VISIBLE LIGHT PHOTON COUNTERS FOR DETECTING VERY LOW LEVEL LIGHT

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ABSTRACT

Visible Light Photon Counters (VLPCs), which were produced by Rockwell International Science Center for UCLA, can detect visible light down to the single photon level with a quantum efficiency approaching 80%. They were produced for the SSC Laboratory for a proposed scintillating fiber tracking detector [1]. The VLPCs were tested and characterized at Rockwell and UCLA. They have better than 3 ns time resolution, and demonstrate count rate capabilities on the order of 3×10^7 $mm^{-2}s^{-1}$. Some test results, characteristics of the VLPCs, and applications will be discussed.

INTRODUCTION

There has been a great need for a high quantum efficiency, fast photodetector for the wavelength range between 450 and 600 nm. To develop such a photodetector, UCLA made a contract with Rockwell International Science Center. The contract was supported by the Department of Energy and the Superconducting Supercollider Laboratory. The photon detector needed to have high quantum efficiency for the visible wavelengths and low quantum efficiency for the infrared region. The detector was called the Visible Light Photon Counter (VLPC) with a subtitle of High Intensity Scintillating Fiber Tracking Experiment (HISTE). Three attempts were made to achieve this goal on this contract: HISTE I, HISTE II, HISTE III. In this paper we will talk about results obtained from those VLPCs used as photodetectors for scintillating fibers. The goal is to produce a very high rate, central tracking system capable of handling luminosities up to 10^{34} $cm^{-2}s^{-1}$. The Superconducting Supercollider (SSC) in the U.S.A. and the Large Hadron Collider (LHC) at CERN may need such scintillating fiber trackers. At present, the DØ group at Fermilab is working on a scintillating fiber central tracking system for an upgrade to higher luminosity runs. There are two other experiments at Fermilab, CDF and E835, also considering the use of scintillating fiber tracking systems.

At UCLA we have demonstrated that the VLPCs, as photodetectors for scintillating crystals, could be used in excellent medical imaging systems. We will briefly discuss this application. The VLPCs can be used for biological and pharmaceutical research as well.

OPERATIONAL PRINCIPLE OF THE VLPC

The VLPCs are Impurity Band Conduction (IBC) devices with low quantum efficiency in the infrared region while they are maximized in quantum efficiency for the wavelengths around 550 nm relative to the original solid state photomultiplier invented by Rockwell International Science Center [2]. Here we will briefly describe the operation principles of the VLPCs since it was well described in an earlier publication [3].

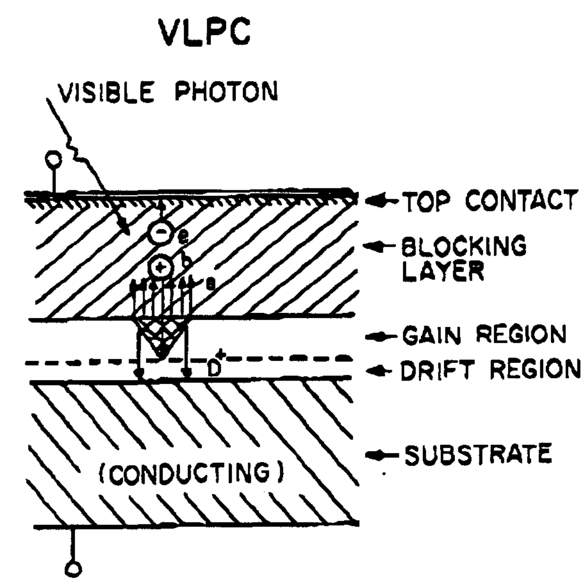

Figure 1: Schematic of the operational principles of the VLPC.

In a VLPC a neutral donor is a substitutional ion with an electron bound to it in a hydrogen-like orbit with an ionization potential of about 0.05 eV. When the concentration of impurities is sufficiently high they form an energy band separated from the conduction band by the ionization potential. When the applied electric field is sufficiently high, about 10^3-10^4 V/cm, each initial electron starts an avalanche of free electrons within 10^{-9} s. The avalanche size may reach up to 5×10^4 depending on the applied potential which is on the order of 6 to 7 volts. Figure 1 shows a schematic view of the VLPC operation. When a photon is absorbed in the blocking layer or the gain region it will produce about the same size of avalanche due to local space charge saturation. The avalanche occupies about a 10 μm^2 area for about 1

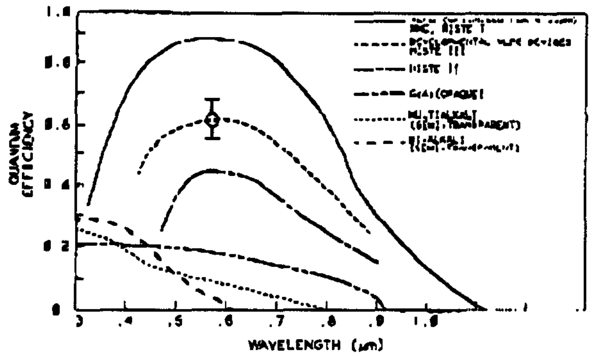

Figure 2: Quantum efficiencies of the VLPC as they were developed. For comparison, it also shows the quantum efficiencies of vacuum photomultipliers.

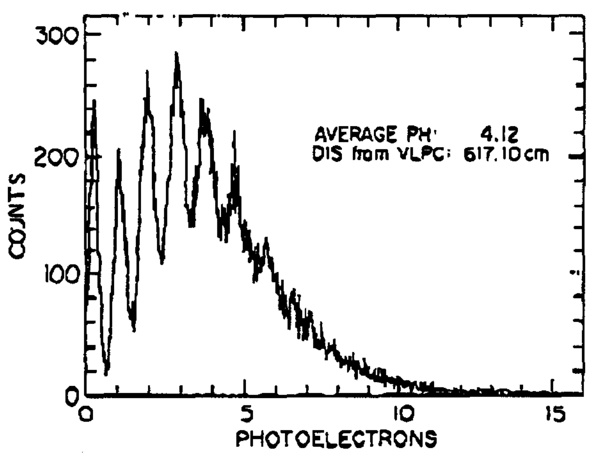

Figure 3: An impressive spectrum show the photon counting capability of a VLPC. Up to the 8th simultaneous photoelectron, the multiple photoelectron peaks are discernible.

μs. During this time the rest of the VLPC area is still available for more photons to be detected. The dynamic range of the VLPC was measured to be linear up to 3000 photoelectrons detectable simultaneously [1]. Due to the impurity bandgap energy being is so small, that is, at or below the rotational and vibrational energy levels of the impurity atoms (i.e., phonon excitation levels), the VLPCs need to be cooled to temperatures around 7°K. Together with Dr. Michael Petroff (Rockwell International Science Center) we have developed a very simple cryogenic system that can achieve and easily maintain the required low temperature. The full enthalpy of the cold gas is used, with the cryogenic units minimizing the liquid helium usage.

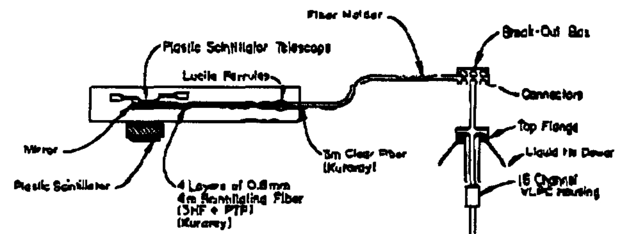

Figure 4: Experimental arrangement for the cosmic ray tests.

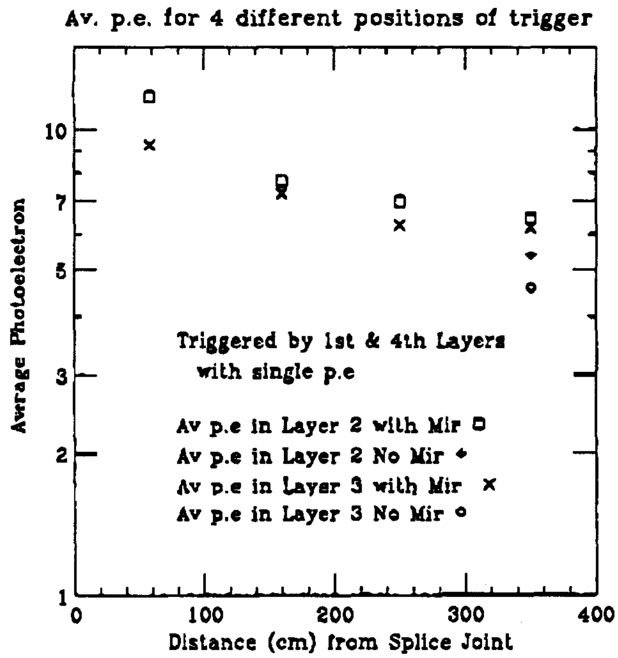

Figure 5: Photoelectron yield from 0.785 mm core of PTP/3HF scintillator as a function of the cosmic ray track position.

SOME EXPERIMENTAL RESULTS

The history of the VLPC development is shown in Figure 2. It shows the quantum efficiency as a function of the wavelength for each device developed. HMC devices were used for most of the test results that will be described, as the HMC devices were the best solid state photomultiplier-like devices. Figure 3 shows the photon counting capability of a device. We can clearly count the 8th peak indicating that there were 8 photons detected simultaneously for the pulses under the peak. The gain dispersion for a single photoelectron was less than 30%. For the spectrum a ^{60}Co source was held at the end of a 4 meter scintillating fiber that is coupled to 3 meters of clear optical fiber transmitting the photons to the device. The HMC was 875 μm by 875 μm in size and the scintillating fiber consisted of a single PMMA cladding on a 785 μm (polystyrene) core doped with the fluors PTP and 3HF. This spectrum was used for calibrating the

FASTBUS ADC. Figure 4 shows the arrangement for detecting cosmic rays. The number of photoelectrons detected with this experiment as a function of scintillating fiber length is shown in Figure 5 [5]. The plot shows that an average of 5 photoelectrons are detectable from the end of 7 meters of fiber. Some of the typical cosmic ray tracks are shown in Figure 6.

Some recent results obtained from double clad Kuraray fibers show that about a factor of 1.7 more photons are attainable [6]. These fibers have a fluorinated acrylic outer cladding (in addition to the standard PMMA cladding layer) resulting in a larger numerical aperture, thus capturing more than 5% of the photons from the scintillating fiber in each direction. Figure 7 shows the improvement factor when double clad fibers are used.

OTHER APPLICATIONS

We believe that VLPCs are going to be used for medical imaging, biophysics and astroparticle physics. Tests at UCLA showed very encouraging results with small scintillating crystals readout by VLPCs.

CONCLUSIONS

A system consisting of several hundred individual VLPCs has been successfully demonstrated. We are convinced that the VLPCs are excellent photodetectors for detecting photons very efficiently down to the single photon level. We hope that they will be used extensively for the applications mentioned above.

REFERENCES

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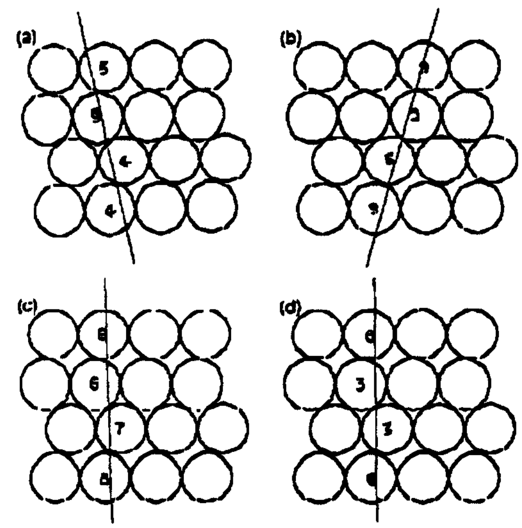

Figure 6: Typical charged particle tracks. The number of photoelectrons detected from each fiber is indicated. The tracks are very clean. For the events, a 0.5 photoelectron threshold was set. There was no detectable crosstalk between the fibers.

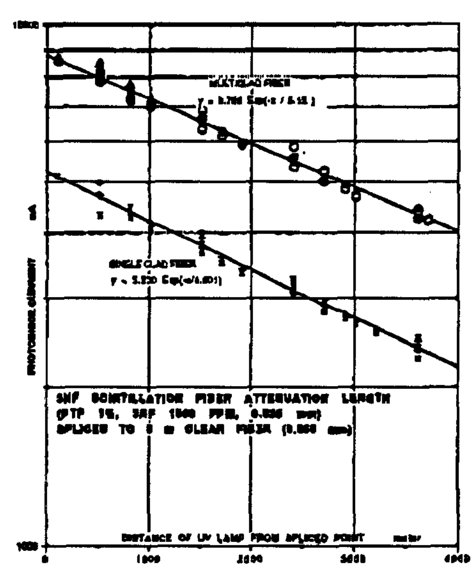

Figure 7: Relative photon yield from the multiclad and standard PTP/3HF fibers of Kuraray Co. as a function of the position of where the photons were produced.