VISIBLE LIGHT PHOTON COUNTERS FOR DETECTING VERY LOW LEVEL LIGHT(*)

M. Atac(1), J. Park, D. Cline and D. Chrisman
UCLA, Los Angeles, CA 90024, USA

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

INTRODUCTION

There has been very much need for high quantum efficiency fast photodetectors for the wavelengths between 450 to 600 nanometer. For developing such a photodetector UCLA has 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 HISTE (High Intensity Scintillating fiber Tracking Experiment). Three attempts were made to achieve the above goal: HISTE I, HISTE II, HISTE III using the contract. In this paper we will talk about results obtained from these VLPCs using scintillating fibers toward producing very high rate tracking system. Such a system would make good central tracking that could run luminosities up to 10^{34} cm^{-2} sec^{-1}. The Superconducting Supercollider(SSC) in the U.S. and the Large Hadron Collider (LHC) at CERN may need scintillating fiber trackers for central tracking. Presently D0 group at Fermilab is working on a scintillating fiber central tracking system for an upgrade for higher luminosity runs. There are two other experiments, CDF and E835, considering using scintillating fiber tracking systems. At UCLA we have demonstrated that the VLPCs with scintillating crystals could make an excellent medical imaging systems. We will briefly discuss this application. The VLPCs can be used for biological and pharmaceutical research as well.

* This work was supported by the US DOE under Contract No.DE-AT03-883440384 with UCLA.(1)Also works at Fermilab,MS No.205, P.O.Box 500, Batavia, IL 60510, USA.

OPERATION PRINCIPLE OF 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 originally invented solid state photomultiplier by Rockwell International Science Center (Ref. 2). Here we will briefly describe the operation principles of the VLPCs since it was well described in an earlier publication (Ref. 3). 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 a nanosecond. The avalanche size may reach up to 5×10^4 depended on the applied potential which is in the order of 6 to 7 volts. The Fig.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 10 micron area for about 1 microsecond. During this time rest of the VLPC area is available for more photons to be detected. The dynamic range of the VLPC was measure to be linear up to 3000 photoelectrons detectable simultaneously (Ref. 4). Due to impurity bandgap energy being is so small, around or below rotational and vibration energy levels of the impurity atoms

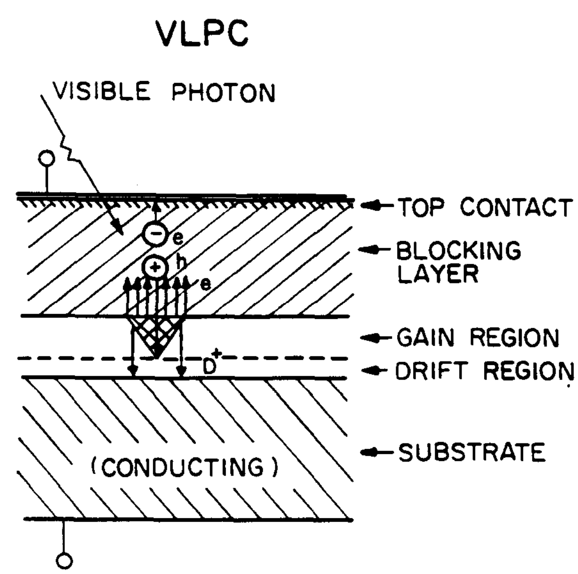

Fig.1. Operation principles of the VLPC with schematic structure.

(phonon excitation levels) the VLPCs need to be cooled at temperatures around 7 Kelvin. Together with Dr. Michael Petroff (Rockwell International Science Center) we have developed very simple cryogenics that achieving the low temperature and keeping this low temperature has been very easy. The full enthalpy of the cold gas is used with the cryogenic units minimizing the liquid helium usage.

SOME EXPERIMENTAL RESULTS

History of the VLPC development is shown in Fig.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 given in the followings. The HMC devices were the best solid state photomultiplier-like devices, thus they were used for the tests. Fig.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 Co 60 source was held at the end of a 4 meter scintillating fiber that is coupled to a 3 meters of optical fiber transmitting the photons to the device. The HMC was 875 micron by 875 micron size and the scintillating fiber was single clad (PMMA) on 785 micron core of 3HF. This spectrum was used for calibrating the FASTBUS ADC. The Fig.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 Fig.5 (Ref. 5). The figure shows that an average of 5 photoelectrons are detectable form the end of 7 meters of fiber. Some of the typical Cosmic-Ray tracks are shown in Fig.6. Some recent results obtained from double clad Kuraray fibers show that about a factor of 1.7 more photons are obtainable (Ref. 6).These fibers have fluorinated polymer second clad producing larger numerical aperture, capturing more than 5% of the photons from the scintillating fiber in each direction. Fig.7 shows the improvement factor when double clad fibers are used.

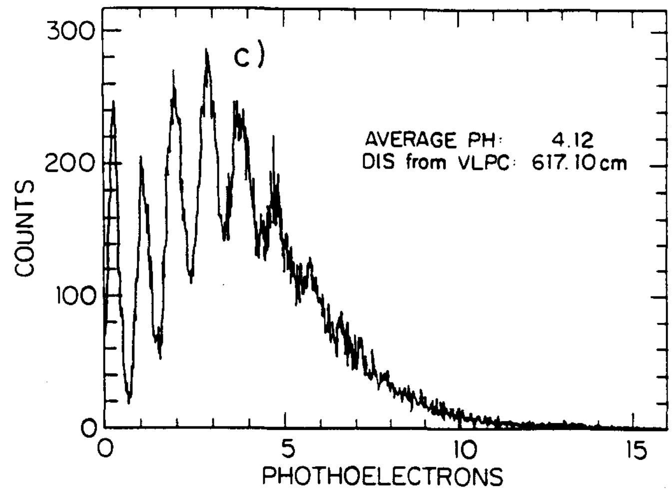

Fig.3. An impressive spectrum shows the photon counting capability of a VLPC. Up to 8 simultaneous photoelectrons the multiple photoelectron peaks are well resolved.

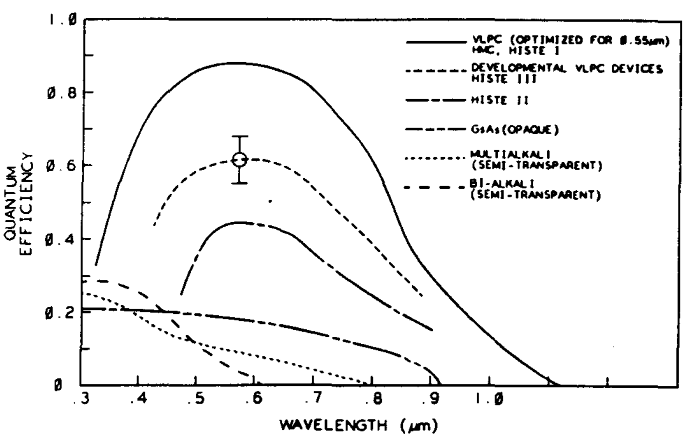

Fig.2. Quantum efficiencies of the VLPC as they were developed. It also shows quantum efficiencies of the vacuum photomultipliers in comparison.

OTHER APPLICATIONS

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

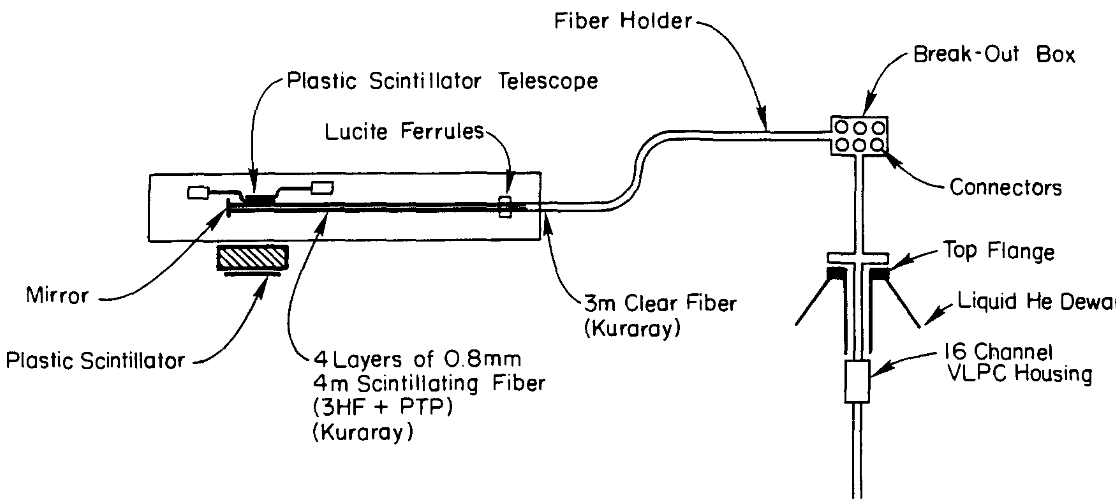

Fig. 4. Experimental arrangement for the Cosmic-Ray tests.

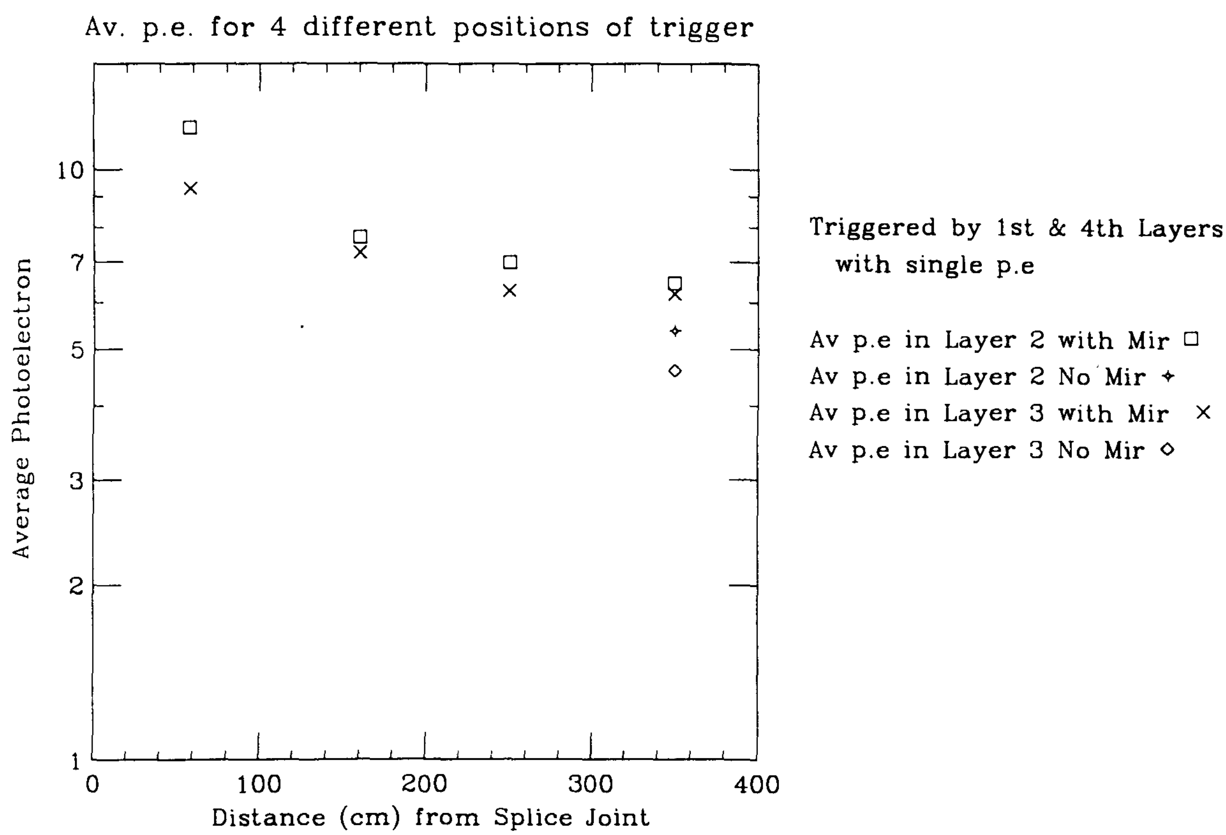

Fig.5. Photoelectron yield from 0.785mm core of 3HF scintillator as a function of Cosmic-Ray track position.

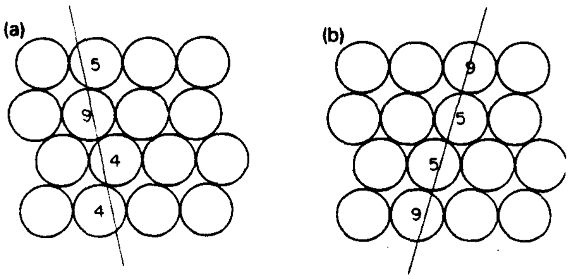

Fig. 6. Typical charged particle tracks. The number of photelectrons detected from each fiber is indicated. The tracks are very clean. For the events, a 0.5 photoelektron threshold was used. There was no detectable cross-talk between the fibers.

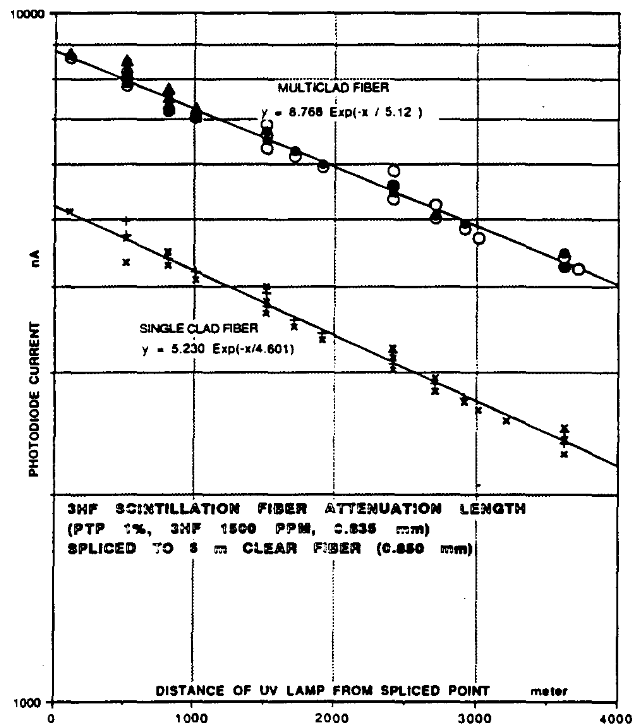

Fig.7. Relative photon yield from the multiclad and standard 3HF fibers of Kuraray Co. as a function of the position of the photons where they were produced.

CONCLUSIONS

Several hundred system operation of VLPCs have been successfully demonstrated. We are convinced that the VLPCs are excellent photodetectors for detecting photons very efficiently down to a single photon level. We hope that they will be used largely for the applications mentioned above.

REFERENCES

[1] B.Abbot et al., Symposium on Detector R&D for the SSC (1990) 90 .

[2] M.D. Petroff and M. Atac, IEEE Trans.Nucl. Sci. **NS-36** (1989) 163.

[3] M. Atac, J. Park, D. Cline, D. Chrisman, M. D. Petroff and E. Anderson, Nucl. Instr. and Meth. in Phys. Res. **A314** (1992) 56.

[4] M.D. Petroff, private communication.

[5] M. Atac, et al, Nucl. Instr. and Meth. in Phys. Res. A **320** (1992)155.

[6] M. Atac, A. Bross, C. L. Kim, D. Koltick, M. Mishina, R. Ruchti, unpublished report.