DC-Gun Test Bench
And
Superlattice GaAs As Photocathode

ERL2005 Workshop
March 19 - 23, 2005
Newport News, Va, USA

T. Nishitani, E. J. Minehara, R. Hajima
(JAERI)
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**

**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

**NEA-GaAs’s advantages**
- QE: Extracting electron number to incidence photon number

**Potential structure of an NEA-GaAs**
- Negative Electron Affinity (NEA) surface formed by Cs- and Ga-atom
- When electron escapes to vacuum, the energy is as low as thermal energy.

**NEA-GaAs’s advantages**
- Small initial emittance: exciting photon energy should be tuned to band gap energy.
- High QE of bulk structure GaAs photocathode

**NEA-surface’s disadvantage**
- Fragile surface
  - Destructive factors to NEA-surface:
    - Absorption of residual gas to NEA-surface
    - Ion back bombardment between the electrodes
- Requirement of a clean surface
  - A surface before NEA-activation should be clean and uniform without any contaminations.

For the realization of small emittance, exciting photon energy should be tuned to band gap energy.
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 → Not to damage NEA-surface
- 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

MBE Chamber with NEA Act-System

XHV Gun Chamber

XHV: extreme high vacuum

Long life-time NEA-surface

Extreme high vacuum chamber

Base pressure

MBE: ~10^{-9} \text{ Pa}, Gun: <10^{-10} \text{ 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

Base pressure

MBE: ~10^{-9} \text{ Pa}, Gun: <10^{-10} \text{ Pa}

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 have the limited state of energy. (mini-band)

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

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

• 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*.


Large JDOS 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.

Selective excitation for high QE and small emittance is possible.

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

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

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

Simulation of a band structure (Kronig-Bastard-Penny model)

Fabrication of gun chamber and electrodes

Extreme high vacuum test

NEA-surface activation test

Photocathode fabrication test

Extreme high vacuum test

High voltage test

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

Vacuum test of MBE chamber

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

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.

JAERI DC-gun

(Extreme high vacuum DC-gun MBE apparatus)

We began to development an extreme high brightness electron source.

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