Development and Studies of Novel Microfabricated Radiation Hard Scintillation Detectors With High Spatial Resolution

A. Mapelli, B. Gorini, M. Haguenauer, S. Jiguet, N. Vico Triviño, and P. Renaud

***Abstract*—A new type of scintillation detector is being developed with standard microfabrication techniques. It consists of a dense array of scintillating waveguides obtained by coupling microfluidic channels filled with a liquid scintillator to photodetectors. Easy manipulation of liquid scintillators inside microfluidic devices allow their flushing, renewal, and exchange making the active medium intrinsically radiation hard. Prototype detectors have been fabricated by photostructuration of a radiation hard epoxy resin (SU-8) deposited on silicon wafers and coupled to a multi-anode photomultiplier tube (MAPMT) to read-out the scintillation light. They have been characterized by exciting the liquid scintillator in the 200 micrometers thick microchannels with electrons from a $^{90}\mathrm{Sr}$ yielding approximately 1 photoelectron per impinging Minimum Ionizing Particle (MIP). These promising results demonstrate the concept of microfluidic scintillating detection and are very encouraging for future developments.**

***Index Terms*—Liquid scintillation, microfabrication, microfluidics, particle detection, SU-8 negative-tone photoresist.**

I. INTRODUCTION

THIS paper presents the study of a novel scintillation detector based on standard microfabrication techniques. It consists of a fine pitch array of hollow waveguides filled with a liquid scintillator and optically coupled to an array of photodetectors. The scintillation light produced by a particle traversing one of the waveguides is detected by the corresponding photodetector. Such a microfluidic device can be designed and processed to meet the requirements of a wide range of applications like medical imaging, homeland security and high-energy physics (HEP) experiments.

Microfluidic devices can be fabricated in a single photolithographic step with dimensional resolutions of the order of the micrometer. They allow the easy manipulation of fluids inside capillaries overcoming the difficulties encountered with previous liquid scintillation detectors made of capillary bundles [1]–[3]. The possibility to circulate, flush and renew the liquid scintillator makes the active medium of the detector intrinsically radiation hard. Moreover by changing the scintillator in the capillaries the same detector can be used for different types of measurements.

Prototype detectors have been fabricated by structuring a photosensitive resin (SU-8) deposited on silicon substrates. The SU-8 resin exhibits outstanding properties such as good adhesion on different types of substrates, high mechanical strength and chemical stability [4]. Moreover, its high level of resistance to radiation damage, comparable to Kapton film, makes it a good candidate for novel microfabricated radiation detectors [5]. The fabrication of the first generation of prototype devices has been adapted from a standard microfabrication process. The SU-8 resin is spin-coated on a silicon wafer. It is then exposed to UV light through a mask to polymerize the desired structures after which the non-polymerized resin is dissolved in a solvent to develop the structures defining the microchannels. Finally a metallic coating is applied and the wafer is diced to separate the individual microchips, which are then placed in a mechanical setup to close the channels for microfluidic manipulation and to optically couple them to the photodetectors.

II. MICROFLUIDIC SCINTILLATION DETECTION

Detectors based on capillary bundles have been studied in the past achieving results comparable to plastic scintillating fibres devices [1]. The fast response and the radiation hardness of liquid scintillators make them particularly interesting for particle tracking [2] and calorimetric detectors [3] in HEP experiments. Even though good experimental results have been obtained, the construction of capillary detectors was reported to be rather complicated leading to many possible imperfections in the various steps of the fabrication process.

Microtechnologies offer the possibility to construct similar capillary detectors by adapting standard microfabrication processes. The simple microfluidic device presented in this paper consists of a single microchannel [Fig. 1(a)] designed to define a dense array of optically separated scintillating waveguides [Fig. 1(b)].

Typical cross-sections of microfluidic channels are of the order of tens of micrometers for total lengths that can go up

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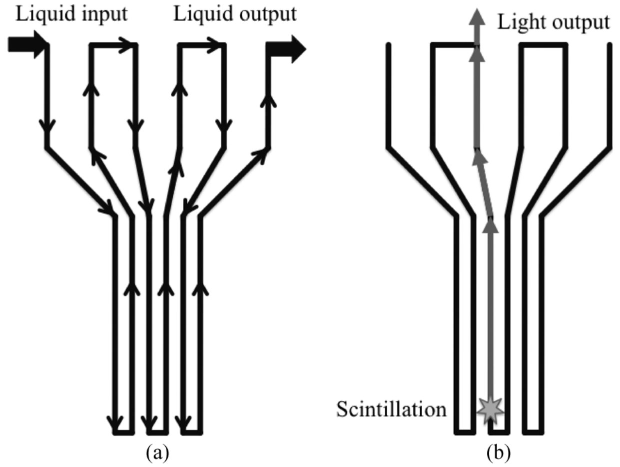

Fig. 1. Principle of operation of the microfluidic scintillation detector. (a) A single microfluidic channel defines (b) an array of optically separated waveguides. The serpentine microchannel acts as a single fluidic entity going back and forth with a single fluidic input and output. When a particle interacts with the liquid scintillator in one of the branches the scintillation light is guided towards a photodetector.

to many centimeters. The microfluidic device is fabricated by photostructuration of the radiation hard epoxy resin SU-8 [4], [5] deposited with a controlled thickness on a silicon substrate and coupled to a multi-anode photomultiplier tube (MAPMT). SU-8 is a negative type photoresist developed by IBM for the microelectronics industry [6], [7]. It is composed of an EPON epoxy resin, an organic solvent and a photoinitiator. This photoresist is commonly used for MEMS [8] and microfluidic devices [9] but also for the fabrication of micro-pattern gas detectors [10] and X-ray imagers [11]–[13].

The microfluidic scintillation detector is made of a single channel with a serpentine geometry. The fluidic operation of such a device is very simple as it has only one inlet and one outlet. By filling it with a liquid scintillator, the densely packed array of capillaries, separated by thin structures, defines a high spatial resolution detector.

III. FABRICATION

The parameters of a standard microfabrication process have been optimized to construct prototype scintillation detectors. The photolithographic structuration of the negative photopolymer SU-8 is achieved through the process described in Fig. 2. The photoresist is dispensed on a silicon substrate by spin-coating [Fig. 2(a)]. The thickness of the photoresist layer is determined by its viscosity and the rotation speed of the substrate. The devices presented in this paper were fabricated by spinning the low-viscosity resin SU-8 GM-1075 from Gersteltec at 1250 revolutions per minute to obtain uniform layers of 200 micrometers. A thermal cycle, the soft bake, is performed to evaporate most of the solvent contained in the spinned SU-8 followed by a relaxation time to improve the uniformity of the thickness and evaporate some of the remaining solvent. The resin is illuminated by UV light through a mask to polymerize the desired structures [Fig. 2(b)] and undergoes another thermal cycle, the post-exposure bake, for cross-linking of the exposed resin. To reveal the structures, the non-polymerised resin is dissolved in a solvent, propylene glycol methyl ether acetate (PGMEA), as shown in Fig. 2(c). Once developed, the structures are rinsed with Isopropanol and heated to improve the polymer reticulation and, as a consequence, its adhesion to the substrate. As shown in Fig. 2(d), a thin film of 200 nanometers of gold is then deposited by sputtering to increase the optical properties of the microfluidic channels guaranteeing an efficient light transmission from the interaction point to the photodetector. The final step of the microfabrication process is the dicing of the silicon wafers to separate 16 devices from a single wafer with a footprint of 1.5 × 2 cm (Fig. 3).

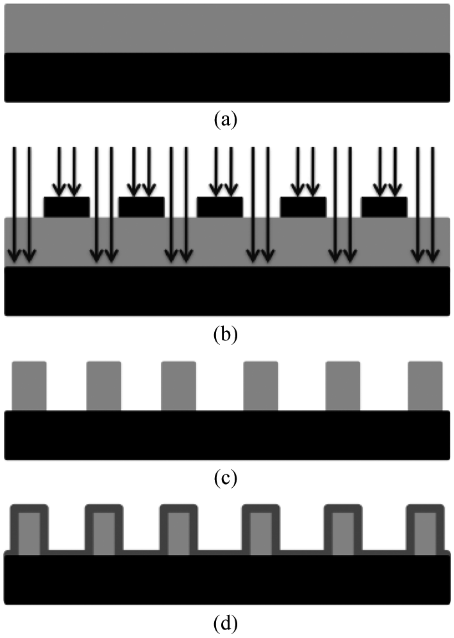

Fig. 2. Microfabrication process-flow: (a) spin coating of SU-8 resin on silicon substrate, (b) exposure of SU-8 resin to UV light through a mask, (c) development of SU-8 in PGMEA, (d) metallization of SU-8 structures.

The design of the prototype detectors defines an active area of approximately 1 centimeter by 300 micrometers. The 50 micrometers wide scintillating microchannels are separated by 10 micrometer SU-8 walls. The pitch of 60 micrometers fans out to a pitch of 2.3 millimeters to match the inter-pixel distance of the MAPMT (H7546B by Hamamatsu) of the experimental test bench. The channels are filled with the liquid scintillator EJ-305 by Eljen Technology, selected for its high light output (80% of Anthracene) and for its emission spectrum peaking around 425 nm, in the most sensitive region of the MAPMT.

IV. EXPERIMENTAL

The performance of the microfluidic scintillation detector with MIPs was measured by exposing the liquid scintillator to electrons from a collimated $^{90}\mathrm{Sr}$ source (Fig. 4). The detector was optically coupled to an MAPMT, which was read out by a VME charge-to-digital converter (CAEN QDC V792). The coincidence of two plastic scintillating fibres (Kuraray SCSF-78 0.5 millimeter square cross-section) read-out by 2 single channel PMTs (H3165 by Hamamatsu) and placed underneath

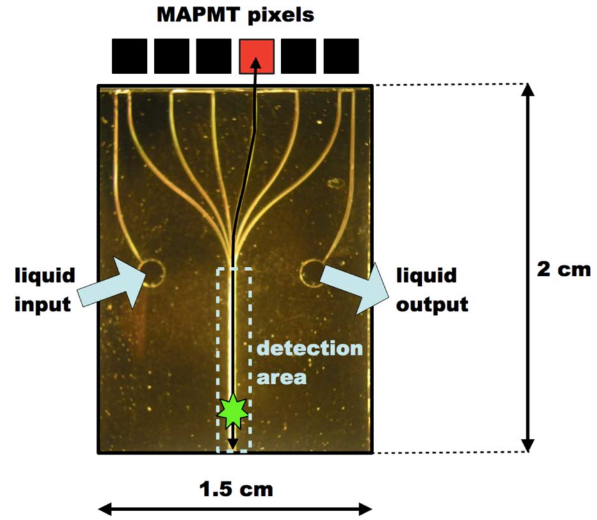

Fig. 3. Top view of the microfluidic scintillation detector.

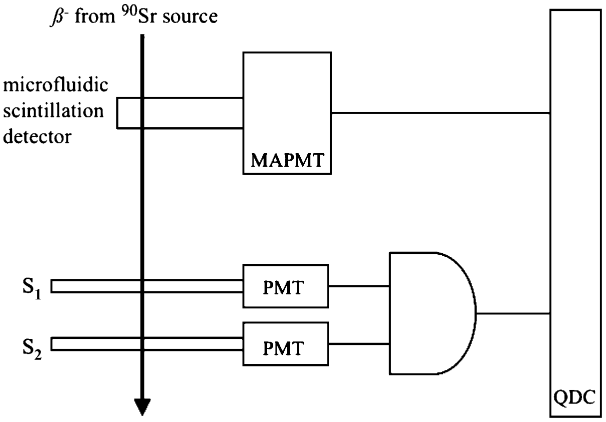

Fig. 4. Schematic view of the experimental set-up used to measure the photoelectric yield of the microfluidic scintillation detector read-out by an MAPMT.

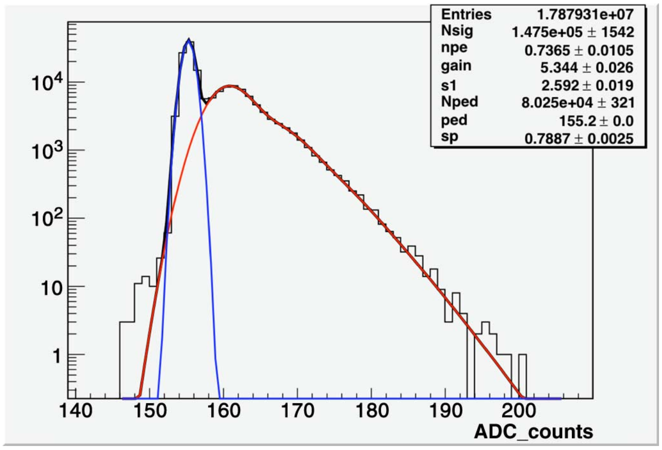

Fig. 5. Typical spectrum of a single microchannel. The pedestal is fitted with a Gaussian and the detector response with the sum of Gaussians convoluted with Poissonians.

the detector was used as external trigger. The MAPMT and the 2 PMTs were biased at -1000 Volts.

V. RESULTS AND DISCUSSION

Fits of the spectra give an average of about 0.74 photoelectrons per MIP (Fig. 5) traversing a 200 micrometers deep microchannel. This result is well in agreement with the expected photoelectric yield of the microfluidic device [14]. It demonstrates the principle of operation of this new type of scintillation detector made with simple microfabrication techniques.

The limited detection efficiency of the prototype detectors comes mostly from three factors: the reduced thickness of the devices, the design of the channels, and the non-optimal coupling to the external photodetectors. The limited thickness of the device is due to technological limitations at the time of the fabrication of the prototypes and it results in a low light yield. The fan-out of the channels, required to match the photodetector's pitch, induces light losses along the light path. Finally, the packaging of the chips does not guarantee a good optical contact between the devices and the photodetectors. The project is still in a very early phase and these issues should be addressed to progress from an experimental device to an actual detector. The promising results obtained with the microfluidic scintillation detectors are very encouraging for this development. Moreover, the possibility to easily adapt the microfabrication process to a wide range of detector geometries and dimensions allows obtaining state-of-the-art spatial resolution and fill-factors of 100% with low material budget. The fabrication process as well as the materials can be selected and optimized in order to comply with different physics requirements.

VI. CONCLUSION

The principle of operation of a new type of scintillation particle detector has been demonstrated experimentally. The parameters of a standard microfabrication process have been optimized to fabricate prototype detectors. The photoelectric yield of these detectors has been measured in the order of 0.74 photoelectrons per MIP traversing the 200 micrometer deep microchannels read-out by an MAPMT.

The fields of applications of microfluidic scintillation detectors could range from X-ray imaging to homeland security or medical applications such as PET scans, dosimetry, pharmacological studies, and non-destructive material analysis. Their intrinsic high spatial resolution and increased radiation hardness makes them particularly interesting in the field of HEP where these detectors could be used for tracking, calorimetry or beam instrumentation.

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