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A COMPACT VLPC PHOTON TRANSDUCER SYSTEM*

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A COMPACT VLPC PHOTON TRANSDUCER SYSTEM

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We have developed a compact Visible Light Photon Counter (VLPC) system. A VLPC is a solid state photomultiplier able to transduce single photons from scintillating fibers with quantum efficiency of 60-70%, gain greater than 10^4 and rates greater than 10^7 photons/sec without decreased operating efficiency. The complete system is capable of operating 16 cryogenic modules each containing 256 VLPC channels for a total of 2048 channels. The system uses about one liter liquid helium per hour and is capable of operating in various orientations.

1 Introduction

The original motivation for designing a compact Visible Light Photon Counting (VLPC) system was to take advantage of physics opportunities at the Superconducting Super Collider (SSC) in Texas. However, even though the building of this machine was canceled, the design constraints that it imposed were quite general and we have gone on to complete a prototype compact VLPC transducer system. Our goal was to develop a high rate tracking system appropriate for charged particle tracking based on multimode scintillating fiber technology [1]. Such technology makes affordable the prospect of tracking charged particles with high spatial and temporal resolution, low occupancy and good efficiency. Clearly this technology is very general and for example would perform well as a medical imaging transducer or as an astrophysics x-ray transducer using light amplification techniques in xenon [2].

The original design goals for this transducer system were as follows:

- Capable of detecting single photons over a broad wavelength range from about 300 nm to 1000nm.
- Have high quantum efficiency in the range of 60%-70%.
- Have gain greater than 10^4 and be capable of rates of 10^7 photons/sec without decreased operating efficiency.
- Insensitive to high magnetic fields.
- Capable of operating in various orientations with respect to gravity in order to fit into complex spaces.

- Capable of operating with multi-mode fibers up to 1mm in diameter.
- Compact as possible and low cost so that a large number of channels can be deployed.

Because space becomes more and more valuable as one gets closer and closer to the interaction region, the over all system must be as compact as possible. Our cryostat is only 13 cm in radius and 46 cm in height and is capable of operating 2048 VLPC channels.

2 VLPC

A VLPC is a solid state photomultiplier invented and produced by Rockwell International[3,4]. A VLPC is multiple layers of epitaxially-grown single crystal silicon. Fabrication begins on a single-crystal substrate wafer highly doped with antimony, which functions electrically as a (common) cathode. The structure has both As-doped and undoped epitaxial layers and in the doped layers the As dopant density is sufficiently high for the formation of impurity bands. Individual VLPCs are delineated using relatively standard silicon microlithographic techniques. Ion implants form the optically-transparent anode contact. A thin transparent dielectric coating over the pixel area serves as an antireflection coating.

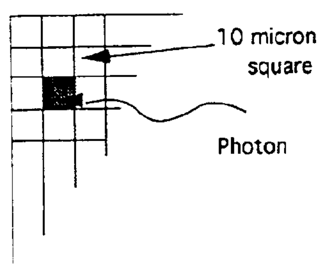

Figure 1: A VLPC pixel divided into avalanche regions

The pulse created by the conversion of a photon into an electron-hole pair is composed of two components[5]. One associated with the electrons and one with the positive holes. The electrons sweep out very rapidly, in less than 1 nanosecond and are too fast to measure with available preamplifiers. The positive charged holes move very slowly and remain for up to a millisecond. The holes left behind after the avalanche reduce the effective field, inhibiting subsequent avalanches. Fortunately the size of the inefficient region is only about 10μm.

A simple model used to calculate the response of VLPCs in a specific appication to a given photon flux is to divide the pixel into 10μm by 10μm cells, as illustrated in Figure 1. Then allow each cell a 60% quantum efficiency and a gain of 10,000. If the pixel cell is hit by a photon consider it unresponsive for 1 millisecond.

While the measurements necessary to verify this crude model are still underway some work has been completed. Figure 2 shows the linearity of the VLPC output as a function of the number of photo-electrons produced [6]. The experimental results are consistent with this model.

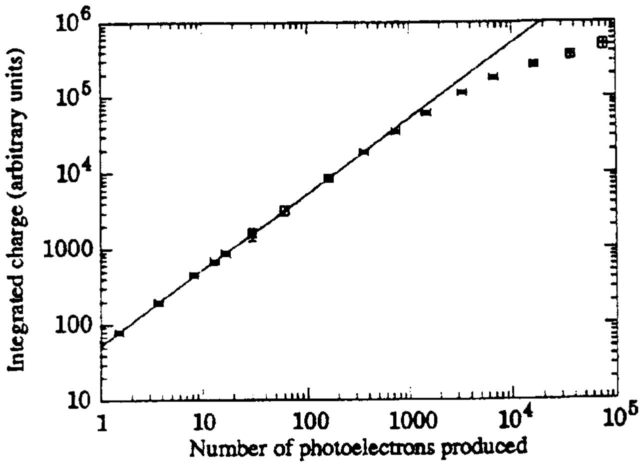

Figure 2: The gain linearity of a 1mm diameter VLPC as a function of the number of produced photo-electrons produced. The curve is consistent with the simple model.

Another important parameter in the characterization of the VLPCs to a specific application is the dark count rate. With each new generation(HISTE) of VLPC devices the dark count rate has improved. The dark counts are dominated by single electrons that are promoted to the conduction band and become amplified. Hence a threshold cut can remove a large portion of this count rate if the source signal expectation is significantly greater than 1 photon. The dark current is a function of the operating temperature as is the quantum efficiency. The present optimal operating condition is 65% quantum efficiency and approximately 5kHz dark count rate [7]. This relationship is shown in Figure 3.

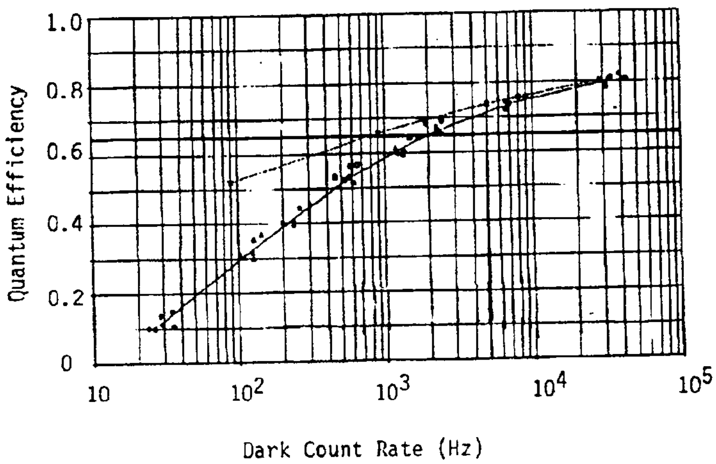

Figure 3: The dark count rate versus quantum efficiency.

The VLPCs we are using are designated HISTE V by Rockwell International. These devices are shown in Figure 4, fully mounted and ready for operation in a cryogenic module. Each VLPC is 1mm in diameter and is connected to a polystyrene multiclad, multimode wave guide fiber. Each pixel is contained on an 8 channel array.

The VLPC mounting system is simple. The eight channel VLPC array is precision mounted onto the silicon substrate using a set of jigs and held in place with epoxy. The electrical traces on the silicon substrate and VLPC are connected using conductive epoxy. A precision molded torlon fiber holder is then epoxied only along one edge to the silicon substrate. It is positioned using precision jigs. The multimode waveguide fibers are cut and polished and then epoxied into place in the torlon fiber holder. The fibers are positioned against the VLPC while warm but at liquid helium temperature they draw away from the VLPC surface. The parts used in our mounting scheme are shown in Figure 5. Every effort has been made to minimize the thermal stress in the design and construction of VLPC module.

This system when operating with scintillating fibers should be capable of a spatial resolution of $< 100\mu m$. The temporal resolution of the VLPC is inherently better than one nanosecond, however this is not realized because of the line capacitance necessary to take the signal out of the cryostat. More realistic temporal resolution may well be limited to about 4-5 nanoseconds due to line capacitance.

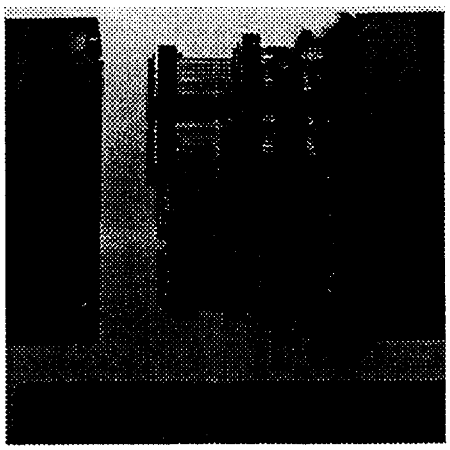

Figure 4: VLPCs fully mounted and ready for cryogenic operation.

3 Liquid Helium Cryostat

The cryostat is a forced-flow liquid helium cryostat able to maintain the VLPC modules at ±0.2K in the temperature region 6.0K to 7.0K even when orientated up to 70° off of vertical [8]. The cryostat design is show in Figure 6. Liquid helium is used to cool the cassette through a heat station located just above the VLPC photo-detectors. The first heat station is kept at ~5.5K. The VLPC detectors are in thermal contact with a copper bus that is slightly heated to bring the detector temperature to ~6.5K. The cold helium gas is then used to intercept the heat at two additional heat stations at about 30K and 90K. The Helium is then exhausted out of the system to be recovered and recycled or sent back to the helium refrigerator.

The temperature of the copper heat stations in the cryostat is controlled by adjusting the flow rate of the liquid helium. The flow is controlled at the entrance to the cryostat, where the helium is a single-phase, sub-cooled liquid. This makes the flow rate constant and the temperature of the heat stations very stable. Since the cassette housing, just above the detectors, is cooled to below the operating temperature, a small amount of heat is added to the cold-plate to achieve the desired temperature. All the cassettes are inserted into a common heat sink which allows the use of only one heater and temperature

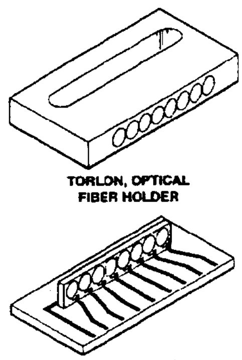

Figure 5: VLPC mounting system.

sensor to control the entire system. This greatly simplifies the temperature control scheme and improves system reliability.

The helium used to cool the heat stations is contained inside conduits and does not mix with the static helium in the cryostat that serves as an exchange gas, thus there is no contamination of the recirculating helium supply due to outgassing from the VLPC modules. Non-vertical operation requires only that the void regions in the cryostat be filled with an insulating material to prevent convection currents.

The compact nature of this transducer system capable of operating 2048 channels is shown in Figure 7. Tests have shown that the cryostat operates stably as a function of time, well within its design parameters. With 16 dummy modules in place the cryostat used 1 liter of liquid helium/hour and easily maintained the temperature to within ± 0.1K.

We plan further tests of this system and intend to assess its applicability to relevant applications.

Acknowledgments

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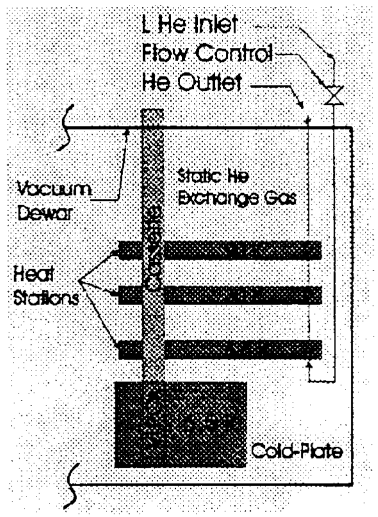

Figure 6: The compact VLPC transducer cryostat design.

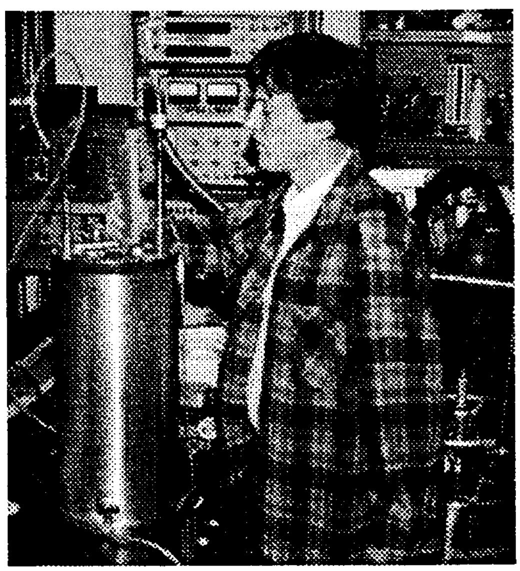

Figure 7: The VLPC module being inserted in the compact cryostat system.

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