R&D for Advanced Photo-Cathode

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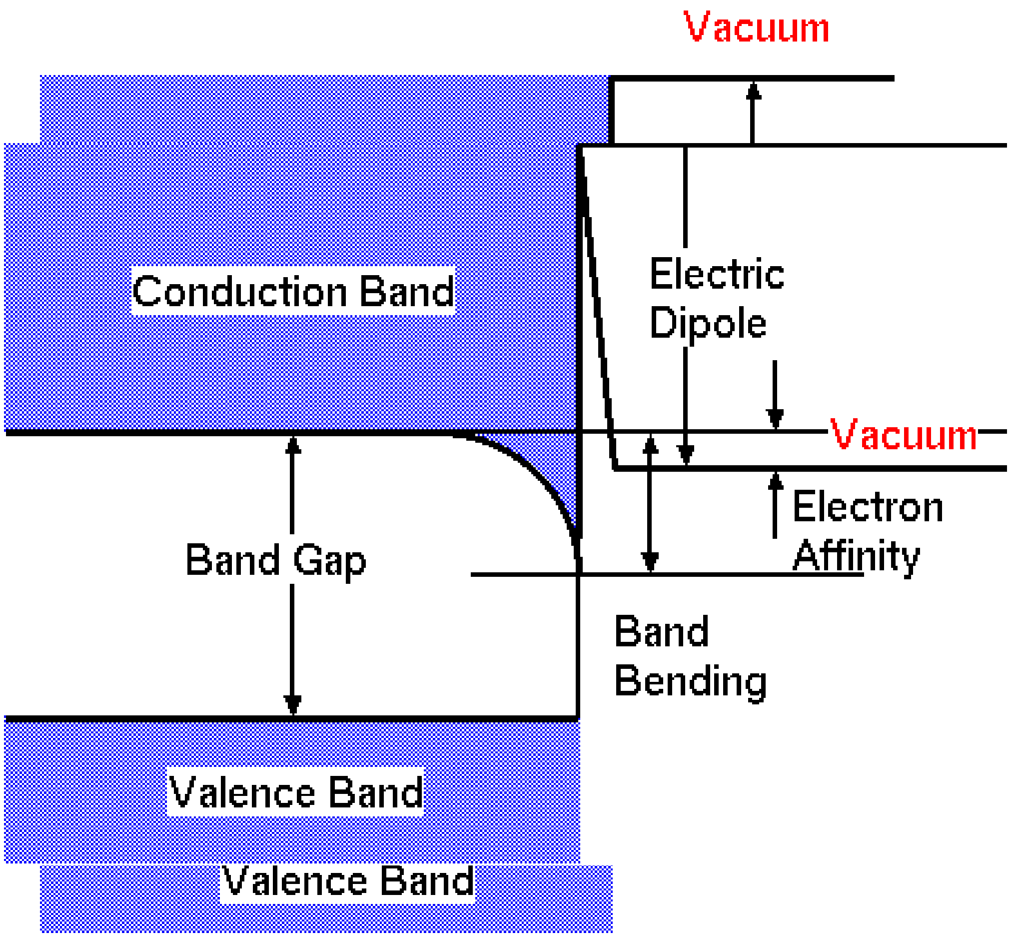
Contents

Goal of Cathode R&D

- High performance: Super-low emittance, high polarization
- High Power：High Quantum efficiency, Optimized for high power laser
- Long Operational lifetime
  - Robust cathode
  - Less damage by better vacuum
- Introduce to the Q-beam system, ERL, ILC, CLIC, SRIPES, SPLEEM, etc.

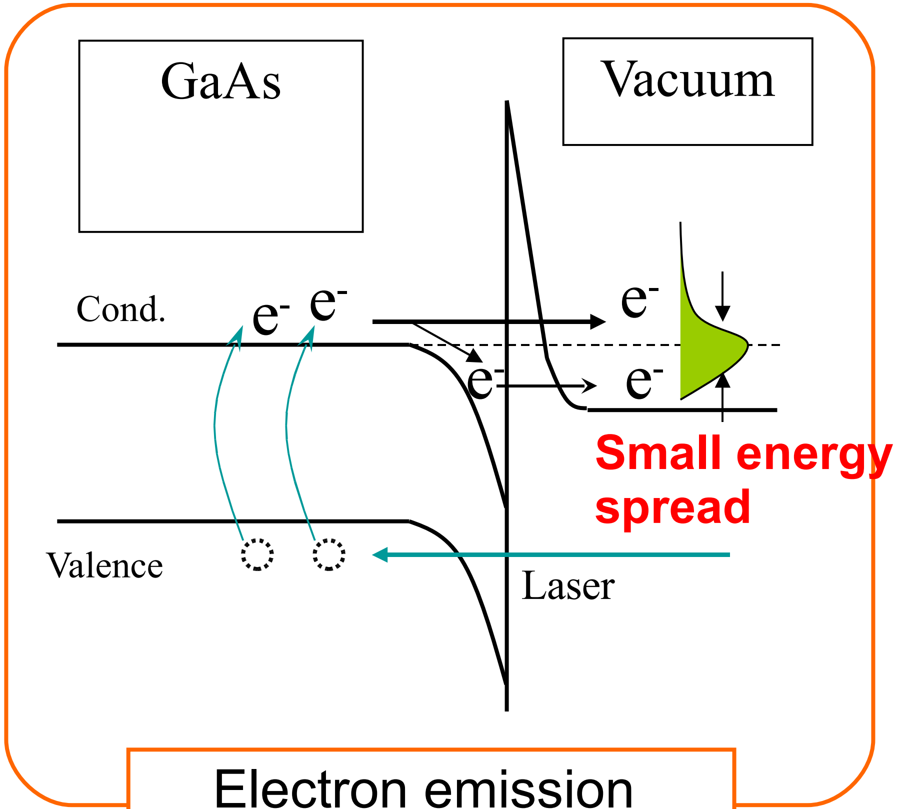
GaAs cathode and EA

- GaAs：NEA surface is artificially made.
  - PEA（Positive Electron Affinity):electron in conduction band is confined.
  - NEA(Negative Electron Affinity):electrons in conduction band is extracted to vacuum.



Electron emission from NEA

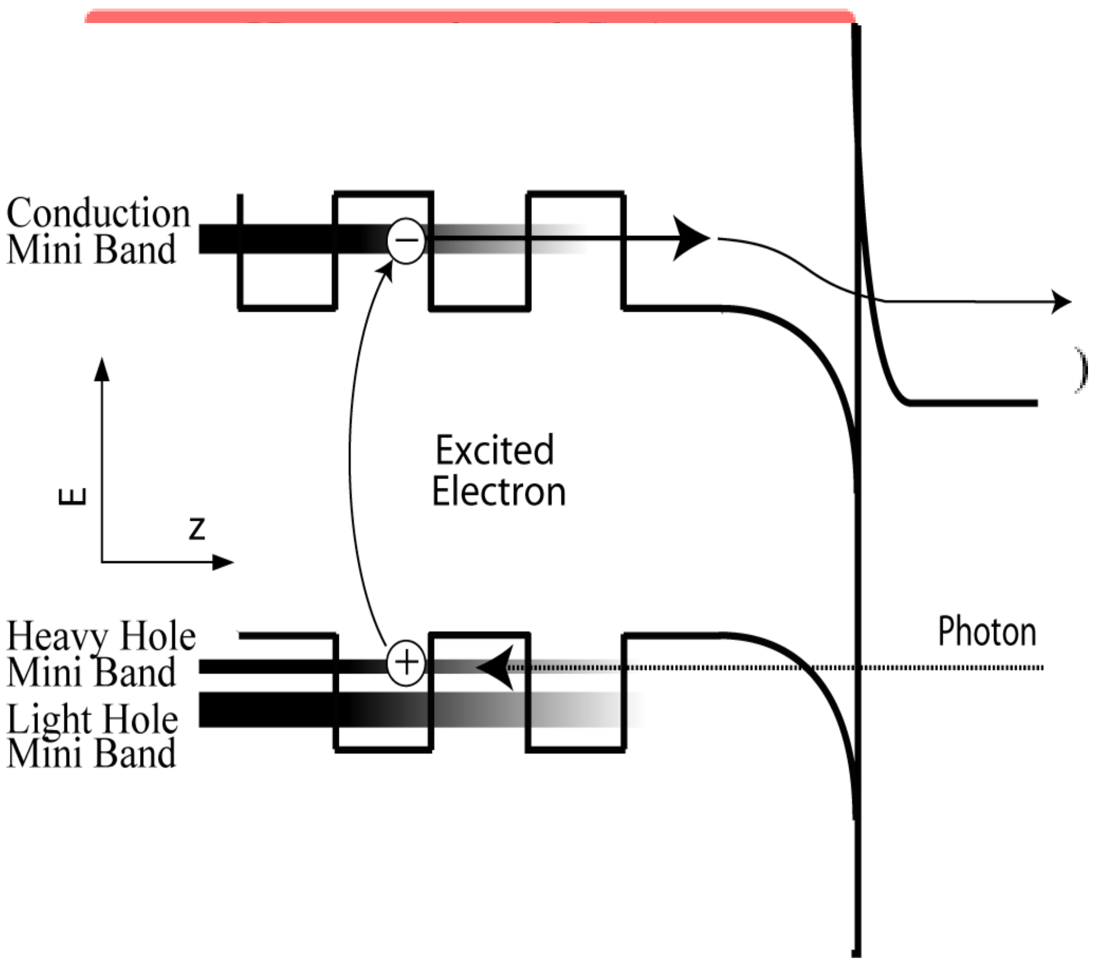
- Electron excited to conduction band is easily emitted to vacuum : High Quantum efficiency (1-20%)
- Excitation by optimized laser and thermalization results that the electron beam has small energy spread: super-low emittance beam
- Helicity selection by circularly polarized laser : polarized electron.



Electron emission from NEA surface

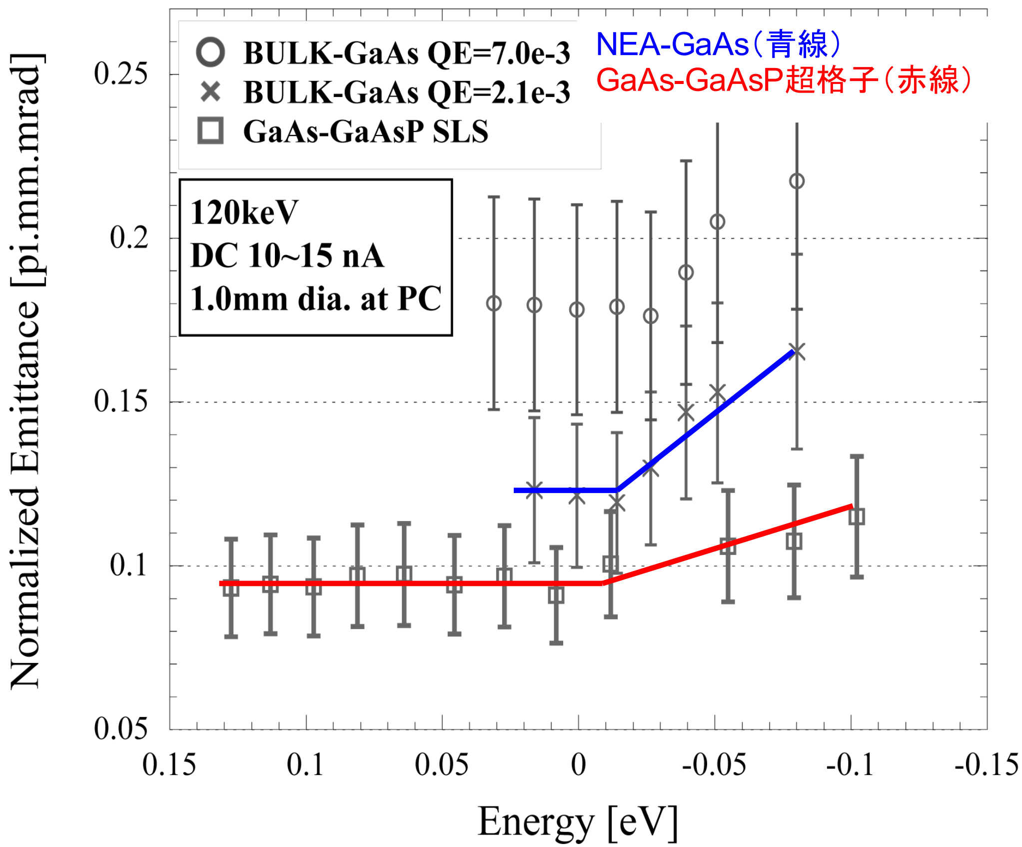
Super-lattice Cathode

- ►GaAs-GaAsP super-lattice: Mini-band is formed in conduction and valence bands, respectively.
- ►Selection on the transition is enhanced both for energy and heliciy.
  - High polarization (90%)
  - Super-low emittance （0.1mm.mrd)



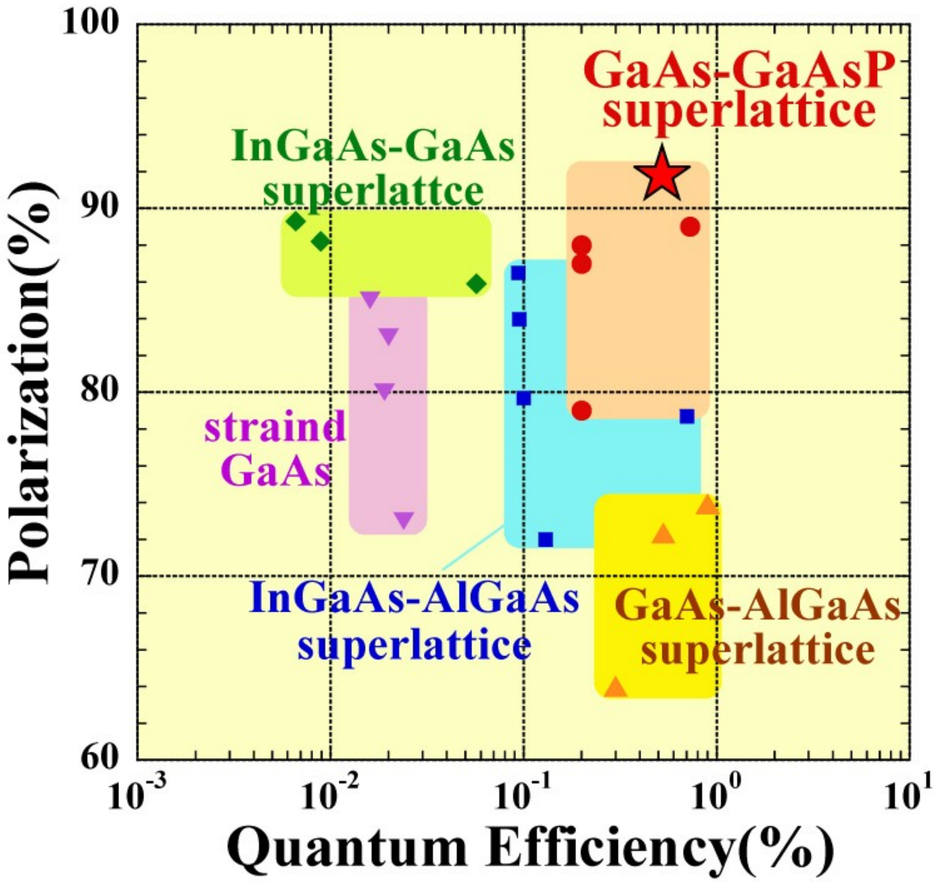
Super-lattice Cathode

Super-low emittance



Nagoya-KEK

High Polarization



Nagoya

Issues for GaAs cathode

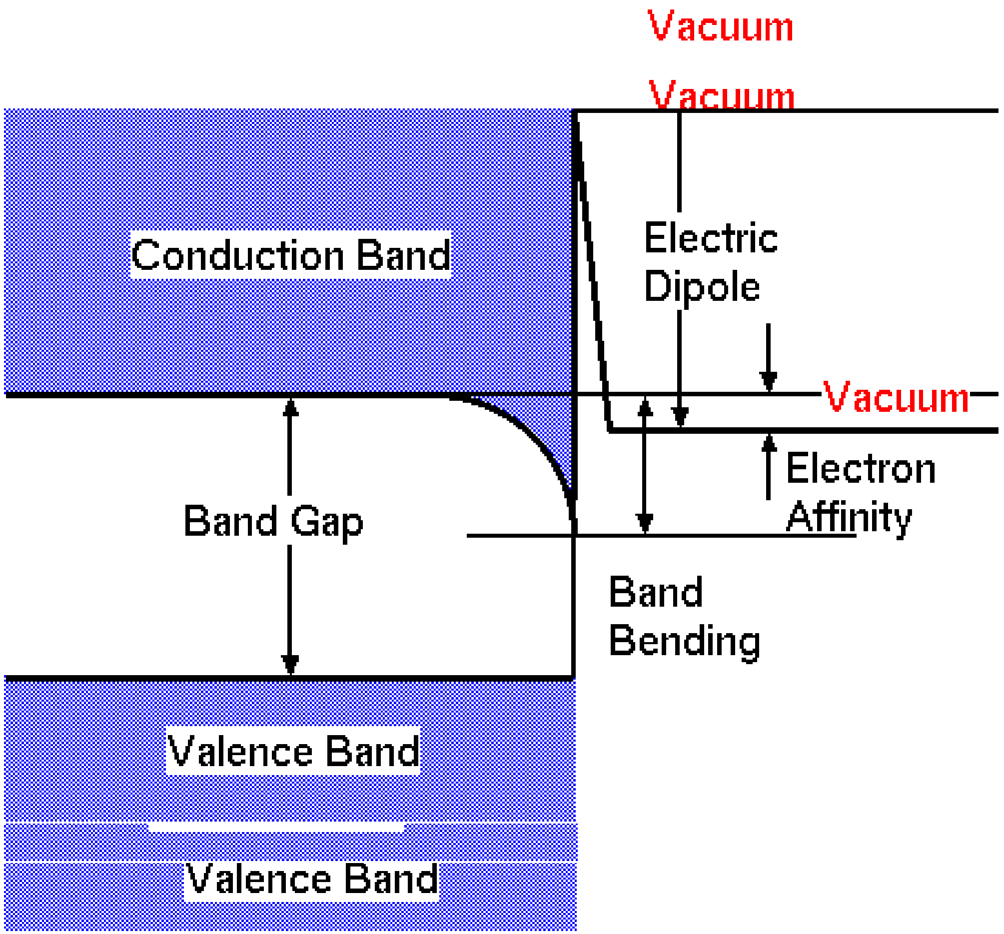
- GaAs-GaAsP super-lattice cathode is developed for high polarization (ILC), but it is also useful for super-low emittance cathode (ERL).
- Performance is excellent, but the operational lifetime is limited.
  - Robust cathode
  - Super high vacuum

Issues for GaAs cathode

- ►Band gap energy of GaAs cathode corresponds to 800nm.
- ►Ti:S laser is widely used, but high average power operation is critical due to thermal effects and less efficiency for pumping.
- ►If the band gap is optimized to 500nm, SH of a stable full solid-state laser (Yb:YAG, Yb fbr, etc) can be used for the drive laser without emittance increment.
- ►E_g optimization to 500nm is desirable for high power and super-low emittance beam.

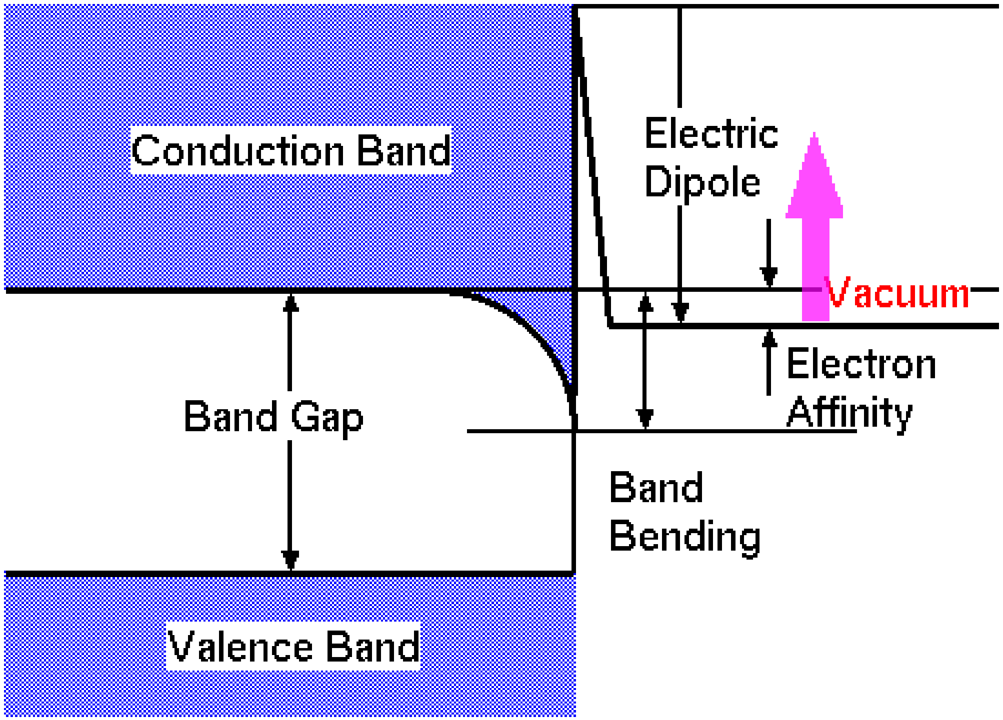
Band Structure Optimization

- NEA surface is made by two treatment.
  - Band bending by P-doping: $E_{BB} \propto E_g$
  - Electric dipole by cesiation: E_{Cs}
  - $E_a = E_{a0} - E_{BB} - E_{cs}$
- Smaller E_a is achieved with smaller E_{a0} and larger E_g.



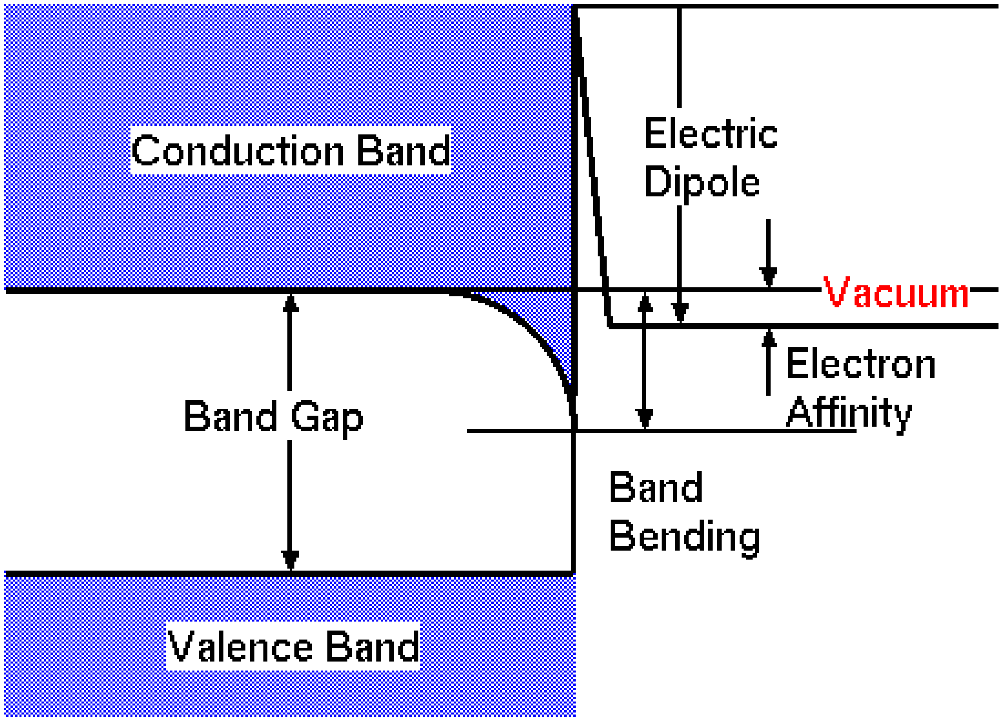
Damage on Cathode

- Damage on Cs layer (NEA surface) increases E_a, which degrades the electron emission.
- The limited operation life time is caused by this damage.
- If the initial NEA is large, the operational life time could be longer.
- Super high vacuum is also helpful.



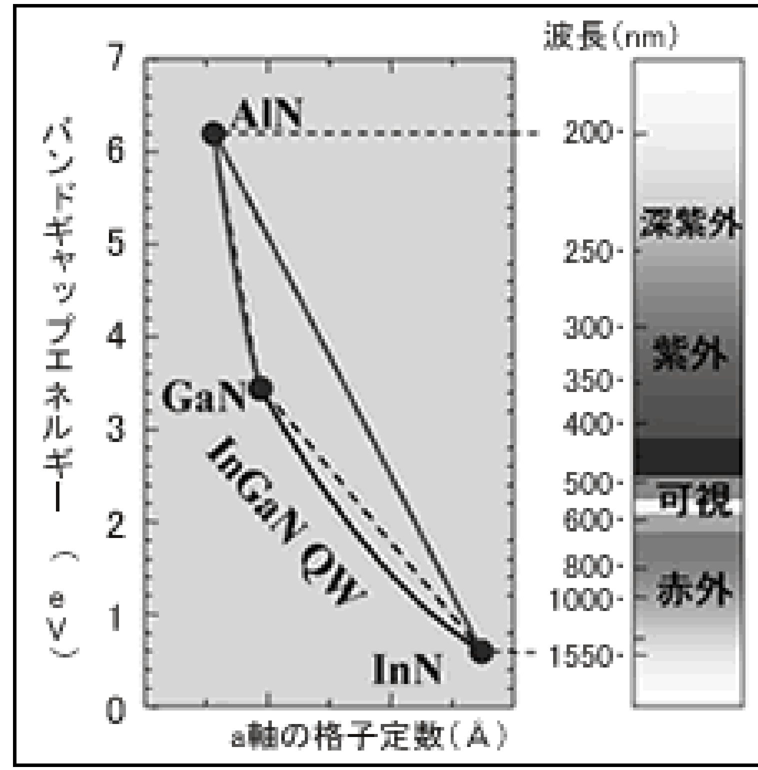
Band Structure Optimization, Again

- $E_a = E_{a0} - E_{BB} - E_{cs}$
- Smaller E_a is achieved with smaller E_{a0} and larger E_g.
- Materials with small E_{a0} and larger E_g is candidates of robust cathode.



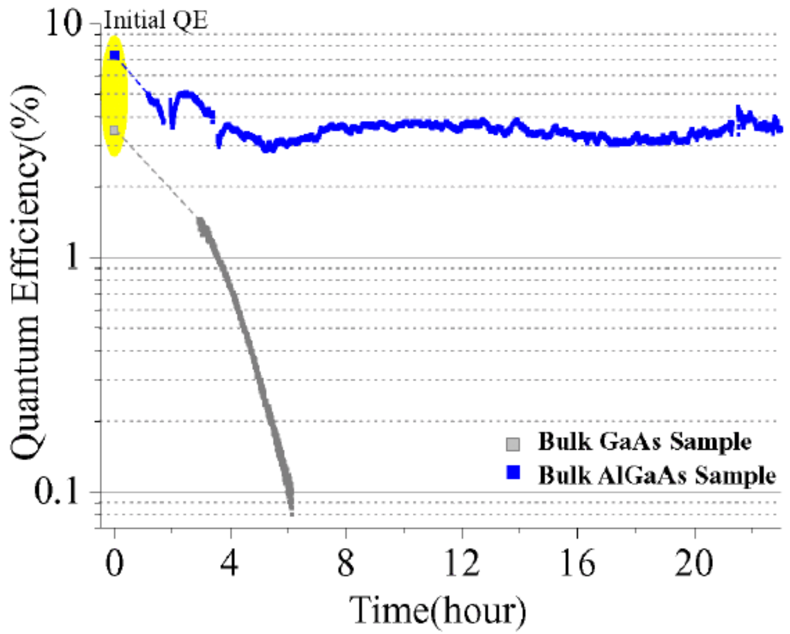
AlGaAs/InGaN Cathode

- Band gap energy, E_g and electron affinity, E_{a0} :
  - GaAs E_g=1.42eV, E_{a0}=4.1eV
  - AlAs E_g=2.17eV, E_{a0}=3.5eV
  - GaN E_g = 3.3eV, E_{a0}=4.1eV
  - InN E_g=0.6-2.0eV, E_{a0}=??
- AlAs, GaN : Large E_g
  - Longer life time
  - Smaller wave length
- $Al_xGa_{1-x}As$, $In_xGa_{1-x}N$: Optimization on E_g and E_{a0} by Mixed Crystal.



AlGaAs/InGaN Cathode

- $Al_xGa_{1-x}As$:
  - Longer lifetime than that of GaAs is already demonstrated.
  - Larger E_g makes less E_a.
- $In_xGa_{1-x}N$:
  - Longer lifetime is expected because of large E_g.
  - E_g optimization to 500nm laser is also possible.



T. Nishitani et al., Proc. of the 28th International FEL Conf. (FEL2006), pp319-322, 2006

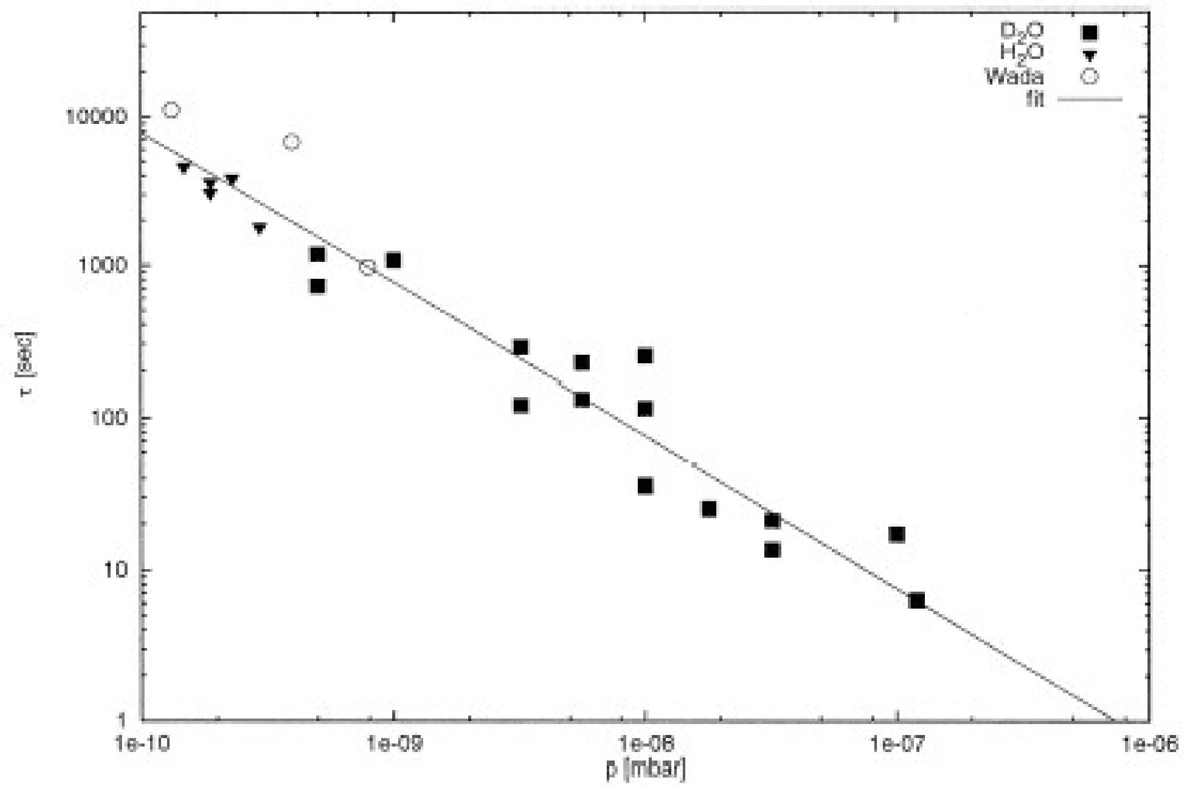
Super High Vacuum

- Limited operational lifetime of GaAs cathode
  - Chemical dilution by H_20, Hydro-carbon, etc.
  - Ion back-bombardment.
- These effects should be compensated by better vacuum
  - Current：1E-8～1E-9Pa
  - Goal：1E-10～1E-11Pa

Operational Lifetime and H_20 pressure

- ► Lifetime is inversely proportional to H_2O pressure.
  - τ_{H_20}~290h at 1E-10Pa.
- ► The pressure should be even lower than that level by considering beam operation.

Lifetime vs H_20 pressure

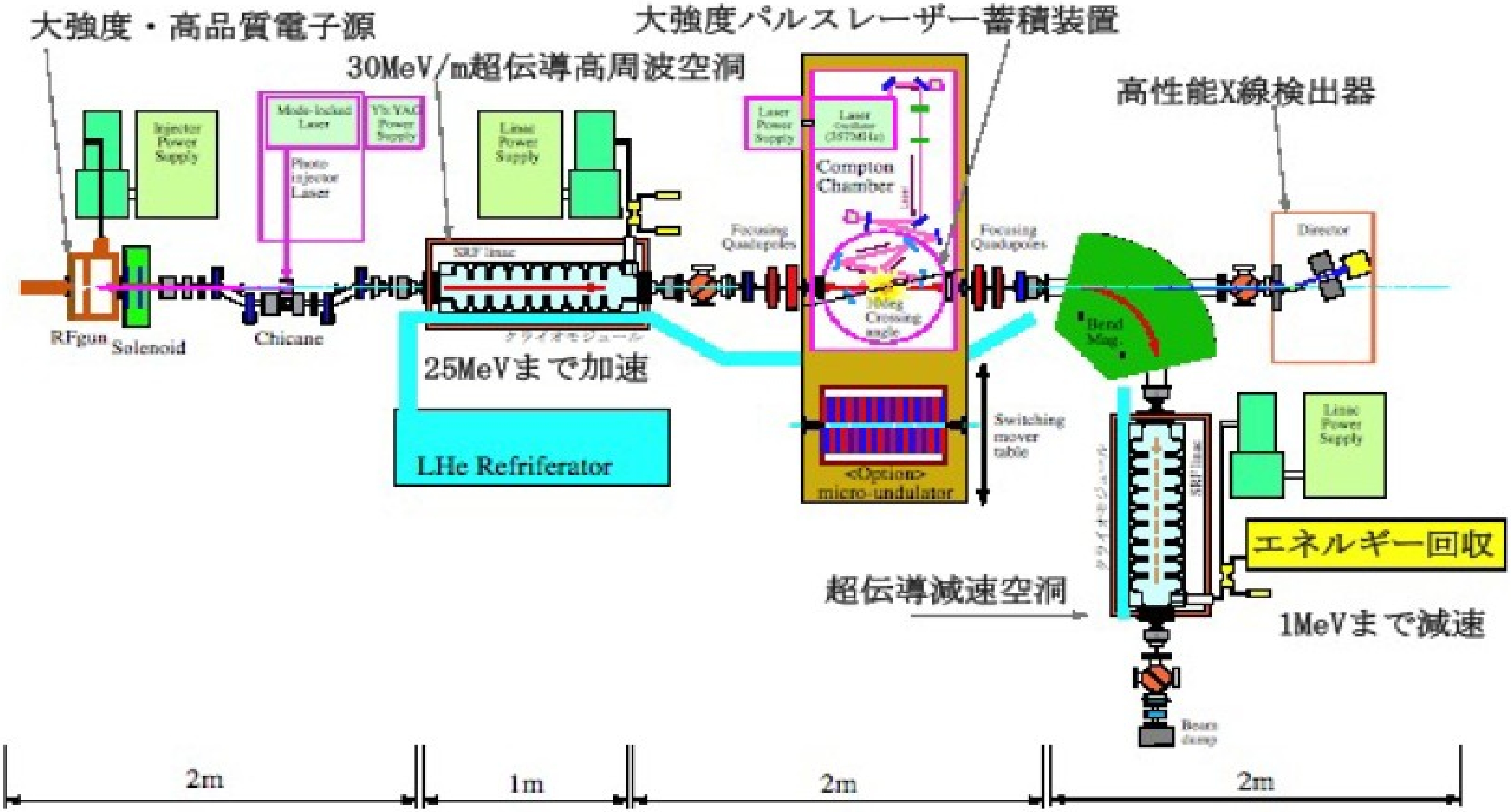


D. Durek et al., Applied Surface Science 143 (1999) 319–322

Super High Vacuum (2)

- EP SUS chamber + Ion pump + NEG pump:1E-9Pa
  - Pumping speed is decreased in super-high vacuum.
  - Pump is a source of out gas.
- CP Ti chamber + Cryo-pump + NEG： less than 1E-10Pa ?
  - Cryo-pump is better than Ion pump for Super high vacuum?
  - CP Ti has less out gas rate than that of EP SUS.

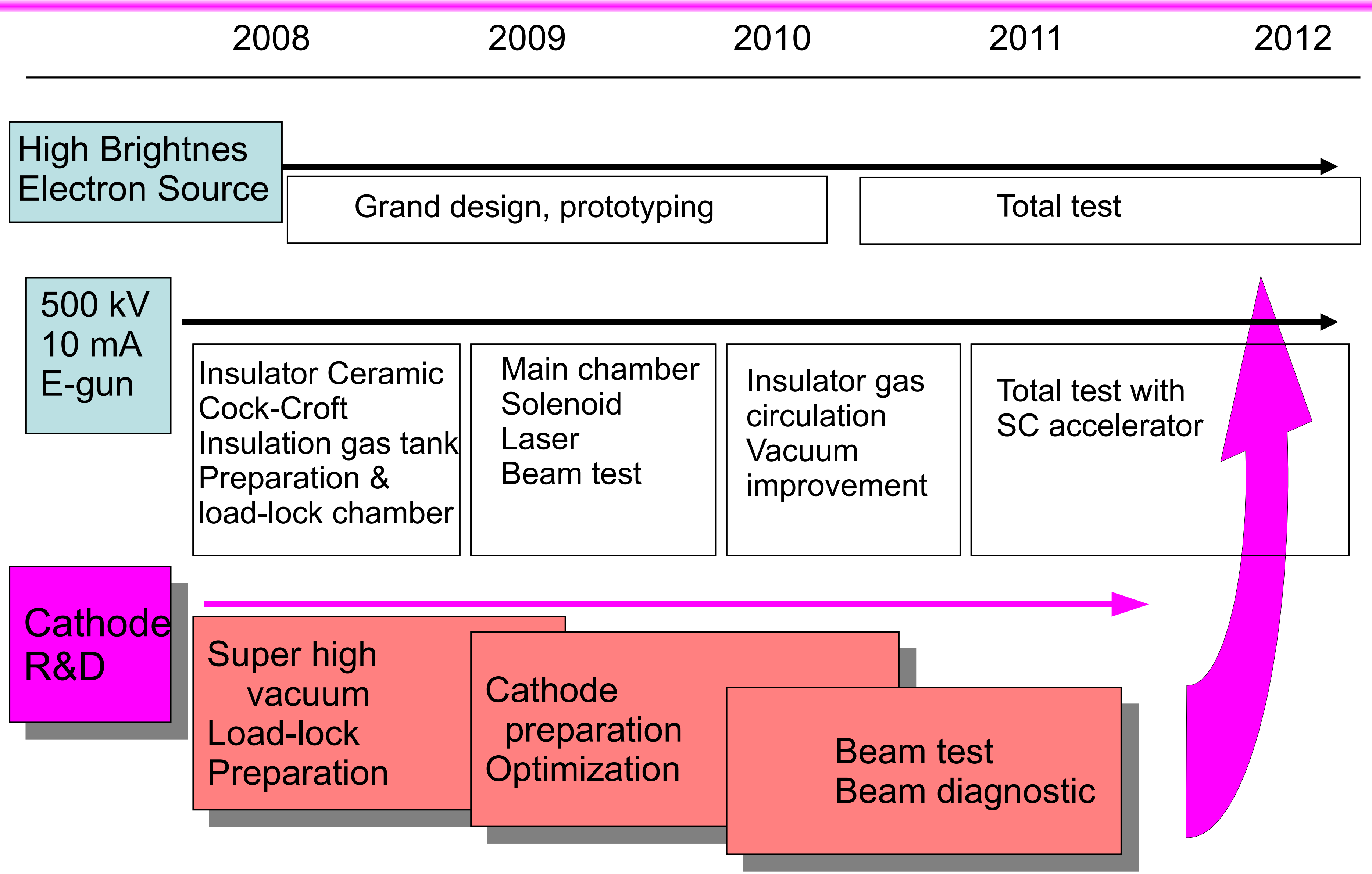
Q-beam System



R&D Plan

- ►2008-2009：Cathode Test Chamber
  - Super high vacuum chamber design and manufacturing:CP Ti chamber + Cryo-pump + NEG pump
  - Load-lock chamber, Activation chamber design and manufacturing
- ►2009-2010：AlGaAs, InGaN cathode preparation,optimization
- ►2011：Further optimization,beam test
- ►2012：Implementation to the electron gun

Electron source R&D plan in Quantum Beam Project



Summary

- Long life time cathode and high power operation are aimed for future projects;
  - Band structure optimization on $Al_xGa_{1-x}As$、 $In_xGa_{1-x}N$
    - Longer lifetime by smaller E_a
    - 500nm E_g driven by SH of solid state laser
  - Super high vacuum for less damage on cathode
    - CP Ti chamber
    - Cryo-pump + NEG pump
- Robust and high power cathode will be introduced to the final system of Q-beam project, ERL, ILC, CLIC, SRIPES, SPLEEM, etc.

Back Up Slides

Grand Plan

項　目	1年度目	2年度目	3年度目	4年度目	5年度目
超伝導空洞装置開発 （年額 3.1 億円、 その他 0.5 億円含む）	空洞製作技術高度化 超伝導空洞製作 高周波源小型化 ビーム制御機器開発			システム組立・調整 総合試験・性能確認	
電子源開発 （年額 0.53 億円）	高効率・長寿命フォトカソード開発 500 kV 直流電子源開発 ビーム生成実験				
レーザー蓄積・ X線検出装置開発 （年額 0.21 億円）	レーザー蓄積装置設計 レーザー蓄積装置製作 X線検出器試験				