The silicon photomultipliers in the detector subsystems of the GlueX experiment

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Abstract. The subsystem detectors of GlueX experiment use silicon photomultiplier (SiPM). Around five thousand SiPM’s in total uses in the detectors of experiment. The detectors operate in condition of load level 2MHz and up to $10^4$ pixels «fired» with ~0.3ns time resolution. The list of such detectors: the tagger microscope, the pair spectrometer, the start counter which surrounded the liquid hydrogen target; the electromagnetic barrel calorimeter to measure energy and direction of secondary photons comes from the target. We present the results of the time resolution measurements and the relaxation time measurements for two SiPM types in experimental conditions.

1. Introduction

The main goal of GlueX experiment is to study photoproduction of mesons with exotic quantum numbers using beams of linearly polarized photons [1]. The photon beam is produced using a bremsstrahlung technique by a 12 GeV electron beam incident on a thin (20 µm) diamond radiator. The main components of the beamline are the tagger microscope (TAGM), the broad band hodoscope (TAGH) and the pair spectrometer (PS). The TAGM and TAGH are used to determine the energy of a beam photon by detecting the bremsstrahlung electron after radiation. The PS is used to measure the spectra of linearly polarized photons. GlueX liquid hydrogen target is surrounded by the start counter (SC), whose main goal is to detect hits from tracks and therefore to identify the beam bucket associated with the interaction. Photons originating in interactions of the beam with the target are detected using the forward and barrel calorimeters (BCAL) [2].

Silicon photomultipliers were chosen for the instrumentation of the BCAL and the SC, which are positioned in the solenoid’s magnetic field of about 2 T, and the TAGM and the PS detectors, where light from scintillators is collected using small light guide fibers. The sensitive area of SiPMs used for the TAGM, SC, and PS is 3x3 mm². Light collection from the BCAL is performed using an array of 4x4 SiPM sensors (each sensor has a sensitive area of 3x3 mm²), which was specially designed for GlueX by Hamamatsu [3].

The TAGM and the PS are used for timing measurements and should provide time resolution better than 300 ps. The TAGM will be operated at a relatively large rate of up to 2 MHz. For the instrumentation we considered sensors with pixel sizes 50 µm (MPPC S10931-050P) [4]. Time resolution was also estimated for the array S12045. Measurements were performed using a laser with a...
pulse width of 70 ps. The response from scintillator was simulated using a fast blue light emitting diode (LED).

2. Photon beam detectors
The main components of the beamline are tagger microscope, the broad band hodoscope and the pair spectrometer. A schematic view of the GlueX beamline is shown in figure 1.

![Figure 1. A schematic view of the GlueX beamline.](image)

The phonon beam is produced by 12GeV electron beam incident on a thin (20μm) diamond wafer. After passing through the wafer, the electron beam is bent by a dipole magnet into the beam dump. A small fraction, about 0.01% of the electrons, emits a photon via incoherent or coherent Bremsstrahlung. After the radiator, the electrons will be swept away by a 1.5 T dipole magnet and detected by two hodoscopes to tag the energy of the associated photons (figure 1). A fine-resolution (TAGM) consisting of 120 scintillating fiber bundles will cover the 8.4 – 9.0 GeV coherent peak with an energy resolution of 0.1%, while the broader energy range of photons between 3 – 11.6 GeV will be tagged by the TAGH. The TAGM figure 2 consists of a two-dimensional array of scintillation fibers with the cross section of 2x2 mm. Fiber optics attached to the ends of the scintillation fibers transmit light on the MPPS S10931-050P manufactured by Hamamatsu Corporation shown at figure 3. The temporal resolution should be less than 300 ps.

![Figure 2. Design of a segment of the tagger microscope.](image)

![Figure 3. Hamamatsu MPPC S10931, effective area 3x3 mm².](image)

The spectrum of linearly polarized photons is measured with a magnetic spectrometer electron-positron pairs (PS) formed in the converter thickness of $10^3$ radiation lengths [5]. Electrons and positrons deflected in a dipole magnet (figure 4) and registered in two scintillation hodoscopes consisting of a thin 1-2 mm scintillation plates. Wavelength shifting fibers, glued to the ends of the plates transmit light at 145 SiPM Hamamatsu S10931-050P. The hodoscopes positioned symmetrically with respect to the photon beamline figure 5.
3. The detectors of experimental setup

3.1. Start counter

The GlueX liquid hydrogen target surrounded by the start scintillation counter (SC) consists of 30 rectangular plastic scintillators paddles (figure 6). The light from each paddl is collected by four SiPM connected to the end face of the scintillator (figure 7). Using track information SC has a time resolution of 0.3 ns.

3.2. Electromagnetic calorimeter

Among the detector subsystems is a cylindrical barrel calorimeter (BCAL) consisting of 48 identical sectors (figure 8) built using grooved lead sheets with gloves and scintillating fibers position inside them as it shown at figure 9.

Light from the fibers is recorded by 3840 Hamamatsu S12045 SiPM’s shown at figure 10. Each of them is a 4x4 matrix of the SiPM’s with a sensitive area of 3x3 mm². The required time resolution of the calorimeter is 400 ps.

Figure 4. Dipole magnet and vacuum chamber.  
Figure 5. Two scintillation hodoscopes.

Figure 6. Thirty scintillating paddles around the GlueX target.  
Figure 7. Four SiPM’s (MPPC S10931) per paddle.

Figure 8. The GlueX BCAL: (a) BCAL schematic; (b) a BCAL module side view; (c) end view of the BCAL showing all 48 modules and (d) an end view of a module showing readout segmentation.
Figure 9. The BCAL fiber matrix.

Figure 10. Hamamatsu (MPPC S12045) SiPM array of 16 3x3 mm² (pixel size 50 μm).

4. SiPM timing measurements

We measured the time resolution of the detectors using SiPM Hamamatsu with sensitive area 3x3 mm² and pixel size of 50 microns for various operation rate. Measurements made with using picosecond laser pulse and the light produced by an LED with total pulse width of 8 ns. In the first case, the time resolution is limited by readout electronic. In the case of using LED, the main contribution to the timing resolution comes from the rise time of the light pulse ~ 3ns. The rise time is a comparable with the time for which the light collection time from a scintillator using transparent fibers or wavelength shifter. This SiPMs are most sensitive in "blue" light (∼ 470 nm), which is consistent with the spectrum of the emitted light from scintillator EJ - 212.

We also measured the dependence of the time resolution on the number of fired pixels for the SiPM array at a room temperature and 50°C. The dependence of the time resolution of the SiPM with the pixel size of 50 μkm on the number of fired pixels and the LED pulser rate is shown at figure 11 and figure 12 respectively.

Figure 11. The dependence of the time resolution on the number of fired pixels.

Figure 12. The dependence of the time resolution on the number of LED rate.

The same measurements were done with Hamamatsu PLP 10 laser. The laser pulse width is about 60 ps. Timing resolution as a function of the number of fired pixels of MPPC S12045 at room and working temperatures shown on figure 13. The resolution of the array was found to be a factor two worse due to substantial increase of the dark noise by combining of 16 SiPM’s.

Figure 13. Timing resolution as a function of the number of fired (a) MPPC S10361-050P, (b) MPPC S12045 at 25°C (upper panel) and at working temperature of 50°C (lower panel).
5. Pixel recovery time
The setup used to measure SiPM recovery time is presented at figure 14. For the studies we used SiPMs, which characteristics are similar to MPPC S10931. A pulse generator (BK Precision 4071) was used to synchronize two other pulse generators (HP-8116), which drove the two LEDs. The first LED provided a high intensity light flash and illuminated about 80 - 90% of SiPM pixels. The second LED had smaller light amplitude and produced a flash after the first one at a programmable delay. We measured amplitude of the SiPM signal from the second LED for different delays between the two flashes and various amount of light. The SiPM recovery time is defined as the time between the two flashes when the amplitude from the second LED drops by 20%. Amplitude of the second LED as a function of the delay for different number of fired pixels is shown at figure 15. The typical SiPM recovery time was found to be about $\tau = 35 - 40 \text{ ns}$ for SiPMs with 50 $\mu$m pixel sizes.

![Figure 14. Thirty scintillating paddles around the GlueX target.](image)

![Figure 15. Four SiPM's (MPPC S10931) per paddle.](image)

Time resolution of SiPMs measured using an LED (by simulating signals from a fast scintillator) was found to be less than 300 ps for a SiPM operated at a rate up to 2.5 MHz. The resolution of the array was found to be a factor of two worse than that of the 3x3 mm$^2$ sensors. The array has a substantially higher noise level, which can account for some temperature dependence of the time resolution in the region with a fewer number of fired pixels. The typical SiPM recovery time was measured to be $\tau = 35 - 40 \text{ ns}$ for the 50 $\mu$m sensors. No degradation of the time resolution was observed up to the SiPM rate of at least 2 MHz, which is the expected maximum operating rate of SiPMs in GlueX. The 50 $\mu$m MPPC S10931-050P was chosen for the instrumentation of the GlueX start counter, the tagger microscope, and the pair spectrometer [6]. Light collection from the BCAL is performed using an array of 4x4 SiPM sensors S12045.

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