RF Gun

SuperKEKB review @ 14, Mar, 2018

SuperKEKB upgrade for low emittance electron beam

High charge		KEKB obtained (e+ / e-)	SuperKEKB Phase-II required (e+ / e-)	SuperKEKB Phase-III required (e+ / e-)
&low emittance is required for SuperKEKB.	Beam energy	3.5 GeV / 8.0 GeV	4.0 GeV / 7.0 GeV	4.0 GeV / 7.0 GeV
	Bunch charge	$e- \rightarrow e+ / e-$ 10 \rightarrow 1.0 nC / 1.0 nC	$e- \rightarrow e+ / e-$ 10 \rightarrow 0.5 nC / 1.0 nC	e- → e+ / e- >10?→ 4.0 nC / 4.0 nC
	Beam emittance (γε)[1σ]	2100 μm / 300 μm	40 μm / 150 μm	15 μm / 20 μm

4 nC 10 mm-mrad electron beam generated by RF gun.

+ 10mm-mrad emittance preservation is required.



Injector configuration



RF-Gun for 5 nC

- Space charge is dominant.
 Longer pulse length : 20 30 ps
- Stable operation is required.
 - Lower electric field : < 100MV/m</p>
- Focusing field must be required.
 - Solenoid focus causes the emittance growth.
 - Electric field focus preserve the emittance.

Epaxial coupled cavity : BNL Annular coupled cavity : Disk and washer / Side couple





S-band RF-Gun development strategy for SuperKEKB

- Cavity : Strong electric field focusing structure
 - <u>Disk And Washer (DAW)</u> => 3-2
 - <u>Quasi Traveling Wave Side Couple</u> => A-1
 - <u>Cut Disk Structure</u> => A-1 90 deg line and normal laser injection
 - => Reduce beam divergence and projected emittance dilution
- Cathode : Long term stable cathode
 - Middle QE (QE=10⁻⁴ \sim 10⁻³ @266nm) and long lifetime
 - Solid material (no thin film) => Metal composite cathode
 - => Started from LaB₆ (short life time)
 - => <u>Ir₅Ce has very long life time with QE>10⁻⁴</u> @266nm
- Laser : Stable laser without/with temporal manipulation
 - LD pumped laser medium
 - Nd doped solid laser => 3-2
 - <u>Yb doped fiber and Nd/Yb solid hybrid laser</u> => A-1 ground/underground
 - Both side irradiation to QTW
 - Temporal manipulation => posteponded until Phase-III
 - => Minimum energy spread

Cathode : Quantum Efficiency Map

Spatial dependence of QE on the Ir_7Ce_2 cathode surface was measured.

[Sample]

Photocathode in the QTWSC-RF gun using Spark Plasma Sintering (SPS)





[Results : Non-activation]

QE > 10^{-4} in off-line measurement (10^{-6} Pa). QE = 10^{-5} in operation condition because of vacuum level (10^{-5} pa).

Redundant Yb:Fiber + Nd:YAG Hybrid Laser System



First MENLO Oscillator →1064nm Generation Self Phase Modulation (SPM)



Nd-laser system for SuperKEKB phase II

• Nd laser system is used for SuperKEKB phase II

(Both SuperKEKB ARC (R70) and RF gun review comment)

- Two lasers synchronous injection, the second line is built.
- Two lasers injection \rightarrow low emittance and high charge (3.6 nC achieved)



• Laser with vertical polarization, fiser with horizontal polarization

Laser Beam Profile



Virtual cathode monitor was installed (SuperKEKB ARC)

Laser Beam Profile (Current)



Nd-laser system for SuperKEKB phase II







B-sector Wire Scanner SP_A1_G 1.2nC 3-wire ABC :γεx=23.314、γεγ=19.939 3-wire ABD :γεx=27.558、γεγ=21.983 3-wire ACD :γεx=22.752、γεγ=35.889 3-wire BCD :γεx=25.387、γεγ=20.515 4-wire ABCD: γεx=24.958、γεγ=18.640

Laser Monitors



Laser monitors for fiber laser part and every amplifier stage were installed. We can justify the error part immediately from these logs. (SuperKEKB ARC R71)

Controllable optical system for adjustment

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 16 remote control actuators for laser fine adjustment by fully remote control (mirrors, BBO, telescope, wave plates)

Long term (2.5 month) operation history





Summery for Phase-II & Upgrade for Phase-III

Phase-III

- Stable operation using Yb:Fiber+Nd:YAG laser with many monitors and remote controls.
- Required charge & emittance for Phase-II were achieved
- Current maximum charge output is 3nC due to lower quantum efficiency of 10⁻⁵ compare with off-line QE of over 10⁻⁴.
 <u>High quality IrCe cathode</u> & Increase ion pump & Cathode cleaning system
- Laser system with flat top pulse shaping using <u>pulse stacking method</u> for both Nd and Yb.

Single crystalline (SC) IrCe

[Advantage of Single crystalline Metal]

- **Higher QE** than that of multicrystal^[1]
- **Better QE uniformity** than that of multicrystal^[2]

Our group collaborated with H. Sugawara (Kobe university) to develop the large size single crystalline IrCe compound.

[Developed SC IrCe]

<u>SC Growth Method</u> Czochralski Process

Succeeded in the crystal growth of 4mm diameter

[Czochralski Process]



Larger-diameter crystal growth experiments are in progress.

[1] D.A. Reis, at al., 'Transverse Emittance Measurements from a Photocathode RF Gun with Variable Laser Pulse Length', SLAC-PUB₇8018
 [2] P.R. Boltona, et, al., 'Photoinjector design for the LCLS', SLAC-PUB-8962

Electron beam (EB) heating type cathode plug

[Design of EB heating type cathode plug] EB heating is ... a main cathode is bombarded by an Iridium cerium photocathode accelerated electron beam as a thermal source behind the cathode. Ta heat shield **(** RF shielding structure **)** (electrode) Choke 0 structure S-parameter (dB) -20 -40 W filament -60 Reflection -80 Transmission -100 Insulator 2.5 3.5 4 2 3 Frequency (GHz)

Heating Test

[Cathode plug]







[Experimental Setup & Results]



Heater Current (A)	16
Heater Voltage (V)	3.38
Intermediate electrode (V)	-25
High Voltage (kV)	2.3
Beam current (mA)	23
Beam Power (W)	52.9
Surface Temperature (degC)	1029

Heating a photocathode over 1000°C by EB heating method was succeeded.

Pulse shaping in time domain

 In order to get low energy spread in a strong space charge effect, laser pulse with rectangular temporal shape is required



- 30 ps and 40 ps rectangular laser pulses are achieved by one stage and two stages stacking system separately
- Available to both Nd and Yb laser system

* Supported by Dr. Yosuke Honda

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Backup



Closed gap makes focus field

Side coupled cavity is one candidate (or DAW / ACS / CDS ...)



This structure has focusing field. Long drift space is problem.

Design of a quasi traveling wave side couple RF gun

Normal side couple structure

Quasi traveling wave sidecouple structure



RF-Gun comparison



Cavity design







cathode





Mechanical design and manufacturing













Cut Disk Structure(CDS) installed in 90-deg line



Cathode : Advantage of metal composite cathode (LaB $_6$ or Ir $_5$ Ce)



Lifetime measurement (LaB₆ / Ir_5Ce)





Second Nd laser line for SuperKEKB phase II

