Masked Photocathode for Photoinjector

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In this research note, we propose a scheme to insert a photocathode inside a photoinjector for generating high brightness electron beam. Instead of mounting the photocathode onto the electrode, a masked electrode with small hole is used to shield the photocathode from the accelerating vacuum chamber. Using such a masked photocathode will make the replacement of photocathode material very simple by rotating the photocathode behind the mask into the hole. This will significantly increase the usage lifetime of a photocathode. Furthermore, this also helps reduce the dark current or secondary electron emission from the photocathode. The hole on the mask also provides a transverse cut-off to the Gaussian laser profile which can be beneficial from the beam dynamics point of view.

I. INTRODUCTION

Photoinjector is one of the key components to provide high brightness electron beam for next generation light sources. The lifetime of the photoinjector depends on the lifetime of the photocathode. The lifetime of a photocathode varies from hours to months depending on the details of photo emissive materials and operating conditions. For example, for the $GaAs$ photocathode used in the free electron gun (FEL) at Jlab, the $1/e$ lifetime is about 50 hours at an average current of 5 mA under 5×10^{-11} Torr vacuum pressure [1]. For the Cs_2Te photocathode at the photoinjector at the DESY FLASH FEL facility, the lifetime is months [2]. When the quantum efficiency of the photocathode becomes low, the photocathode needs to replaced, reactivated, or recesiated. This process can take from hours to weeks depending on what needs to be done for the photocathode material. For example, if only recesiation needs to be done for the $GaAs$ cathode, it probably takes less than an hour by using a semi-load lock system [3]. On the other hand, if reactivation has to be done, it might take much longer time [4]. Furthermore, the photocathode inside the vacuum chamber also makes significant contribution to the dark current and second electron emission inside the photoinjector due to the low work function of the photocathode material [5–7].

In this research note, we propose a masked photocathode design that separates the photo emissive material from the accelerating vacuum chamber using a mask electrode with a small hole. This removes the dark current and secondary electron emission from the photocathode. This also protects the photocathode from the damage of ion-back bombardment and multipacting electrons. Furthermore, by rotating the photocathode behind the mask electrode, a new photo emissive surface can be put into use through the hole. Such a rotation can be done within minutes without taking the photocathode out. This significantly increases the usage lifetime of the photocathode by order of magnitude.

II. MASKED PHOTO-CATHODE DESIGN LAYOUT

Figure 1 shows a schematic plot of the side view comparison of the conventional photocathode and the masked photocathode. In the conventional photocathode, the photocathode material is mounted onto an electrode made of conducting material such as Mo. The photocathode surface facing the accelerating vacuum chamber will be exposed to the incident laser and also the back

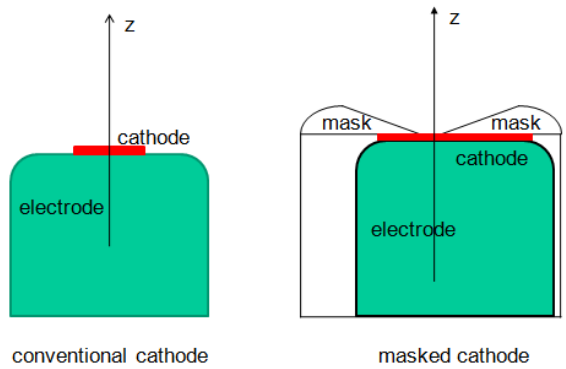

FIG. 1: Side view of conventional photocathode (left) and masked photocathode (right).

bombardment of ionized ions and multipacting electrons. In the masked photocathode design, a mask electrode with a small hole is put in front of the photo emissive material. The size of the hole is used to control the transverse size of the photo electron beam. The transverse size of electron beam is on the order of 1 millimeter. It is much smaller than the conventional size of photocathode which is on the order of a few millimeters. This helps cut off tails from a Gaussian laser beam. Using a mask electrode protects the photocathode material from the bombardment damage of back ions and electrons. It also prevents the dark current and the secondary electrons being generated from the photocathode surface. The size of the photocathode behind the mask can be made relatively large (on the order of centimeter) with an axis different from the axis of the mask electrode. Figure 2 shows a top view of the masked photocathode. By rotating and moving the axis of the photocathode behind the mask electrode, the new photo emissive surface can be moved into the hole for generating electrons after the depletion of the active photo emissive material inside the hole. Since the surface area of the photocathode is order of magnitude larger than the area of the hole, this means that an order of magnitude of new photocathode holes can be produced by simply moving the photocathode behind the mask electrode. This significantly shortens the time used for photocathode replacement in the conventional photocathode. To move the photocathode behind the mask, the close contact between the photocathode and the mask electrode is released slightly. This will avoid the damage to the photo emissive surface due to the friction between the photocathode and the mask.

III. DISCUSSION OF POTENTIAL ISSUES

Given the advantages of masked photocathode described above, there could also exist some potential problems with this cathode. First, the accelerating electric field on the photocathode surface will decrease due to the shielding of the hole. To evaluate this problem, we used a simple model of parallel plates with a static DC voltage to study the decrease of the field on the photocathode surface inside the hole. Figure 3 shows a schematic plot of computational geometry of the two-plate structure and contours of electric potential from the Poisson-Superfish calculation [9]. Here, the mask electrode is tapperd with a miminum thickness 0.2 mm near the hole. The radius of the hole is 1.5 mm. The distance between two plates is 1 cm. The applied voltage between two plates is 100 kV. The anode plate also has a hole for electron passage.

Figure 4 shows the on-axis accelerating electric field without and with the mask electrode. Without the mask electrode, the peak of the electric field is on the photocathode surface. With the mask, the accelerating electric field on the photocathode inside the hole is reduced by about 10%

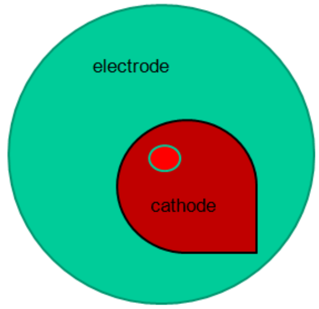

FIG. 2: Top view of the masked photocathode.

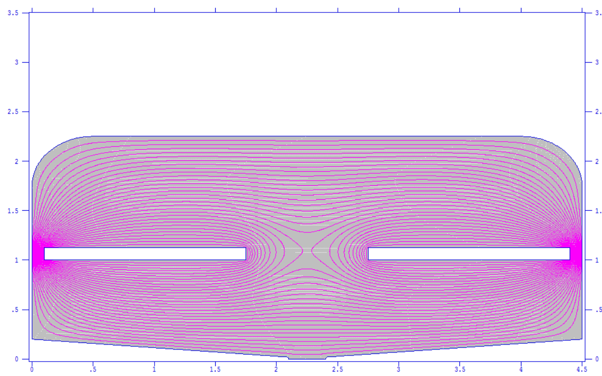

FIG. 3: A schematic plot of masked photocathode together with the anode plate.

in this example. The peak of the field is moved 0.3 cm downstream. It will generate a transverse field helping to focus the beam transversely.

The accelerating electric field on the photocathode depends on the depth of the hole and the radius of the hole. Figure 5 shows the photocathode surface electric field normalized by the no-mask surface field as a function of mask thickness at the hole with a fixed hole radius (1.5 mm) and as a function of the hole radius with a fixed thickness (0.2 mm). It appears that surface accelerating field is quite sensitive to the depth of the hole (i.e. the thickness of the mask). In order to maintain 80% of accelerating field at the photocathode surface, the thickness of the mask has to be controlled below 0.5 mm with a given 1.5 mm radius. This condition might be relaxed with the use of larger hole size. The right plot of the figure shows that the accelerating field increases with larger hole radius since more field will be able to penetrate into the hole.

Putting a masked electrode in front of the photocathode also results in larger electric field on the surface of the mask electrode. Using above numerical example, we found that the maximum electric field on the mask surface is around 10 MV/m that is about 20% higher than the electric field on the photocathode surface without mask. Whether this increased field will cause field emission dark current depends on the material used for mask electrode and the amplitude of electric field. Using a high work function material helps reduce the chance of dark current from the mask electrode surface. Coating the mask surface facing the accelerating vacuum chamber also helps lower the dark current. Recent report using nitrogen-implanted silicon oxynitride film to coat an electrode surface demonstrated order of magnitude improvement in suppressing the field emission [8].

Another potential problem with the masked photocathode is the damage of the photocathode due to the diffusion of the photo emissive material into the mask electrode because of the close contact between the photocathode and the back surface of the mask electrode. Such a problem

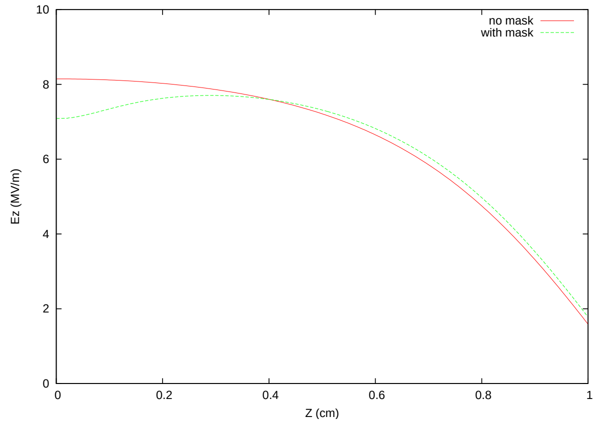

FIG. 4: On-axis electric field with/without mask electrode.

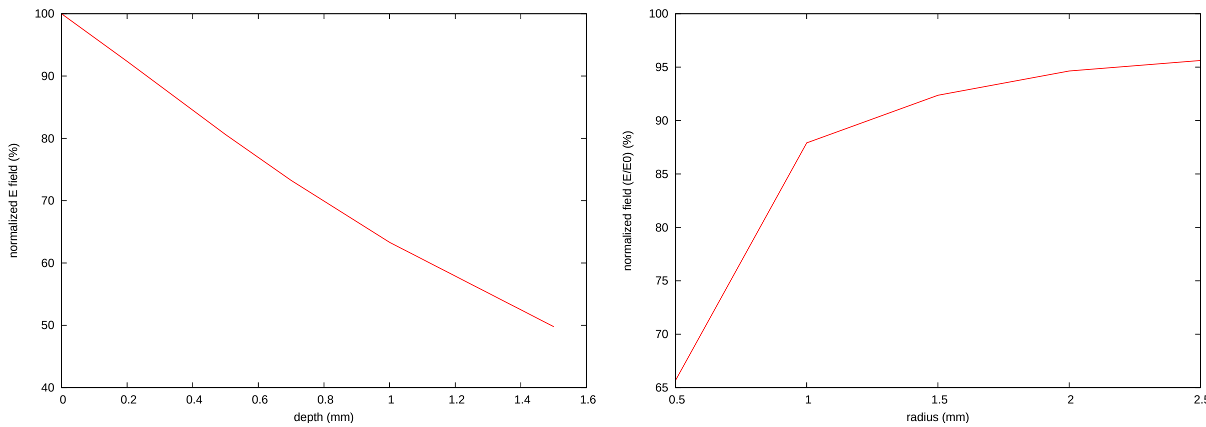

FIG. 5: Electric field on the cathode as a function of mask depth (left) and mask radius (right).

might be overcome by using material (e.g. Mo) to minimize the interaction between the photo emissive materials and the mask metal electrode. Another possible way to solve this problem is to coat the back surface of the mask electrode with the same photo emissive material.

From engineering point of view, to build the masked photocathode might require some extra efforts and cost. This includes building a mask electrode with very thin tip (below 0.5 mm), and building a photocathode supporting electrode with the capability to move the cathode around. However, these extra efforts will be paid back by significantly improving the lifetime of the photocathode usage in order of magnitude. In such a case, the load-lock system used in the conventional photocathode system might not be needed.

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