Project name

Micro-machined Vacuum Photodetectors

Classification (accelerator/detector:subsystem)

Detector:subsystem

Institution(s) and personnel

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Project Overview

Introduction:

In conjunction with NanoSciences Corporation, Oxford CT and Burle Industries, Lancaster PA, we propose to develop the next generation of high efficiency lightweight, low noise, high rate, large area multi-pixel photomultiplier tubes. Many new experiments rely, in part, on state-of-the-art light detection technology. In this proposal we present a novel approach to developing both silicon micro-machined MCP/dynodes and a high secondary electron yield diamond based transmission secondary electron (TSE) dynode photomultiplier that could play an important role in producing a detector suitable for use in:

(a) High Magnetic Field Applications, such as in collider detector calorimeters or trackers.

(b) High Rate Photon Counting applications, often in all of the above.

Using proximity focus, the transmission dynode gain mechanism is relatively insensitive to magnetic fields. Additionally, Si-MCP may have channels as small as 1-2 microns, thereby also enhancing high magnetic field performance.

The robust negative electron affinity condition that can be stabilized on diamond film surfaces together with newly discovered methods for highly textured growth of (100) oriented diamond films coupled with a miniaturized silicon micro-machined approach for supporting a transmission dynode stack making possible a low profile light weight imaging photomultiplier with excellent single photoelectron detection.

Coupled with the above, advances in micro-machined silicon or amorphous quartz MCP or dynodes or channelized voltage-standoffs offer a significant performance potential. Micro-channel plates (MCP) have been fabricated from standard silicon wafer substrates using a novel silicon micromachining process, together with standard silicon photolithographic process steps. The resulting Si-MCP micro-channels have dimensions of ~0.5 μm up to ~25 μm, with aspect ratios up to 300, and have the dimensional precision and absence of interstitial defects characteristic of photolithographic processing, compatible with positional matching to silicon electronics readouts. The open channel areal fraction and detection efficiency may exceed 90% on plates up to 300 mm (12”) in diameter. The resulting silicon substrates can be converted entirely to amorphous quartz (qMCP). The strip resistance and secondary emission are developed by controlled depositions of thin films, at temperatures up to 1,200°C, also compatible with high-temperature brazing, and can be essentially hydrogen, water and radionuclide-free. Novel secondary emitters and cesiated photocathodes can be high-temperature deposited or nucleated in the channels or the first strike surface. Summary of Si-MCP features:

- Pore Sizes/Resolution: Between ~0.5 μm - ~25 μm
- Pore Size Uniformity: <±0.5% in x and y.
- Pore Placement/Position Uniformity: <±0.5 μm in x-y over 25 mm plate.
- Absent/Missing/Displaced Pores: None
- Aspect Ratios: may exceed 300:1
- Open Pore Areal Fraction/Detection Efficiency: >95% with tapered channel input.
- Plate Sizes: to 90 mm diameter now, extendable to ~300 mm (12” wafer substrates).
- Chevron: up to 45° tilt demonstrated.
- Bake-out temperatures: <l,200°C Si-MCP, <1,400° Q-MCP
- Plate Resistance/Current: Adjustable from 1 KΩ - 10 MΩ/cm^2.

- Activation Processes: CVD, electroplating. gas, liquid &; phase reactants, (others).
- Gain: >1,000 at 1KV, comparable to lead-glass MCP
- SE Materials: silicon oxides, metal oxides & silicides, diamond, GaP, (others).
- Compatible with direct-front-surface deposited cesiated photocathodes.
- Compatible with high temperature deposition of high SE first strike materials.
- Compatible with high temperature metal/ceramic brazing.
- Low or negligible hydrogen or water content.
- Low or negligible self-radioactivity possible.
- High radiation resistance
- Fully compatible with silicon lithographically patterned readout, silicon processing.
- Fully or partially oxidizable to amorphous quartz.
- Optically opaque channel walls if not fully oxidized.

Background

Forecasts for the near future include a fusion of photomultiplier and imaging technology, which combine the response time of photomultipliers with the high quantum efficiency and multi pixel (imaging) capability of CCD-like devices. It is envisioned that future developments will include the realization of multi-pixel devices capable of fast readout, similar to a photomultiplier, and with photocathodes having high quantum efficiency and broadband spectral response. The realization of such a dynode, based upon diamond, and diamond like carbon layers, will lead to a new class of simple, efficient, low-noise multi-pixel photomultipliers (PMT's) as well as improved imaging devices with lower noise factors, for military, scientific and commercial applications. Our premise is to start with a detection mechanism that has inherent high gain with excellent signal to noise performance and incorporate that mechanism into a micro-machined, monolithic structure that is readily interfaced to high speed digital signal processing and memory circuits using surface mount technology. The advantages of this approach are: (1) high gain can be achieved in a compact structure, (2) superior noise and imaging characteristics, (3) elimination of the many hand assembly steps in conventional PMT manufacturing through parts consolidation, (4) complete compatibility with Si fabrication processes, (5) ability to integrate with high speed read out, digital signal processing (smart pixels) and nonvolatile data storage circuitry, (6) low power consumption when coupled with a compact Cockcroft-Walton or Greinacher-type voltage multipliers for individually powered dynodes avoiding a resistor biasing chain, (7) extremely low transit times due to the small dynode depth and (8) the low angle electron trajectories, resulting in low transit time jitter and fast rise times.

In order to demonstrate the device can be built, several major technical hurdles must be surmounted. First substantial TSE gain from a diamond structure must be demonstrated, second, the noise properties of the TSE in a proximity focused imaging device need to be investigated and third, fabrication of the micro-machined dynode structure, photocathode deposition and transfer and vacuum enclosure needs to be developed. This proposal deals with the first and second hurdles and employs a proximity focused MCP based intensifier as a means of studying the diamond TSE even though a multi diamond TES miniature

PMT is the desired final structure. The MCP based intensifier is a convenient and relevant laboratory for investigating the diamond TSE performance.

The technical objectives of this proposal are (1) to explore the use of highly (100) textured diamond films as high yield TSE dynodes for use in compact high efficiency photomultipliers, (2) to develop and verify the TSE gain, noise and MTF of diamond films in an intensifier arrangement, (3) verify gain rate and lifetime characteristics of Si-MCP.

Proposed Research and Development:

- Growth of textured diamond films
- Measurement of TSE yield
- Diamond TSE-Si-MCP tube fabrication
- Tube Tests
- Final Report

Growth of textured diamond films

This task develops the deposition of highly (100) textured diamond films on Si using an Astex plasma diamond growth reactor. Films will be grown on (100) Si substrates which will be subsequently processed to open up windows on the Si revealing the diamond film. The window structures will be prepared using lithography and silicon anisotropic etching. During the final stages of diamond film growth boron will be introduced into the diamond reactor to make the final diamond surface conducting. This surface will be on the input side for the electron beam. The B doped surface will have a positive affinity while the diamond surface revealed by removal of the Si will be processed to an NEA condition before the TSE yield measurement. This task is given 4 months to complete from mask ordering to part production.

Measurement of TSE yield

This phase involves many measurements of the transmission secondary electron yield of the thin film dynodes fabricated above. The TSE yield will be measured using a secondary electron measurement that Fairfield and NanoSciences has constructed for measuring reflection secondary electron yields. The TSE yield measurement will be carried out as a function of incident electron energy with and without a bias voltage applied across the diamond film. The electron affinity of the diamond surface will be measured using UPS, ultraviolet photoelectron spectroscopy in a VG Microlab 310 surface analysis machine. The TSE yield will be correlated to the degree of preferred orientation in the film to try and verify our assertion that highly textured films will show higher TSE yield.

Tube Construction

The Diamond TSE dynode structures measured above will be sent to Burle when they will be fabricated into intensifier tubes, using a Si-MCP so that sufficient gain for measurements can be obtained. Fairfield will obtain Si-MCP from NanoScience with rims and electrodes matched to the requirements from the diamond TSE dynode provided to Burle. The intensifiers will be similar to that shown in partial cross-section in Figure 4, using proximity focusing between photocathode and the diamond TSE and between the diamond TSE and the MCP input face. The photocathode will be a standard type either bi-alkali or better in the visible, depending on immediate availability.

Tube Tests

The tubes will be shipped to Iowa for TSE gain, Si-MCP gain, linearity, rate, and spatial resolution tests. Tests in magnetic fields up to 2T will be performed. A very important test will be lifetime tests of both the Si-MCP and the diamond TSE dynodes. These tests will last at least 2 months.

Task 4: Final Report

A final report will be prepared summarizing the results and proposing follow-on R&D.

Budget-FY03-04

Institution	Item	Cost
Iowa	Diamond TSE (from NanoSciences)	$70,000
Iowa	Si-MCP (from NanoSciences)	$10,000
Fairfield	Diamond TSE/Si-MCP imaging PMT (from Burle Industries	$25,000
Fairfield	Operations (travel, M&S, tech labor, overhead)	$8,000
Iowa	Operations (travel, M&S, tech labor, overhead)	$12,000
Iowa	Iowa total	$92,000
Fairfiled	Fairfield total	$33,000
	Grand total	$125,000

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