Tracking with Silicon Photomultipliers in NEXT

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Abstract – NEXT is an experiment to search for neutrinoless double beta decay using a radiopure high-pressure gaseous xenon TPC, filled with 100 kg of xenon, enriched with Xe-136 isotope. The NEXT tracking system, the procedure developed with the joined effort of IFIC and ICMOL for coating these SiPMs with TPB, and the measurements performed to characterize the coatings and the response of the coated SiPMs in the VUV range.

I. INTRODUCTION

The NEXT experiment aims at the search of the neutrinoless ββ decay of the 136Xe isotope, using a 100 kg high pressure xenon gas TPC, with 90% gas enrichment, operated in electroluminescence (EL) mode. The energy of the events from EL signals is recorded with near 1% energy resolution at Qββ (2.48 MeV) by an array of UV sensitive photomultipliers (PMTs) located at the TPC cathode [1]. The advantage of the gaseous xenon over the liquid xenon is the possibility to convert the UV light into visible light, where the sensors have their maximum photon detection efficiency. In this paper, we describe the NEXT tracking system, the procedure developed with the joined effort of IFIC and ICMOL for coating the SiPMs and the measurements performed to characterize the coatings and the response of the coated SiPMs in the VUV range.

SiPMs have been chosen for the tracking readout in NEXT. For the tracking purpose, they offer comparable detection capabilities as standard small PMTs and APDs, with the additional advantages of high spatial resolution, ruggedness, radio-purity and cost-effectiveness, essential for a large-scale radiopure detector. Their main drawback is their poor sensitivity in the emission range of the xenon scintillation (peak at 175 nm). This makes necessary the use of a wavelength-shifter (WLS) to convert the UV light into visible light, where these sensors have their optimal detection efficiency. Tetraphenyl-Butadiene (TPB) has been used, as its emission spectrum matches best the sensitivity spectrum of the SiPMs. This organic WLS, used in Dark Matter experiments to coat PMT windows [2], [3], has not been applied yet to SiPMs. The main issue addressed for coating these sensors with TPB is the choice of the coating thickness, as this is known to influence the conversion efficiency [4]. Other relevant issues for coating sensors with an active area of a few mm², are the uniformity and the quality of the depositions.

We describe in this paper the SiPM tracking system of NEXT1-IFIC, a large NEXT prototype operated in EL mode and used as a test bench and demonstrator of the final NEXT detector (so-called NEXT-100). We also describe the use of TPB coating on the SiPMs and the measurements performed to characterize the TPB depositions and the response of the coated SiPMs in the VUV.

II. NEXT TRACKING SYSTEM

A first NEXT tracking system was built for the TPC prototype NEXT1-IFIC [1]. It is composed of 248 Hamamatsu S10362-11-025P MPPCs, arranged to cover a circular plane of 16 mm diameter. The MPPCs are soldered onto Daughter-Boards (DB) of 38×38 mm² (Fig. 1) made of PTFE electroplated with oxygen-free copper.

The DBs are plugged onto a large Mother-Board (MB) containing the printed circuits for biasing the SiPMs (Fig. 2). A common bias is shared by the sensors of a same DB, chosen to have very close gains (see Fig. 3). The features of the SiPMs chosen (Hamamatsu S10362-11-25P) are small size (1 mm² active area), high gain (2.75×10⁵ at the nominal voltage ~71 V), photon detection efficiency (PDE) comparable to PMTs (25% at 440 nm) and a wide dynamic range due to their large number of pixels (1600).

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In the tracking system, the SiPMs are selected and calibrated to have minimal gain dispersions (< 3%) within the DBs and over the whole tracking area. The average gain and its standard deviation were measured for each DB, biased at its average nominal voltage. The average SiPM in the tracking plane is $2.4 \times 10^5$ with a relative standard deviation of 2.3%. This indicates a reasonable uniformity for tracking using EL signals.

Another known disadvantage of the SiPMs is the dependence of the gain with temperature. For the stable operation of the SiPMs in NEXT, it is therefore necessary to monitor the gain variation with the temperature changes. A high voltage supply system has been developed to supply the SiPMs with a temperature dependent correction of the bias, to compensate for the gain drifts due to temperature, during the operation of the detector [5].

A test of the tracking sensors, the electronic and the DAQ chain developed for the readout [6] has been performed, using a LED emitting at 240 nm in pulsed mode (26 kHz frequency, 1 µs pulse width). The single photon response of the SiPMs, recorded in ADC channels, is shown in Fig. 4. Gaussian fits to the single peaks allow the determination of the ADC calibration factor or number of photoelectrons per channel. 16 full electronic channels corresponding to one DB have been successfully tested and used for recording 16 SiPM signals.

The ADC used has shown to be linear in the full dynamic range (1024 channels). The parameters of the full tracking chain (SiPM gain, amplifier gain, etc) were set to record a maximum of 230 p.e./µs (full ADC dynamic range), enough for tracking with EL signals in NEXT1-IFIC.

### III. TPB COATING PROTOCOL

The active area of the SiPMs is covered with a protective layer, usually made of a resin or PVC, which absorbs short wavelength photons, preventing them from reaching the silicon region where they can be detected. The alternative considered here is the use of an appropriate WLS to convert short wavelength VUV light into the visible region. Among the commonly used organic WLS fluors, TPB of > 99% purity grade [7] absorbs light in a wide UV range and re-emits it in the blue, with an emission peak around 430 nm, where the SiPMs have their optimal response. TPB can be applied by vacuum-evaporation [8] onto different substrates.

The coating facility of Instituto de Ciencia Molecular (ICMOL) was used. The coating system (Fig. 4) consists of a vacuum chamber or evaporator enclosing 4 ceramic crucibles which may melt simultaneously up to four different compounds. The evaporator is enclosed in a glove-chamber filled with N$_2$, where the manipulation of different compounds takes place in an oxygen and moisture free environment. One crucible only was used for NEXT TPB campaign. The crucible temperature is monitored and the evaporation rate is
controlled to prevent bubbling and sputtering of the TPB onto the substrate. The substrate is positioned on a sample-holder fixed on a spinning disk above the crucible. The TPB deposition rate and thickness were measured with high precision using a Quartz Crystal Microbalance (QCM) sensor, located half way between the crucible and the substrate. The vacuum system of the coating facility is composed of a diaphragm pump and a turbo-molecular pump, that allow to reach vacuum levels close to $10^{-7}$ mbar in the evaporator.

The substrates used for the calibration and characterization purposes are glass plates of 30×30 mm$^2$ and a set of SiPM boards consisting of 5 SiPMs (Hamamatsu S10362-11-025P and -050P). The SiPM DBs of the NEXT1-IFIC tracking plane were thoroughly cleaned for the TPB deposition and stored in the N$_2$ atmosphere of the ICMOL glove chamber until their introduction into the evaporator.

Following the coating protocol normally used at ICMOL, several depositions of a chosen thickness have been successfully produced on glass plates and on 5-SiPM boards. The coating quality has shown to be reproducible as long as the batch of TPB powder used has been conserved in appropriate environmental conditions.

IV. CHARACTERIZATION OF THE COATINGS

The substrate samples coated with different TPB thickness have been tested and characterized with different UV light sources. The TPB fluorescence spectrum was measured for a glass plate coated with 0.1 mg/cm$^2$ of TPB, using a xenon lamp coupled to a monochromator for the selection of the input wavelength. The re-emission spectrum of the TPB, obtained in a spectrometer, for the input wavelength of 246±2.5 is shown in Fig. 5. The peak corresponding to non converted input light is observed, well separated from the fluorescence peak lying at 427±20 nm. This fluorescence peak originates from the S1 singlet states of the TPB molecules. The phosphorescence peak, which originates from the T1 triplet states of the molecules, is also seen at 680 nm. TPB coatings of different thickness (0.6, 0.2, 0.1 and 0.05 mg/cm$^2$) deposited on glass plates, were used to characterize the quality of the depositions. The deposition uniformity, the transmittance and the TPB conversion yield as a function of thickness were measured, using various photo-sensors (SiPMs and PMTs). These measurements allowed to establish the operational mode of coating that ensures the optimal uniformity, fluorescence yield and transmittance of the converted light. The TPB thickness of 0.05 mg/cm$^2$ has been found to allow higher fluorescence yield, which confirms previous studies on TPB depositions from the literature [2],[4]. On the other hand, the deposition homogeneity was found to decrease with the thickness. The quality of the coatings was also found to improve substantially if spinning of the substrate is applied during the TPB evaporation process.

Depositions of various thicknesses were also performed on 5-SiPM boards. The SiPMs were biased individually using the operation voltages provided by the manufacturer to insure a uniform response within the board, and were illuminated by a collimated LED emitting at 260 nm and operated in a continuous mode. The output current of the SiPMs was measured with a picoammeter prior and after coating, at the same illumination and temperature conditions and for different coating thicknesses. The response of the coated SiPMs increases with decreasing coating thickness and is higher at 0.05 mg/cm$^2$. The coating thickness chosen however for NEXT1-IFIC SiPMs, was 0.1 mg/cm$^2$ as it provides good deposition homogeneity and high fluorescence efficiency.

V. RESPONSE TO VUV LIGHT OF COATED SIPMs

The response of SiPMs coated with TPB when illuminated with VUV photons was investigated using the experimental
A xenon lamp coupled to a band-filter for the selection of the Xe scintillation wavelength (173 ± 20 nm) was used. A SiPM DB coated with TPB was connected to the MB and used for the measurement. The lamp and the photo-sensors were enclosed in a glove box filled with N₂ to avoid the absorption of the VUV light by the air. The lamp was placed at a long distance from the MB, so that the amount of light reached in the sensors was low enough to avoid saturation. The gas box was placed inside a black box to avoid the exposure of the sensors to the ambient light. The current from the SiPMs was recorded with a picoammeter and also through the electronic chain (amplifier, ADC) developed specifically for NEXT tracking system. The xenon lamp was operated in pulsed mode (1 µs pulse width, 100 Hz maximum frequency) and the ADC sampling was performed at a rate of 1 MHz. The signal from the coated SiPMs was amplified and recorded in ADC channels. A typical ADC spectrum showing the response to VUV light of one of the TPB-coated SiPMs is shown in Fig. 7 and compared to the spectrum of a non-coated SiPM.

As seen in this figure, the non-coated SiPM does not respond to 173 nm light, while TPB-coated SiPM has a significant response, observed for all the SiPMs of the coated DBs. The xenon lamp setup was used also to evaluate the response uniformity in the coated DB, by measuring the current deviation in the SiPMs when illuminated by a uniform VUV light. This latter is obtained by projecting the Xe light onto a PTFE reflector, placed at a long distance from the DBs. The current dispersion obtained in the SiPMs of the coated DB is found compatible with the gain dispersion measured prior to coating. This indicates a quite good uniformity in the TPB deposition.

TPB coated DBs have been stored in vacuum (<1 mbar) immediately after the coating process. DB samples have been tested with UV light after coating and retested 9 months later at the same illumination and temperature conditions. No significant current deviation was measured after storage in vacuum, which indicates no ageing effect in the TPB coatings.

VI. CONCLUSIONS

A tracking system based on 248 SiPMs has been constructed for NEXT1-IFIC TPC prototype. The test performance of 16 electronic channels has shown good ADC linearity and wide enough dynamic range for NEXT1 experiment. The SiPMs coated with 0.1 mg/cm² of TPB have shown significant response at the Xe scintillation wavelength (173 nm). The uniform response of the SiPMs selected and calibrated, is shown to be conserved by the TPB coating.

REFERENCES