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NEA-GaAs (Cs, O) PHOTOCATHODES FOR THE ELBE SRF GUN

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Abstract

At HZDR a preparation chamber for NEA-GaAs (Cs,O) has been built and tested. GaAs is the next photocathode material for the ELBE SRF gun, which has been successfully operated with Cs_2Te photocathode in last years. GaAs photocathodes are advantageous because of their high quantum efficiency (QE) with visible light and the extensive experiences of their use in DC guns. Furthermore, GaAs photocathodes provide the possibility to realize a polarized SRF gun in the future. In this presentation we will introduce the new preparation system and the first results of the GaAs tests. The new transfer system under construction will be also presented.

MOTIVATION

The superconducting rf photo-injector (SRF gun) at HZDR has been put into operation since 2007 and succeeded in driving an IR-FEL in ELBE radiation source [1]. This type of photo-injector is a promising candidate of high current and high brightness electron source for the new light sources and big accelerator facility, such as FEL, ERL and so on. There exist a lot of opportunities to improve the quality of the beams, and among them enhanced photocathodes can play a big roll.

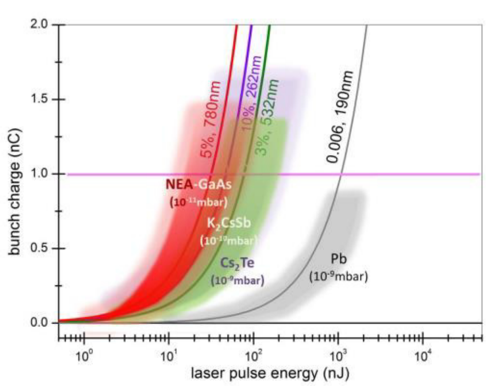

Figure 1: The compare of different photocathodes for superconducting rf gun.

The photocathode materials for SRF photo-injector must be compatible to the superconducting rf niobium cavity besides high QE and long life time. Pb is considered as real superconducting photocathode, but its low QE and high work function cause much difficulty on the driver laser [2]. Cs_2Te has been used in ELBE SRF gun and it is satisfying for medium current operation [3]. K_2CsSb is also a successful candidate, and has been used in DC guns [4]. GaAs(Cs, O) is experienced in DC guns for high average current [5] and the polarized electron sources [6]. Figure 1 shows a conceptual comparison of these photocathodes to produce 1 nC bunch charge and their vacuum requirements. NEA-GaAs has critical operation request (vacuum better than 10^{-11}mbar) compared to the other materials.

Recently GaAs(Cs,O) is considered to be combined with the SRF gun technology [7]. It is interesting for the development of ELBE SRF gun, because it shows high QE in the visible light range, instead of Cs_2Te photocathode driven by UV light. And the UV laser profile shaping is more complicated than in the case of longer wavelength laser. GaAs(Cs,O) requires only green to blue drive laser, which saves laser power and then the cost on laser building. If higher bunch charge than 1 nC with special bunch shape is required in the future, the present Cs_2Te photocathodes and the UV laser system will face an extremely big challenge. Furthermore, the realization of the operation of GaAs photocathode in SRF gun may approach a new polarized electron source with higher bunch charge and lower emittance than the present status.

Figure 2: The GaAs preparation chamber in clean room. The magnet manipulator is used to install a new substratum.

PREPARATION CHAMBER

Due the extremely high requirement during the GaAs(Cs,O) activation, in 2013 a new sphere chamber was assembled (Figure 2). The main parts include an ø 300mm sphere chamber, a manipulator for the sample

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handling, rest gas analyser (RGA), a loading load-lock system with magnetic manipulator and the vacuum pump system.

Cathode Plug Design

In order to reduce the volume of the vacuum suitcase, the cathode tip (called plug) will be transported instead of transferring the whole cathode body. The plug is an Ø 10 mm puck with the length of 8 mm while the cathode body is longer than 10 cm. For this purpose, the new cathode plug fixed with CuBe spring on the cathode body has been developed (see Figure 3). This plug can be mounted onto the cathode body in vacuum through a manipulator. The GaAs wafer will be embedded in this plug with Ø 4 mm area open to vacuum. The generating of particles during the handling and the thermal contact between the plug and the body are also considered.

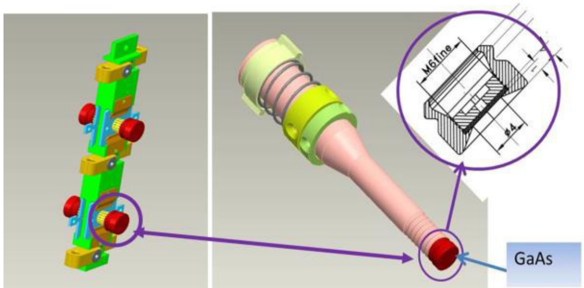

Figure 3: The design of new photocathode plug. Up to four plugs can be transported with this carrier. The plugs are fixed on the flags (in blue) with CuBe springs (in yellow) and the flags can be handled by magnet manipulator [8].

Preparation Chamber Design

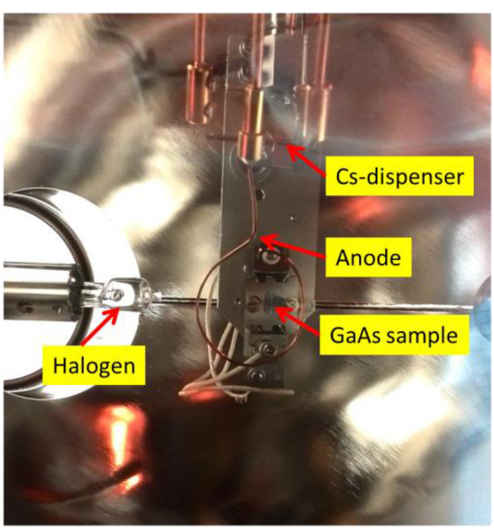

Figure 4: Insight view of the GaAs preparation chamber.

Two CF100 view windows are installed in sphere chamber to watch over the process. Three CF40 optical windows are mounted in equator at different position for the light sources. The flag with sample is clamped on the rotatable manipulator, which brings the sample to different station (see Figure 4).

Heating station is a halogen light with the reflector, which is able to focus the light right on the cathode surface and also works as a thermal shielding for the heating module.

The SAES cesium dispenser and the anode are in the second station, which also faces to an optical window. Green light with 532 nm wavelength can illuminate cathode surface for photocurrent detect. The photocurrent can be measured through the sample holder with Keithley picoampere meter.

O_2 leaking rate is precisely controlled by the voltage on the piezo valve. RGA shows that the O_2 partial pressure is 1×10^{-11} mbar with 400 V on piezo. After turn off the O_2 valve, the rest O_2 can be pumped away quickly.

Vacuum

The most important issue for the preparation chamber is the high vacuum. For this reason, the sphere chamber was electrical polished and then baked in vacuum. All parts used in the chamber can be baked at more than 200 ^{o}C. The assembling of the chamber was done in clean room to minimize the particles inside.

After evacuating the chamber with pre-pump station, a baking at 200 ^{o}C has been done for 10 days. Then the two NEG modules were activated and the ion getter pump was switched on. The vacuum in chamber achieved 4×10^{-11} mbar after the system cooled down. And it can be again improved by baking the chamber at higher temperature. However, the pressure was found increases to 10^{-9} mbar level during the heating treatment and cesium deposition, which causes trouble for the activation.

FIRST TEST RESULTS

The commercial 400 µm bulk p-type GaAs (Zn highly doped) semiconductor is chosen as our first test sample. The 2-inch wafer was cut in the clean room to 5 mm ×5mm pieces for the treatment tests.

We used the published acid etching process [6] to clean up the wafer surface. Optical mirror like surface is homogenous and shows good crystal quality. From the EDX measurement, one can find that the O content on the surface is reduced by the etching process. Another important cleaning for GaAs wafer is the heating at typical 600 ^{o}C. In our preparation chamber, the temperature can be measured with the thermal couple berried in the sample holder, on which the sample flag with GaAs wafer is fixed. Halogen light was used to heat the wafer. However, because the reflector behind the halogen light was still missing, the temperature didn't reach the required level. Moreover, the vacuum dropped down during the heating process to 10^{-9} mbar.

An unactivated GaAs wafer has been transferred in to the SRF gun and tested with RF field. This sample was covered by a copper desk with an Ø 4 mm free area. The goals were to measure the dark current (field emission) from GaAs and the dielectric rf loss in GaAs wafer.

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Figure 5 shows the dark current measurement results. The red points present the dark current from the cavity with unactivated GaAs wafer, which are equal to the black stars' value, the niobium cavity without cathode plug. This means that there is no detectable field emission from GaAs bulk at achievable gradient.

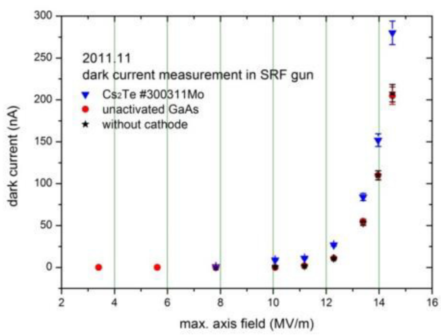

Figure 5: Dark current from SRF gun with Cs_2Te, GaAs, respectively.

The first activation with cesium and O_2 has been performed. After heating treatment, "Yo-yo" process was applied. Firstly cesium was released from dispenser with very low rate. After half an hour the photocurrent appeared. This growing lasted about 20 minutes and then was in a standstill. After stopping the cesium flow, O_2 was leaked into the chamber. The photocurrent immediately dropped down. We closed O2 and restarted cesium, the next photocurrent peak appeared. After 2 times "Yo-yo" the photocurrent peak increased more than twice. However, in this first test QE was very low due to the low treatment temperature and the bad vacuum during the cesium evaporation.

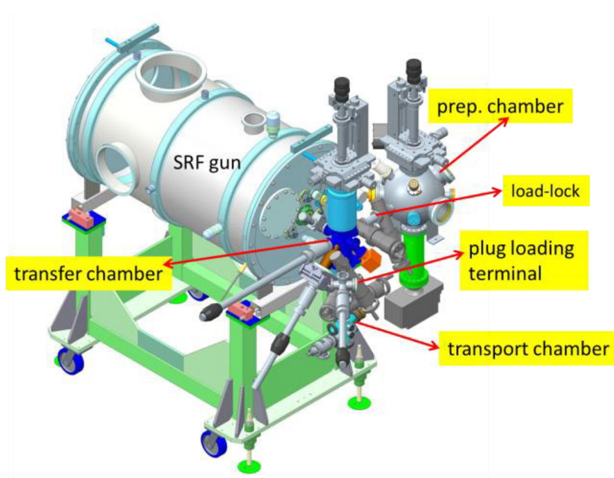

Figure 6: SRF gun with the new photocathode transfer system. The GaAs(Cs,O) will be in situ activated and then quickly transported into SRF gun.

TRANSFER SYSTEM

HZDR has cooperated with Helmholtz center Berlin (HZB) and the Johannes Gutenberg University Mainz (JGU) to develop a net-working transport chamber (Figure 6.). The small plug carrier with four plugs (shown in Figure 3) will be safely fixed in the ceramic chair. One advantages of this design is that the QE of the cathodes can be measured during the storage and transport. Each cathode can be detected by illuminating the surface through a CF16 window and measuring the photocurrent through a feed-through. A CF40 VAT all-metal valve is used to connect it with the load locking system to the cathode insertion part.

In this transport chamber, the extreme high vacuum (XHV) as good as or (better than) 1×10^{-11} mbar is required. The vacuum will be maintained by ion getter pump and SAES non-evaporation getter (NEG) pump [9].

CONCLUSION

At HZDR the effort of preparation and operation of NEA-GaAs (Cs,O) ina SRF gun is carrying on. The new preparation system have been finished and tested. Static vacuum achieves 4×10^{-11} mbar and it will be improved continuously. The transport system is in designing and it will be finished in the next year. The first try on "Yo-yo" activation has been performed, although the QE was still very low because of the low heating treatment temperature and insufficient vacuum. The improved heating module with higher efficiency will be installed in the summer so that we can solve this problem.

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