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Development of an alkali transfer photocathode for large area microchannel plate-based photodetectors

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Abstract

The goal of the Large Area Picosecond Photodetector collaboration is to produce 8-inch by 8-inch microchannel plate-based photodetectors, with fast timing resolution of the order of 1-100 ps and high spatial resolution of 0.1-10 mm. At Argonne, the transfer photocathode process being developed is based on a recipe for manufacturing photomultiplier cathodes. Starting with a commercial PMT fabrication facility, the photocathode recipe and growth system will be scaled up using a custom-built glass vessel to produce transfer photocathodes. This leads to the production of the 8-inch by 8-inch photocathode that will be incorporated with the photodetector assembly system.

Alkali photocathode; transfer photocathode; large area photodetector; visible light photodetector

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1. Introduction

There are several motivations for the need to develop a new generation of large-area, high-gain photodetectors. This includes the need for inexpensive, fast, high resolution photodectectors in medical applications and scientific research, particularly for very large water Cerenkov detectors used in high energy physics [1]. Recent advances in materials science and high speed electronics have opened the doors for the production of such photodetectors. The Large Area Picosecond Photodetector (LAPPD) project [2] is a multi-disciplinary, multi-institution effort whose goal is to produce large (8 inches by 8 inches), flat, fast, photodetectors that can be tiled together to form large area arrays. The microchannel plate (MCP)-based photodetectors are designed to have time resolutions of the order of 1-100 picoseconds and spatial resolutions of the order of 0.1-10 millimeters. A schematic layout of a photodetector tile is shown in Figure 1.

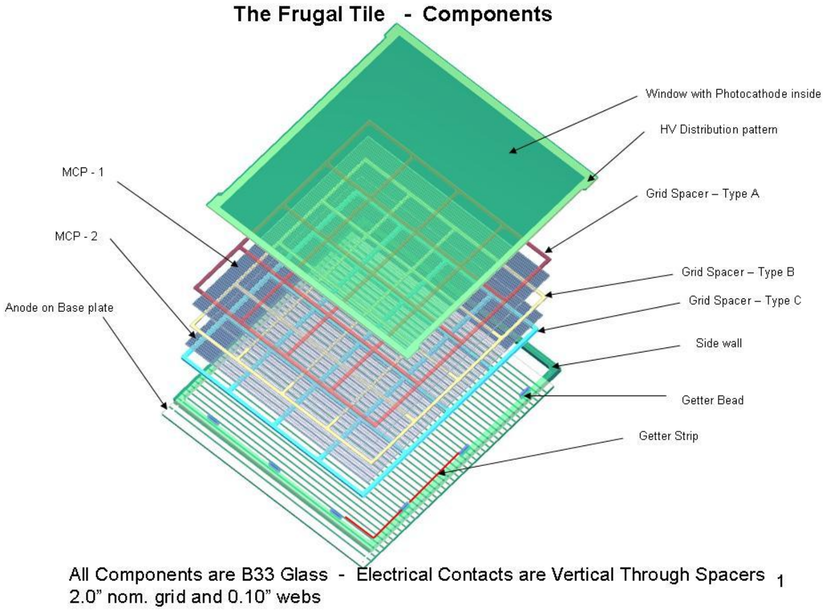

Figure 1. Schematic construction of the LAPPD photodetector tile. The photocathode is on the inner surface of the top window, shown in green at the top of the drawing..

An essential component of the photodetector is the photocathode. In the LAPPD project, the goal is to produce a transfer photocathode [3] with a quantum efficiency (QE) and dark-current comparable to commercial tubes (20-25% QE, dark current ~100-1000 electrons/sec/cm^2), a long lifetime, and a spatial uniformity of better than 5%. A longer-term goal is the further development of photocathodes with QE greater than 50%.

The photocathode development within the LAPPD collaboration consists of two parallel efforts. One of these is being carried out at the Space Science Laboratory, University of California-Berkeley [4]. That work consists of developing a bialkali photocathode using a well-tested transfer technique suitable for making custom photodetectors. The second effort, which is being carried out at Argonne National Laboratory, consists of developing, studying, and optimizing a transfer technique suitable for large scale production starting with the alkali recipes from the commercial PMT production world.

2. The Starting Point: Commercial PMT Photocathode Recipes

The geometry associated with thin, large area flat panel photodetectors requires the use of a transfer photocathode process rather than the in-detector photocathode growth process used in many commercially manufactured PMTs. A typical transfer-cathode process is grown relatively slowly in a large volume tank with high pumping power and correspondingly low partial pressure of the alkali vapor. In contrast, the growth of a PMT photocathode inside the smaller glass enclosure of the tube itself is faster because it allows high partial pressure of alkalis and takes advantage of the larger fraction of the total surface area covered by the photocathode reducing unwanted contamination of the alkali vapor and pumping on non-photocathode surfaces. Additionally, the processing in glass envelopes permits the growth of different oxide-layers used for optimized wavelength response [5].

The starting point for the LAPPD photocathode effort at Argonne is to grow relatively small photocathodes using the well-established recipes of commercial photocathode PMT production and the substantial accumulated knowledge of alkali photocathode growth in glass envelopes [4,6,7]. There is also recent considerable progress in the development of high QE photocathodes with indications of opportunities for further improvement [8,9,10,11]. By starting with recipes which have been successfully used commercially for setting all the parameters involved in growing photocathodes we can immediately engage in a systematic effort to understand both the correlation between these photocathode growth recipes and the chemical and structural properties of the cathodes and the correlation between the microscopic structure of a cathode and its QE, wavelength response, and dark current.

Figure 2. The PMT photocathode growth facility acquired from Photonis, installed at Argonne. Bialkali photocathodes with QE ~24% have been successfully grown at Argonne using this system.

To gain expertise in growing photocathodes, we acquired a PMT photocathode growth unit from Photonis (see Figure 2). Through a series of training exercises, coached by Photonis, we have fabricated Cs-K-Sb photocathodes with 24% QE. An optical characterization system was assembled to enable measurements of QE, transmission, and reflectivity [12]. We show the QE scans using a Hamamatsu PMT in the same figure. There is an excellent agreement between the scan from Hamamatsu and the one done at the optical station. These setups have become the initial building blocks which we are using to understand and optimize the photocathode growth process by systematically screening the growth parameter space with in situ characterization tools to reveal the photocathode chemical composition and crystalline structure. The fast process time and low vacuum requirements associated with the commercial photocathode growth process and equipment result in low production costs which make a systematic study of cathode growth and characterization practical and rewarding.

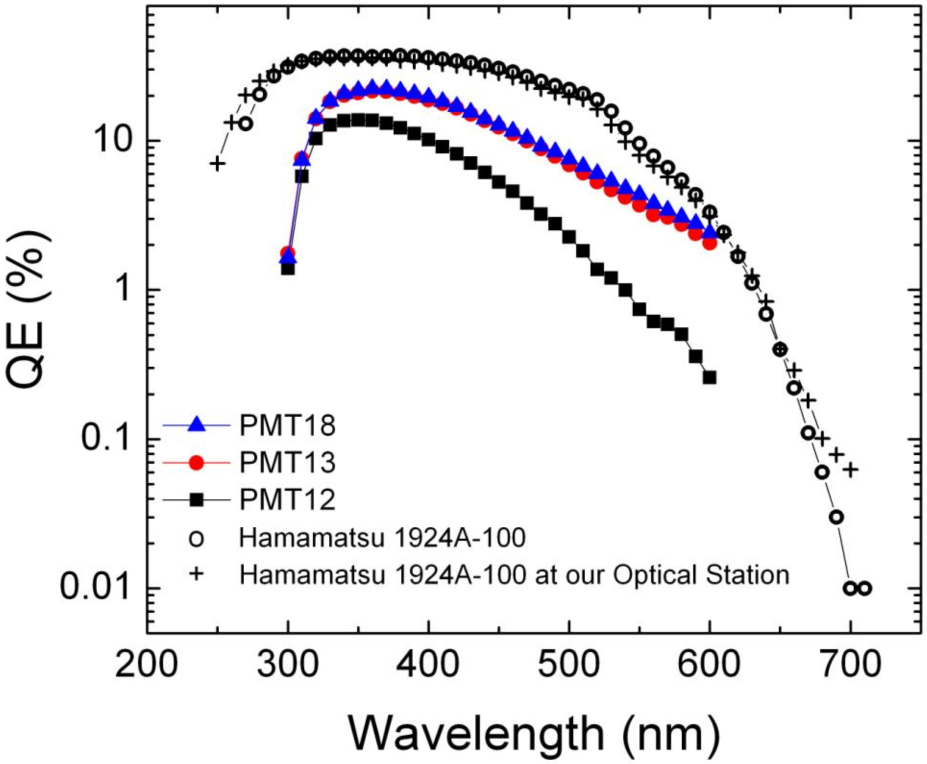

Figure 3. QE scans of three K-Cs-Sb bialkali photocathodes grown at Argonne using the PMT photocathode growth system acquired from Photonis. The QE values were measured using our new Optical Station system. A scan of a Hamamatsu PMT with “Super Bialkali” photocathode is also shown as part of the commissioning procedure of the Optical Station. The open circle shows the Hamamatsu’s QE scan, while the cross shows the scan done at our Optical Station.

3. Transfer Photocathodes: The Glass Chalice

Although much can be learned about photocathode characterization by growing and studying small photocathodes, it is essential to demonstrate that the process which grows optimum, small-area photocathodes in glass envelopes is scalable to large-area transfer photocathodes. To do that, we first modify the commercial PMT-recipe, especially the concept of evaporation inside a glass vessel. We adapted the concept to the production of a large flat photocathode inside a custom-made, medium-sized glass envelope that fits into the same Photonis apparatus mentioned earlier. This glass vessel, dubbed the `chalice', will be installed inside the Photonis oven and interfaced to the vacuum system of the Photonis commercial PMT facility. In situ instrumentation to measure the photocathode performance during and after growth is described elsewhere [13]. This system will enable us to scale up the recipe that was employed in photocathode PMT growth. Most importantly, the system will give us the ability to systematically investigate and characterize the parameters, conditions, and procedures of recipes for photocathode growth in a volume comparable to that of a large-area tube production facility.

The chalice has been designed to grow photocathodes inside a glass enclosure, a process very similar to that carried out in the existing PMT growth unit (see Figure 4). To allow a large number of experiments with a short turn-around time, we designed a glass-body with a replaceable 8 inch top-window, a 4-inch by 4-inch active cathode area, and an evaporator inset which can be easily installed and removed from the chalice. Window and evaporator insets are disposables, and will be replaced for each experiment.

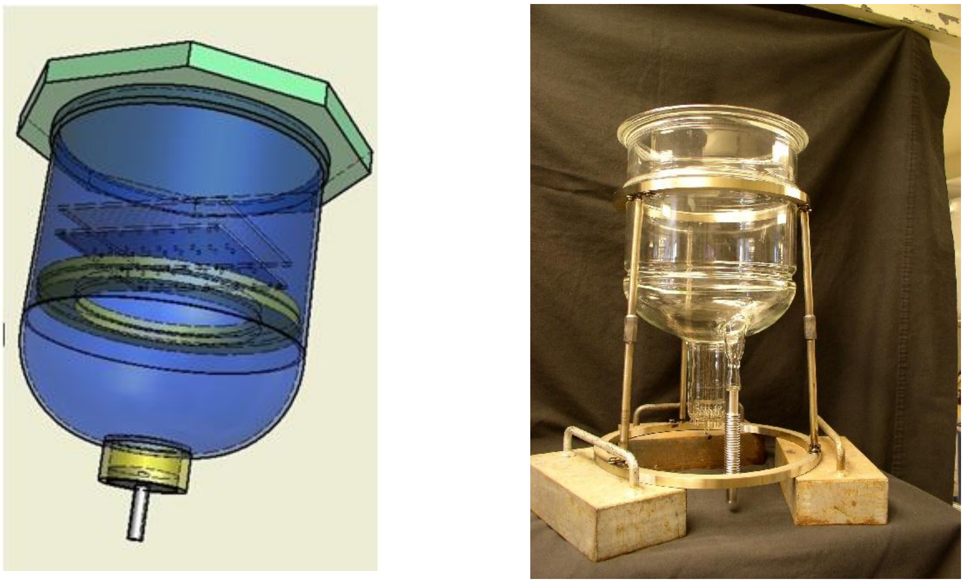

Fig. 4. Schematic and photograph of the glass chalice vacuum vessel, designed to fit in the oven and to interface to the vacuum system of the Photonis PMT facility. The removable 8” window is at the top. A metal plate on the top (outer) side provides an electrical ground; the photocathode is deposited on the inner surface. A plate which supports an array of antimony sources is placed a short distance under the photocathode. Below this is a screen used for oxygen plasma cleaning of the inner surface before and during deposition. A glass plate under the screen supports the alkali metal sources. All electrical leads enter the chalice through a glass seal at the bottom of the chalice [12]. The entire inner assembly is connected to the chalice with a demountable glass 21-pin connector for renewing/modifying the sources.

Similar to the PMT design, we built the evaporator in three levels: the line-of-sight antimony evaporation which is closest to the window, an alkali evaporation level which is furthest from the window, and a perforated counter-electrode, which is above the alkali evaporator and blocks its line of sight to the photocathode and can be used both for applying RF-power for plasma treatments or for extracting photocurrent for performance measurements. The number, geometry, and contact mechanism of the individual evaporator sources can be easily modified.

The antimony evaporation system uses an array of beads melted to thin, electrically-conducting but thermally-insulating wires. The beads contain either pure antimony metal (between 2.3 and 20 mg) or a 1 to 1 ratio of antimony-platinum alloy [14]. All alkali salt sources are mounted in the lower, much larger compartment where they are largely protected from antimony contamination by the counter-electrode.

The vacuum conditions inside the chalice are strongly influenced by the physical placement of the antimony beads close to the window, with the alkali sources placed below. This ensures that the window surface area dominates the total area coated with antimony. This ratio is important as the high sticking coefficient of the alkali vapor during the growth process, and desorption effects during other parts of the fabrication cycle, would make the alkali partial pressure be strongly dependent on temperature and residual gas composition if large areas are coated with antimony. This could result in an unstable system vacuum [15]. In addition, the highly reactive alkali vapor in the lower compartment acts as a trap for the residual gas impurities from the out-gassing alkali sources.

A key component in our photocathode growing approach is to create an optimally homogeneous thickness of the antimony film on the cathode substrate. To do this, we have made numerical calculations of antimony film growth from point-like antimony beads placed on a rectangular grid symmetric with, and parallel to, the flat glass window. The calculation assumes that each bead evaporates identically, that antimony atoms travel in straight lines to the window, and the sticking probability of the antimony atoms to glass does not depend on the incidence angle. Figure 5 shows an optimal configuration for four antimony beads.

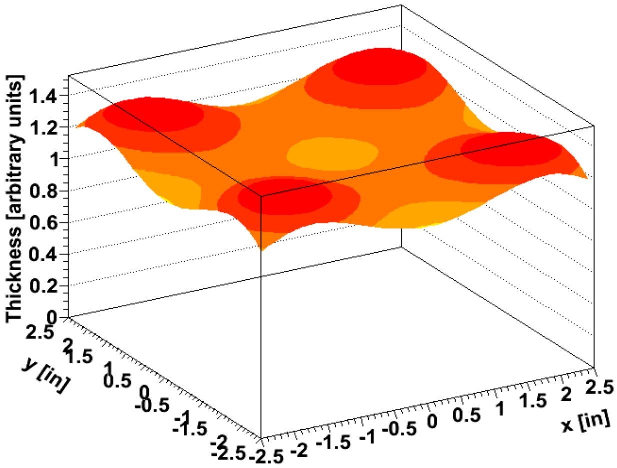

Figure 5. A simulation of the thickness (in arbitrary units) of the antimony film produced from a matrix of antimony beads in close proximity to the glass window surface. The layout of the beads gives a ±5% non-uniformity of the antimony layer [15]. As an example, the calculation was performed for a 5 inch by 5 inch window.

4. Summary

We have described the strategy used at Argonne National Laboratory to develop the infrastructure for producing a transfer cathode growth recipe suitable for a thin, large area photodetector starting from a commercial PMT cathode growth recipe. We have acquired and commissioned an industrial facility and grown bialkali photocathodes with peak QE of 24% for small PMT housings. The use of a commercial PMT fabrication facility allows us to grow conventional PMT cathodes which are used in baseline experiments to study photocathode properties. A glass chalice, simulating the production environment of a large PMT, is used to scale up and optimize the evaporator system in developing growth recipes for larger area, transfer photocathodes.

5. Acknowledgements

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[3] Because of the thin, flat geometry of the large area photodetector, the cathode cannot be grown inside the assembled detector like most PMT photocathodes but has to separately produced, transported to the detector assembly, and sealed to it.

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