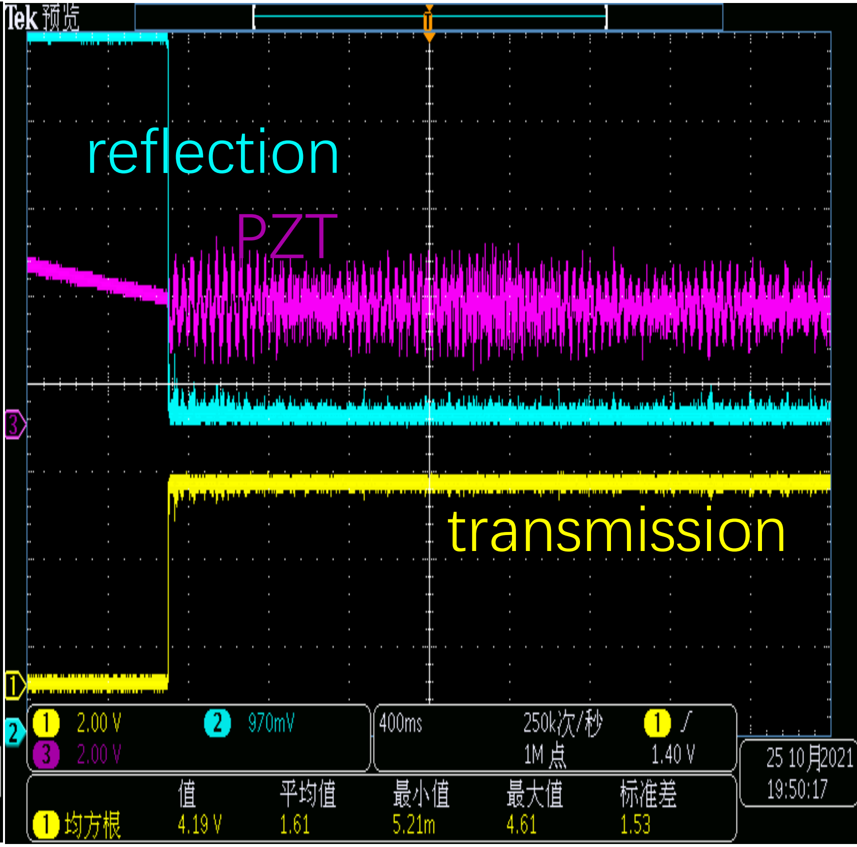
Locking results:



only slow digital loop
(first lock)



only slow digital loop with
good PID parameters



with two closed loop

Coupling efficiency: ~56%

OEC Power stability: ~1.1%

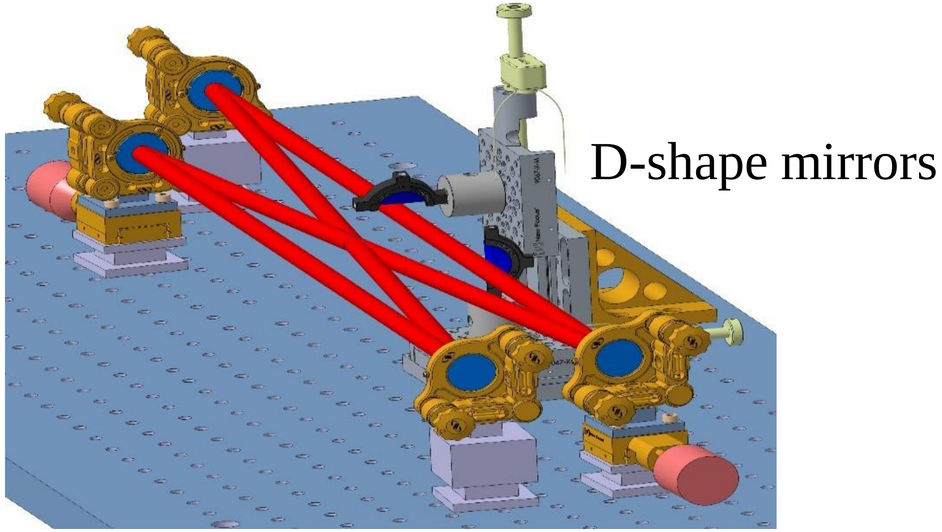
Next steps for OEC development

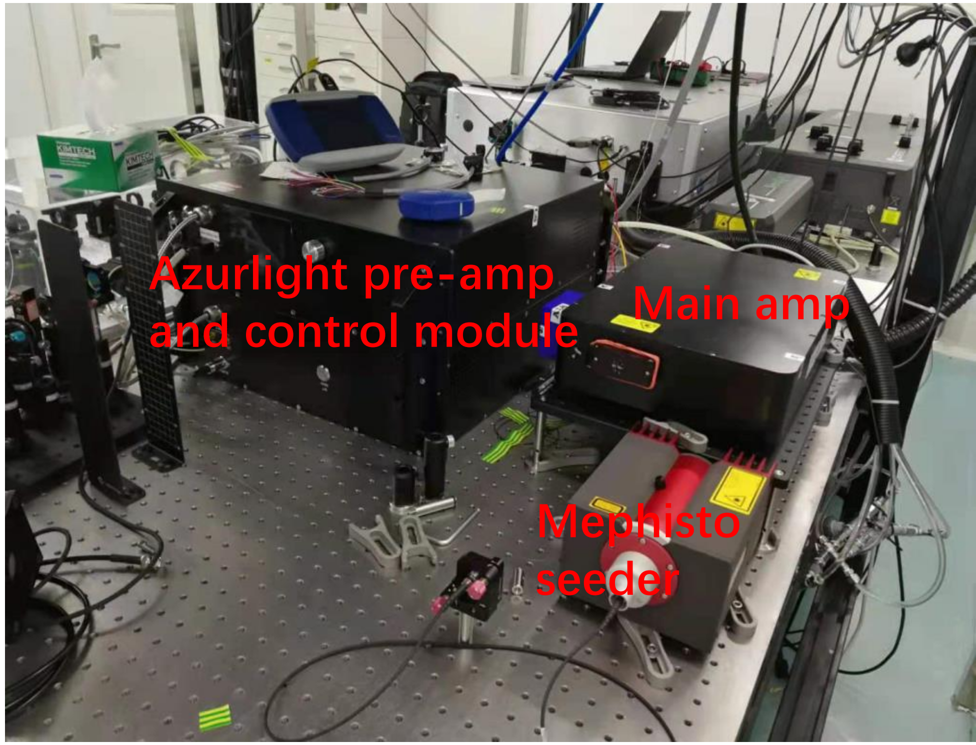
Future high power cavity experiments

- Injection power: ~130W
- Cavity gain: ~10,000
- OEC power: ~1MW

Suppression of modal instabilities

- **implement D-shape mirrors** in between M1 and M2
- dump degenerated high order mode





Injection laser system

Summary

- High power EUV source based on SSMB mechanism has great potential for the development of advanced EUV lithography technology.
- To demonstrate multi-turn SSMB physics at MLS in Berlin, we’ ve developed a high repetition rate high power pulsed laser with high phase stability as the modulator, seeded by an iodine-frequency-stabilized CW laser. The laser would be ready at the end of this year.
- We’ re also being devoted to developing high power (~1MW) CW optical enhancement cavity (OEC) technologies which would support the construction of a real SSMB EUV light source. Progress has been made recently.

Acknowledgement

- THU SSMB Laser Development Group:
  - Xing Liu, Xinyi Lu, Huan Wang, Qili Tian, Lixin Yan, Xiujie Deng, Alex Chao, Wenhui Huang, Chuanxiang Tang
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Thanks for your attention!