An Action Plan of Laser Development for ERL

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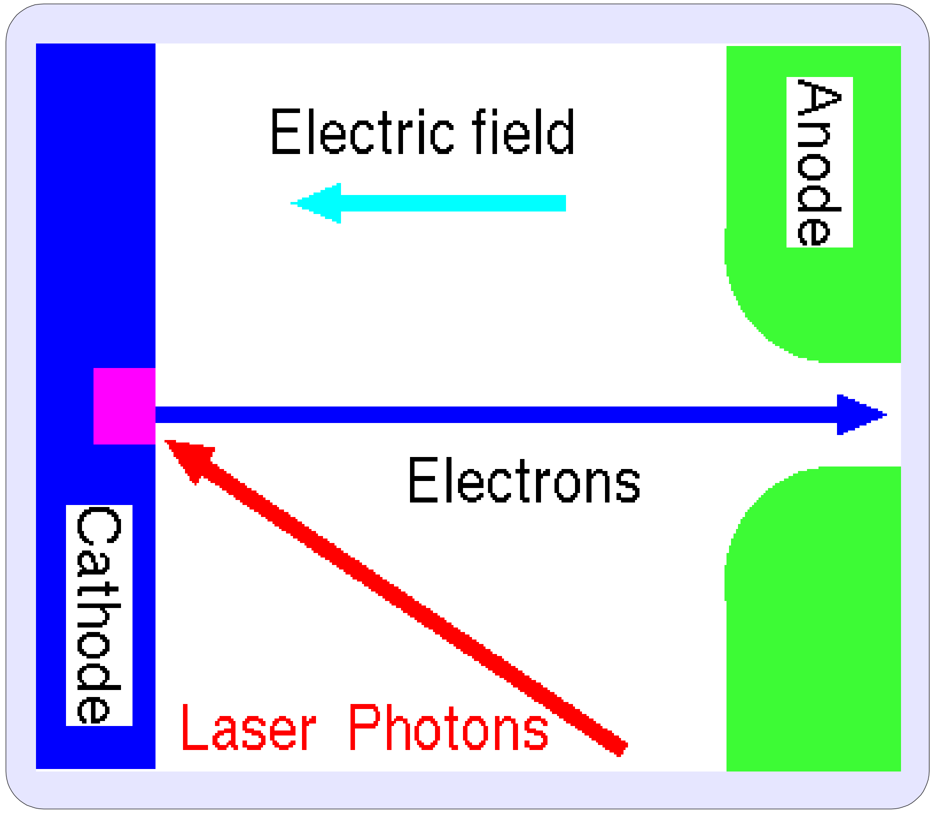
Roll of laser (1)

Parameters	
Micro pulse length	10 – 20ps
Pulse reputation	1.3 Ghz
Charge per pulse	77pC
Peak current	7.7A
Emittance (norm.)	0.1 – 1.0 μrad
Laser energy per pulse (*)	12 nJ
Laser power (*)	15 W
Laser wave length	800nm, tunable

* 1% cathode QE and 100mA beam current are assumed.

Roll of laser (2)

- NEA GaAS photo-cathode + laser generates CW pulse train.
- Beam extraction by a static electric field (>250 kV).
- Beam structure is determined by laser profile.



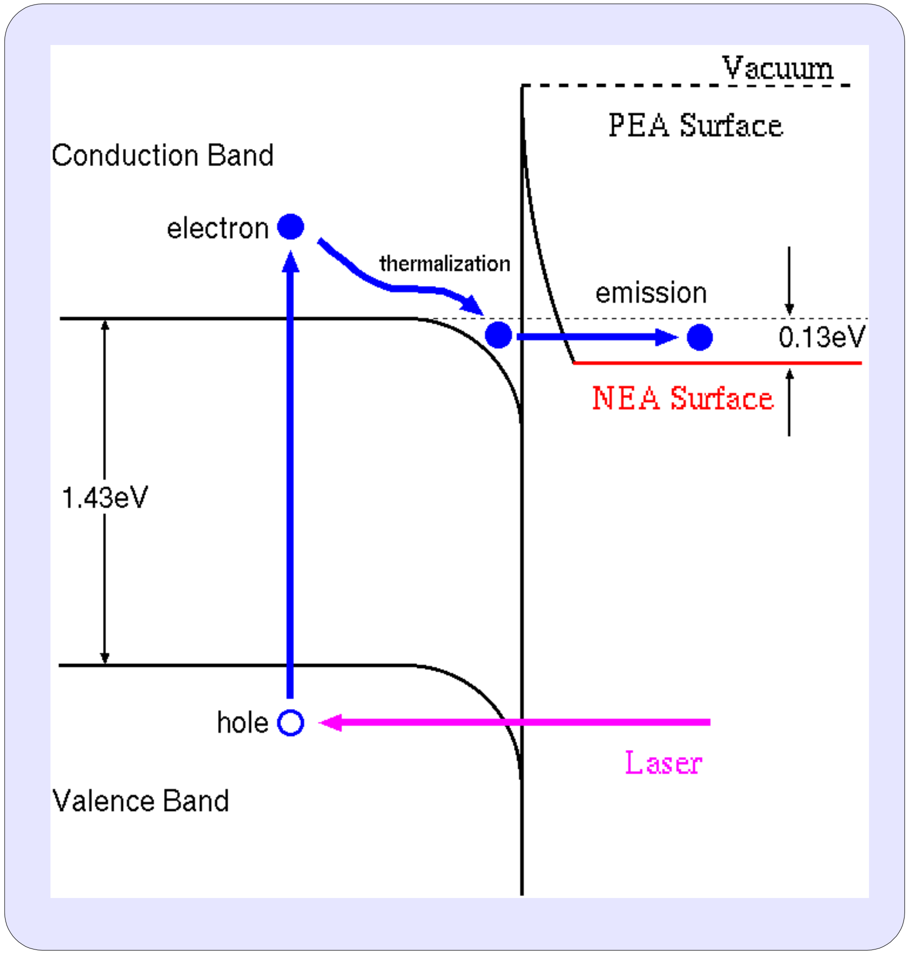
ERL Roll of laser (3)

- Initial emittance

$$\epsilon_x = \frac{R}{2}\sqrt{\frac{h\nu - \phi_0}{3mc^2} + \frac{kT}{mc^2}}$$

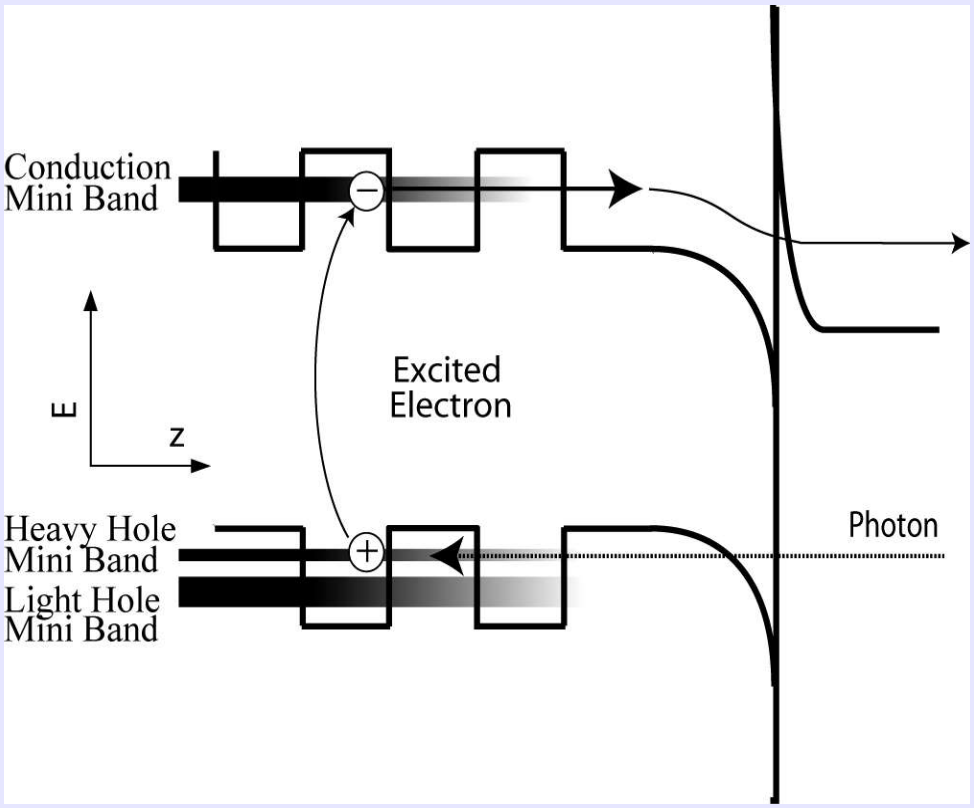
  - $h\nu$-ϕ_0 can be 20meV, R=1mm -> ε~0.01nm @5GeV (0.1 μrad norm)

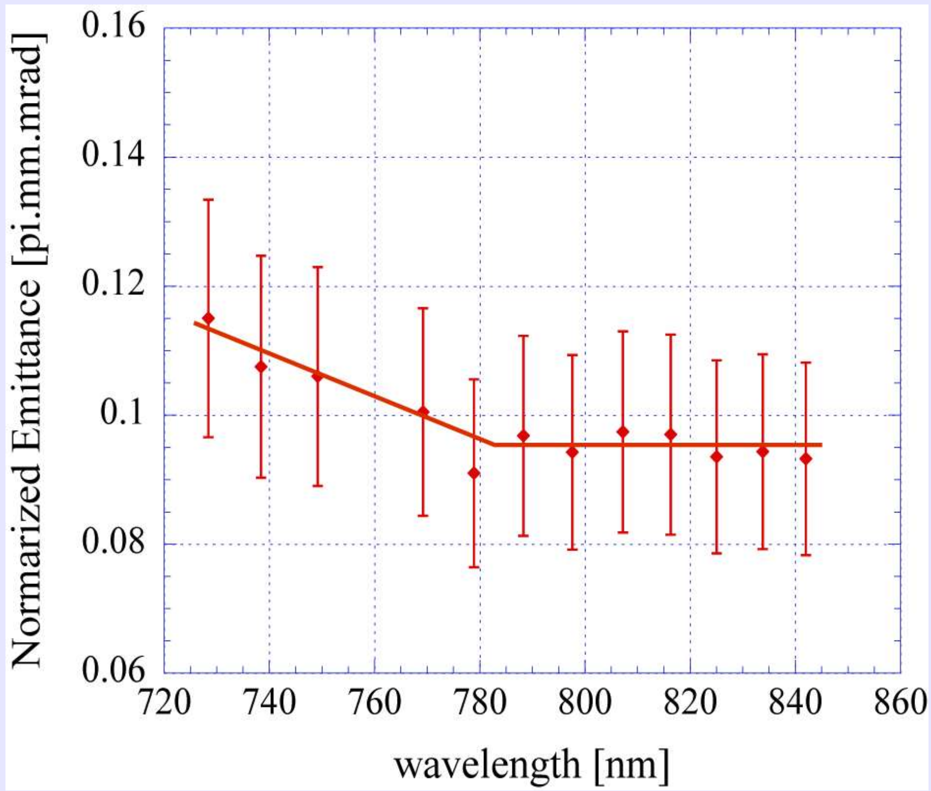
- To obtain the minimum emittance, the laser wavelength should be optimized to the band gap, which depends on the cathode material/structure.



ERL Roll of laser (4)

- 0.1 μrad (norm) is demonstrated by GaAs super-lattice cathode (N. Yamamoto et al., TO28、proc. of PASJ, 2006）





Laser (1) Ti:S

- Spontaneous mode-locking by Carr effect, bunch length > 17fs 。
- Wide band width for lasing (700-1100nm), wave length tune-ability by filtering.
- Require 488nm light for pumping; SH of Nd:YAG/YLF is employed.
- Huge pumping power is required; The heat removal is an issue; The system is unstable.

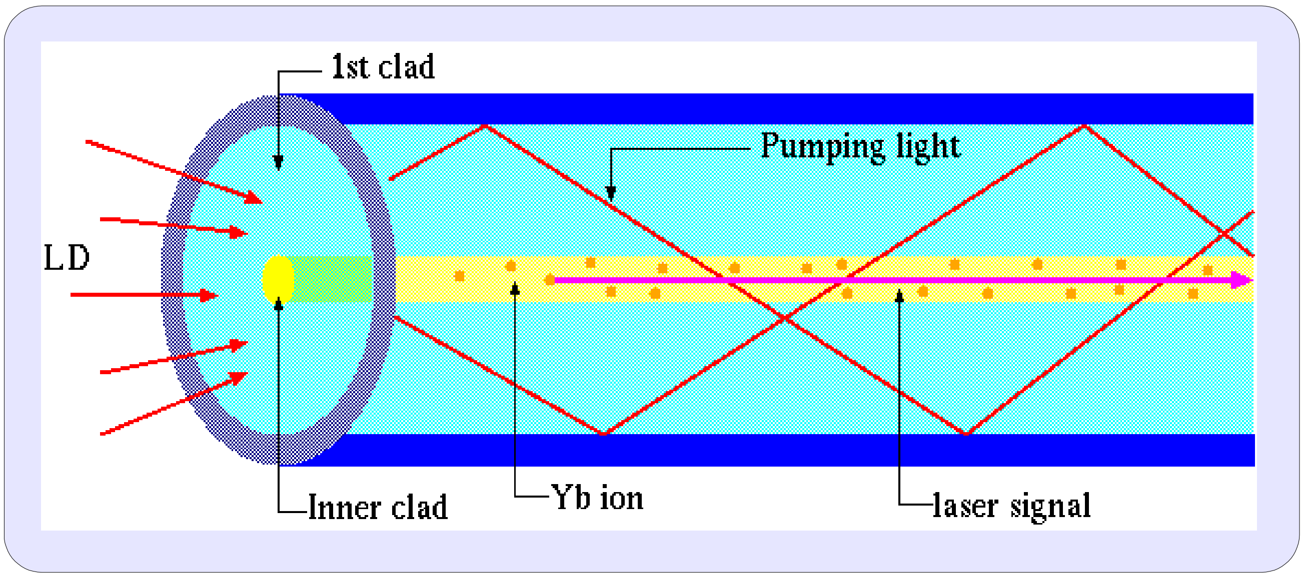
Laser (2) Yb:YAG Laser

- Laser wave length 1030 nm。
- Band width 10 nm, which allows 100fs pulse length by mode-locking.
- Pumping light wave length is 940 nm; LD (InGaAs laser diode) can be employed; Yb:YAG is a candidate of full solid stable high-power laser system.
- The heat removal is also a problem, but easier than that in Ti:S case.

ERL

Laser (3) Yb fiber laser

- Double clad-core optical fiber; Yb ion is doped in the inner core.
- InGaAs LD (940nm) is introduced into 1st core for pumping.
- Signal, who propagates only in the inner core, is amplified by stimulated emission.
- High efficiency, low-loss, high-power, very stable due to excellent heat dissipation.



Laser (4) Laser Summary

Laser Crystal	$Ti:Al_2O_3$	Yb:YAG	Yb fbr
Wave length (nm)	700-1100	1030	1030
Wave length tune-ability	Yes	No	No
Luminescence time μs	3	1000	1000
Pump light (nm)	488	940	940
Stability	Marginal	Good	Excellent
Note	Wavelength is tunable, unstable	High stability by LD pumping	Excellent stability and high power by LD pumping and good heat dissipation.
Feasibility as ERL driver	Feasible, but the system becomes huge and unstable.	Feasible if the wave length can be tunable.	Feasible if the wave length can be tunable.

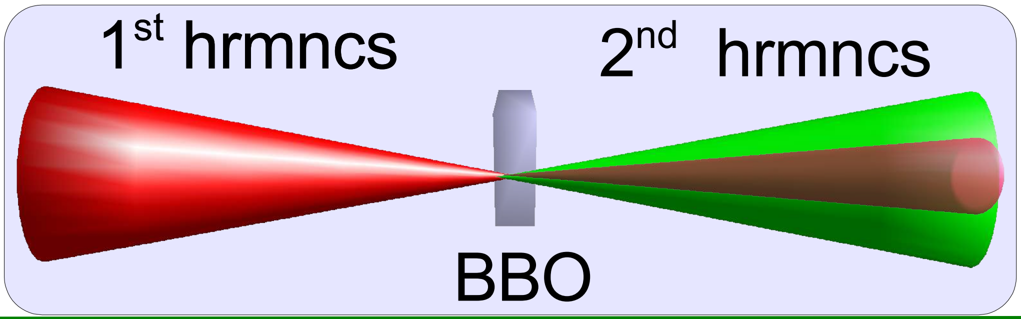
ERL Laser (5) Parametric Amplification

►Harmonic Generation

- Non-linear polarization of atom is induced by focusing laser light in the non-linear crystal (KPD,BBO,etc).
- If the phase matching condition is satisfied, higher harmonics is generated from the polarization. Otherwise, there is no harmonic generation due to the incoherence.
- Generally, diffraction index is increased by frequency (normal dispersion); the matching condition is satisfied only by material, which has double refraction.

Phase matching

$$n_1\omega_1+n_1\omega_1=n_2\omega_2$$



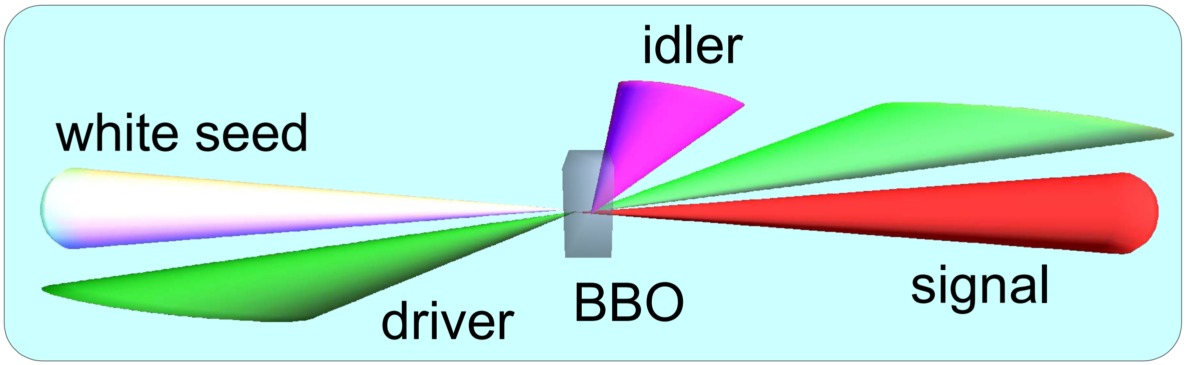
Laser (6) NOPA*

*Non-collinear Parametric Converter

- Parametric amplification with non-collinear condition make a wave length tune-ability.
  - For example, 515nm (Driver) -> 800nm(signal) + 1500nm (Idler).
- It extends our selection range for laser system.
  - Yb:YAG + Yb fiber for ILC/ERL driver.

Phase Matching

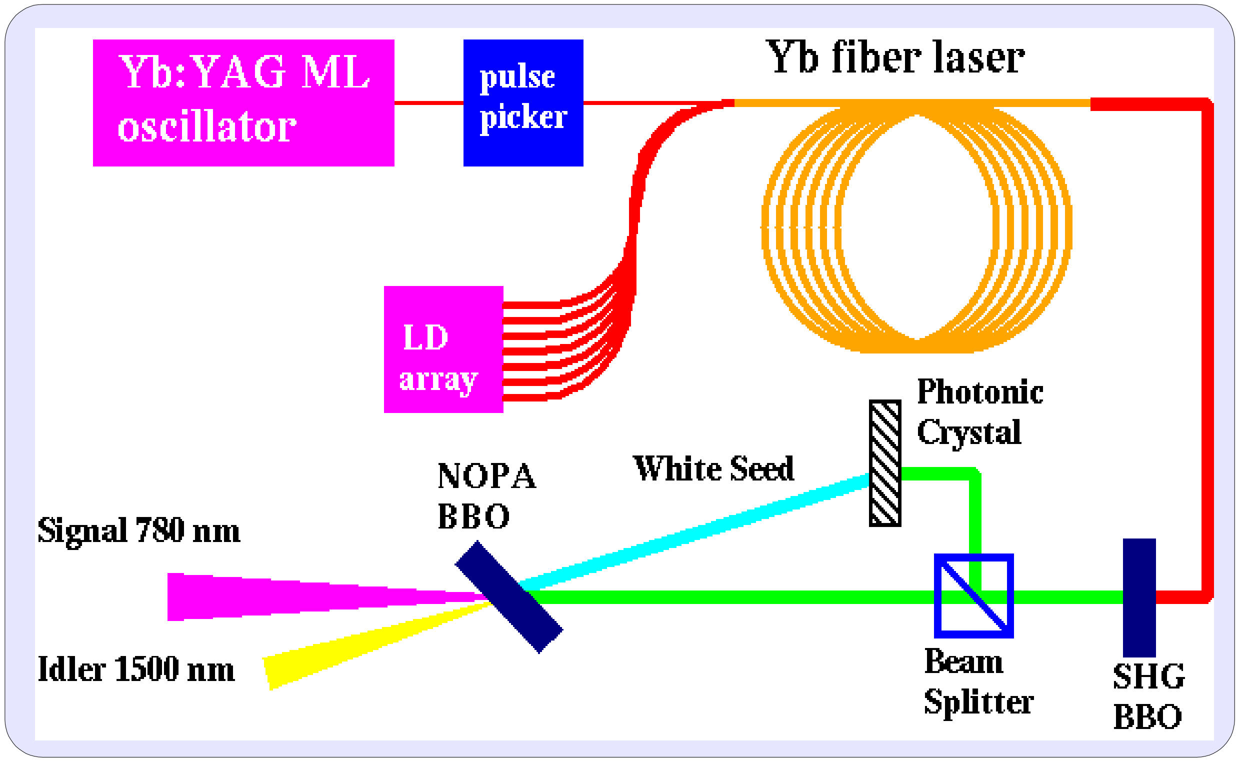
$$n_1\omega_1+n_2\omega_2=n_3\omega_3$$



ERL Yb fiber base system

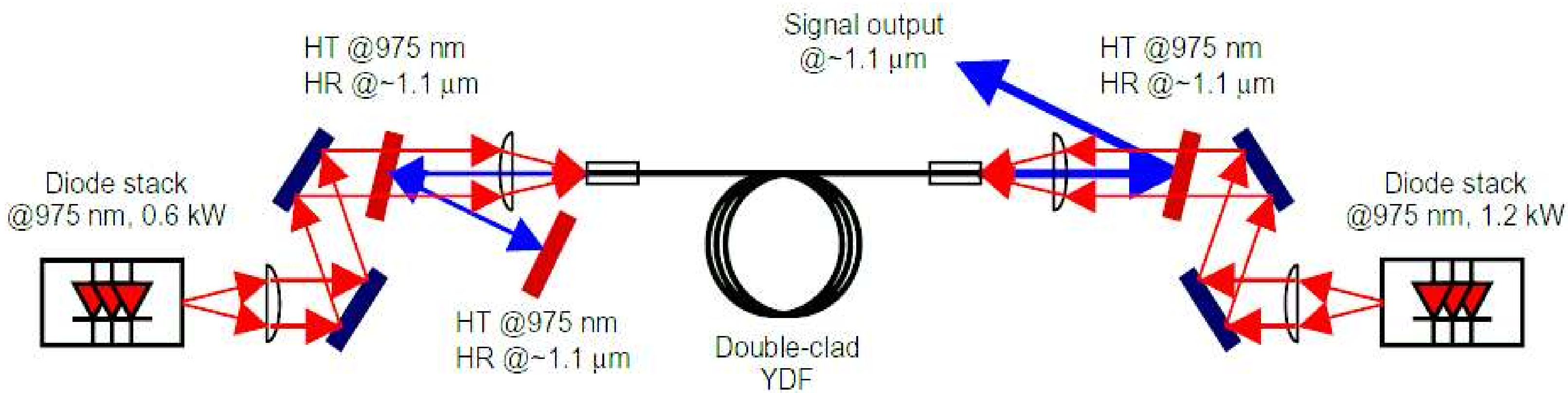
- Yb:YAG mode lock + PP + Yb: fiber laser amp. + NOPA。
- LD pumped-full solid super stable laser.

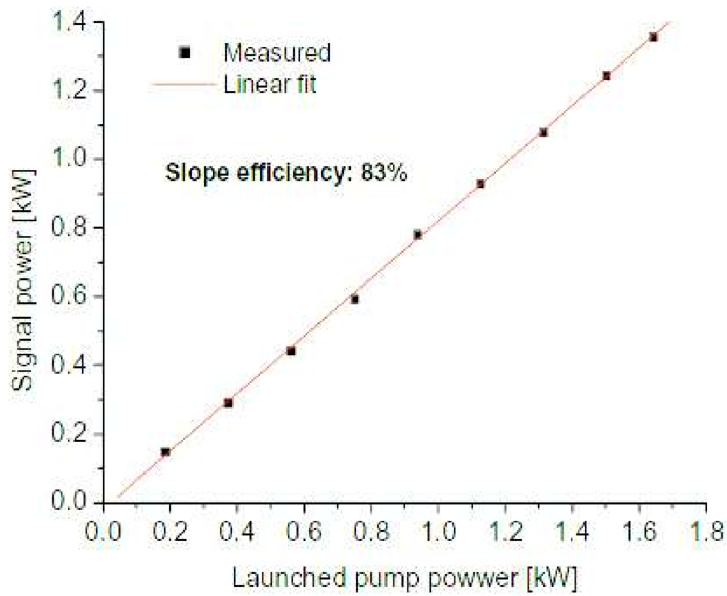
- Yb fiber laser allows high power up to several kW.
- Wave length tunability by NOPA (Need a demonstration).

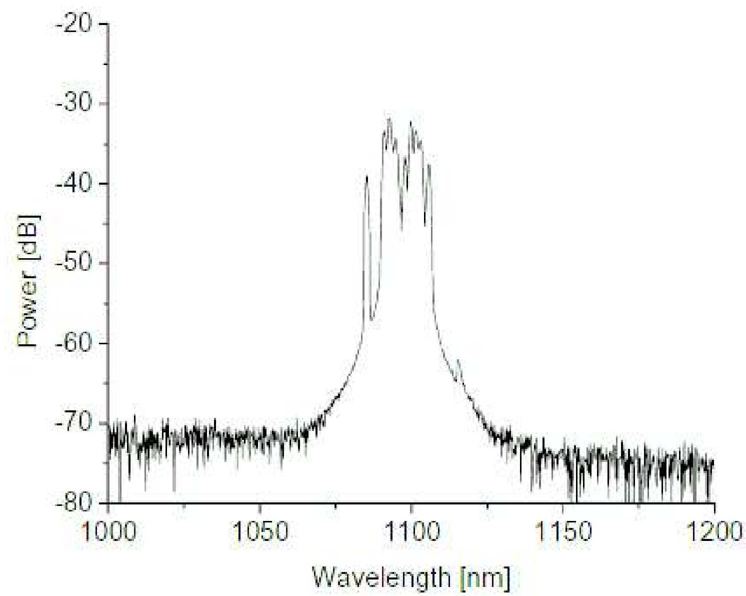


ERL Yb fiber laser (CW)

- 1.36 kW CW at 1μm with 83% slope efficiency .
- The power is limited only by available pump power.
  - Y. Jeong et al., Optics Express, Vol. 12, Issue 25, pp. 6088-6092

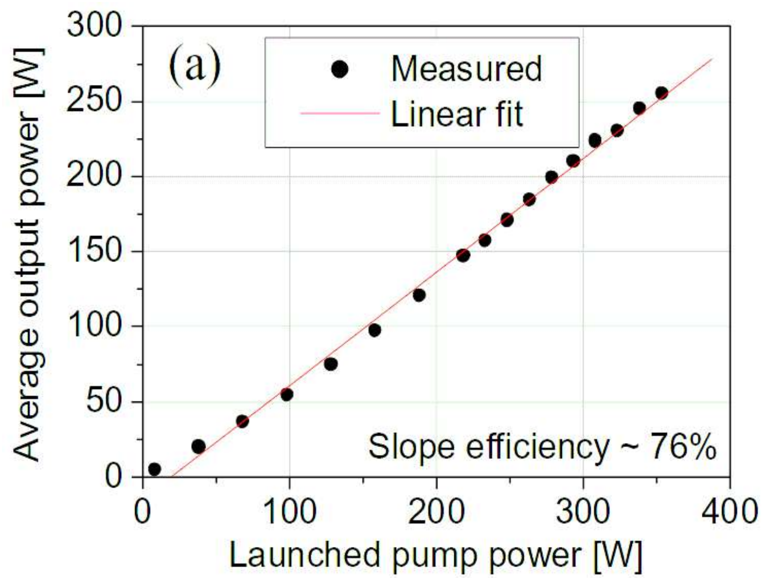


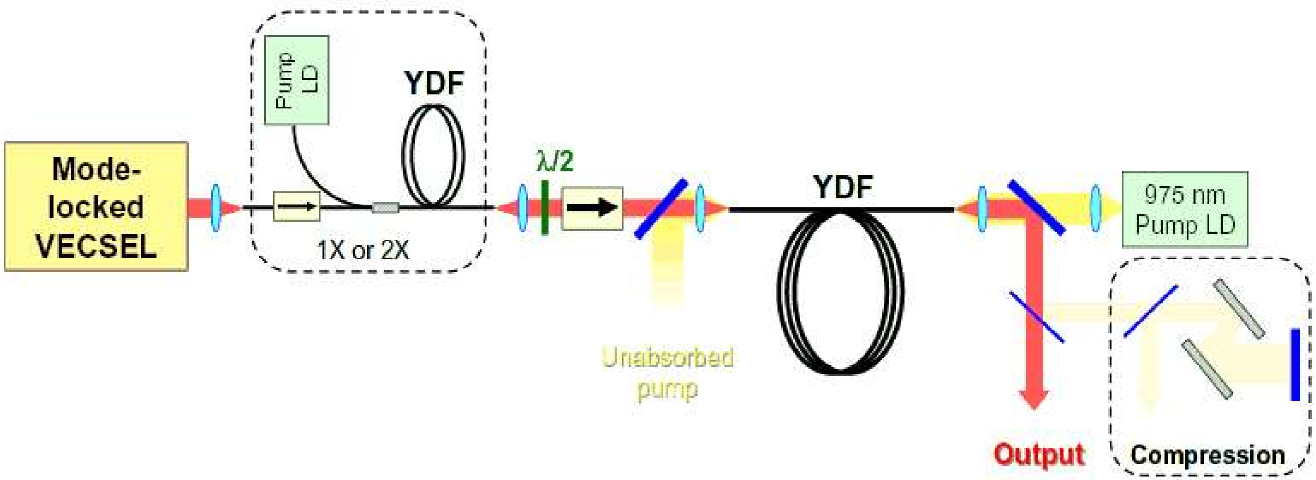


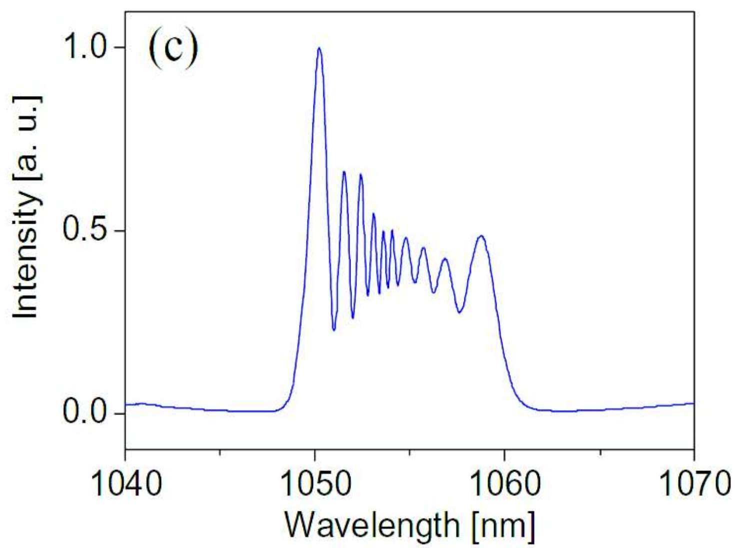


Yb fiber laser (pulse train)

- ► 1GHz, 4.6ps, 200W pulse train with MOPA by passively mode-locked VECSEL and Yb fiber amplifier. (P. Dupriez, et al., OPTICS EXPRESS 9611, Vol. 14, No. 21, 2006)







ERL

Commercial Products

- IMRA (USA)
  - FCPA μJewel (pulse): 1045nm, 1μJx1MHz (1W), 100fs.
- Fianium (UK)
  - FemtoPower 1060-x : 1064nm, 20-100MHz, up to 15W, <20ps.
- IPG (UK)
  - YLR 2000: 1070-1080nm, 2kW CW (QCW with 5kH modulation)
  - YLP-1: 1070-1080nm, 1mJx20kHz (20W), 100ns.

Purchase a fiber laser

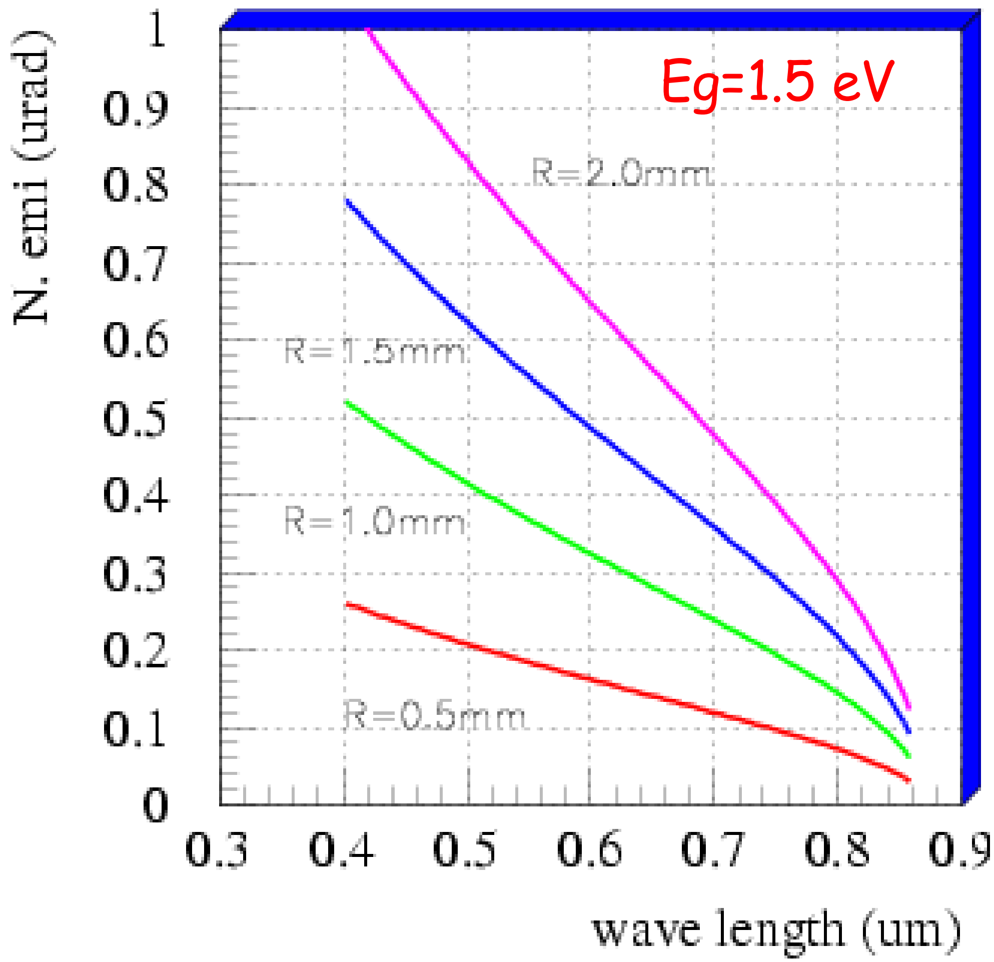
- There is no fundamental difficulties making the pulse train by MOPA based on Yb fiber laser.
- There are several companies delivering Yb fiber laser, whose performance is partly fit to our requirements.
- The reason that there is no laser, who satisfies fully our requirements, is just lack of market needs. Our purpose is very special and ambitious.
- A good company + system integration + R&D = ERL drive laser.

Action Plan

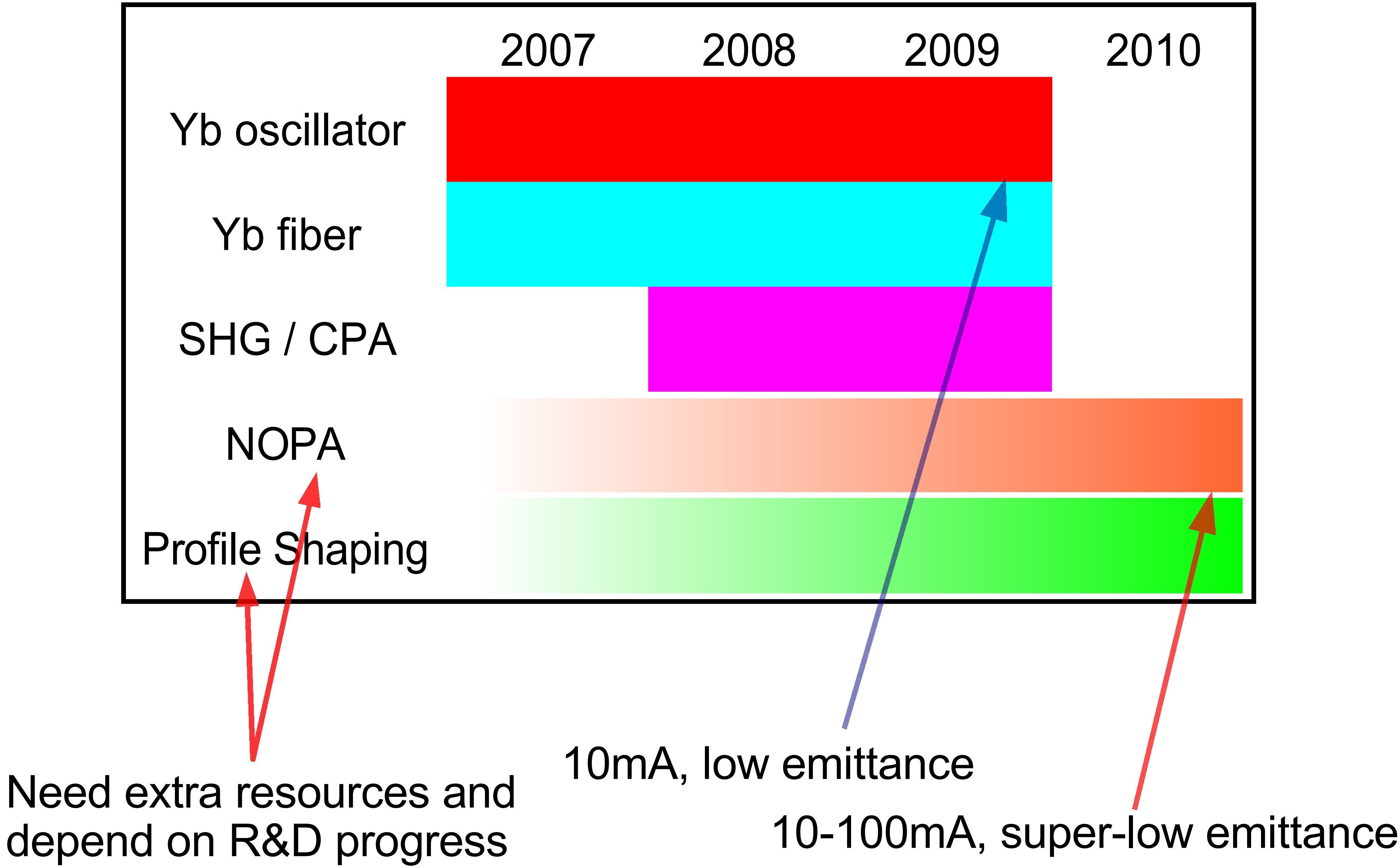
- By considering limited resources for laser development, the following schedule is a compromised plan;
  - Develop/purchase a Yb:YAG or Yb fiber 1.3 Ghz (or lower freq) oscillator in mW class.
  - Purchase Yb fiber amplifiers from a company.
  - Implement Chirped pulse amplification and SHG.
  - SH(500nm) pulse train in several Watts class could be possible in this period.
  - According to a calculation, ~0.4πmm.mrad with 1mm radius is possible.

Action Plan (2)

- Full demonstration is not possible with this 500nm laser, but its could be achieved partly with trade offs among
  - Emittance,
  - Beam current,
  - Bunch length,
  - Beam size, etc.



Action Plan (3) Time Chart



Action Plan (4) note

- A solution based on Yb fiber laser is likely to be promising, but core members, who integrates existing technologies, is necessary.
- Please do not forget still we have some risk(s) that the system does not work as expected.
- We should continue some R&D activities on the wave-length tune-ability and pulse shaping technologies with the available resources towards our final goal.
- Injector based on other technology (thermionic or FE cathode) may satisfies our specifications partly, but no further extendability.