DC-Gun Test Bench And Superlattice GaAs As Photocathode

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Motivation

☆High performance electron source for an ERL Injector

- Requirements of large current, small emittance and long life-time

  Average current 100mA（77pC×1.3GHz）, Normalized emittance ~1mm-mrad
  → < 0.1mm-mrad (Coherent X-ray)

- NEA-GaAs photocathode has the advantage of small initial emittance beam.

☆NEA-surface life-time problem

- Preparation of an uniformly clean surface
- Residual gas in a vacuum chamber
- Ion back bombardment

☆Strategies

- **XHV DC-Gun with MBE**

  (XHV: extreme high vacuum, MBE: molecular beam epitaxy)

- **Superlattice photocathode**

NEA-GaAs photocathode

NEA-GaAs's advantages

Small initial emittance

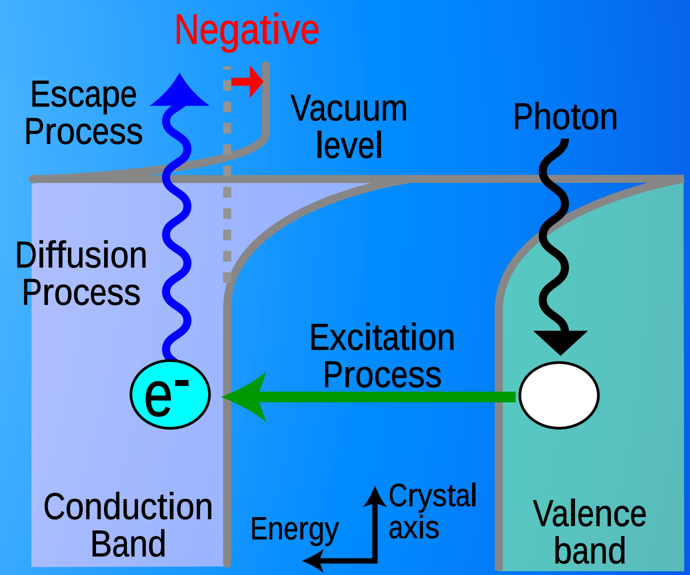
When electron escapes to vacuum, the energy is as low as thermal energy.

High QE

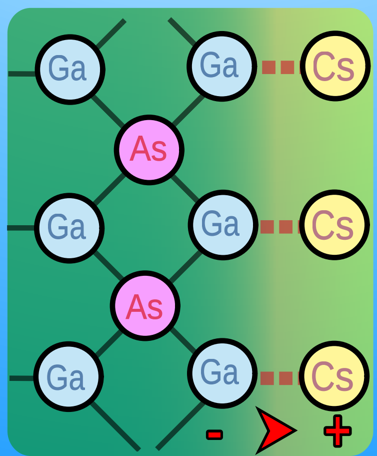
QE of bulk structure GaAs photocathode is several % by exciting photon energy around band-gap

QE：Extracting electron number to incidence photon number

Potential structure of an NEA-GaAs



For the realization of small emittance, **exciting photon energy** should be tuned to **band gap energy**.



NEA surface (Negative Electron Affinity) formed by Cs- and Ga-atom

NEA-surface's disadvantage

Requirement of a clean surface

A surface before NEA-activation should be clean and uniform without any contaminations.

Fragile surface

Destructive factors to NEA-surface

- Absorption of residual gas to NEA-surface
- Ion back bombardment between the electrodes

Strategies for the realization of high performance photocathode DC-gun

JAERI DC-gun

Extreme high vacuum DC-gun with MBE for fabricating a photocathode. (MBE; Molecular Beam Epitaxy)

- XHV gun chamber →Preservation of NEA-surface
- Fabrication of photocathode in XHV →Quality NEA-surface activation
- Load-lock system
- Small field emission electrodes material

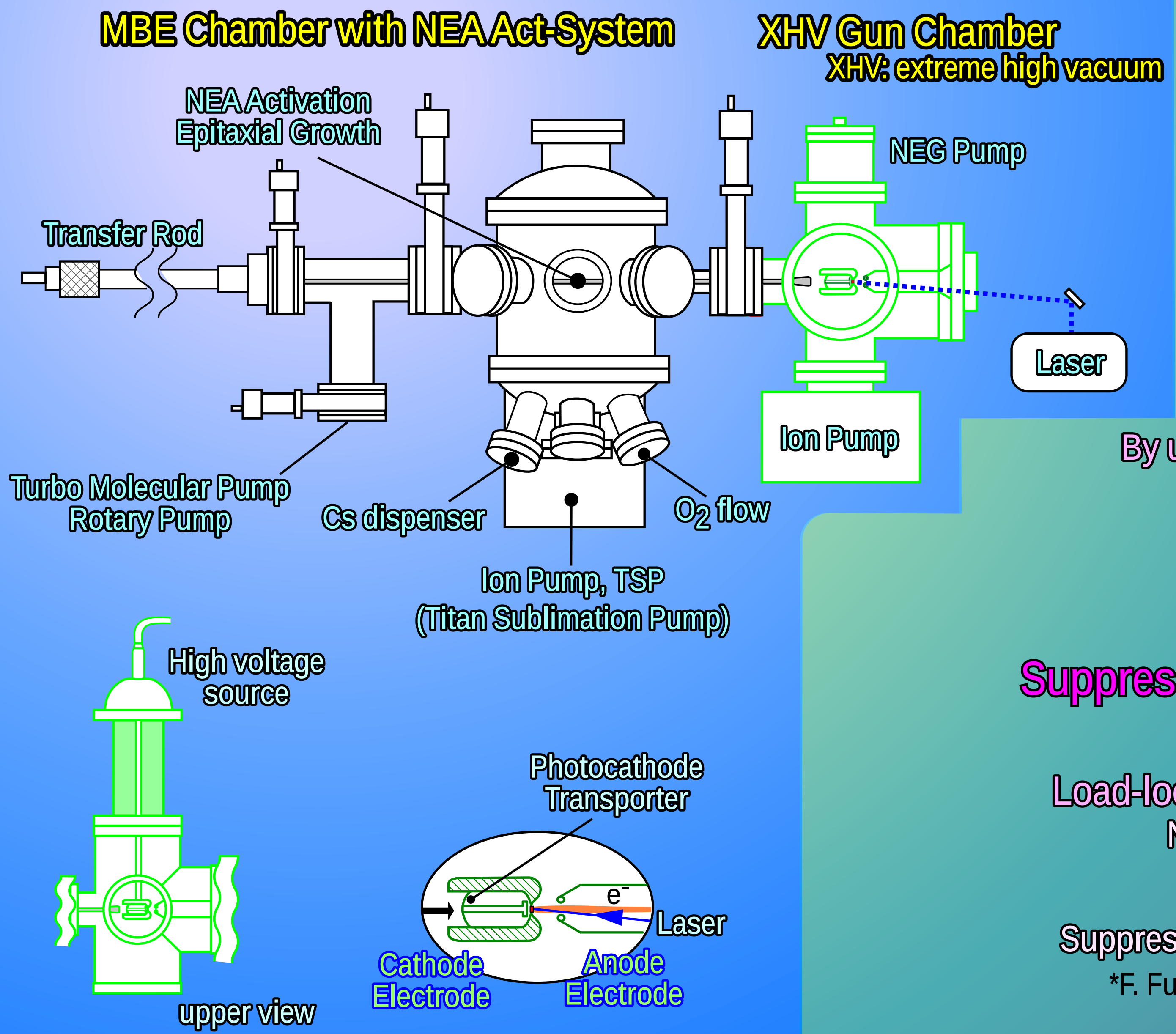
→Not to damage NEA-surface (Load-lock system; Small field emission electrodes material)

High performance photocathode

Superlattice photocathode

→ Realization of higher QE and smaller emittance than an existing NEA-GaAs

System of JAERI DC-gun



Long life-time NEA-surface

Extreme high vacuum chamber

Base pressure
MBE: ~10^{-9} Pa, Gun: <10^{-10} Pa

Uniformly clean surface

By using MBE, we can make a clean surface by fabricating photocathode in XHV.

Surface cleaning is needless any more.

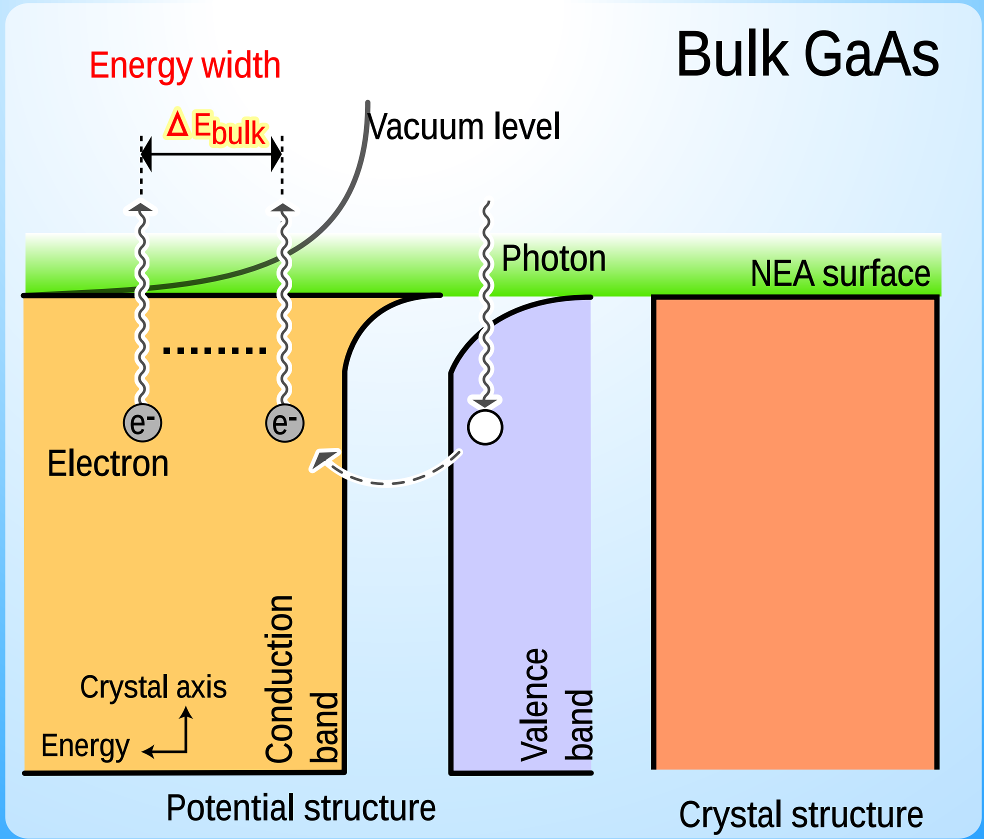
Suppression of ion back bombardment damaging NEA-surface

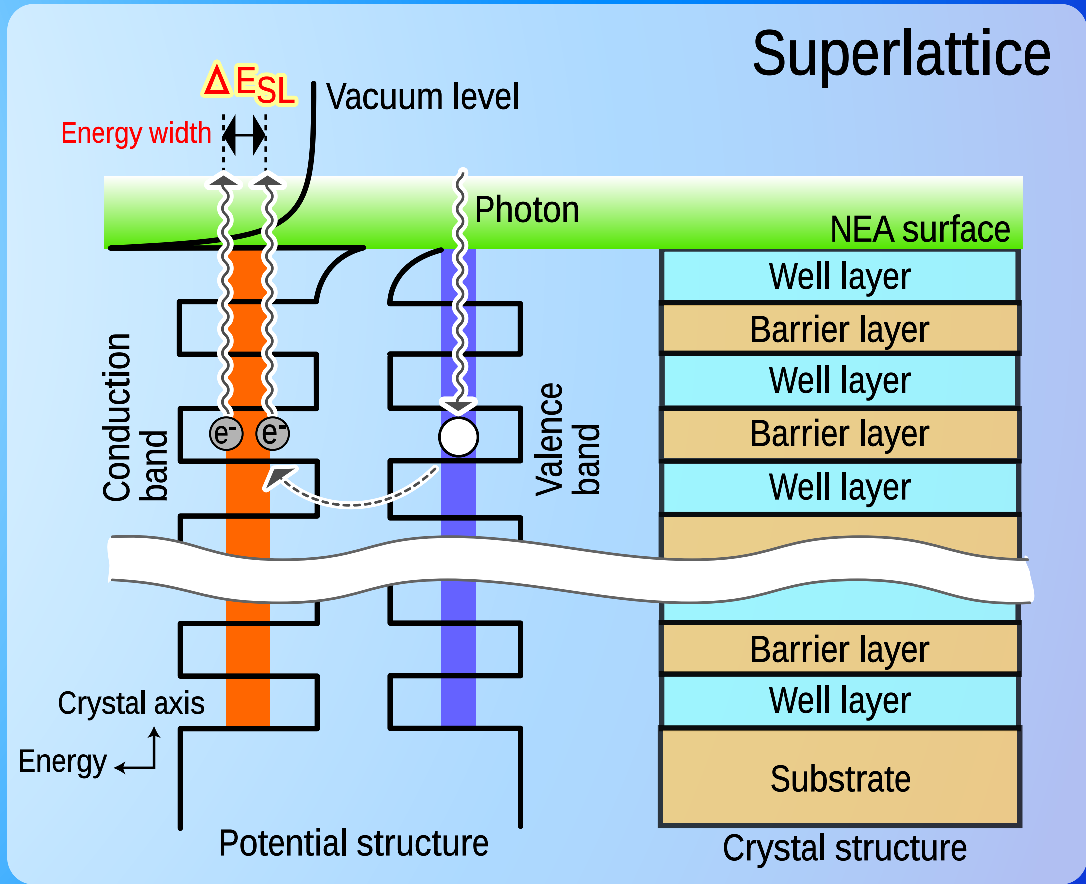
Load-lock system (photocathode transport)
No Cs absorption to a cathode electrode

Ti and Mo for electrodes material*
Suppression of dark current between electrodes

*F. Furuta, et al., Nucl. Instr. and Meth. in Phys. Res. A538 Issues 1-3 (2005) p. 33-44

Superlattice





A superlattice structure consists of more than two kinds of semiconductor, each thickness of the barrior is less than 10nm. (multi-quantum well)

In the conduction band of bulk-GaAs, an electron can have any states of energy.

In a superlattice, an electron in the conduction and the valence-band may has the limited state of energy. (mini-band)

Advantages of Superlattice

- By selecting appropriate semiconductor, band-gap of a superlattice can be larger than that of bulk-GaAs.

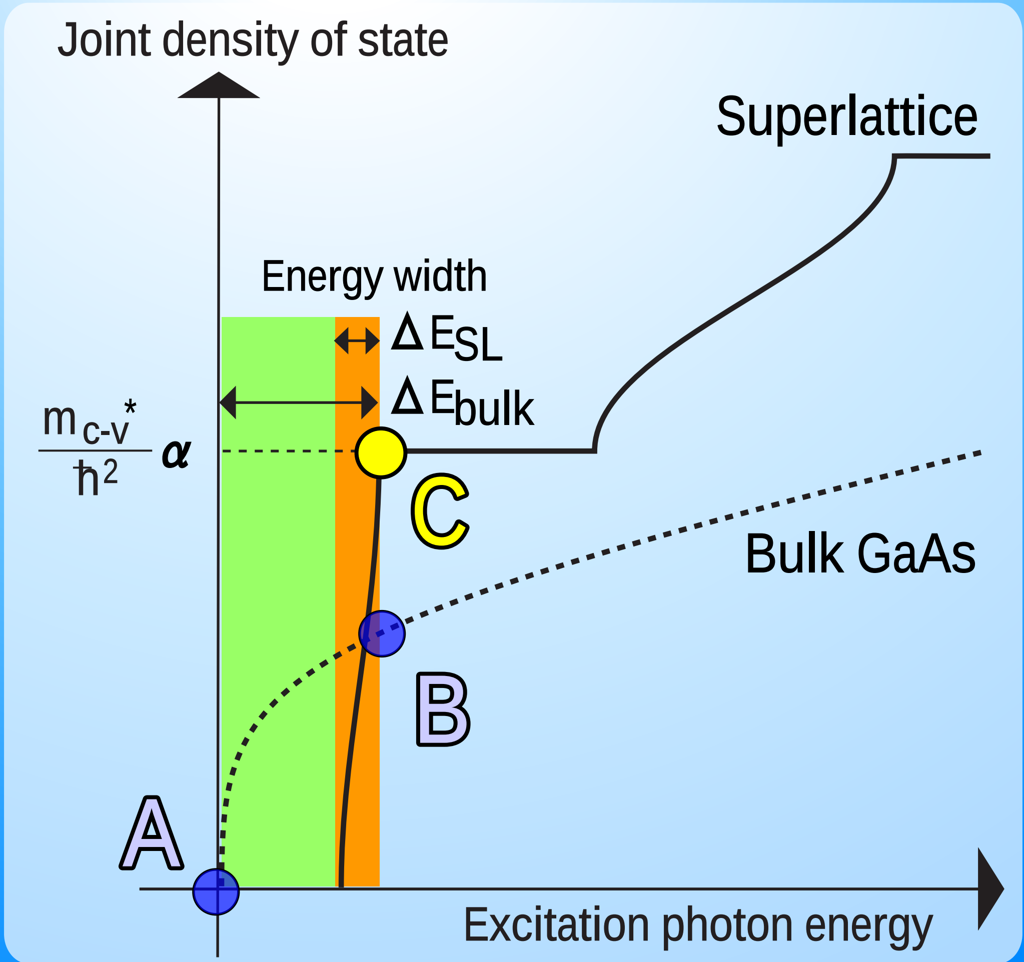
  *Larger band-gap photocathode is more suitable for higher QE photocathode.
  (T. Nakanishi, et al., AIP Conference Proceedings 421 (1998) p. 300-310)

- Joint density of state in a superlattice fulfills the requirements for high QE and small emittance.

Joint Density Of State (JDOS)

JDOS is the density of electrons excited to the conduction band by certain photon energy.

JDOS of superlattice is derived by Kronig-Penny-Bastard model, JDOS corresponds to QE*.
(*T. Nishitani, et al. to be published in J. Appl. Phys.)



- Large JODS causes large QE.
- Narrow excitation photon energy width causes small emittance.

These conditions have to be simultaneously satisfied for the generation of a high brightness electron beam.

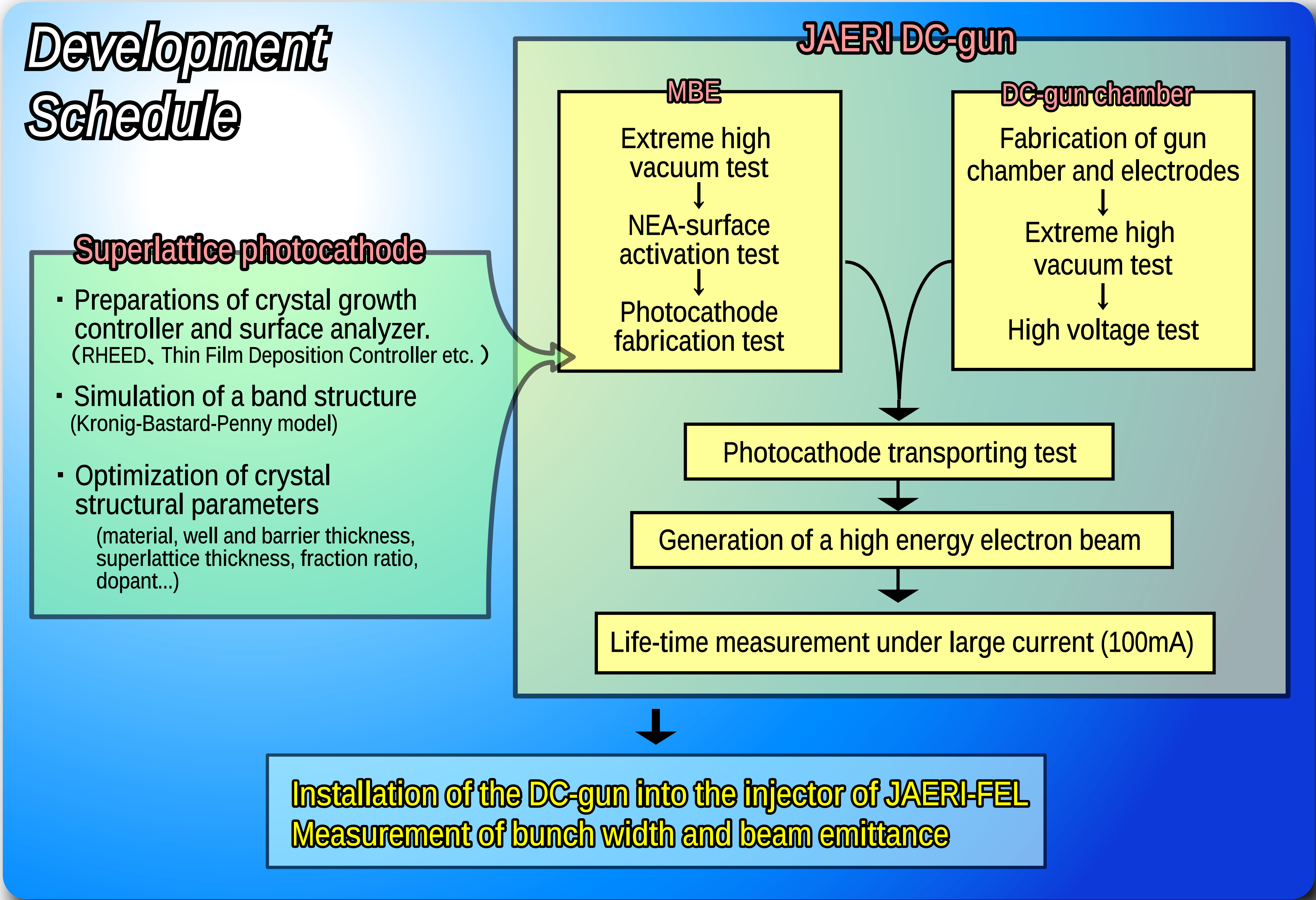
Bulk GaAs

A When excitation photon energy is tuned to small emittance, → QE is low.

B When excitation energy is tuned to high QE, → emittance is large.

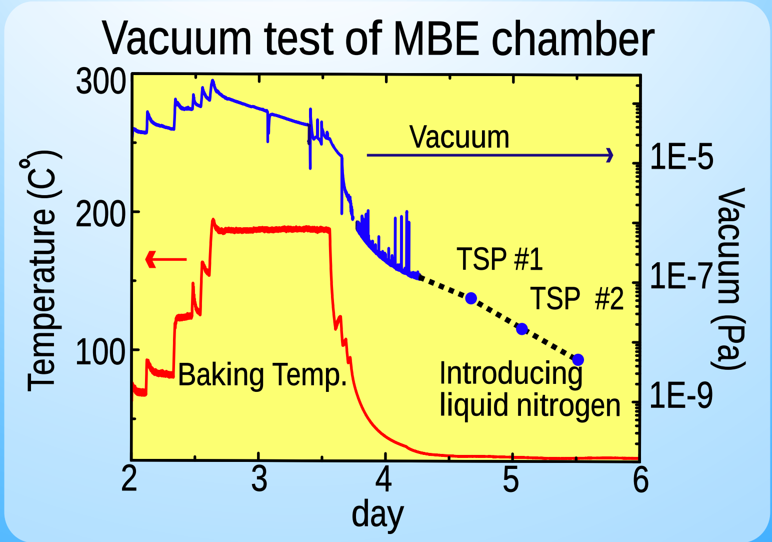
Superlattice

C Selective excitation for high QE and small emittance is possible.


Development Schedule
JAERI DC-gun
MBE
Extreme high vacuum test
NEA-surface activation test
Photocathode fabrication test
DC-gun chamber
Fabrication of gun chamber and electrodes
Extreme high vacuum test
High voltage test
Superlattice photocathode
・Preparations of crystal growth controller and surface analyzer.
（RHEED、Thin Film Deposition Controller etc. ）
・Simulation of a band structure
(Kronig-Bastard-Penny model)
・Optimization of crystal structural parameters
(material, well and barrier thickness, superlattice thickness, fraction ratio, dopant...)
Photocathode transporting test
Generation of a high energy electron beam
Life-time measurement under large current (100mA)
Installation of the DC-gun into the injector of JAERI-FEL
Measurement of bunch width and beam emittance

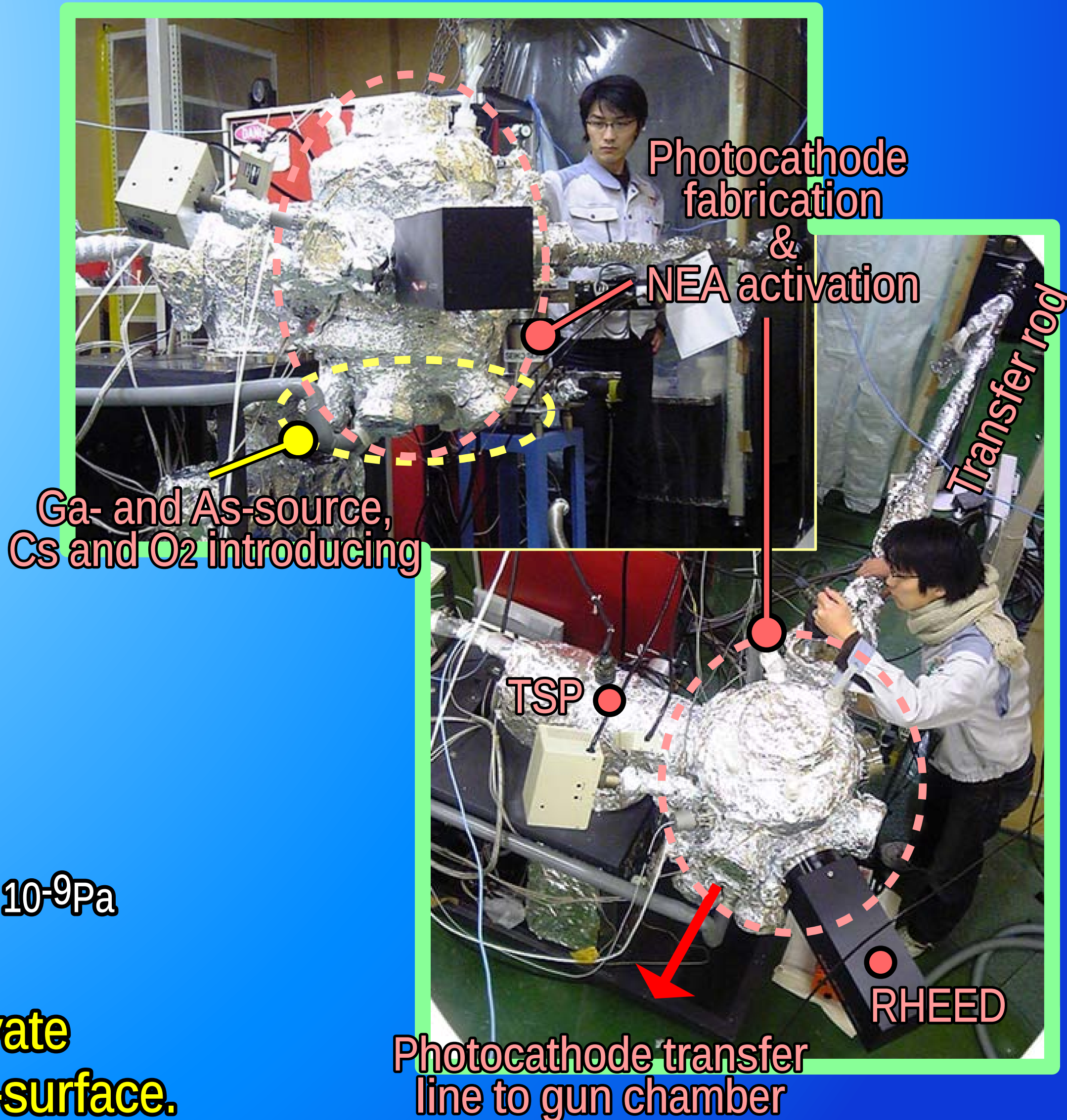
Present state of JAERI DC-gun

MBE preparation



MBE chamber vacuum → Extreme high vacuum of 10^{-9}Pa

→Vacuum of an MBE is enough to activate quality NEA-surface and to hold NEA-surface.



Summary

We began to development an extreme high brightness electron source.

JAERI DC-gun

(Extreme high vacuum DC-gun MBE apparatus)

We designed a photocathode DC-gun to satisfy the requirement of long life-time performance.

The DC-gun can carry out NEA-activation, photocathode fabrication and transportation under XHV.

Superlattice photocathode

We aimed at the superlattice features of band-gap and JDOS

We found out that a superlattice is expected to have higher QE and smaller emittance than a bulk GaAs.