Development of an electron gun for the ERL project in Japan

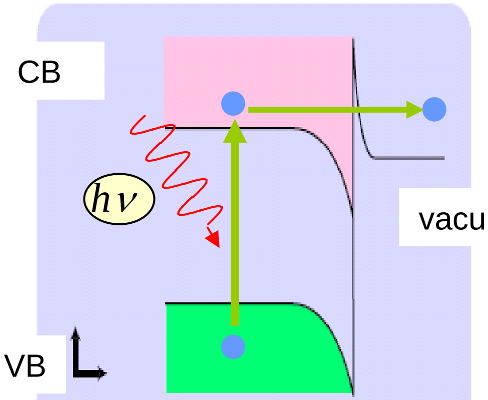
R. Hajima, T. Nishitani, H. Iijima,
R. Nagai, N. Nishimori
ERL Development Group
Japan Atomic Energy Agency

March 12, 2007.

R&D issues for ERL guns

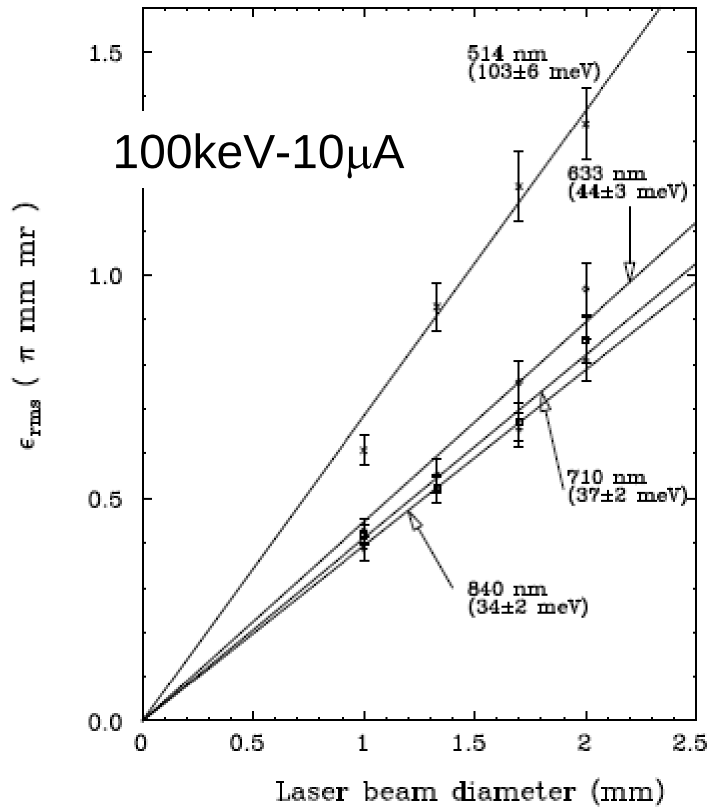
- Performance of ERL-LS relies on its electron gun.
- High-average current (~100mA) and small emittance (~0.1mm-mrad) are essential.
- Further improvement from the existing technologies is required (JLAB-FEL=10mA and XFEL=1mm-mrad).
- “NEA cathode + DC gun” is only the practical solution.
- many R&D issues exist.

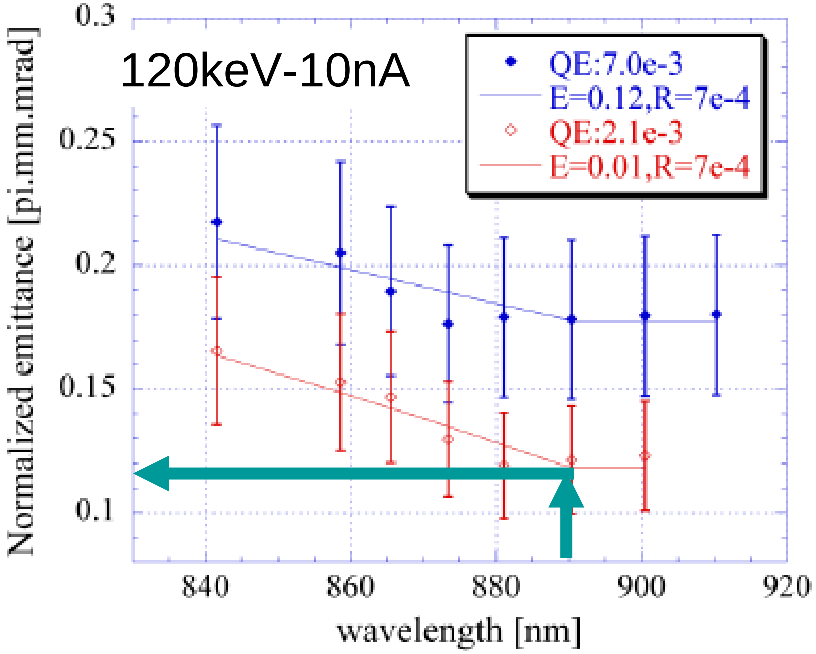
emittance of NEA photocathode



emittance is a function of laser wavelength and laser spot size.

B.M. Dunham et al., PAC-1995, 1030.





emittance vs laser wavelength

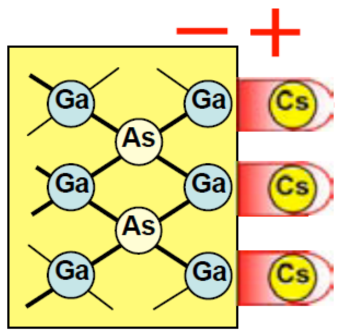
N. Yamamoto et al.
Proc. Acc. Meeting in Japan (2006)

~0.1mm-mrad is available at small current

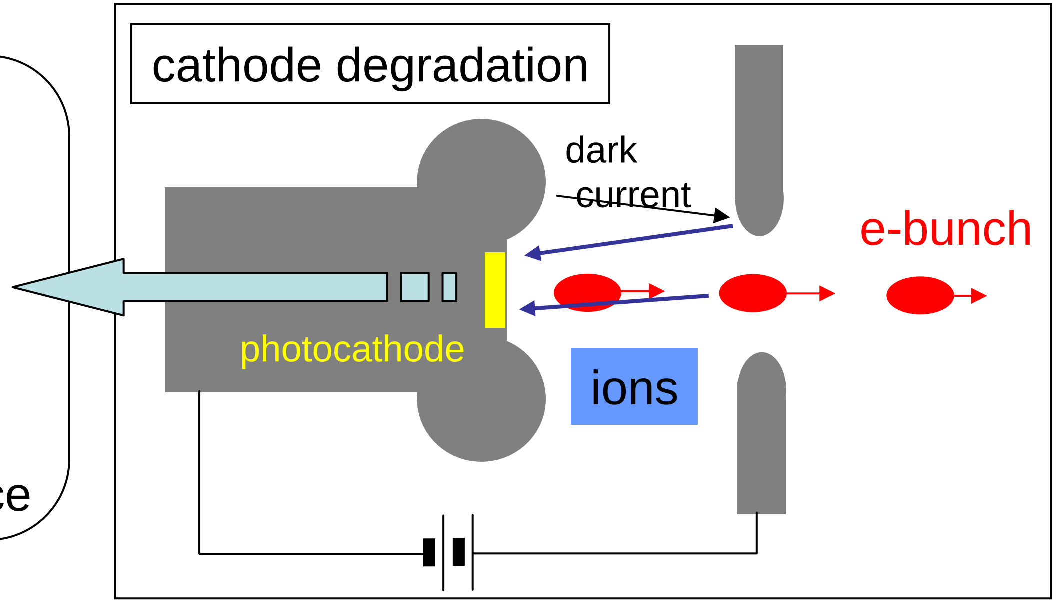
improvement is required

0.1mm-mrad and 100mA is not proven.

cathode life limitation by ion back-bombardment



re-cesiation recovers Q.E.
→ damage is only at the surface



- collision, deposition of residual gases
- dark current (and its enhancement)
- ion back bombardment

existing guns

CEBAF polarized gun（100kV, 0.1mA）

life ~ 2×10^5 C/cm^2

JLAB-ERL gun（350kV, 9mA）

life ~ 2×10^3 C/cm^2

improvement is required

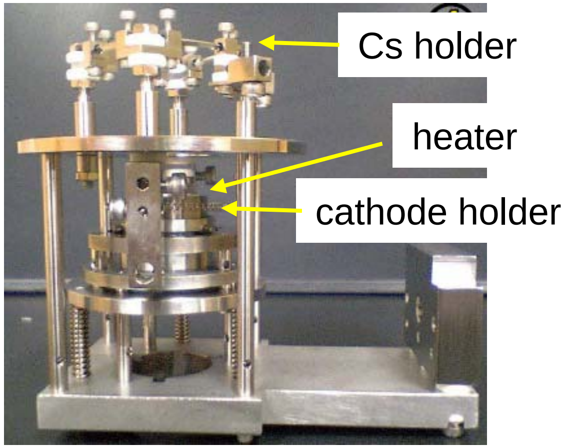
ERL-LS

life ~ 10^6 C/cm^2

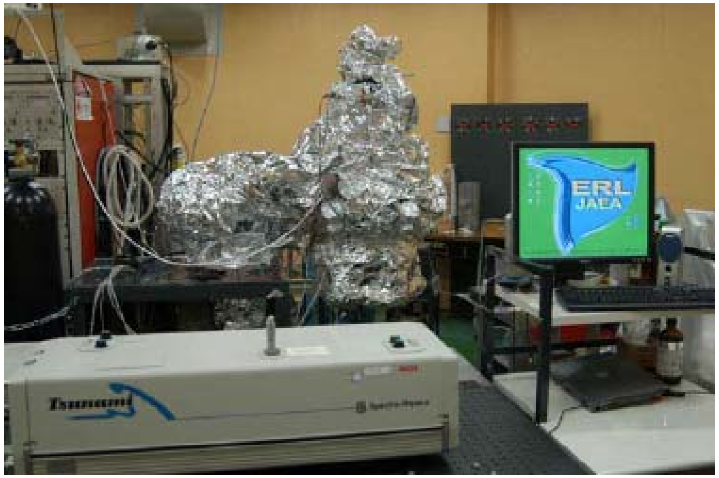
100mA / ϕ2mm、100 hours

a photocathode test bench at JAEA

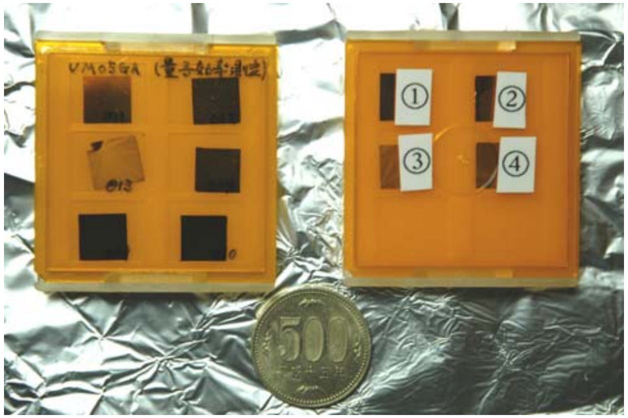
cathode holder



UHV chamber and laser



Optimization of cathode material for the better QE and life.



photocathode prepared at Nagoya Univ(1).

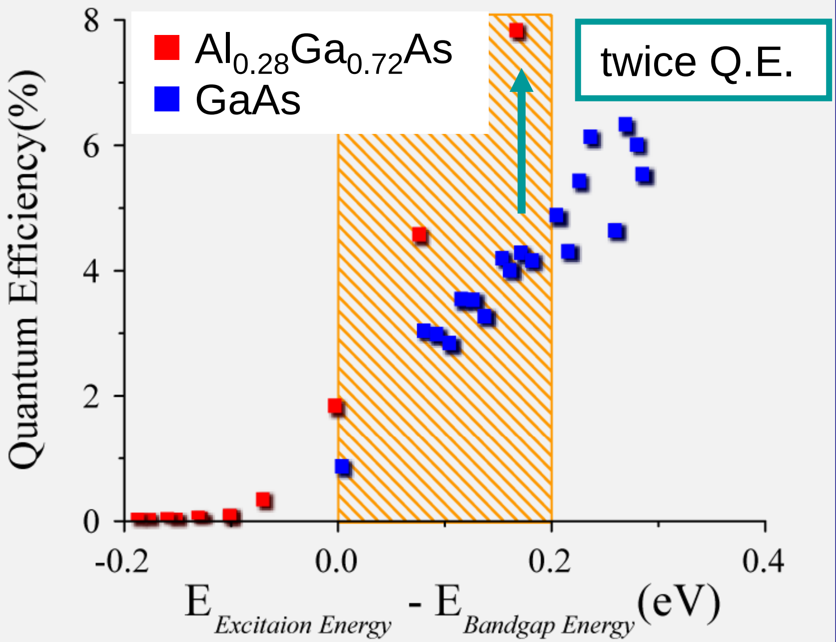
GaAs, $Al_xGa_{1-x}As$

x=0.17, 0.28

(1) Venture Business Laboratory, M. Tabuchi, Y. Takeda et al.

Performance of GaAs and AlGaAs

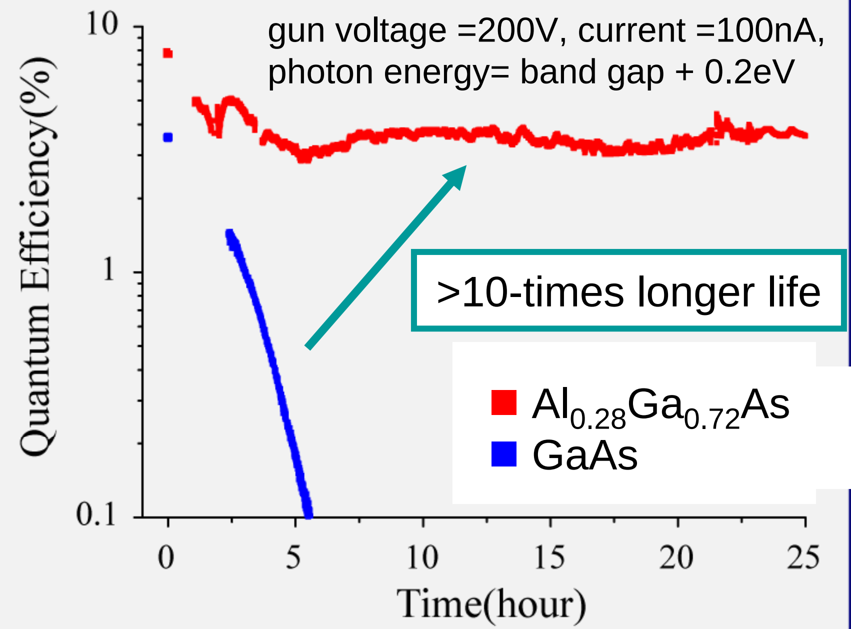
Quantum Efficiency



AlGaAs shows higher QE than GaAs

larger band gap = higher DOS
→ more efficient excitation of electrons

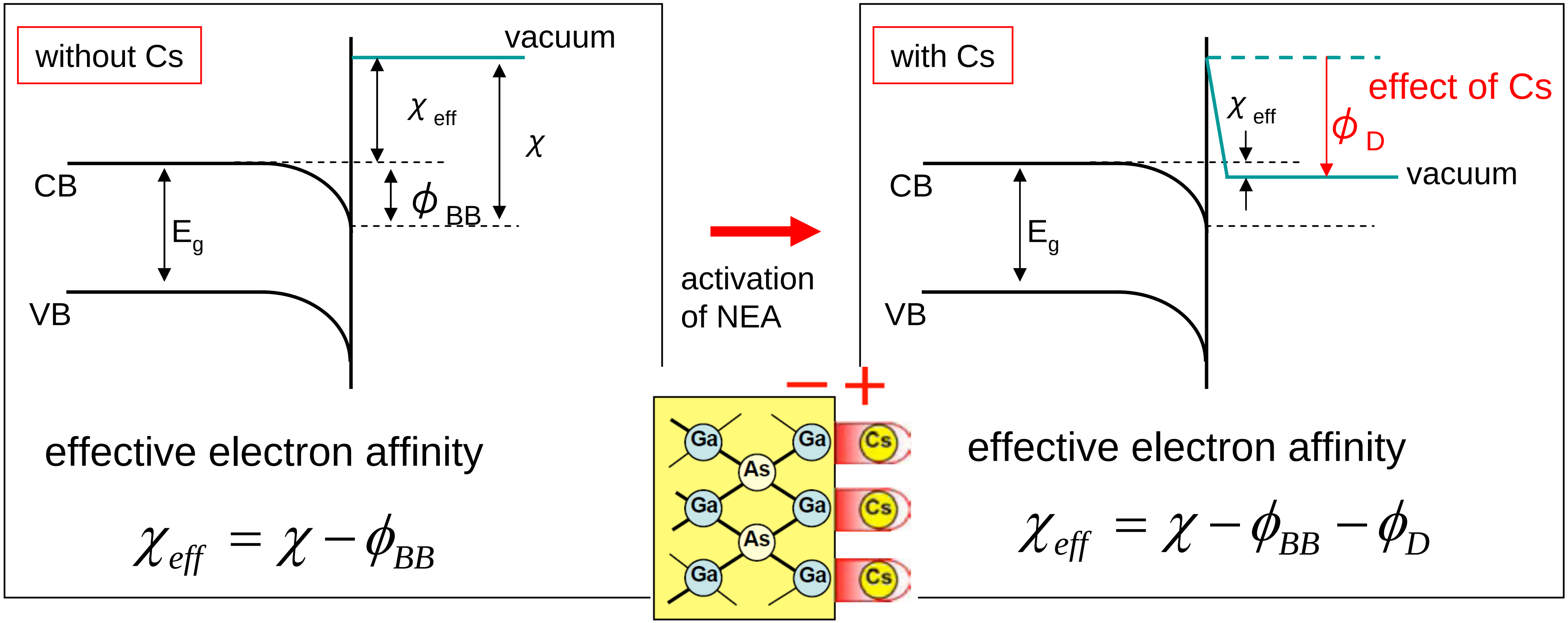
Cathode Lifetime



AlGaAs shows longer life than GaAs

electron affinity
GaAs = 4.1 eV
$Al_{0.28}Ga_{0.72}As$ = 3.8 eV

How to design a long-life cathode



damage on the Cs layer → a rise of vacuum potential

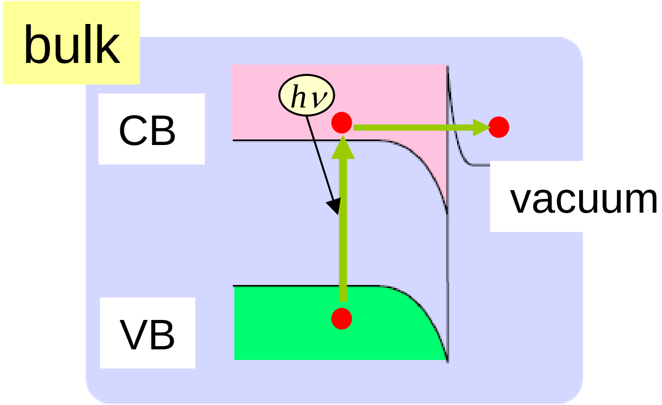
cathode material with smaller χ is preferable for keeping the NEA state (χ_{eff} <0)

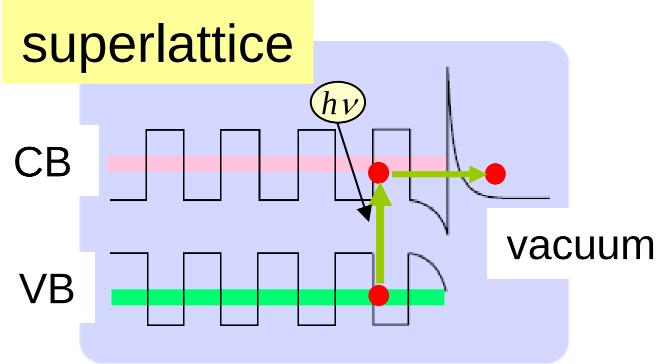
χ =4.1 eV (GaAs), χ =3.8 eV ($Al_{0.28}Ga_{0.72}As$)

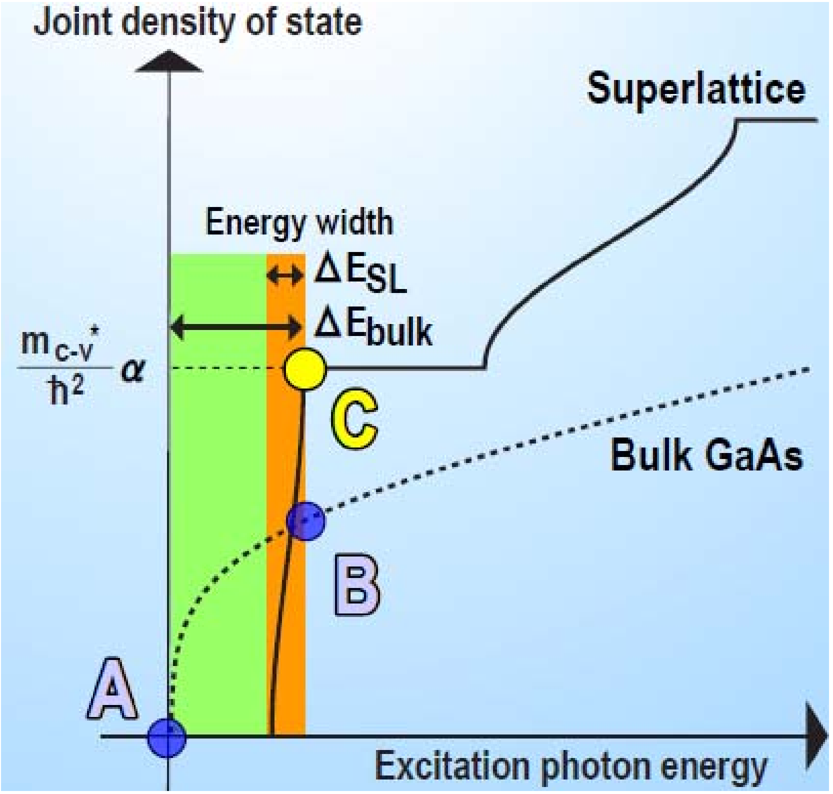
superlattice for high-QE and small-emittance

From the measurement of GaAs, AlGaAs, we have confirmed that QE and life can be improved by optimizing band structure.

⇨ proposal of superlattice cathodes



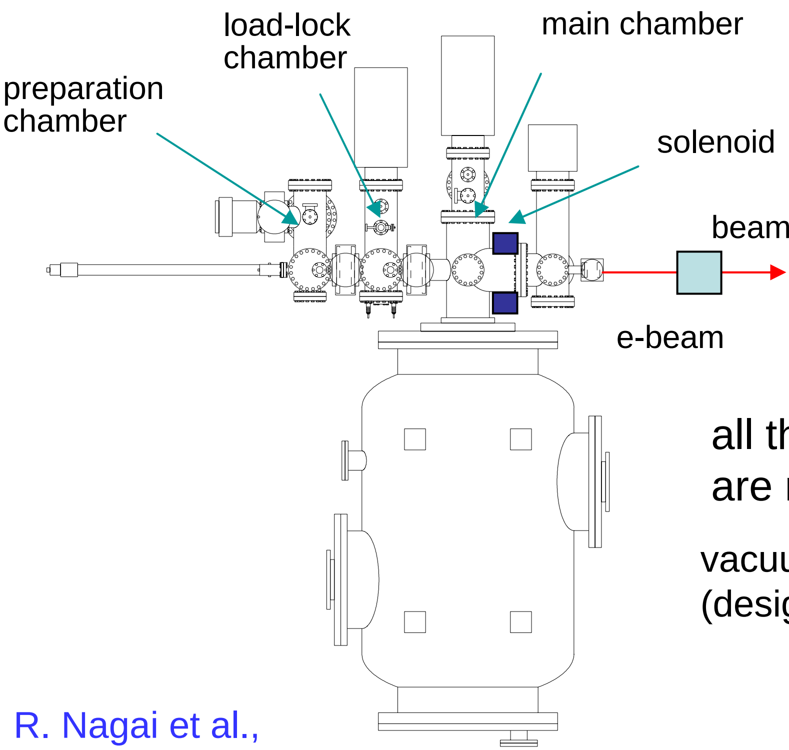


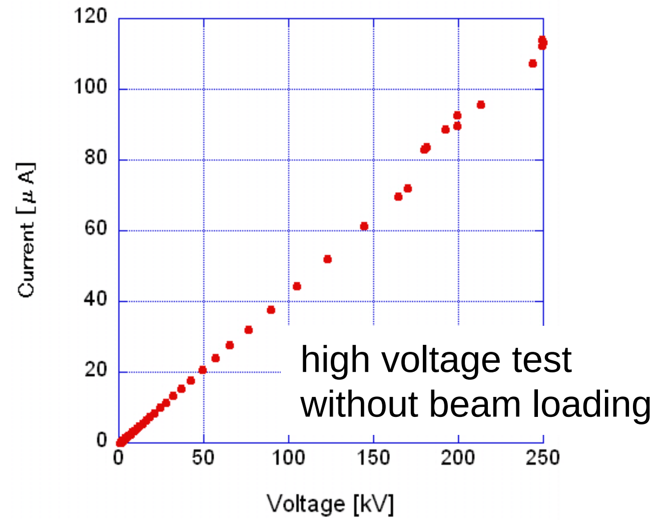


	QE	emittance
A	small	small
B	large	large
C	large	small

Development of a 250 kV-50 mA DC gun

A DC gun is under development.

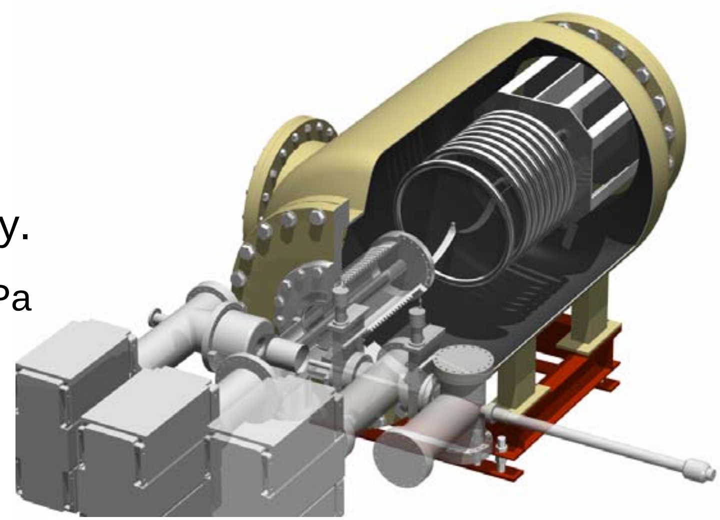




H. Iijima et al.,
Proc. Acc. Meeting in Japan (2006)

all the chambers
are made of Ti alloy.

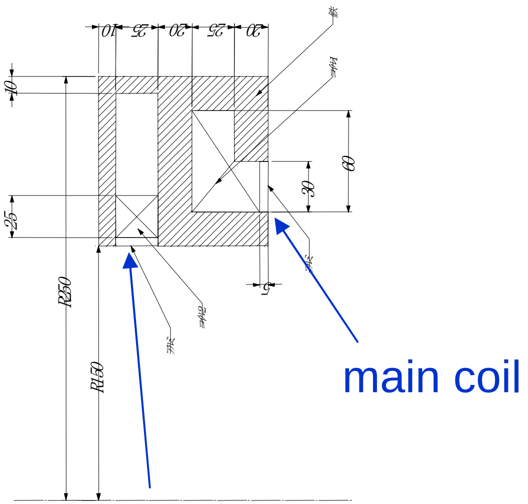
vacuum = 2-3 x 10^{-10} Pa
(design value)



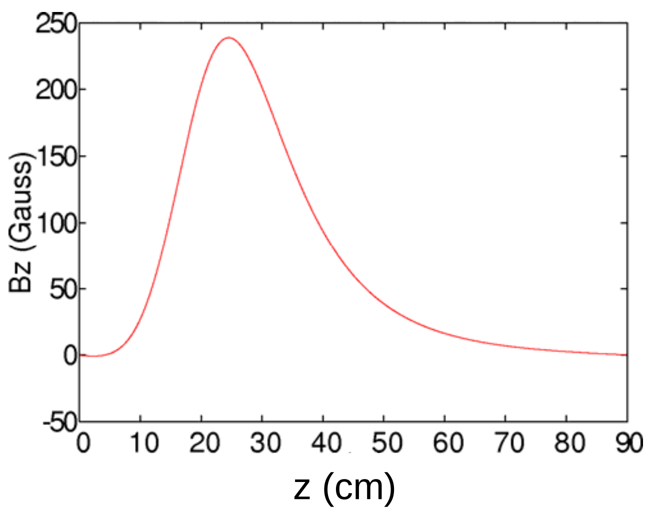
R. Nagai et al.,
Proc. Acc. Meeting in Japan (2006)

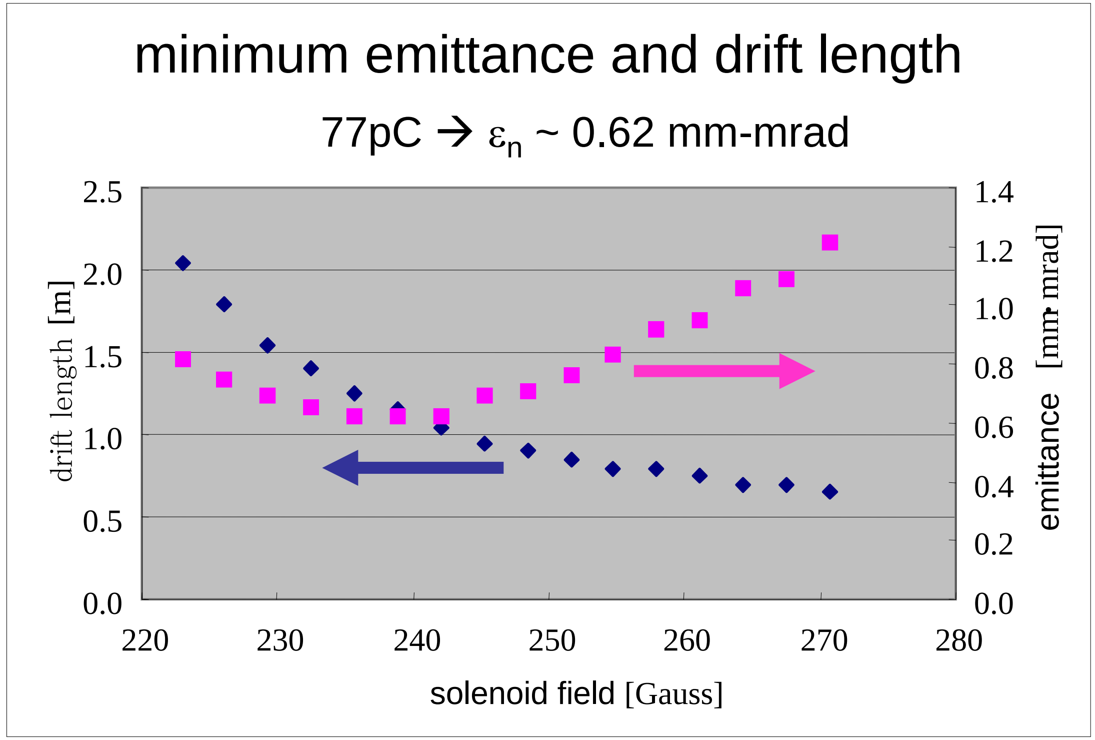
simulations for a 250-keV beam

solenoid magnet



bucking coil to compensate
B_z at the cathode surface





emittance of a 250-keV electron bunch (PARMELA)

0.62 mm-mrad for 77 pC

0.14 mm-mrad for 7.7 pC

(initially, Gaussian in longitudinal
and uniform in transverse)

Action Plan of
Laser Development for ERL

KURIKI Masao (KEK)

Laser (4) Laser Summary

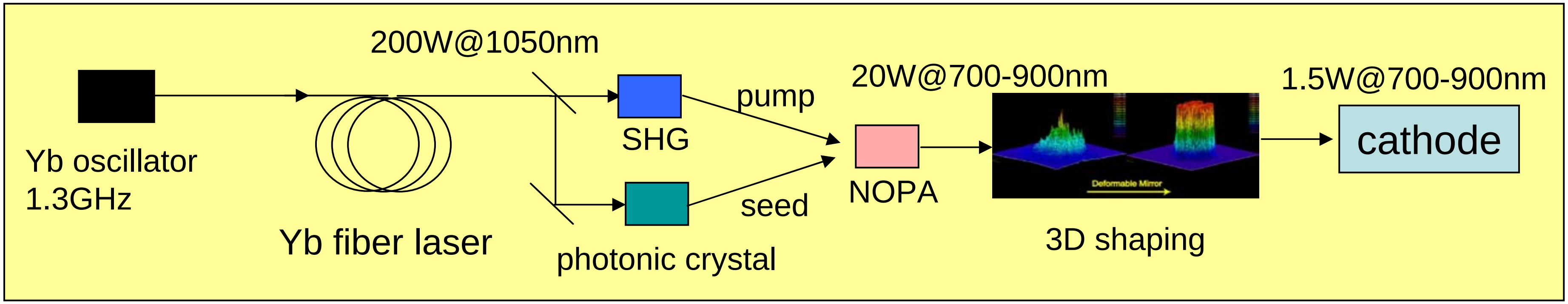
Laser Crystal	Ti:Al203	Yb:YAG	Yb fbr
Wave length (nm)	700-1100	1030	1030
Wave length tune-ability	Yes	No	No
Luminescence time μs	3	1000	1000
Pump light (nm)	488	940	940
Stability	Marginal	Good	Excellent
Note	Wavelength is tunable, unstable	High stability by LD pumping	Excellent stability and high power 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.

drive laser

1.3 GHz, 700-900 nm (tunable)

fund bidding - MEXT-KAKENHI, 2007-2010, ~1M USD for the laser.

20 W @ 700-900nm → 100 mA, ~1 mm-mrad
1.5W @ 700-900mm, 3D shaping → 10 mA, ~0.1 mm-mrad



NOPA = non-collinear optical parametric amplifier
3D shaping = deformable mirror (transverse) + pulse stacker (longitudinal)

gain-switched LD will be replaced by Yb solid-state oscillator in due time.

related description is found in ERL-REPORT-003 (Aug. 17, 2006)
http://pfwww.kek.jp/ERLoffice/info/index.html

ERL

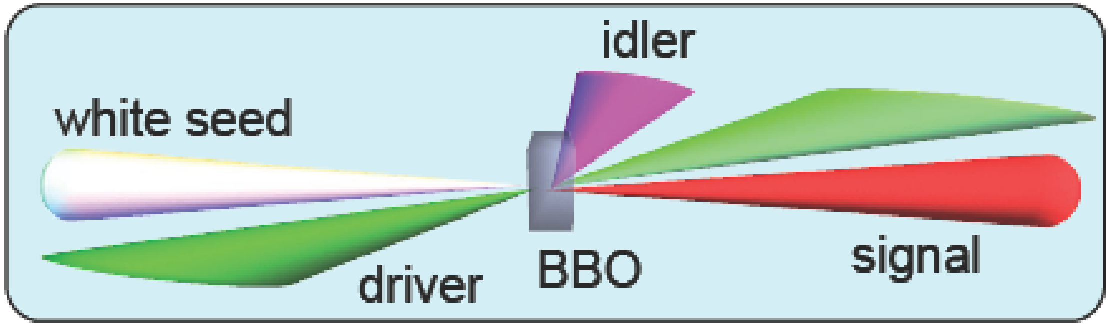
Laser (6) NOPA*

*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.

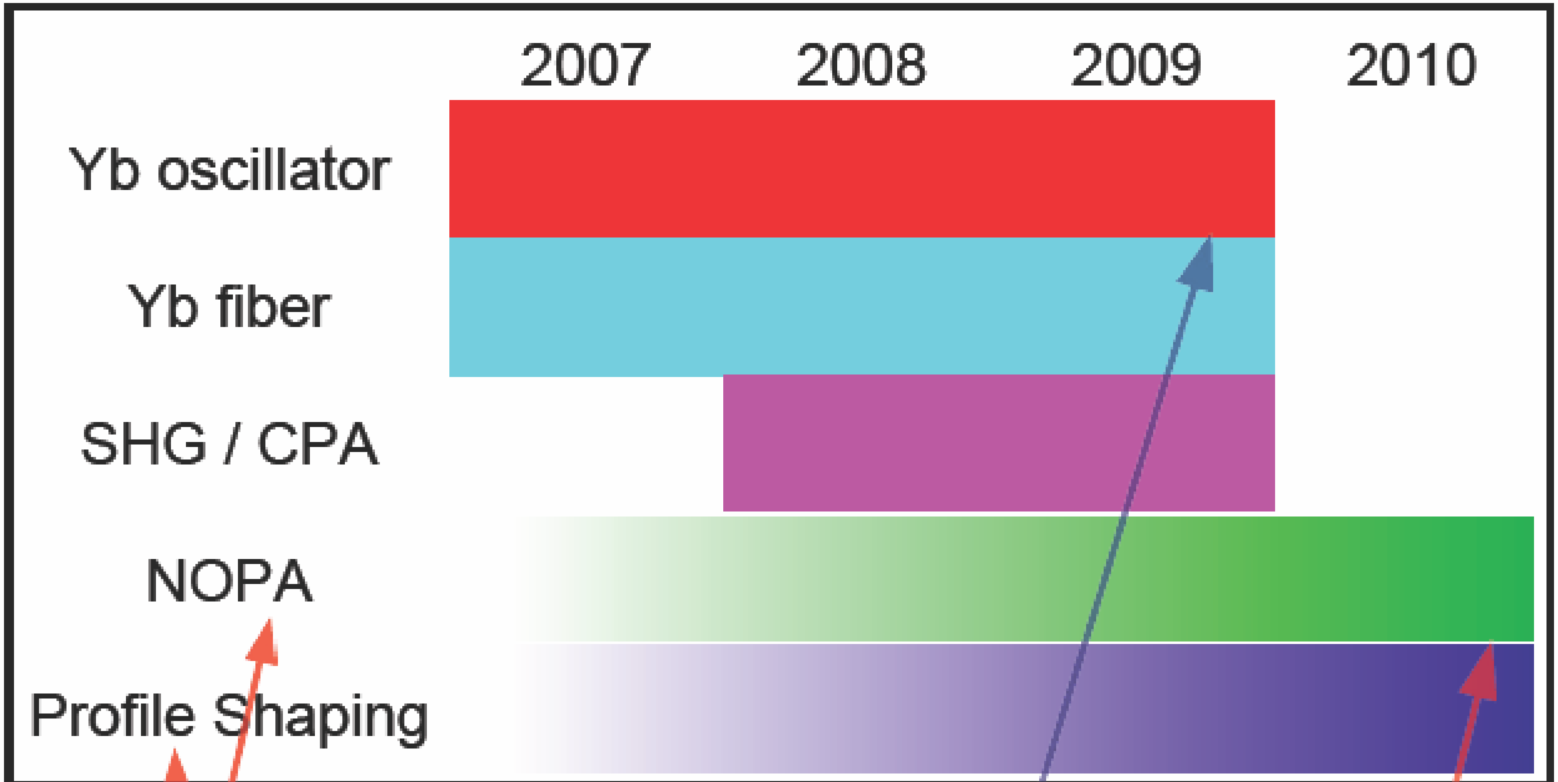
Phase Matching

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



ERL

Action Plan (3) Time Chart



Need extra resources and depend on R&D progress

10mA, low emittance

10-100mA, super-low emittance

Summary

- we have initiated R&Ds for a photocathode DC gun.
- QE and life have been measured for GaAs and AlGaAs.
- AlGaAs shows better QE and life as predicted by semiconductor theory. (QE ~ 2x, life ~ 10x)
- a 250kV-50mA DC gun is under development.
- normalized emittance is expected to be ~0.6mm-mrad for 77pC, ~0.1mm-mrad for 7.7pC at 250-keV.
- the first beam from the gun will be summer this year.
- a superlattice cathode is also under development.
- design of a drive laser is under way in cooperation with a virtual laboratory, LAAA (Laser- aided Accelerator Association).