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Photocathodes for High Brightness Photo Injectors

Rong Xiang*, Jochen Teichert

Helmholtz Zentrum Dresden Rossendorf (HZDR), 01328 Dresden, Germany

Abstract

The development of the photo injector has become a key technology for accelerator-based light sources and for the electron collider. There are a lot of opportunities to improve the injector quality, as well as photocathode function. A better photocathode can reduce the specification requirements of the drive laser system. The identification of better photocathodes is always a principal technical challenge, especially for the high brightness injectors. In this contribution, we will briefly review the status of photocathode research and the developing trends that are foreseen for the future.

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*Keywords:*photocathodes, high brightness, photoinjector

1. Introduction

For each accelerator facility, e.g. the light source and the future electron-ion collider, the development of the photo injector is a key technology. There are various solutions of photo injectors for different application requirements, but the common challenge is to obtain a high quantum efficiency (QE), long lifetime and cold photocathode. Especially in the high luminosity collider, x-ray Free Electron Laser and Compton backscattering facilities, a high brightness source is a crucial part. The definition of the normalized beam brightness shows that higher brightness results from higher beam current and/or lower emittance:

* Corresponding author. Tel.: +49-351-2603548; fax:+49-351-260 3690.
E-mail address: r.xiang@hzdr.de

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$$B_n = \frac{2I}{\pi^2 \varepsilon_{n,x} \varepsilon_{n,y}} \quad (1)$$

Here B_n is the normalized brightness, I is the electron beam current, $\varepsilon_{n,x}$ and $\varepsilon_{n,y}$ are the normalized transverse emittances.

Thus, for the high brightness electron guns, there are four important aspects for the photocathodes: high QE for high current, low thermal emittance and prompt time response for low emittance, long life time for sufficient user beam time. The QE needs to be more reliable, and the cathode material must be more robust. Thus there is strong motivation to push cathode R&D: on one hand to modify the present cathodes; on the other hand to search for new materials.

There are two main types of photocathodes - metallic and semiconductor photocathodes. In the metallic cathodes, the "conventional" normal conducting (NC) metallic photocathodes, such as copper and magnesium, are most robust for radio frequency (RF) guns, but their QEs are unfortunately very low, mostly at the level of 10^{-5} to 10^{-6}. The superconducting photocathodes consisting of niobium and lead have been well investigated for superconducting RF (SRF) guns, but the deep UV drive laser is still challenging. Recently the new plasma-enhanced metallic cathodes and alkali-activated metal cathodes have been developed and are very promising for future application.

The semiconductor photocathodes, alkali antimonites, Cs_2Te and GaAs(Cs), have the best QE of 1~10% but a critical working environment is mostly required. Among them, Cs_2Te is relatively robust and can be used in most RF/SRF guns. And Cs_2KSb achieves the highest current record 65 mA in the Cornell DC gun [1]. Although GaAs(Cs) relies on very high vacuum technology, it is attractive because it is up to now the unique candidate for a polarized electron source and also has high QE for non-polarisation application.

2. Metallic photocathodes

Copper has been used for a long time as the preferred material for the RF gun cavity and for a robust photocathode. However, its work function at 4.5 eV is so high that the QE is rather poor for high current application [2]. In spite of the low work function Φ (less than 3 eV), the pure alkali metals are practically difficult to be operated as photocathodes. Magnesium is a metal with low work function of about 3.66 eV [2] and can be applied in the RF photoinjector [3]. The best QE record for Mg photocathodes reaches 0.2 % [4].

For SRF guns niobium and lead are considered to serve in the niobium cavity at BNL and DESY, because of the high transition temperature and acceptable work function (4.25 eV for Pb and 4.3 eV for Nb) [5]. Although the deep UV drive laser is challenging, Pb has been well investigated to achieve a high QE up to 10^{-3} by Smedley et al. [6]. The test in the SRF gun showed however a relatively low QE of 9×10^{-5} at 258 nm by Barday [7], showing that it is possibly not suitable for high brightness electron sources.

If the metal cathode is activated with a low work function alkali metal, for example, cesium (Φ =1.95 eV), the QE will be greatly increased. The QE for a commercial dispenser cathode was found to be as high as 0.22% at 266 nm by Jensen et al. [8]. The activation can be realized with vacuum deposition or ion implantation [9]. Recently a new plasma-enhanced metal cathode has been developed by Mustonen et al. [10] and shows very promising characteristics (see section 5.1).

3. Semiconductor photocathodes

D. H. Dowell et al. [11] has listed most of photocathode materials. For semiconductor photocathodes, the band gap and the electron affinity define their response spectra and experimental QEs for a given wavelength. The band gap, i.e. the difference between the top of the valence band and the bottom of the conduction band, is the intrinsic character of a semiconductor. However, the electron affinity, the difference between the surface energy level and the vacuum energy level, is affected by the surface conditions. Thermionic electrons in the conduction band have more chance to overcome lower electron affinity, leading to a higher QE. Some materials have even negative electron affinity (NEA), which means all electrons with thermal energy in the conduction band are able to escape the solid surface.