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The ForFire photodetector

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ABSTRACT

The objective of the ForFire project is the development of an outdoor fire detection system by using an innovative solar blind camera based on the technology of photosensitive gas and solid-state detectors. The development of this new sensor together with an appropriate algorithm for pattern recognition aims to provide a high capability and a high reliability flame-detection system with cost effectiveness, early detection and accurate localization of fire hazards. This is achieved by focusing specifically on the detection of the VUV part ($180\ \text{nm} \leq \lambda \leq 260\ \text{nm}$) of the electromagnetic spectrum emitted by the fire source. The advantage of this approach is that on Earth only fire flames emit in this spectral range thus avoiding potential interferences with other wavelength sources where the Sun is a dominant background.

1. The UV detection with micromegas

1.1. Principle

The choice of Micromegas [1] photodetector scheme is motivated by earlier promising results obtained with a UV sensitive CsI photocathode [2] and also the ability to fabricate low cost detectors using industrial processes. The excellent spatial resolution is also important for good imaging and localization of the fire and at the same time the signal to noise ratio is improved. These detectors provide high gain due to the suppression of photon feedback which is very effective especially in the reflective mode case, where CsI film is deposited on the top surface of the Micromegas cathode mesh. A particular advantage of Micromegas, compared to other gaseous detectors, is its good energy resolution giving a sharp peak for single electron. The benefit is that high single photon efficiency can be achieved at moderate gas gains.

The main idea is to deposit a solid photocathode on the metallic mesh on the side which does not face the amplification gap (Fig. 1), in such a way that the avalanche is not seen by the photocathode. In this configuration, the divergent process induced by the photon feedback electron, which limits the maximum achievable gain, is strongly suppressed. Another advantage is the operation of the photodetector in the reflective mode which is twice as efficient as in the semi-transparent mode which compensates the loss of photons through the mesh holes. The UV light extracts electrons from the photocathode by photoelectric effect. Then the electrons are guided with a limited electric field to the final amplification gap.

Simulation of the electric field lines originating from the upper side of the micromesh shows that they cover the whole surface of the photocathode and all of them reach the amplification region. One can therefore expect good photoelectron extraction and collection efficiency.

2. The ForFire prototype

2.1. Principle and field studies

High photon detection efficiency is a critical requirement for the Forfire photodetector, thus its operation in the reflective mode is preferable compared to the semi-transparent mode. However, the deposition of the CsI photocathode on the Micromegas mesh is not such an appropriate procedure for mass production purposes and it would exclude the possibility of using bulk technology [3] with woven mesh, since the deposition is preferably performed on flat surfaces.

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This problem can be bypassed if the CsI is deposited on the external surface of the Micromegas drift electrode instead of the mesh. In this case the drift electrode consists of a thin Ni (5 μm) foil with 40 μm diameter holes and a pitch that allows low optical transparency (~15%). The electrons extracted by UV light can be led towards the drift region like in the case of CsI on the mesh. However, the electric field is much weaker in the region of the drift and therefore, a net of thin metallic wires is placed above the drift mesh at the same potential in order to force the field lines toward the drift region. The field in this region is strong enough to achieve some pre-amplification before entering the avalanche region. This new concept (Fig. 2) has all the advantages of the operation in reflective mode, separates the production and manipulation of the photocathodes from Micromegas itself and allows large flexibility on the choice of the final detector type and design. On top of it, operation with pre-amplification allows us to use strips instead of pixels for imaging, since diffusion will spread the charges over a sufficient area. Already existing 2D readout schemes and electronics can be used for the laboratory prototype.

2.2. *Efficiency*

The quantum efficiency of the Forfire prototype detector for the UV light is depending on the electric field that is applied on the drift and on the amplification regions. There are three effects that depend on the field configuration and determine the overall performance, i.e. the *effective surface* of the photocathode, the electron *extraction efficiency* and the micromesh electron *transparency*.

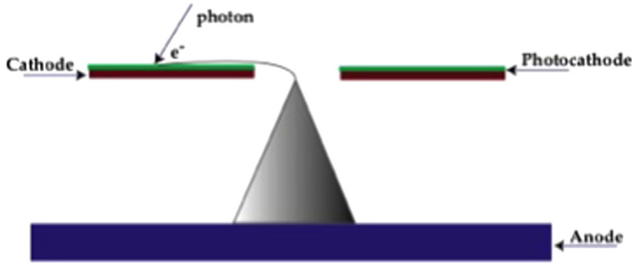

Fig. 1. The CsI deposited on top of the mesh is shown in green. A UV photon produces a photoelectron which is extracted and amplified in the Micromegas gap. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this paper.)

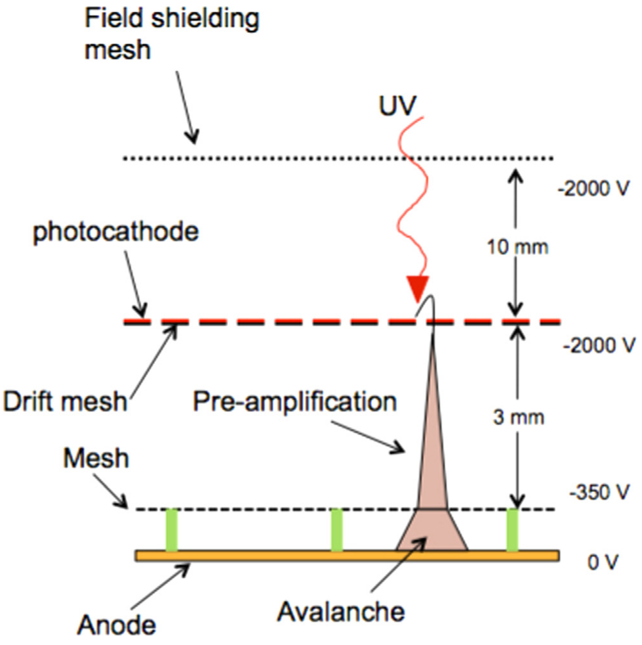

Fig. 2. Working principle of the ForFire detector. A UV photon extracts an electron from the CsI photocathode that is placed on top of the micromegas drift electrode; the electron is being led to the drift region where pre-amplification and diffusion occur, before the final amplification.

As it can be seen in Fig. 2 the CsI is deposited on the top surface of the drift electrode (which is a thin mesh). Two different mesh types have been used with 50% and 75% opacity. The less transparent mesh is absorbing a bigger fraction of the incoming photons, although not all of them are driven towards the drift region. For a given geometry, the effective surface is increasing with the applied electric field up to the total surface of the mesh. This electric field is however limited by electric stability aspects. The value of the electric field for which the whole mesh surface is useful can be reduced by increasing the density of the shielding wires, or by replacing them with a high transparency (~99%) woven micromesh. This solution has been adopted for the final detector.

Besides the drift electrodes effective surface, the electron extraction efficiency is increasing with the intensity of the electric field. On top of it, the probability of recombination (and thus loss) of electrons to the photocathode is decreasing for higher field values.

On the other hand, the electron transmission of the micromesh depends on the ratio of the amplification field to the drift field. For high field ratios and sufficient drift field value, the electron transmission is 1. If the drift field value increases, the field ratio is decreasing and the electron transmission of the mesh is dropping, leading to an efficiency loss. This loss is increasing with the field until preamplification starts to occur in the drift region. After this field value the loss starts to decrease and with a sufficient preamplification value (~10) the loss is practically recovered.

A paper is in preparation describing thoroughly this research.

2.3. *The actual sensitivity of the final ForFire prototype*

The ForFire Micromegas detector operating in the amplification mode has an excellent sensitivity to UV light in the solar blind band. Given the overall efficiency and the imaging capability, a photon flux as little as $10^3\ \mathrm{s}^{-1}\ \mathrm{cm}^{-2}$ arriving in the detector can provide an alarm under outdoor conditions (In Fig. 3 one can see the efficiency of the ForFire photodetector). This number is estimated assuming a

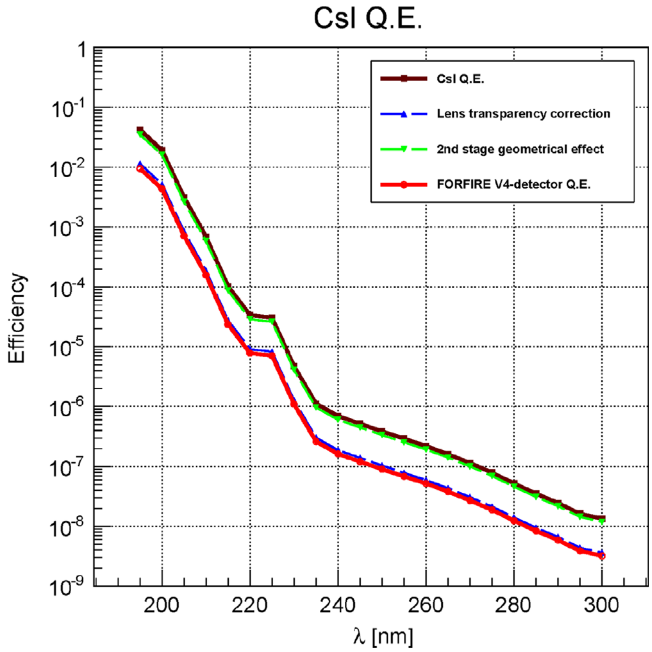

Fig. 3. Efficiency of the CsI photocathode.

1 kHz ambient background (10 Hz per pixel) and the measured mean quantum efficiency of 2×10^{-4}.

During the tests with a candle flame we measured a rate of 6.2 kHz at a 5 m distance, concentrated in a single pixel. This implies for a candle flame a rate of 62 Hz at 50 m, or a five standard deviation effect (confidence level of false alarms 5.7×10^{-7}) at 200 m for an integration time of 10 s.

For information, the sensitivities of some of the best commercial detectors are given below:

- Simtronics DM-TV6-V (combined UV and IR flame detector no imaging) hydrocarbon detection range: 45 m (0.3×0.3 m^2 flame)
- Simtronics DM-TV6-T (IR flame detector no imaging) hydrocarbon detection range: 40 m (0.3×0.3 m^2 flame) http://www.simtronics.eu/
- Drager[2] Flame 5000 (visible light with imaging) gasoil flame detection range: 44 m (0.1 m^2 flame) http://www.draeger.com/

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