AS-TEXONO/98-09
December 4, 1998

A Research Program on Solid State Photo-detector in Taiwan : An Invitation for Feasibility Studies [1]

Henry Tsz-king Wong[2]
Institute of Physics, Academia Sinica, Taiwan

on behalf of
The TEXONO[3] Collaboration

Abstract

An R&D program in solid state photo-detectors is well-motivated from the physics point of view, and can conceivably be pursued in Taiwan. These notes summarize the reasons why they are attractive, what are the specific requirements for our applications, and what are commercially available at present. It is hoped that these notes will generate interests among the opto-electronics groups in Taiwan, so that some feasibility studies will be initiated.

[1]Available from http://hep1.phys.sinica.edu.tw/~exono/TEXT/TEXONO/texono9809.ps
[2]E-mail Correspondence: htwong@phys.sinica.edu.tw
[3]**T**aiwan **EX**periment **O**n **N**eutrin**O**

1 Goal of the Program

The ultimate goal of this proposed research direction is to be able to "build our own photo-detectors" for high energy physics and neutrino physics experiments, which are competitive from the performance-to-cost points of view, or may even turn out to be a new and unique device among the world's market (like the world-famous Hamamatsu 50 cm diameter photo-multipliers).

2 Motivations (Why Attractive and Conceivable?):

1. **Silion is Everywhere and Anywhere.** A lot of infrastructures and experience have been built up in the silicon technology. There must be room for major improvement and innovations beyond what is currently available

2. **Taiwan is Strong in the Silicon Technology.** This is one of the arenas we can compete with the world.

3. **Many Potential Applications in High Energy Physics.** Being compact, fast and insensitive to magnetic fields, solid-state devices already play a major role in silicon detectors as inner trackers (where the NCU group has much experience already) for high energy physics experiments. As photo-detectors, photo-diodes are massively used in electro-magnetic calorimeters (like the CsI(Tl) calorimeters in Belle and BaBar). Improvements on the current performance will certain enhance their already important roles.

4. **The Device can Sell!** Photo-multipliers have been used widely in industrial and medical applications. Solid-state photo-detectors can replace them in the future if they are able to compete in the performance-to-cost ratio. This can make a major impact in a lot of areas.

3 Our Specific Applications:

In high energy and neutrino physics experimentation, solid state devices offer several attractive features, compared to photo-multipliers:

1. **Compactness:** In both collider and underground experiments, space *is* money.

2. **Insensitive to magnetic field:** This is very important in collider detectors which typically has to operate in a O(1 T) magnetic field.

3. **Low Background components:** In underground experiments, the crucial ingredients is the control of background, a major component of which comes from radioactivity (^{238}U and ^{232}Th cascades, ^{40}K) in the detector components placed inside the shielding materials. In its most simplistic form, a solid-state photo-detector consists merely of high-purity silicon, porting materials and cables. The device is much better to be made radioactively pure than the complicated and large photo-multipliers.

The challenge to turn solid-state photo-detectors into a practical and competitive device seems to be their limited surface area. One of the directions which the TEXONO Collaboration is investigating as its long-term goal would be a 50 ton crystal calorimeter to study solar neutrinos. Such an experiment would require, from the readout side :

1. The range of 50000 readout channels, such that each channel should cost less than 200 USD (that is, a budget of 10 MUSD on the readout).

2. Large photo-sensitive (wavelength range 400-600 nm) area, with size larger than 10 cm^2. Position-sensitivities within the active area is not necessary for this application. One can tolerate inactive spots or lines on the active surface - it is the total active (light-collecting) area that matters.

3. Device in the "integrated" mode - that is, a single chip that does both photo-detection and provides electronic amplification. This can be an "avalanche photo-diode" or an "integrated photo-diode with pre-amplifier electronics".

4. Full control in each and every material used in the device. Silicon should not give much problems since it has to be clean and pure to be fabricated into a working device. The concern is on the porting materials and lead cables.

That is, the (naive physicist's) vision is that a module would simply be "a chip stuck to the crystal and with 3 cables (signal, voltage, ground) coming out".

4 What are Commercially Available at Present:

The TEXONO Collaboration is current pursuing a "pilot experiment" [1, 2] with 500 kg of CsI(Tl) crystal scintillator with photo-diodes readout. There will be a total of 500 channels needed. A pre-amplifier circuit developed by us will be attached to each photo-diode and the output will be brought out of the shielding.

We initially selected Hamamatsu Large-Area (10×20 mm^2) Si PIN Photodiodes S2744-08 becase this has been widely used in other electro-magnetic calorimeters (e.g. Belle and BaBar). The specification sheet, performance characteristics and mechanical drawings are depicted in Figures 1, 2, and 3, respectively. It is about 100 USD a piece.

However, we found out subsequently that the standard "shelf-item" photo-diode has the silicon grown on a ceramics substrate, a known (and proven by our measurements) radioactively bad material. After communications with Hamamatsu, they proposed a custom-designed photo-diode (S2744-08 SPL) for our applications, with the silicon grown on aluminium substrate and signals coming out through "flexible copper strips". After initial tooling cost, the unit price will be similar to the standard S2744-08. The mechanical drawing is shown in Figure 4. We are pursuing along this direction at present.

Hamamatsu also produces Silicon Avalanche Photo-Diode (APD). Most of the catalog products have their spectral response peak at the 800 nm range. There is a class of "Short Wavelength Enhanced" APDs whose specifications and performance characteristics are shown in Figures 5 and 6, respectively. The maximum diameter is only 5 mm (active area 0.2 cm^2).

There is another interesting new product from Hamamatsu called "Hybrid Photo-Detector" (HPD) as displayed in Figure 7. The model R7110U-07 has superb "single photo-electron" sensitivities and resolution. The diameter is 8 mm (active area 2 cm^2). The unit price is about 2000 USD but is expected to drop later on.

5 Outlook

The TEXONO Collaboration invites all interested groups to pursue a feasibility study in the fabrication of high-quality photo-detectors. There are potentials that we can make major impact in these directions. The Collaboaration will be happy to provide support and information. The organization and funding structures are totally open for discussions at this point.

References

[1] H.T Wong and J. Li, AS-TEXONO/98-04, LANL e-print hep-ex/9805024, to be published in *Procs. of the Workshop on the Japan Hadron Facilities Science* (1998), also in *Procs. of the XVIII Int. Conf. in Neutrino Physics and Astrophysics* (1998).

[2] C.P. Chen et al., TEXONO Collaboration, Technical Report, AS-TEXONO/98-07.

Large-area Si PIN Photodiodes

Type No.	Remarks	Outline*1	Window*2 Material	Active*3 Area (mm)	Spectral Response Range λ (nm)	Peak Sensitivity Wavelength λp (nm)	Photo Sensitivity S Typ. Peak (A/W)	BGO 480 nm (A/W)	CsI (Tl) 540 nm (A/W)
200 μm Wafer Thickness Types									
S3590-01	10 × 10 mm active area	1	Epoxy resin	10 × 10	320 to 1060	920	0.58	0.28	0.31
S2744-01	10 × 20 mm active area	2		10 × 20					
S3588-01	3.4 × 30 mm active area	3		3.4 × 30					
500 μm Wafer Thickness Types									
S3590-05	9 × 9 mm active area	1	Epoxy resin	9 × 9	320 to 1120	980	0.6	0.25	0.3
S3204-05	18 × 18 mm active area	4		18 × 18					
S3584-05	28 × 28 mm active area	5		28 × 28					

*1 See pages 10 and 11 for outlines.
*2 Windowless types (suffix "-02" series for 200 μm wafer thickness types and "-06" series for 500 μm wafer thickness types) are also available.
*3 This is the useful area for detecting light from the UV to near IR. For direct detection of radiation particles, the active area is expanded to a size equivalent to the depth of the depletion layer.
*4 Measured at following Reverse Voltage
S3590-01, S2744-01, S3588-01 : 30 V
S3590-05, S3204-05, S3584-05 : 100 V
*5 NEP (noise equivalent power) is given by

$$\mathrm{NEP} = \frac{\text{Noise Current } (\mathrm{A/Hz^{1/2}})}{\text{Sensitivity at } \lambda p\ (\mathrm{A/W})}$$

(Ta=25 °C)

Dark Current ID*4 Typ. (nA)	Dark Current ID*4 Max. (nA)	Cut-off*4 Frequency fc Typ. (MHz)	Terminal*4 Capacitance Ct f=1 MHz Typ. (pF)	NEP*4*5 Typ. (W/Hz^1/2)	Absolute Maximum Ratings: Reverse Voltage VR Max. (V)	Operating Temperature Topr (°C)	Storage Temperature Tstg (°C)	Type No.
1.5	5	35	75	3.9×10^{-14}	50	−20 to +60	−20 to +80	S3590-01
2.0	10	16	150	4.5×10^{-14}				S2744-01
2.0	5	35	80	4.5×10^{-14}				S3588-01
8	30	20	25	6.4×10^{-14}	150	−20 to +60	−20 to +80	S3590-05
15	90	20	80	1.2×10^{-13}				S3204-05
20	100	10	200	1.3×10^{-13}				S3584-05

Figure 1: The characteristic features of the Hamamatsu Large-Area PIN Photo-diodes. Our Pilot Experiment will use the equivalence of S2744-08.

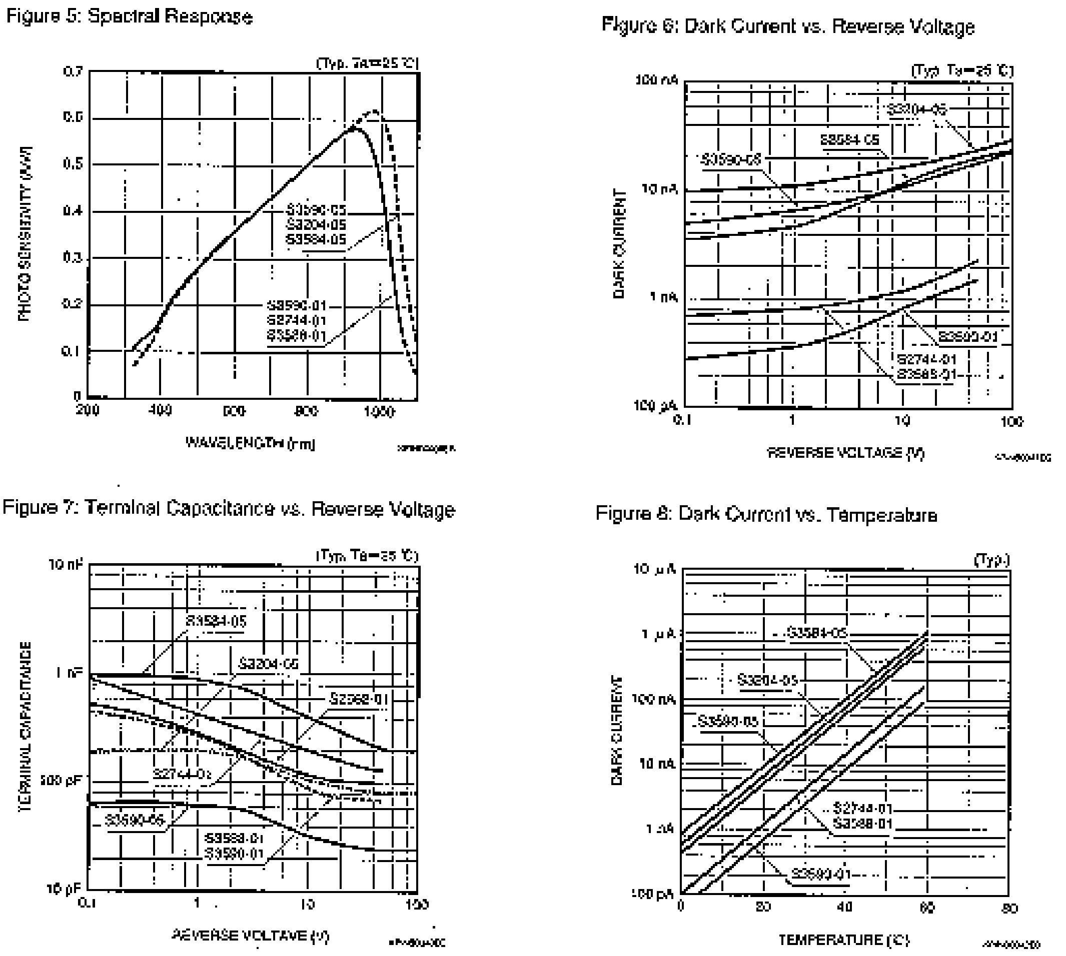

Figure 2: The characteristic curves for Hamamatsu Large-Area PIN Photo-diodes.

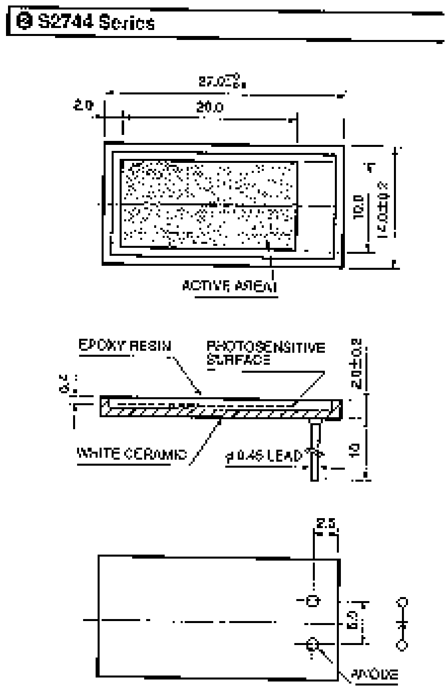

Figure 3: The mechanical drawing for the S2744 series.

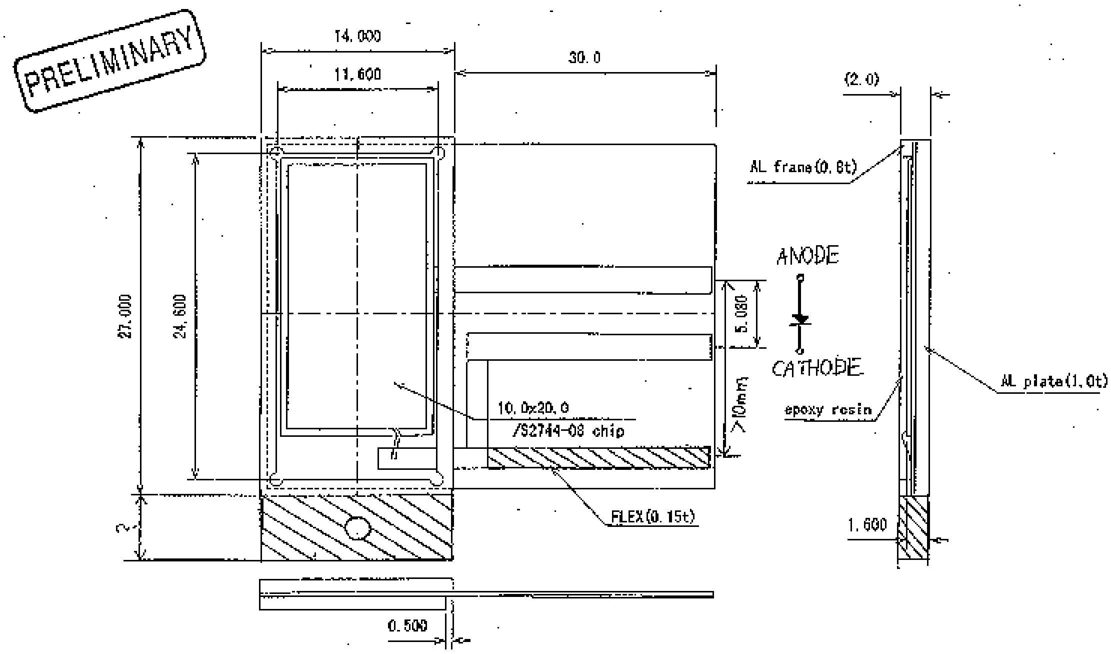

Figure 4: The mechanical drawing for the S2744-08 SPL which is custom-designed for the pilot experiment.

Si APDs (Short Wavelength Enhanced)

Type No.	Dimensional Outline (P.44,45)/ Window Material[A]	Package	Effective Active Area[B] Size (mm)	Effective Active Area (mm²)	Spectral Response Range λ (nm)	Peak[C] Sensitivity Wavelength λp (nm)	Photo Sensitivity M=1 λ =620 nm (A/W)	Quantum Efficiency M=1 λ =620 nm (%)
S5343	⑦/U	TO-18	ϕ1.0	0.78	200 to 1000	620	0.42	80
S5344	⑩/U	TO-5	ϕ3.0	7.0				
S5345	⑩/U	TO-8	ϕ5.0	19.6				

Ⓐ Window material. U: UV glass window
Ⓑ The range that allows multiplication
Ⓒ Measured with the gain listed in this specification table

(Ta=25 ℃)

Breakdown Voltage V_{BR} I_D=100 μA (V) Typ.	Breakdown Voltage V_{BR} I_D=100 μA (V) Max.	Temperature Coefficient of V_{BR} (V/℃)	Dark Current[C] I_D (nA) Typ.	Dark Current[C] I_D (nA) Max.	Cut-off[C] Frequency f_c R_L=50 Ω Typ. (MHz)	Terminal[C] Capacitance Ct Typ. (pF)	Excess Noise[C] Figure x λ=650 nm Typ.	Gain M λ=650 nm	Absolute Maximum Ratings: Operating Temperature Topr (℃)	Absolute Maximum Ratings: Storage Temperature Tstg (℃)	Type No.
150	200	0.14	1	10	250	15	0.28	50	−20 to +60	−55 to +100	S5343
			20	100	25	120					S5344
			300	1000	8	320					S5345

Figure 5: The characteristic features of Hamamatsu Silicon Avalanche Photo-Diode with short wavelength enhanced.

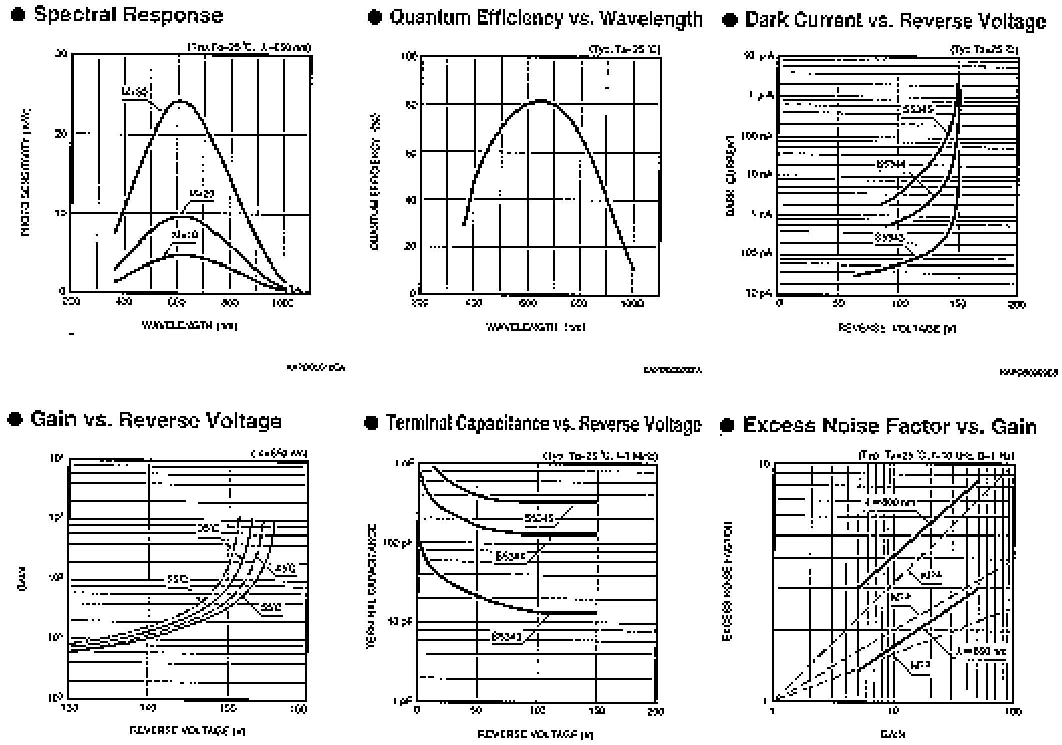

Figure 6: The characteristic curves for Hamamatsu Silicon Avalanche Photo-Diode with short wavelength enhanced.

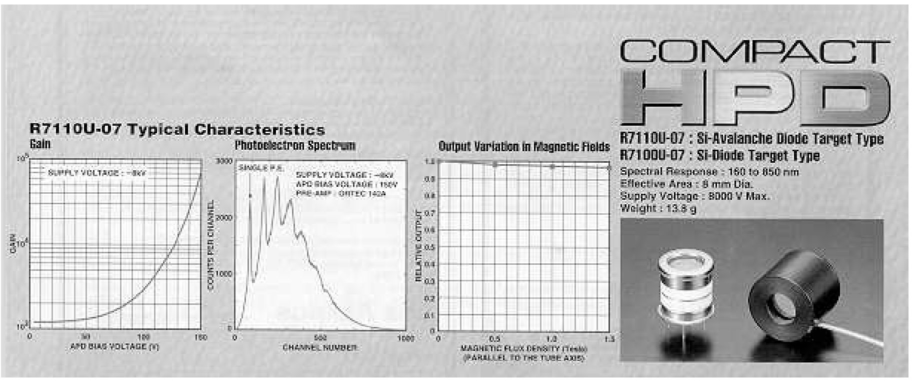

Figure 7: The characteristic curves for Hamamatsu Hybrid Photo-Detector.