

# Commissioning and Operation of DC-SRF injector at PKU

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# Outline

- Development of DC- SRF injector at PKU
- Experimental facilities
- Experiments and results
- Summary



#### Concept of DC-SRF Photocathode injector



Pierce structure + SRF cavity

- The concept of DC-SRF was proposed in 2001
- Compatibility of photocathode and SC cavity and compact structure
- Could be operated at CW mode and simulations show good beam quality

Electric field on cathode surface could not be very high
Emittance compensation solenoid is far from cathode

Could handle moderate average current (1~10mA)



#### Feasibility Test at 4K



Prototype with a pierce gun and a 1.5-cell superconducting cavity Test operation at 4K in 2004 : Gradient ~6MV/m , energy gain~ 1MeV , emittance~5 $\mu$ m

Promoted the design of an upgrade DC-SRF gun with 3.5 cell cavity



## 3.5 cell cavity DC-SRF injector





- Design and manufacture were started in 2007 and 2008
- Vertical test of 3.5-cell cavity at Jlab: 23.5 MV/m @ Q<sub>0</sub> >1E10
- Assembled and connected to 2K cryogenic system in 2010
- RF test experiments and preliminary beam test in 2011
- Upgrade of RF power supply, beam line and .... in 2012



## Main coupler





- Capacitive coupling structure similar with KEK design proposed in 2005
- Four parts connected by flanges
- Disk ceramic window, without contacting inner conductor
- Compact structure, easy for accembling and repare
- Stress on ceramic window is not strong



#### ERL project at Peking University



Peking University Superconducting ERL Test Facility (PKU-SETF)

First THz with lower bunch charge and then ERL-FEL with higher bunch charge



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#### Closed loop 2K cryogenic system at Peking University



Main parts from Linde, transfer lines made in China, Designed cooling capacity: 57.5W @2K Heat load of the 2K transfer lines: <0.5W/m



#### Stable operation of 2K cryomodule



# Commissioning stability of the cryogenic system

- Successive approximation method: the high and low limits of the control valves were preset and finely adjusted to avoid large fluctuation of the helium pressure and level.
- The stability of the helium pressure can be controlled within ±0.1 mbar and the helium level is within ±5%.



# The recovery processes with the jumps of the heat load

- When jump of heat load caused by the change of cavity gradient and the duty factor of RF power.
- 2K cryogenic system can be recovered from the pressure instability and helium level instability within short time.
- ➤Total cooling capacity: more than 65 W at 2.0 K



# On-line Cs<sub>2</sub>Te photocathode preparation system



- Vacuum in deposition chamber has been improved to 2X10<sup>-7</sup> Pa with a bigger sputtering ion pump (600L/s).
- >A SAES NEG pump (200L/s) has been equipped
- The plug polished mechanically, rinsed in ethanol and acetone ultrasonically, heated at 120-150 degree for more than 10 hours



- Seed laser: Timebandwidth GE-100 XHP 5W at 1064nm
- > Amplifier: 40W
- SHG: 10W for green light (532nm)
- FHG: 1W for UV light (266nm)
- Repetition rate : 81.25MHz

QE of fresh Cs<sub>2</sub>Te photocathode is around 8% and stabilized at 0.5% for months Used photocathode can be rejuvated by heated at 120 degree and laminated under the Hg lamp



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#### 1.3GHz 20kW solid-state RF power source in 2011



- > 1.3 GHz 5kW solid-state RF power supply was replaced with the new one
- Can work in both pulse mode and CW mode
- Output RF power can achieve 20kW with matched load, and 16kW with total reflection
- 3dB bandwidth is more than 30MHz



#### LLRF control system



Digital Low Level Radio Frequency (LLRF) control :

- Two feedback control loops for amplitude control and phase control.
- PI controller in FPGA adjust output signal to compensate the deviation

Recent improvements:

- A DC offset block was added in the FPGA to compensate the DC offset observed in the tests
- For pulse operation, gate signal was added to the feedback path and the control algorithm was modified to handle lorentz detuning
- A hardware UDP core was implemented for high speed signal monitoring.
- new control UI offers run-time plotting and modifying for many internal parameters



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#### Conditioning of main power coupler



- Temperature at several points inside the coupler was monitored by temperature sensors
- Cavity was non-resonance during the conditioning
- Highest power was 20kW with duty factor of 40%



#### $\mathsf{E}_{\mathsf{acc}}$ in different conditions have been investigated

Phase-lock:  $E_{acc}$  was increased up to 17.5MV/m in pulsed mode with a duty factor

of 10% and a repetition rate of 10 Hz.

 $\rm E_{\rm acc}$  reached 14.5MV/m for CW mode

LLRF control:  $E_{acc}$  was 12.9MV/m for a long-term test.



Amplitude (up) and phase (below) signals of 3.5-cell DC-SRF injector at 12.9MV/m without beam load



#### **Cavity microphonics**



- Real-time measurement of cavity microphonics was done
- The vibrations at the frequency of 2Hz and 14.5 Hz may affect the cavity.
- > The investigation of the sources of these vibrations is underway.



- Beam tuning with a low beam current, reducing the duty factor of laser rather than reducing laser power to keep the same bunch charge for different average current.
- > When the duty factor of laser was 1% at 10 Hz, the average beam current is about  $2.5\mu$ A.
- Duty factor was increased gradually to 100% and the average current increased to 250µA with certain laser power
- Degassing of the dump faraday cup became serious with higher beam current

E<sub>acc</sub> was 8.0MV/m during the beam test

- Beam energy gain is about 3.3 MeV at this accelerating gradient
- beam energy estimated with bending magnet and energy spectrum of radiation were 3.2MeV and 3.1MeV

Reflected and pickup RF signals with pulsed beam load



#### Transverse emittance measurement by multi-slits method

- >Beam emmittances were measured at different DC voltages of 50kV, 42kV and 36.6kV
- Normalized emmittances are all around 3.0 mm·mrad
- > Space charge effect is weak at this situation



Beam passing through multi-slits (left) and relative intensity (right)



RF power supply, photocathode preparation system, LLRF control system and beam line are impeoved

> Progress has been made on the 3.5-cell DC–SRF photocathode injector

- >0.25mA CW electron beam has been obtained
- Imitation is degassing of dump faraday cup
- > 1mA beam is expected with a beryllium window before the dump
- > DC-SRF injector will be used for THz radiation and then for ERL-FEL test facility





# Thank you for your attention !





#### Design Parameters of the DC-SRF injector (DC voltage 90KV)

Drive laser									
Pulse length (FWHM)	10ps								
laser spot (FWHM)	3.0mm								
Repetition rate	81.25MHz								
Bunch charge distribution	transverse uniform , longitudinal Gaussian								
Injector	ERL mode	THz mode							
gradient	13 MV/m	15MV/m							
Bunch charge	60~100 pc	20рс							
energy	5MeV	<5MeV							
Transverse emittance (rms)	1.2mm·mrad	2.1 mm·mrad							
Longitudinal emittance (rms)	15 deg—KeV	3.0deg—KeV							
Bunch length (rms)	3ps	0.55ps							
Rms beam spot	0.3mm	1.7mm							
Energy spread	~0.5%	0.55%							



#### Electric field distribution of the 3.5cell cavity

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0 -L			ļ			20	25		35 III		Working	1300 MHz
	4					100			R3-SYUL.TBL	9-15-2005 9:29:48	frequency	
1.5	•	1			1						Q <sub>0</sub>	$1 \times 10^{10}$
1					ł		1				Eacc	13 MV/m
.5					ļ						Effective Length	0.417 m
0	***	******	******	******	•••••	******	<b>****</b> ****	******	++++++++++++++++++++++++++++++++++++++	*****	G-factor	242 Ω
5			ł		 				1		Shunt Impedence	417 Ω
-1					•			•	4		r/Q	
-1.5			ł						1		$E_{\text{peak}}/E_{\text{acc}}$	2.12
	-5	5 I	0 5	i 1	.0	15	20	25 30	35 4	0 45	B <sub>peak</sub> /E <sub>acc</sub>	4.95 mT/(MV/m)
Z (cm)												



#### Electric field of DC pierce stucture





Electric field distribution of the DC-gun

SRF2013, Paris, September 23-28

IHIP, Peking University, China 28



#### Effect of DC voltage on emittance



#### Transverse emittance v.s. DC voltage (100pC, 13MV/m)



#### Drive laser system



Seed laser is commercial picosecond oscillator (Time-Bandwith GE-100 ) and was upgraded. Upgraded system compose of amplifier, SHG, FHG, lenses, control system and cooling system





The UV laser power on the surface of the photocathode is about 0.1 W, and the photocurrent is 350 uA

No degradation was found during the two weeks' experiment



#### Fourier Transform Far-Infrared Spectrometer



Spetral range :  $8000-10cm^{-1}$  (  $1.25\mu m - 1.0mm$ ) Resolution: better than  $0.07cm^{-1}$