RESEARCH ACTIVITIES ON PHOTOCATHODES FOR HZDR SRF GUN

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Abstract

Since 2005 the photocathode laboratory has been in operation at HZDR. The main goal is to prepare Cs_2Te photocathodes for the SRF gun. A vacuum transport system with UHV is used to move the cathodes from preparation lab to accelerator hall. Up to now 34 Cs_2Te photocathodes have been deposited and eight of them have been used in the SRF gun. Quantum efficiency (QE) of 1% and life time of months can be maintained during the gun operation. At the same time activities are directed towards new photocathode materials with high Q.E. for high current electron sources. Cs_3Sb and GaN(Cs) photocathodes have been tested as new candidates, and the design of a preparation system for GaAs(Cs, O) is ongoing.

INTRODUCTION

The development of photocathode guns has become a significant technology for large accelerator facility and light sources. There exist a lot of opportunities to improve the electron source. For photo-guns producing high average current up to mA level, searching for better photo cathodes is a sustained effort, while there is still space to improve the photocathode both in the the quantum efficiency (QE) and the life time.

Numbers of photocathode materials have been considered for the electron source [1,2]. The metallic cathodes, like Cu, Mg used in normal conducting rf guns, Pd, Nb used in superconducting guns, have QE in the level of 10^{-4}, which means UV lasers with a few Watts are required for only µA average current. By using antimonide cathodes and GaAs (Cs) the requirement for drive laser can be greatly deemphasized however these cathodes material are extremely sensitive to any contamination and so the preparation process needs 10^{-11} mbar XHV. Cs_2Te is a compromise choice, which has QE up to 10% and requires only 10^{-9} mbar vacuum for production and storage.

The Rossendorf superconducting rf photo injector (SRF gun) developed within a collaboration of the institutes HZB, DESY, MBI and HZDR has been operated since 2007. The maximum energy of the electron beam reaches 3.3 MeV, bunch charge 300 pC and transvers emittance is measured as 3±1 mm mrad @80 pC [3].

The SRF gun requires photocathodes with QE higher than 1% in weeks. The HZDR photocathode lab is responsible to prepare Cs_2Te photocathodes for the SRF gun operation [4]. From last year activities are directed also to new photocathode materials with high QE for high current electron sources. As a test facility of superconducting rf gun technology, the SRF gun is also a platform to test diffirent photocathode materials.

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CS_2TE STANDARD CATHODE

Because of its good efficiency and robustness in rf field, Cs_2Te has been chosen as the standard photocathode for the SRF gun. From 2007 on, eight Cs_2Te photocathodes have served for the SRF gun beam production.

UV laser is used to driven the photocathode. Up to now, the Nd:YLF laser system produces CW pulses with variable repetition rates up to 250 kHz, pulse length of 12–15 ps FWHM and mean power of 200 mW at 262 nm wavelengths. The development of the 13 MHz laser is finished in MBI and will be commissioned with SRF gun soon.

QE and Life Time

The Cs_2Te photocathodes are prepared in a separated photocathode lab and then transported to gun. The QE of the fresh photocathodes is between 8-15%. The cathodes are stored and transported in the chamber with vacuum in the order of 1×10^{-9} mbar. But the cathode QEs drop down quickly to 1-2% because of the material degradation and also the vacuum variation during transportation.

Once the cathode is installed in the gun cavity, no obvious QE degradation has been found during the beam production. For example, cathode #250310Mo worked in SRF gun for more than 420 days, providing totally beam time over 1000 hours and 35 coulomb charge. Figure 1 shows the photo and the QE map of cathode #250310Mo.

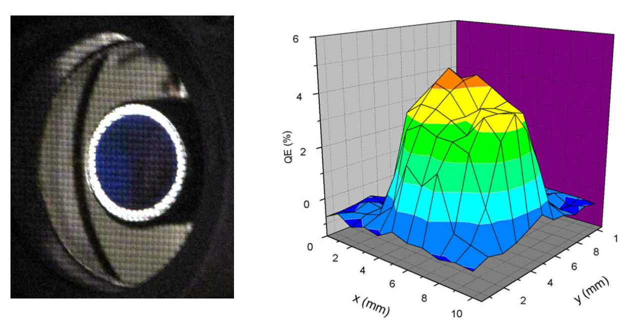

Figure 1: Cathode #250310Mo in vacuum and QE distribution map. It was in gun from 2010.5.25 to 2011.7.26. Total beam time was over 1000 h, and extracted charge was about 35 C.

Dark Current

The main problem for the high gradient operation of SRF gun is that the dark current increases rapidly along with gradient. Dark current has been measured with different cathode shape and materials (Figure 2). The cavity itself, cavity with Mo-plug and also with Nb-plug have the same dark current emission. The Mo-plugs with Cs_2Te layer induced 30% higher dark emission. So the main source of the dark current is believed to be the field emission from the rear wall of the cavity half-cell, and the rest 30% was contributed by cesium atoms. Meanwhile, cesium contamination is considered as the reason of serious multipacting at low gradient. However, his cesium pollution from the preparation system is difficult to be removed. So a kind of photocathode without or with less cesium demanding may have the chance to solve this dark emission problem.

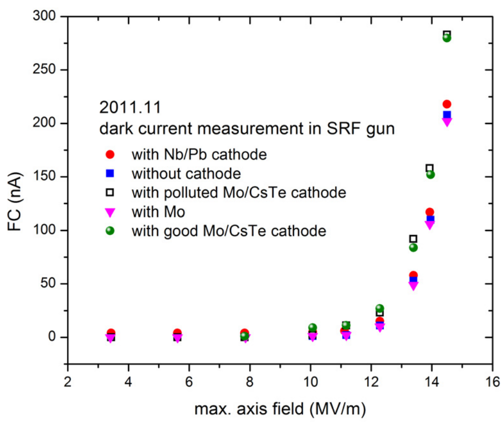

Figure 2: Dark current measurement with different cathode material.

Surface Morphology

Scanning electron microscope (SEM) is used to detect the surface morphology of cathode #060410Mo after it was taken out from gun. This golden cathode had fresh QE of 13% but short life time in gun. Further analysis was done after it was sent back to preparation lab. The golden color was faint and the layer showed inhomogeneous. Energy dispersive x-ray analysis (EDX) was then done to detect the content of Cs/Te. The centre of film had the rate of 2.3, and in the rim it was 2.0. In fact a part of cesium will detach from the deposited layer after the cathode is taken out from vacuum, so the cesium might be too rich in the fresh cathode, which could be the reason of short life time.

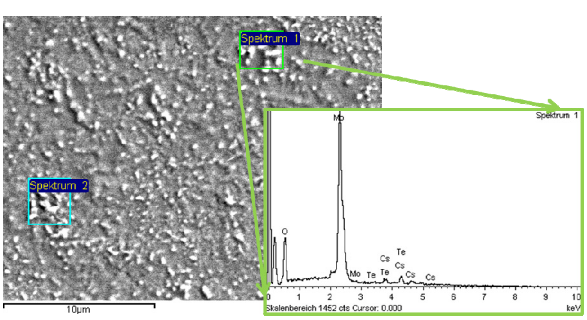

Figure 3: SEM/EDX analysis for Cs_2Te photocathode #060410Mo. Spectrum shows the element content (Cs/Te=2.3) in the center of film.

NEW CANDIDATE CATHODES

For the future application of SRF guns, searching for new photocathodes is one of major technical challenges. The search goal of new cathodes is to find a type of material which promises high QE, long life time and low dark emission. Antimonide cathodes and GaAs (Cs) are still attractive because they don't need UV laser. Gallium nitride (GaN), a novel III-V semiconductor with the wide band gap close to that of the Cs_2Te, has high QE and is more robust than GaAs.

Cs_3Sb Photocathode

Cs_3Sb photocathode is an old topic in photo gun field. [5,6]. With our current preparation system, a Cs_3Sb photocathode was deposited in 2011. After two cycles Yo-yo process was performed in 10^{-9} mbar environment, QE reached 1.5% @ 262 nm. SEM meausrement was done to detect the film quality (Figure 4). The Mo substrate was photographed at first (left). The Cs/Sb layer was deposited with stoichiometric rate of 2.7 on the Mo sample. The substrate was complete covered with homogeneous film. On the film some islands with size of µm level can be seen, which responses actually the cesium rich distribution.

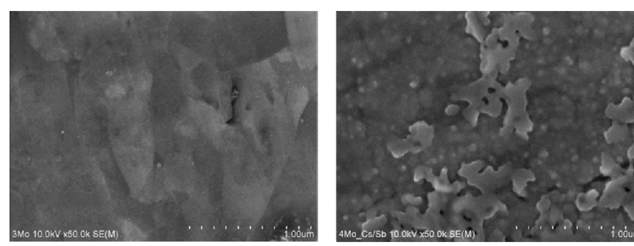

Figure 4: SEM-morphology: (left) optical-polished Mo substratum; (right) Cs/Sb film deposited with rate 2.7 on Mo substratum.

GaN(Cs) Photocathode

GaN(Cs) has some interesting characteristics: QE as high as 50% in the UV range [7]; better stability and a longer lifetime than GaAs [8]; NEA surface can be achieved only with cesium [9]; Efficient reactivation by simple vacuum bakeout; GaN samples are commercially available. GaN(Cs) photocathodes have been considered by accelerator lab in last years [1]. Bazarov and the co-operators studied the thermal emittance and response time of GaN photocathode [10]. Although there was a plan to try GaN for 100mA high current gun in 2004 [11], up to now there is no practical application in the photo gun field.

P-type GaN on sapphire with Au/Ni was used for our first experiment. Only cesium was involved in the activation process. 5 cycles reactivation were done for the same sample, maximum QE 5% was achieved (Figure 5). The original GaN and also the activated one will be tested in SRF gun in the near future.

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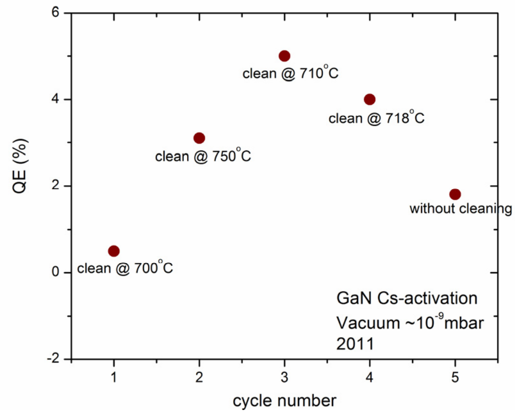

Figure 5: The first series GaN activation tests have been performed on 10^{17}-level p-doped GaN grown on sapphire. The samples could be reactivated several cycles.

GaAs(Cs,O) Photocathode

Because GaAs has QE in visible light range and it is the best polarized electron source, GaAs photocathode is used worldwide in DC electron sources for the large accelerator facilities. A project to apply GaAs in the Rossendorf SRF gun has been started. However, this photocathode is very demanding. The effective activation happens only in the vacuum in the level of 10^{-11} mbar or even better.

For this plan, a new preparation chamber and transporation system will be developed for extreme high vacuum (XHV) 10^{-11} mbar, and a light source in the range of 600-800 nm will be built. In the new preparation system, sample heat-cleaning, cesium-oxygen activation and photo-emission diagnostic will be included in a sphere chamber, pumped with ion getter pump and SAES NEG pumps. The storage system is designed for 6 crystals samples to make up the short life time of GaAs.

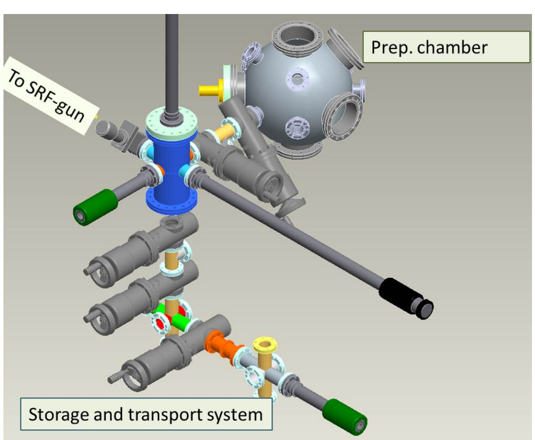

Figure 6: contracture design of new GaAs preparation system.

Production of first GaAs photocathode is planned for next spring. Bulk GaAs crystal will be chosen for the test because it is much cheaper than the strained semiconductor and the superlattice crystal. There are some open questions arose by the application of GaAs crystal in the superconducting rf cavity, such as particle back bombardment, dielectric rf power loss, slow response time, and field emission from NEA surface. In 2011, unactivated bulk GaAs crystal with thickness of 0.4mm was tested in SRF gun to ensure the RF properties of SC cavity. Up to 14.5 MV/m (maxium axis field), cavity was running without any thermal or rf problem, which gives us more confidence to perform GaAs in SRF gun.

SUMMARY

Several semiconductor photocathode materials have been tested in our photocathode laboratory. Cs_2Te photocathodes provide QE of 1% and life time of months for Rossendorf SRF gun. Some other materials with high Q.E. are considered for high current application. Cs_3Sb and GaN(Cs) photocathodes have been prepared with our current preparation system, and a new XHV system for GaAs(Cs, O) is in development.

ACKNOWLEDGE

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