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Performance tests of Hamamatsu 2744-08 diodes for the *BaBar* calorimeter front end readout and proposal for reliability tests.

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In a previous note we described two possible readout schemes for the *BaBar* CsI calorimeter [1]. The first solution uses a 58 mm × 58 mm × 3.5 mm wavelength shifter mounted on the back face of the crystal with a 0.5 mm air gap between the crystal and the wavelength shifter. The wavelength shifter acts as a planar waveguide and concentrates the light onto two 30 × 3.4 mm^2 photodiodes (Hamamatsu S3588-03)mounted on the thin edges of the shifter. The second solution uses two 20 × 10 mm^2 photodiodes (Hamamatsu S2744-03) mounted directly to the back face of the crystal and coupled using Bicron optical grease. Both sets of diodes are 300 μm thick. The direct solution gave an equivalent noise energy (ENE) 15 % less than the wavelength shifter solution but at twice the cost. However Hamamatsu has recently developed a new 20 × 10 mm^2 , 300 μm photodiode (S2744-08) with improved performance at a comparable cost to the 30 × 3.4 mm^2 photodiodes. In this note we evaluate the performance of these new diodes. It is essential to establish the reliability of these new products. We propose an accelerated test to accomplish this.

1 Performance of 2744-08 Hamamatsu Photodiodes

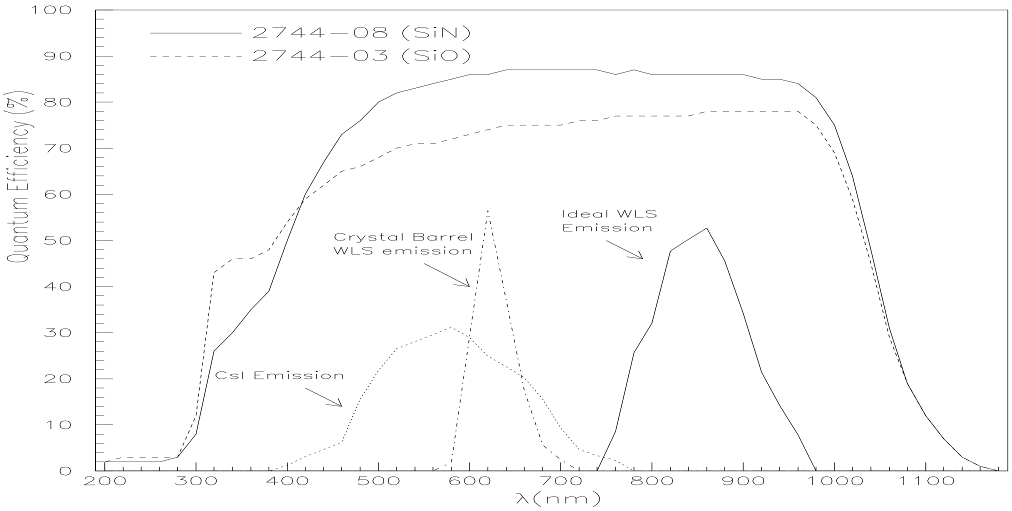

Figure 1: Quantum efficiency of 2744-03 (SiO) diodes and 2744-08 SiN diodes versus wavelength. Data is supplied by Hamamatsu Corporation [5]. Also shown are the emission spectra of a typical CsI crystal , a Crystal Barrel wavelength shifter [2] and and ideal wavelength shifter [1]. The scale is arbitrary for the emission spectra.

Until recently all Hamamatsu PiN diodes have been constructed with a silicon oxide (SiO) protective coat. However the replacement of the silicon oxide with silicon nitride (SiN) allows an improved quantum efficiency. The quantum efficiency versus wavelength is shown in figure 1. Also shown are the emission curves of a typical CsI crystal, the Crystal Barrel wavelength shifter [2] and an ideal wavelength shifter [1]. We can use these curves to estimate the improvement we might expect. For the direct readout we convolute the curves for the CsI emission with the two diode efficiencies and find that the 2744-08 diode should give 15 % better performance. For the wavelength shifter option we convolute the crystal barrel wavelength shifter emission spectra with the two diode efficiencies to find a similar improvement of 15 %. The ideal wavelength shifter will be improved by 10 %. We note however that the new diode technology has not yet been applied to the smaller diodes used for the wavelength shifter option. Note also that the response of the new diode is flatter. Table 1 compares the measured light yield for several different crystals with the two diodes. The photoelectron light yield is increased by about 10 % which is less than expected. This may be due to variations in the CsI emission spectra.

Vendor	Front Dim. (cm^2)	Rear Dim. (cm^2)	Length (cm)	LY 2744-03 (pe/MeV)	LY 2744-08 (pe/MeV)	LY Improvement %
Kharkov	25	25	34	4130	4500	9 ± 2
Kharkov	34	20	34	4010	4330	8 ± 2
Horiba(hex)	28	18	23	7880	8610	9 ± 2

Table 1: Light yield (LY) measurements for full-sized crystals wrapped in three layers of 1.5 mil Teflon. The performance of 2744-03 (SiO) diodes is compared with 2744-08 (SiN) diodes.

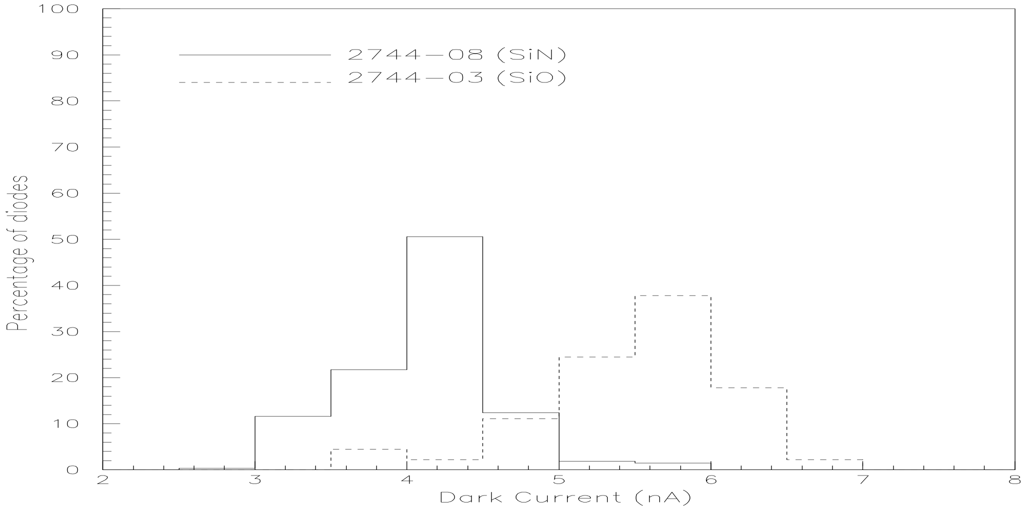

Figure 2: Dark current distribution for 2744-03(SiO) and 2744-08(SiN) diodes. Data is supplied by Hamamatsu Corporation [5].

The 2744-08 (SiN) diodes also have a 30 % deceased dark current as measured by the manufacturer in figure 2. Figure 3 compares the measured noise performance of the two types of diodes when attached to the *BaBar* preamp to be used for the CsI readout. The noise performance is identical despite the decreased dark current because the capacitive noise dominates over the dark current noise.

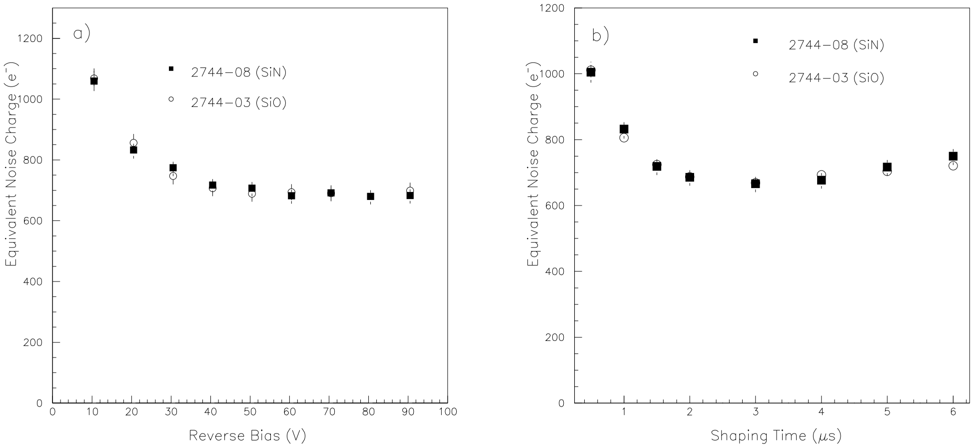

Figure 3: The dependence of equivalent noise charge per crystal on a) photodiode reverse bias voltage b) shaping time for both the 2744-03 (SiO) and the 2744-08 (SiN) diodes.

2 Reliability

It is essential to establish the reliability of these new diodes. The methods and mathematics of reliability engineering with reference to the calorimeter are described in detail in reference [3]. In this note we use data from the CLEO experiment to estimate the “mean time before failure ”(MTBF) for the diodes. We showed in [3] that the necessary reliability can be achieved at 95 % confidence limit with

$$MTBF_{diode} > 1954 \; years \tag{1}$$

This number was derived from CLEO data. It is sufficient to establish that the 2744-08 have an equivalent MTBF. Since we have limited time and diodes with which to test the reliability we must resort to an accelerated test. Aging is due to chemical reactions and the Arrhenius rate reaction law states that the rate depends on a power of temperature R= kT^{α}. Hence by testing at a higher temperature the aging rate is enhanced and the time scale of tests can be shortened. Unfortunately the constant α is unknown and has to be estimated in order to translate the measurement into an estimate of MTBF at operating temperature. We estimate this constant by comparing the results of a CLEO accelerated test done in 1986 with the performance of the calorimeter 1989-1994.

In reference [4] the CLEO collaboration tested 73 diodes at 70°C for 11 months and observed two failures. The failure is defined by a dark current several times greater than specification. The diodes were first screened or "burnt in" by operation at 25°C at 10 V overbias for 1 week. The screening is to remove the defective diodes since one wishes to establish the natural lifetime in the test. Using equation 5 of reference [3] we can establish the MTBF at 95 % confidence level.

$$MTBF_{diode} > 10.87 \ accelerated \ years \tag{2}$$

In the course of the 5 years of operation at 25° C CLEO observed that 48 diodes or connectors failed initially and 14 diodes became noisy. In reference [3] we interpreted this conservatively as 62 diode failures to deduce MTBF > 1954 years (95% C.L.). It is most likely that all 48 initial failures were from bad connectors and so in the following calculations we compute for 14(62) failures over 5 years. The MTBF at 95 % C.L.

$$MTBF_{diode} > 7306(1954) \ operational \ years \tag{3}$$

To estimate the factor α we use

$$\frac{accelerated \ years}{operational \ years} = \left[\frac{T_{acc}}{T_{op}}\right]^{\alpha} \tag{4}$$

Inserting the values above

$$\frac{7306(1954)}{10.87} = \left[\frac{70}{25}\right]^{\alpha} \tag{5}$$

This gives $alpha$ = 6.32(5.04) and a derating factor of 672(180). If we now construct an accelerated test for one month at 70°C to establish an MTBF > 1954 years at 95 % C.L, how many diodes do we need ?. Let N be the number of diodes in the test, n the number of failures,t the time of the test in months, a_{dr} the derating factor then equation 5 of reference [3] can be expressed as.

$$\frac{2Nta_{dr}}{\chi^2_{95\%}(2n+2)} = 1954 \times 12 \; months \tag{6}$$

Using this equation we can now tabulate the number of diodes N needed to establish the reliability in one month for different numbers of failures (Note that this must be a " time truncated test " i.e for a fixed time irrespective of the number of failures. If the test stops after a certain number of failures it is called a "failure truncated test and the statistical inference is slightly different.). We tabulate for the two different derating factors 672(180) which arise from considering the number of failures in the CLEO experiment as 14(62).If the test is for x months then the required number is N/x (e.g for 2 months with no failures then require 105/2 = 53 diodes). It is essential that the diodes used in this test be screened first. Operating the diodes at 25^{o}C for one week at 75 V is an appropriate screen (the normal operating bias is 50 V).

Number of failures(n)	Number of diodes required (N) a_{dr}=672	Number of diodes required a_{dr}=180
0	105	390
1	165	618
2	219	819
3	270	1008
4	318	1190
5	365	1365

Table 2: Number of diodes required for a one month accelerated test at 70^o C to establish required diode reliability. Two different derating factors derived from the CLEO experiment are considered.

3 Conclusions

The 2744-08 photodiode gives a 10 % improved photoelectron yield compared to the same size 2744-03 photodiode. The equivalent noise charge performance is identical. The equivalent noise energy performance (ENE) of the crystal readout is thus improved by 10 %. To estimate the improvement in calorimeter performance we consider our benchmark fullsize Kharkov crystal with standard wrapping(see reference [1]). The wrapping is three layers of 1.5 mil (38μm) Teflon (note that the light yield is strongly dependent on the number of layers and the thickness of the wrapping). The improved diodes will now get a 103 KeV ENE with the direct readout compared to 135 KeV with the wavelength shifter readout scheme (using the old SiO diodes) . If the SiN diodes become available in the smaller wavelength shifter size we may also anticipate a 10 % improvement from 135 KeV to 122 KeV. The cost of the two solutions is comparable and if the reliability of these new diodes is adequate the direct solution is now more favorable. A short term accelerated test with a few hundred diodes should be sufficient to establish the reliability.

References

[1] C. Jessop *et al.* “Development of front end readout for the *BaBar* CsI calorimeter”, *BaBar* Note #216, 1994.

[2] E. Aker *et al.*Crystal Barrel Collaboration CERN-PPE/92-126

[3] C. Jessop *et al.* “Reliability Issues for the *BaBar* CsI calorimeter front end readout ”, *BaBar* Note #217, 1994.

[4] C. Bebek CLEO collaboration Nucl. Instrum. Methods **265**, 258 (1988)

[5] Dr. Yamamoto, Hamamatsu Corporation, Japan. Private communication