PROCEEDINGS OF SCIENCE

Development of a Small Form Factor (6 cm x 6 cm) Picosecond Photodetector as a Path Towards the Commercialization of Large Area Devices

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The Large Area Picosecond Photo-Detector Collaboration (LAPPD) is currently developing a large-area, modular photo-detector system composed of thin, planar, glass-body modules, each with two 20 cm x 20 cm ALD-functionalized MCPs in a chevron geometry. The collaboration is working closely with industrial partner Incom, Inc. towards the commercialization of this technology. In this talk, I will describe the path towards commercialization of the 20 cm x 20 cm devices with Incom, Inc. As an intermediate step towards building a full system for making 20 cm x 20 cm devices, Argonne has also developed a small form-factor (6 cm x 6 cm) photodetector development facility consisting of a four vacuum chamber system: loadlock, bake and scrub chamber, photocathode deposition chamber, and sealing chamber. Successful thermo-compression sealing of the 6 cm x 6 cm photodetector prototypes at the Argonne development facility has been accomplished in the sealing chamber. The entire system has recently undergone a bakeout and is currently achieving an ultra-high vacuum base pressure throughout the system with photocathode fabrication underway. An overview of results from the first working 6 cm x 6 cm active area detectors based on the ALD micro-channel plate, all glass body technology will be presented as available.

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1. Introduction

Photomultiplier tubes (PMTs) have been widely used in the fields of particle physics, astrophysics, nuclear sciences and medical imaging [1-3]. Recent developments in micro-channel plate (MCP) technology [4] have created new opportunities to advance conventional photomultipliers. The large-area picoseconds photodetector (LAPPD) collaboration, a joint effort of Argonne National Laboratory, the University of Chicago, the University of California-Berkeley, the University of Hawaii, and industry partner Incom, Inc., is currently developing large-area, modular photo-detector systems composed of thin, planar, glass-body modules based on newly developed MCP technology [5]. The overall goal of this research project is to develop 20 cm x 20 cm large-area photodetectors capable of mm-scale spatial resolution and pico-second time resolution. This large area picosecond photodetector would have wide applications in various fields, such as large water Cherenkov detectors, nuclear non-proliferation and transportation security, compensating ‘dual-light’ high-granularity pseudo-digital calorimeters, direct dark matter searches with noble gases and positron emission tomography (PET) cameras.

In this paper, we outline a development path for the mass production of large area, pico-second photo-detectors based on micro-channel plate technology at Argonne National Laboratory in collaboration with the Massachusetts firm Incom, Inc. A small photodetector production facility is initially designed and constructed as a low cost, lower risk path towards commercialization of 20 cm x 20 cm large area picosecond photodetectors. Design concept and construction of the small facility will be described, and details of the fabrication of a prototype 6 cm x 6 cm photodetector device using the thermo-compression sealing technique and the results of initial testing will also be presented.

2. The 6 cm x 6 cm small Single Tile Facility

In the course of the LAPPD development work, Argonne concluded that the construction of a system that can produce small sealed photocathode bodies and be the platform for the development of photodetector processes is essential. In addition, a small photodetector production system is consistent with the research role of a national lab. The experience gained from designing and building such a system can then be transferred to industry for large scale production.

To make small factor LAPPD photodetectors, which contain a multi-alkali photocathodes and high efficiency multi-channel plate amplifiers, the processing system has to implement three processes: MCP conditioning, photocathode formation, and the hermetic sealing of the parts in the body. For longevitivy of the detectors, the processes must be carried out in an environment with ultra low pressure and contamination. The reasons for the low internal pressure requirement is (1) to prevent the electrons from being disturbed in their path from the photocathode through the array of micro channel plates and then ending up on the anode readout, and (2) the chemical make-up of the photocathode within the photodetector is extremely sensitive to gaseous contamination. For both of these reasons the detector needs to be assembled in an ultra-high vacuum environment. Using existing vacuum chambers at Argonne, a production system, the small Single Tile Facility (sSTF), was constructed as a low cost system for constructing the 6 cm x 6 cm glass tile photodetectors based on the concept and architecture of LAPPDs.

2.1 Design of a single tile facility

The goal of the LAPPD collaboration is to produce 20 cm x 20 cm photodetectors and transfer the technology to our industry partner Incom, Inc. Initial conceptual designs for building a single tile facility were for a 20 cm x 20 cm system based on a linear lay-out scheme as shown in figure 1. Our approach was to use the procedures employed in the construction of semi-conductor equipment and apply them to the construction of photodetectors. In figure 1, the chambers from left to right are photocathode deposition chamber, hermetic sealing chamber, MCP scrubing chamber and loadlock chamber. The whole system is designed with linear lay out, so that components could be easily transfered between the different chambers during detector fabrication via commercial magnetic tranfer systems.

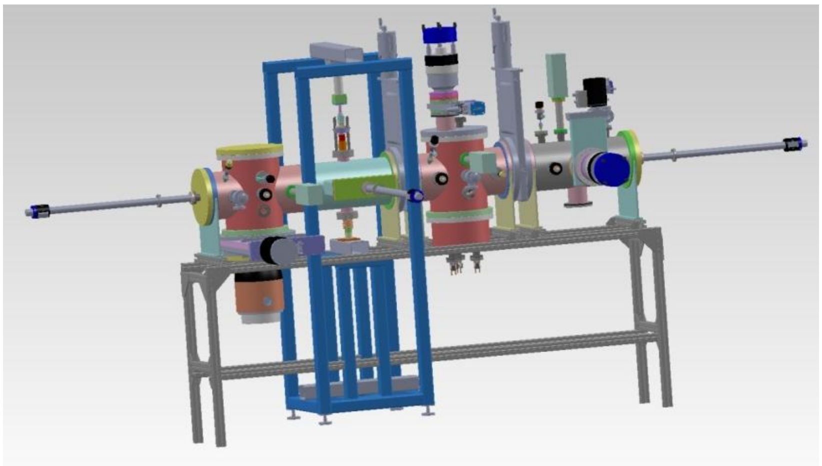

Figure 1. Schematic of 20 cm x 20 cm single tile facility. The facility consists of four major chambers: photocathode deposition chamber, hermetic sealing chamber, MCP scrubing chamber and loadlock chamber from left to right. The system is equipped with magnetic transfer arms to easily transfer components between chambers during detector fabrication.

The single tile facility is designed to fabricate the LAPPD tile through the “transfer process”. In the transfer process, MCPs coated with resistive and secondary emission layer via the atomic layer deposition are scrubbed in the MCP scrubbing chamber to condition the MCPs, and these MCPs are then moved to the sealing chamber, and stacked together with the photodetector housing components. Meanwhile, the photocathode is applied to the under surface of the top window, which is also transferred into position to be sealed to the body of the detector package containing the other component parts. This transfer occurs just prior to the final sealing step, and is done under ultrahigh vacuum (UHV) conditions due to the sensitivity of the photocathode to residual gases. Gate valves are located between each chamber so that the chambers can be used seperately during the photodetector fabrication process.

2.2 Construction of the 6 cm x 6 cm small single tile facility

Our 6cm x 6cm small form factor system shares many of the same design concepts as the 20 cm x 20 cm single tile facility, but was developed as a low cost option with the ability to use pre-exisiting chambers available at Argonne. Much of the process development will be worked out in the small system and these recipes could be ported to the production of 20 cm x 20 cm tiles. The major components used to build the system were based on exsiting chamber systems and off-the-shelf vacuum components to minimize the cost and fabrication lead time.

There are four technologies that are employed in the 6 cm x 6 cm small single tile facility. The first is the in-vacuum sample transport. This technology is employed in industry, it can be purchased in its entirety, and there is a community of users who have used it successfully. The second is the electron conditioning of the MCP's, for which there is a considerable body of research to reference. The 6 cm x 6 cm small single tile facility employed this technology so that studies can be performed for determining suitable operating parameters. The third is the Knudsen Cell evaporation of the photocathode constituents. Knudsen Cells have been in use extensively in the field of Molecular Beam Epitaxial film growth such as for fabricating gallium arsenide semiconductors. Finally there is the technology involved in the sealing of the photocathode top plate onto the body of the photodetector. This has been extensively researched, and 20 cm samples have been successfully sealed and tested here at Argonne where the development has progressed from small sized samples to full sized test pieces. These steps would undergo complete integration in a 20 cm x 20 cm single tile facility.

Figure 2. Picture of the constructed 6 cm x 6 cm small single tile photodetector production facility at Argonne National Laboratory.

Figure 2 shows a picture of the current 6 cm x 6 cm small single tile facility. The entire system is pumped through several turbo molecular pumps and ion pumps. After a thorough baking out at 200°C overnight, the base pressure of the facility reaches a low 10^{-10} Torr level, suitable for the growth of an air-sensitive bialkali photocathode and the fabrication of the photodetector assembly.

3. Fabrication of prototype 6 cm x 6 cm photodetector

3.1 Scrubbing of ALD coated MCP

The major component of making MCP photodetectors is the functionalized microchannel plates. Glass capillary arrays manufactured at Incom, Inc. are first coated on both sides with ~100 nm nichrome layers to serve as electrodes. Next, ALD resistive and emmissive coatings are applied to functionalize the glass. After ALD coating, the MCPs are transferred through the air into the scrubbing chamber of the 6 cm x 6 cm tile production facility.

A standard scrubbing process is necessary to improve the gain and life time of the MCP photodetector [6]. This scrubbing has three effects on the photodetector performance: (1) as the volatiles are removed, the MCP gain is stablized as a function of charge extraction; (2) the scrubbing uniformity affects the MCP gain uniformity; (3) the removal of volatiles during scrubbing process ensures that once the photodetector is sealed, the internal pressure will remain low so that the photocathode remains intact. A uniform MCP scrubbing is critical for the 6 cm x 6 cm photodetector fabrication.

A flat surface metal cathode is used in the scrubbing chamber to perform uniform scrubbing. A high voltage of ~ 2kV is applied to a metal cathode to generate photoelectrons by which the photoelectrons are accelerated to scrub the MCP surface. The scrubbing process removes the adsorbed gas, cracking organics and aging the surfaces. The post-scrubbed MCPs are then transferred to a hermetic sealing chamber, ready for thermo-compression sealing.

3.2 Photocathode growth

The photocathode converts photons into photoelectrons for detection.Two kinds of photocathodes are chosen for the initial 6 cm x 6 cm device fabrication: aluminum and bialkali antimonide. Metal photocathodes, such as aluminum, exhibit very low quantum efficiency but are stable in the air, and consquently they are useful for prototype device testing. Bi-alkali antimonide photocathodes (K_2CsSb) have a high quantum efficiency and have been widely used in commercial photomultiplier tubes. This kind of photocathode exhibits fast reponse time, low dark current, high quantum efficiency, good robustness and low cost, suitable for fast timing and imaging applications. However, the K_2CsSb is extremely sensitive to air exposure. As a proof of concept for future production, effusion cells are used to evaporate the source chemicals. To produce antimony, potassium and cesium vapors, antimony metal pellets, a mixture of potassium chromate and titanium, and a mixture of cesium chromate and titanium are used as source chemicals, respectively. Conventional methods are used to grow the bialkali antimonide photocathode for the 6 cm x 6 cm photodetectors [7].

3.3 Hermetic thermo-compression sealing

For a working photodetector, all the functional components must be hermetically sealed inside the glass housing. Low-temperature indium based hermatic vacuum sealing has been successfully demonstrated in product production which requires vacuum sealing. The lead-free indium solders show strong adherence to most metals and ceramic and glass, and the sealing remains robust for a long time, even at cryo-temperatures. Indium-based solders are also attractive a tile sealant.

In the small form factor facility, the hermetic sealing chamber is equipped with a hydraulic cylinder and accompanying manifold capable of applying loads up to 3000 pounds. For the 6 cm x 6 cm photodetector package, lead-free indium solders with a purity of 99.995% is used as the sealing material. The solder wire is prepared as a rectagular loop fitting on the upper face of the side wall of the package base, so then the scrubbed MCP is moved into the sealing station after which the indium lopp is put into place. It is at this point that the top window, which has the photocathode deposited on it, is set down and the seal is formed by compression.

Performance of the seal is characterized using a helium leak detector with a mounting fixture. For leak testing samples, a pump port is attached to the package side wall connecting to the leak detector via the mounting fixture. By probing a small amount of helium gas along the package, the location of a leak can be determined. 6 cm x 6 cm photodetector frames sealed with indium have been tested and confirmed to be “leak-tight”.

4. Prototype 6 cm x 6 cm photodetector

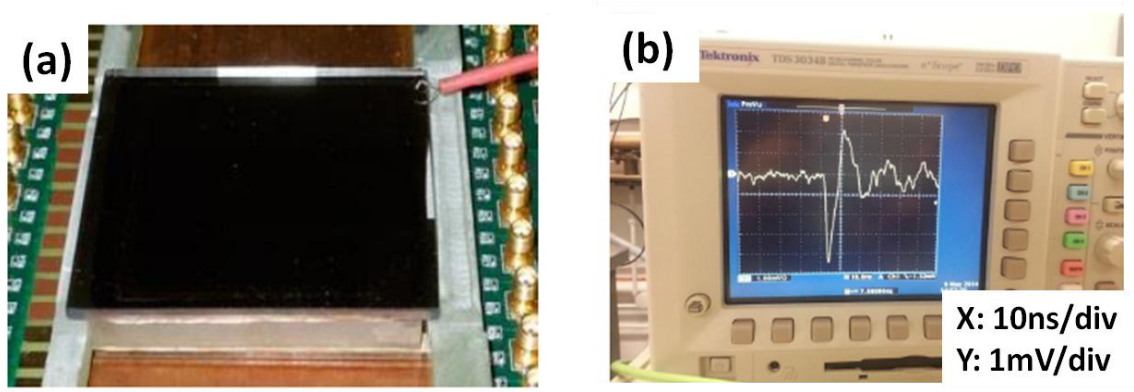

Figure 3 (a) Prototype 6 cm x 6 cm photodetector under testing. The device is connected to electronic readout board through the silver strip lines. (b) Signal generated by the prototype photodetector using 254 nm UV beam.

The first 6 cm x 6 cm photodetector was fabricated after all the processes were commissioned. A glass plate coated with silver readout strips was fritted together with glass sidewalls to serve as base package, and ALD coated functionized MCPs were scrubbed and placed inside the base package together with ALD coated spacers. A glass plate coated with an aluminum photocathode was then sealed on the top of the base package, completing the prototype. Figure 3(a) shows the image of prototype device under testing. With a Penray mercury lamp, giving UV light at 254 nm wavelength, the photocathode was excited to generate photoelectrons. These photoelectrons were then amplified via two functional MCPs with 1200 V bias voltage on each. The amplified electrons were collected by the silver strip lines and readout via oscilloscope. A preliminary signal image captured by the oscilloscope is shown in figure 3(b) indicating the device works as expected [8]. Further analysis of the signal readout data is under investigation.

5.Summary

In summary, we have designed and built a small single tile facility to fabricate 6 cm x 6cm MCP based photodetectors. The system has been commissioned, and further optimization of the processes is currently underway. A prototype photodetector with an aluminum photocathode was hermetically sealed using indium based thermo-compression sealing technique and tested with 254 nm Penray mercury lamp. The signal generated by the UV beam was read-out using an oscilloscope.

Argonne regards the small single tile facility as a low cost path towards the commercialization of 20 cm x 20 cm large area picosecond photodetector devices. The knowledge and experience acquired using this facility is expected to be valuable to the development of future large area photodetector production. In addition, this small production facility should be able to provide the community with small, functional photodetectors for ealy testing on a relatively short time scale.

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