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Optical Radiation Measurements:

Stability and Temperature Characteristics of Some Silicon and Selenium Photodetectors

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Optical Radiation Measurements:

Stability and Temperature Characteristics of Some Silicon and Selenium Photodetectors

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Preface

This is the fifth issue of a series of Technical Notes entitled OPTICAL RADIATION MEASUREMENTS. The series will consist primarily of reports of progress in or details of research conducted in radiometry and photometry in the Optical Radiation Section of the Heat Division and will appear about every six weeks.

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Any suggestions readers may have to improve the utility of this series are welcome.

Henry J. Kostkowski, Chief
Optical Radiation Section
National Bureau of Standards

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STABILITY AND TEMPERATURE CHARACTERISTICS OF SOME SILICON AND SELENIUM PHOTODETECTORS

Kshitij Mohan, A. Russell Schaefer and Edward F. Zalewski*

This paper describes the comparison of some characteristics of selenium barrier layer photocells and silicon PIN and PN type photodiodes operated in the photovoltaic or non biased mode. The work was done to study the suitability of these detectors specifically for goniometric measurements of flux and possibly for other photometric (or radiometric) measurements. The characteristics studied were the stability of detector output over approximately twenty hours, fatigue or light memory effects over short periods of time, and the temperature dependence of detector output.

Key words: Fatigue; light memory; photocells; photodiodes, photometry; radiometry; selenium; silicon; stability; temperature dependence.

1. Introduction

Since the advent of physical photometry, barrier layer selenium photovoltaic cells have been used extensively in photometry at NBS. The selenium cells used were equipped with photopic filters that approximately corrected the response of the detector to match the CIE defined spectral luminous efficiency in photopic vision.

Selenium cells have been found [1,2,3][1] to exhibit certain characteristics, such as fatigue, that are undesirable in goniometric measurements of total flux. In the last decade solid state technology has made available several new kinds of photodetectors, some of which seem promising for photometric applications. In particular, silicon photodiodes appear to be a possible replacement for selenium barrier layer photocells.

We have examined and compared certain characteristics of two selenium detectors and several different types of silicon detectors to ascertain their suitability for use in our work. The study is by no means exhaustive or definitive and was initially meant to be an in-house guide for the selection of a specific detector for a specific purpose. It is being published because we are unaware of any other comparative study of these detectors and also because it may give potential photometric users of these devices a feel for the problems involved.

We have tested photodetectors for three characteristics: the long-term stability over periods of about 20 hours, light memory or fatigue effects over short time periods, and the sensitivity to changes

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*National Bureau of Standards research associate from the Electrical Testing Laboratories (acting on behalf of the Lamp Testing Engineers Conference).

[1] Figures in brackets indicate the literature references at the end of this paper.

in temperature. Not all the detectors were tested for all these characteristics. Appendix A is a list according to the type and manufacturer of the detectors that were tested. In this report we shall refer to each detector by the numbers assigned in Appendix A.

Among the silicon detectors, we have studied the PN type of photodiodes and the PIN type of both the Schottky and planar diffuse varieties. Descriptions of these devices are available in the manufacturers' literature, but for the sake of completeness and as an introduction we shall include descriptions of some typical devices here.

The PN type of photovoltaic cell consists essentially of a junction of two types of material, referred to as p-type and n-type respectively. The p-type is doped with impurities such that it is a "hole" conductor; i.e. there is a deficiency of electrons in the material. The n-type material has been doped to provide a surplus of electrons. At the interface of these two materials the surplus electrons and holes diffuse across the junction to combine with each other and form a depleted "barrier" region which is now free of holes and electrons. The p-type material near the junction, having lost holes, acquires a negative space charge and correspondingly the n-type material near the junction, having lost electrons, acquires a positive space charge. Thus an electric field is maintained across the depletion barrier. This electric field will then inhibit further diffusion of the electrons and holes so that a state of equilibrium is reached. Now, when a photon is incident on the junction it can excite an electron from the valence band to the conductance band. This will happen only if the incident photon has an amount of energy greater than the energy difference between the valence and the conductance bands. This difference is known as the "energy gap" for the material and is different for different kinds of material. The excitation of the electron makes it free to move in the material and a corresponding free "hole" is also created. The process is known as the creation of a hole-electron pair. Ordinarily, if other free holes or electrons are present there would be a recombination of the holes with the electrons or the pair could recombine itself. But if the electron-hole pair is created in the depleted region where there are no other free holes and electrons present then the electron will be accelerated to the positive space charge in the n-region and the hole to the negative space charge in the p-region. If there is a load resistor across the ohmic (external) contacts on the n-region and the p-region, there will be a flow of electrons from the n-region through the load to the p-region. Since by convention a current flow is said to be in the opposite direction of the electron flow, there will be a current flow from the p-region through the load to the n-region.

If every photon incident on the detector were to produce an electron-hole pair, and if all these electrons and holes were to migrate as predicted, the detector would be absolutely linear.

The PIN type of silicon photodiode derives its name from the fact that it consists of a p-type semiconductor and a n-type semiconductor with a layer of nearly intrinsic (i.e. almost pure, non-doped) region of silicon in between. This intrinsic layer acts as an extended depletion layer which can, under appropriate conditions, improve the linearity and response time of the photodiode. In the photovoltaic mode these PIN photodiodes operate in a manner similar to the PN photodiodes described above. In the photoconductive or biased mode, a voltage is externally applied across the electrodes such that there is an electric field completely across the photodiode and the intrinsic region is fully depleted. When a photon is absorbed in the silicon, an electron-hole pair is created and propelled by the external field to their respective electrodes, creating a current through an external load as before.

In the Schottky barrier PIN silicon photodiode, the p- and n-regions are created by depositing a thin gold layer on one side of a pure silicon wafer and an aluminum (or other metal) layer on the other side. The gold layer is transparent and forms the front side of the detector. In the planar diffuse type of silicon photodiodes, a layer of aluminum (or other metal) is evaporated on one side of a silicon wafer and on the other side silicon dioxide is formed. Then through an opening in the oxide, an impurity is diffused into the silicon to form a p-type layer. The spectral response of the detector depends not only on the energy gap of the pure silicon but also on the spectral transmittance of the material on the front surface of the detector.

All the detectors that we studied were operated in the unbiased or photovoltaic mode rather than the photoconductive mode. The advantages of the photoconductive mode are an improved linearity and a faster response time. These arise from the fact that the strong electric field applied externally to the junction fully depletes the intrinsic region and creates greater carrier acceleration. However, the application of an external voltage also leads to a leakage or dark current which is large compared to the signal being measured. This dark current is not constant in time and, therefore, makes the photoconductive mode of operation unsuitable for dc measurements. In the photovoltaic mode the dark current was usually quite small (less than 0.1% of our measurement signals).

2. Experiments and Results

2.1 Stability and Fatigue Effects

One important requirement for a detector that is used in goniometric photometry is that it should be stable; that is, it should maintain its calibration during the course of a set of measurements which could take up to several hours to complete. Another requirement is that the detector should achieve a stable output within seconds after a change of illumination.

We have studied the stability of detector output for periods of approximately twenty hours. We have also investigated the short term stability in a 10-15 minute interval by noting any fatigue effects or other kinds of instabilities that might result after a change in illumination level.

The experimental apparatus consisted of a 120 volt, 750 watt quartz-halogen EHF type lamp that was mounted on one end of a 3 meter optical bench. The lamp was operated at a constant current of 4.8300 ± 0.0001 amperes and the voltage was approximately 75 volts. Mounted at the other end of the optical bench was a detector holder that could hold two test detectors simultaneously. A third detector with an independent current-to-voltage converting amplifier was placed about 50 cm from the lamp and to one side of the optical axis. This detector was used to monitor the output of the lamp in each test.

One may question the stability of the lamp and monitor detector combination. However, previous work by one of the authors (E.F. Zalewski) that compared several lamps of the above type using detector No. 1 had shown this lamp and detector combination to be stable to less than 0.1%. Of the six runs in table 1 in which this detector and the monitor detector are compared, only one run shows a disagreement of more than 0.2% (run No. 3). This run, it should be noted, shows a larger change in the lamp voltage than was observed during any other run. We believe, therefore, that any detector drift that differs by more than 0.2% from the monitor detector is actually a change in detector response and not a change in lamp output.

When examining detectors which did not have built-in photopic filters, a set of infrared and ultraviolet cut-off filters was used to block radiation from all but the visible part of the spectrum. The ambient temperature near the detector holder was monitored by using thermocouples. Except in the case of detectors with built-in amplifiers, the outputs of all detectors were read by using either of the two current-to-voltage converters described in an earlier paper [4] and a digital voltmeter. Automatic data acquisition equipment was used to collect data.

For the long term stability measurements, the outputs of the test detectors and the monitoring detectors, the voltage and current of the lamp, and the temperature of the detector holder were noted at intervals of 20 minutes over approximately 20 hours. As mentioned earlier, all the test detectors were operated in the photovoltaic mode.

Table 1 summarizes the results of the long term stability measurements for the different detectors. The detectors are briefly distinguished in the following manner: Si-S, silicon Schottky; Si-D, silicon diffuse; and Se, selenium. The numbers for the range of noise are the short term fluctuations above and below a straight line approximation of the detector drift. The numbers for the amount of drift for individual detectors have not been adjusted for lamp drift as sensed by the monitor detector. Each row in table 1 represents a single run so that detector drifts appearing in the same row indicate that those detectors were used simultaneously to provide comparisons between them. Where a plus or a minus appears before the number for percent drift, it indicates that the increase or decrease in detector output was approximately monotonic. The cases where the detector output first drifted up then down or vice versa, are indicated in the table. The temperature of the test detector holder was monitored in several runs and found to be within ±0.5 °C. Except for Nos. 2, 4, 5, and 10, the detectors appear to be stable to within 0.02% per hour--a fact that should meet most photometric requirements for stability.

All the measurements had been taken after the lamp had been warmed up for about 20 minutes, during which time the detector was illuminated.

TABLE 1

PERCENT DRIFT IN DETECTOR OUTPUT OVER APPROXIMATELY TWENTY HOURS

Run No.	Lamp Volt. Drift	Temp. Changes	Monitor Detector Drift	Test Detector Drift (in percent)									
				DETECTOR 1 (Si-S)	DETECTOR 2 (Si-S)	DETECTOR 3 (Si-D)	DETECTOR 4 (Si-S)	DETECTOR 5 (Se)	DETECTOR 6 (Se)	DETECTOR 7 (Si-D)	DETECTOR 8 (Si-D)	DETECTOR 9 (Si-S)	DETECTOR 10(Si-D)
1	-0.04%		-0.15%	-0.15	+0.4/6 hrs level/5 hrs -0.15/4 hrs								
2	-0.025		-0.2	-0.25	+0.35/7 hrs then ±0.1								
3	-0.1	+0.25 °C	-0.26	+0.1	level								
4	-0.03	+0.1 -0.3	-0.22	-0.1				-0.7					
5	-0.02	±0.5	-0.25	-0.1					-0.2				
6	<0.01		<0.1			level/4 hrs -0.2/9 hrs +0.15/7 hrs							
7	<0.002		<0.1				+0.8						
8	-0.03		-0.25				-0.55						
9	<0.01	±0.1	-0.15	-0.2			-0.15/7 hrs +0.1/11 hrs						
10	<0.01		-0.05							-0.1			
11	<0.01		-0.1								-0.1		
12			<0.1									<0.1	
13		±0.3	<0.1				-2.0					<0.1	
14		+0.5	-0.2										-1.0
RANGE OF NOISE			0.05	0.05	0.1	0.06	0.05	0.1	0.05	0.1	0.1	0.05	0.3

TABLE 2

DETECTOR OUTPUT DRIFT DURING 10 MINUTES AFTER SHUTTERING FOR 20 MINUTES

DETECTOR	DRIFT	RANGE OF NOISE *Before*	RANGE OF NOISE *After*
1 (Si-S)	less than noise	0.1%	0.1%
3 (Si-D)	less than noise	0.05	0.05
4 (Si-S)	less than noise	0.06	0.06
5 (Se)	-0.4%	0.06	0.20/2 min then 0.06
7 (Si-D)	less than noise	0.1	0.25
8 (Si-D)	less than noise	0.1	0.3
9 (Si-S)	less than noise	0.1	0.1

TABLE 3

TEMPERATURE DEPENDENCE OF DETECTOR OUTPUT IN THE INTERVAL 20 TO 30 °C

DETECTOR	BLOCK TEMPERATURE DEPENDENCE	REMARKS
1 (Si-S)	-0.06% per °C	
2 (Si-S)	-0.02	
3 (Si-D)	±0.07*	Minimum near 24 °C
4 (Si-S)	-0.12	
5 (Se)	+0.06	
7 (Si-D)	±0.07*	Maximum near 24 °C
9 (Si-S)	±0.08*	Maximum near 24 °C
11 (Si-D)	+0.12	

*These temperature dependences went through a minimum or a maximum. The numbers represent the slope on the steep part of the temperature dependence curve.

This was done to avoid any short term fatigue effects. These were studied separately.

Using the same experimental set-up described above, detectors were checked for any fatigue or light hysteresis effects by first warming up the lamp and illuminating the test detector and then shuttering the detector for a period of about 20 minutes. The shutter was then opened and the detector output and other parameters were read out at 20 second intervals for a period of 10 minutes. Table 2 summarizes the drift and noise that were observed after the shutter was opened. The numbers for range of noise *Before* and *After* refer to the noise ranges observed before the detector was shuttered for 20 minutes and after it was again illuminated. No drifts above the noise level were observed except for detector 5 which was a selenium photocell. This detector showed the expected fatigue effect [2,3]. A comparison plot of the output of this detector and detector 1 is shown in the figure. Detectors 7 and 8 did not show any drift, but the noise on both showed a large increase in the 10 minutes after the shutter was opened. It seems that a longer time period is required for them to achieve equilibrium.

2.2 Temperature Dependence

The temperature dependence of a set of detectors was studied over the range of approximately 20 °C to 30 °C. The experimental apparatus remained the same as in the stability studies except that the detectors were mounted in a metal block which was cooled or heated by two thermoelectric plates. The detectors were shielded from room temperature changes by a transparent plastic box surrounding the detector holder.

The temperature of the detector was changed by altering the amount of current passing through the thermoelectric plates. The current polarity determined whether the detector was being cooled or heated. Temperature was measured by two thermocouples, one of which was embedded in the metal block that held the detectors. The metal detector cases were in good thermal contact with this block. The other thermocouple measured the temperature of the air surrounding the detector in the plastic box.

Readings of the detector outputs and other monitoring parameters were taken when both the temperature of the block and the ambient temperature within the box had achieved equilibrium. Table 3 gives the changes in detector output per °C change of block temperature. Two detectors, No. 4 which is a Schottky type PIN device and No. 11 which is a diffuse PIN device, showed temperature dependences slightly greater than 0.1% per °C. Some of the detectors had a temperature coefficient which went to zero (minimum or maximum in the response curve) near room temperature. The maximum slope is, therefore indicated in table 3.

3. Conclusions

As mentioned in the introduction, this study was not meant to be a definitive or exhaustive study of all the different kinds of photodetectors available today, hence we can not draw any general conclusions of the relative merit of any manufacturer of these detectors. Detectors of the

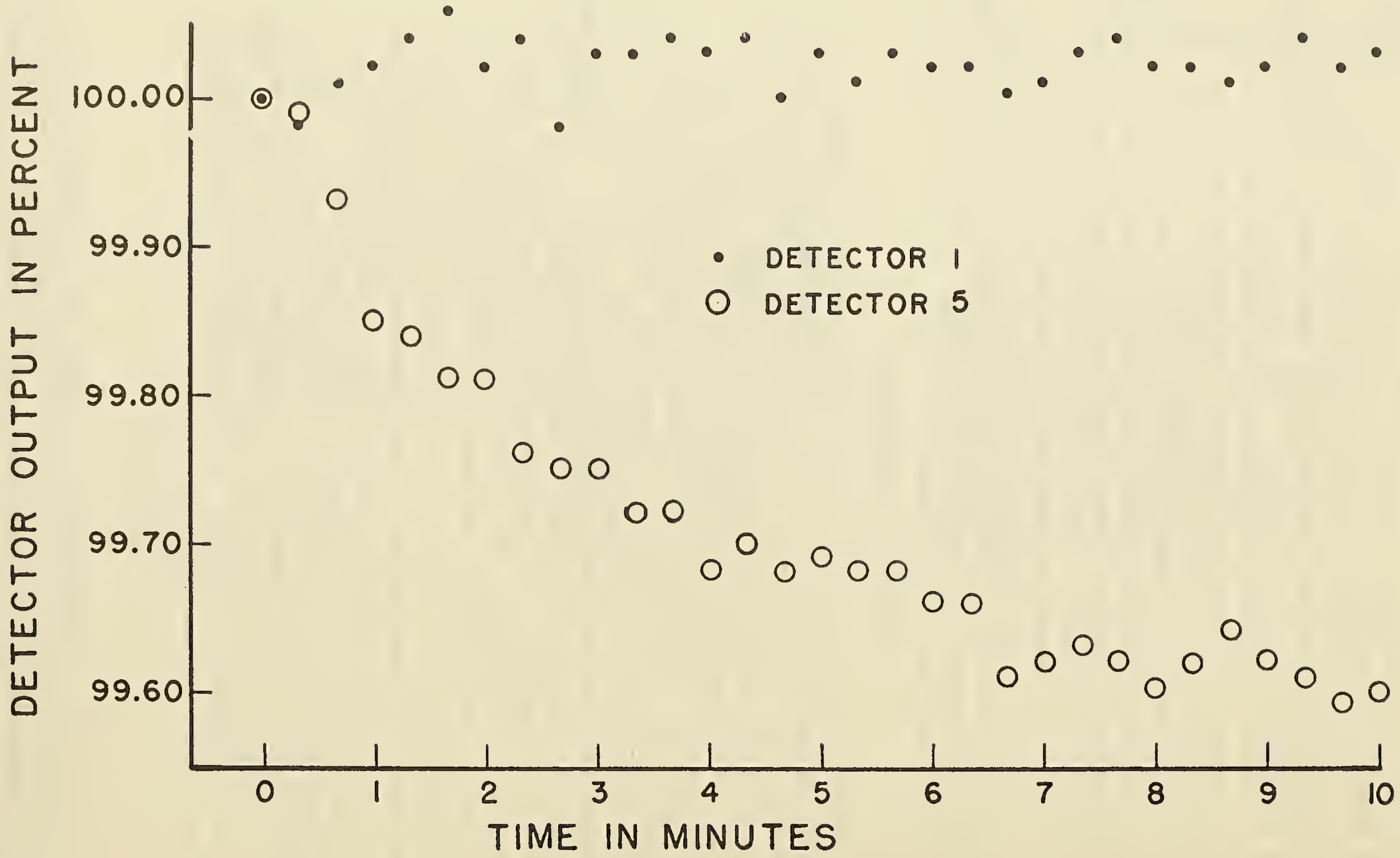

Fig. 1. Initial short term drift in detector output. Output normalized to initial reading.

same type and manufacturer may at times perform differently as is evidenced by the differences in the stabilities of detectors 1 and 2; both were of the same type, were made by the same manufacturer, and had the same model numbers.

We can, however, draw some conclusions and also get an indication of where problems *may* exist. The study also gives us estimates of a part of the uncertainty that should be taken into account when these detectors are used in specific applications.

1. In photometric applications (dc measurements) the silicon detectors of the kinds that we studied should be operated in the photovoltaic or non-biased mode.

2. Several of the silicon detectors studied proved to be sufficiently stable for applications in precise photometry: the instability of output was less than 0.02% per hour. However, some of the detectors were significantly less stable. Thus silicon detectors have to be individually tested and selected for optimum performance.

3. The silicon detectors did not show any identifiable fatigue or light memory effects, whereas the selenium photocells studied showed the expected fatigue. Some silicon detectors are very noisy when first illuminated and it sometimes can take several minutes before the noise decreases and the cells achieve equilibrium. In goniometric measurement of flux, effects due to changing levels in illumination are undesirable. One cannot therefore use the selenium detectors without some sort of arrangement to take account of these effects. However, there are some silicon detectors that can be used; again, the characterization of the specific detector is required.

4. All the detectors showed sensitivity to temperature changes and if they are to be used in photometric work at the few tenths of a percent level of precision, temperature control within ±0.5 °C or less is necessary. For precise photometric work the specific detector chosen should first be characterized for its temperature sensitivity and then the required amount of temperature control should be built into the detector holder.

Detectors 9 and 10 were silicon detectors that had a current-to-voltage converting amplifier built into the detector case. Detector 9 had stability and temperature dependence characteristics that were of the same order as the other silicon detectors. Detector 10, however, showed larger drift and noise. Since these detectors are used without external operational amplifiers, laboratories that do not now have such amplifiers may consider using them.

For goniometric measurements of flux the detectors should also be tested for linearity and spectral response. The linearity, however is more critical than spectral response for our purposes. Some preliminary linearity tests using the inverse square approximation have shown that silicon cells operated in the photovoltaic mode are linear within 0.1% over two decades. Future studies of these detectors will include more detailed linearity and spectral response measurements.

4. References

1. Wilkinson, F. J., "Heterochromatic Photometry with Selenium Photovoltaic Cells", NSL (Australia) Tech. Paper No. 23, 15 pages, 1968.
2. Preston, J. S., Rev. d'Opt. 27, 513 (1948).
3. Preston, J. S., J. Sci. Instrum. 27, 135 (1950).
4. Zalewski, E. F.; Schaefer, A. R.; Mohan, K. and McSparron, D. A.; "Optical Radiation Measurements: Photometric Instrumentation and Research (1970-71)". NBS Tech. Note 594-2, 44 pages, Sept. 1972.

Appendix A

List of Detectors Tested with Assigned Numbers

Assigned No.	Detector Type	Manufacturer
1	Silicon PIN Schottky, photopically corrected	A
2	Silicon PIN Schottky, photopically corrected	A
3	Silicon PIN diffuse	A
4	Silicon PIN Schottky	A
5	Selenium barrier-layer, photopically corrected	B
6	Selenium barrier-layer, photopically corrected	C
7	Silicon PIN diffuse	D
8	Silicon PIN diffuse	D
9	Silicon PIN Schottky with built in op amp, photopically corrected	A
10	Silicon PN diffuse with built in op amp, UV optimized	D
11	Silicon PIN diffuse	A

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16. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)

This paper describes the comparison of some characteristics of selenium barrier layer photocells and silicon PIN and PN type photodiodes operated in the photovoltaic or non biased mode. The work was done to study the suitability of these detectors specifically for goniometric measurements of flux and possibly for other photometric (or radiometric) measurements. The characteristics studied were the stability of detector output over approximately twenty hours, fatigue or light memory effects over short periods of time, and the temperature dependence of detector output.

17. KEY WORDS (Alphabetical order, separated by semicolons) Fatigue; light memory; photocells; photodiodes; photometry; radiometry; selenium; silicon; stability; temperature dependence.

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