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A PHOTOMETER USING SILICON DIODES AS LIGHT DETECTORS

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RESUMEN

Se construyó y probó en el Observatorio de San Pedro Mártir un fotómetro utilizando como detector en el rango espectral de 0.4-1.1μm a un foto-diodo de silicio seleccionado. Se hizo fotometría BVRI de estrellas. De los resultados preliminares, el uso de estos dispositivos en Astronomía es prometedor. La instrumentación y técnicas empleadas son las mismas que para detectores de infrarrojo. Por ello, los diodos de silicio resultan ser un complemento natural de estos últimos en la parte azul del espectro de luz. Utilizando un diodo de silicio y un detector de InSb, es posible hacer fotometría desde 0.3 hasta 5.5μm con un solo instrumento.

ABSTRACT

A photometer using a selected silicon photodiode as light detector in the 0.4-1.1μm spectral range was built and tested at the San Pedro Mártir Observatory. BVRI photometry of stars was obtained. From the preliminary results, the use of such devices in astronomy is promising. The instrumentation and techniques are the same as for infrared photodiodes. Thus, silicon diodes complement in a natural way the latter in the short wavelength range of the spectrum. Using a silicon diode and an InSb detector, photometry from 0.3 to 5.5μm with a single instrument is possible.

Key words: SILICON PHOTODIODES — PHOTOMETRY — INFRARED PHOTOMETRY.

I. INTRODUCTION

The use of silicon diodes as light detectors has diffused itself into many fields, mainly in radiometry, because of the many advantages that such devices offer: a wide spectral response (0.2-1.13μm), high stability over long periods of time, linearity over several decades (within 1% over 6 decades, i.e., a 15^m range), high quantum efficiency (90% at $\lambda = 0.9\mu$m; higher at shorter wavelengths), low noise, fast response, no fatigue or hysterisis effects, and low prices. The peripherical electronics are simple and inexpensive. To our knowledge, their use in astronomy has been very limited. Little work has been done to apply these detectors to intermediate and broad-band photometry. With this purpose in mind, we decided to test these devices. From the results of BVRI photometry carried out at the 84 and 152 cm telescopes

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of the San Pedro Mártir Observatory, the use of such devices in astronomy seems promising. A 16^m star was observed with a signal-to-noise ratio equal to unity (30 Hz bandwidth) in the V band at the 152 cm telescope. Further laboratory and observational work is being done; final results will be published later.

II. SILICON DIODES AS LIGHT DETECTORS

Silicon diodes with absolute responsivities of 0.65 A/Watt at $\lambda = 0.9\mu$m are now commercially available (see, *Technical Data Sheets on Photodiodes,* EG+G Electro-Optics Division, 1973; hereinafter EG+G). For such sensitivities at this wavelength, a quantum efficiency of 89% can be computed. The responsivity curve given by the manufacturer for diodes such as the one used in this work is reproduced in Figure 1. The cutoff of sensitivity at the long wavelength end is produced by the energy gap between the valence and conduction bands of the semiconductor. For intrinsic silicon, photons with $\lambda \leq 1.127\mu$m are able to raise electrons from the valence to the conduction band and can be detected. If photons are too energetic they do not produce photoevents in the depletion layer (they are absorbed before reaching this region) and the capability of the barrier to separate the charge carriers is not used. Electrons and holes eventually recombine without being detected. The actual short wavelength limit for commercial devices is around 0.2μm.

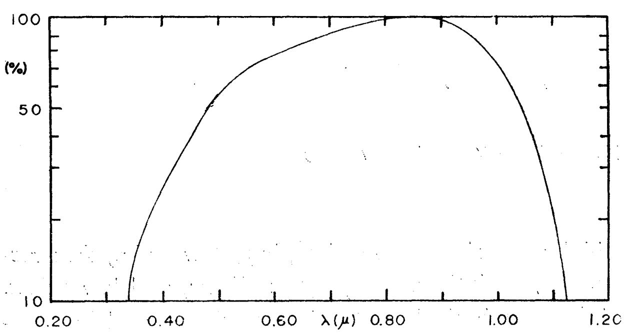

FIG. 1. Relative spectral response of the SGD diode series taken from technical data sheets of EG+G.

The photodiodes can be operated in three modes: photoelectromagnetic, photovoltaic, and photoconductive. In the spectral range of interest in this work, only the last two modes are considered. Photoconductive diodes have a faster response time (lower capacitance). Thus, reverse bias voltage should be used and, if possible, the chopping frequency should be fixed in terms of the signal-to-noise ratio of the device at normal working conditions. Cooling the detector increases the internal effective resistance by a factor of two for each 5°C decrement in temperature (EG+G, 1973). By cooling to −74°C, the responsivity improves slightly in the blue but deteriorates slightly at the longest wavelengths. For all diodes and bandpasses considered in this work, a substantial improvement of the signal to noise ratio (by more than $2^m.5$) with respect to room temperature was observed. This agrees with the qualitative results mentioned by the manufacturer.

The P.I.N. diode SGD-040L (EG+G) was chosen from the ones we had on hand because of its measured noise equivalent power (NEP [0.7μm, 90 Hz, 1 Hz] = 4×10^{-14} Watt $Hz^{-1/2}$). This particular diode has a Corning 7052 lens cap, but for good results in the ultraviolet, a plain quartz window should be used instead. At dry ice temperature, an effective internal resistance (given by the channel impedance between the photodiode and its guard ring) of 10^{11} ohm was estimated, and a dark current of 0.6 pA was measured. A load resistor of 10^{13} ohm was used. Under these conditions, an equivalent noise current of 4.7×10^{-16} A was estimated (shot noise predominant). The input stage of the preamplifier was a cooled field-effect transistor. For the above mentioned conditions and for broad-band photometry with a 152 cm telescope, a star of V = $16^m.9$ would give a signal equal to the noise current. A 16^m field star in the Pleiades Cluster was actually observed, with a frequency bandwidth of 30 Hz given by a passive bandpass filter at the output of the preamplifier (see Figure 2). For a one Hertz frequency bandwidth, one should be able to measure under the same circumstances a $17^m.8$ star. The photodiode (EG + G, UV100B) used by Johnson (1976) in his interferometer has much larger resistance ($\geq 4 \times 10^8$ ohms at 25°C) and a much lower dark current. Our measures of the sensitivity of this detector-amplifier combination yielded an NEP = 1.6×10^{-16} $WHz^{-1/2}$ at 9 000 Å. This is more than a factor of 100 better than we found for the diode used for the stellar observations and it indicates that stars at least as faint as 18^m can be observed with a 152 cm telescope, with excellent precision.

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III. THE PHOTOMETER

The photometer was the JHKL photometer described by Johnson and Mitchell (1962), modified to use silicon diodes and dry ice. No field lens was used. The chopper was aluminized and consisted of a two level mirror. The chopping frequency was set at 90 Hz. Sky and star-plus-sky were measured alternately at this frequency, and after a preamplifier stage, demodulated with a phase sensitive detector built by Johnson (amplifier #8). For stars fainter than $V \cong 13^m$, the amplifier's noise predominated, and for this range, a commercial Lock-in amplifier was used instead. (This amplifier limitation is not fundamental; a higher-gain preamplifier would have overcome the noise of amplifier #8). The synchronous signal was picked up at the mirror-chopper with the help of another photodiode and a three-blade chopper. For a general and comprehensive description of techniques and instrumentation, the reader is referred to the article by Low and Ricke (1974).

The filters selected together with the detector were an attempt to match the BVRI bandpasses (Johnson and Mitchell 1962). The filters are:

B = Corning 5030 + Corning 9782 + 2mm Schott GG13
V = " 9780 + " 3384
R = " 3480 + " 4600
I = " 2600 + " 3850

The system's normalized response curves, considering only the detector's sensitivity and filter transmission, are shown in Figure 3. The respective effective wavelengths (King 1952) and half intensity bandwidths are given in Table 1.

TABLE 1

EFFECTIVE WAVELENGTHS AND HALF INTENSITY BANDWIDTHS

FILTER	$\lambda_0(\mu m)$	$\Delta\lambda(\mu m)$
B	0.48	0.11
V	0.55	0.08
R	0.68	0.08
I	0.89	0.30

The preamplifier used is shown in Figure 2. By cooling the field effect transistor, a substantial improvement in the signal to noise ratio for this device was obtained, in agreement with the report of Craig and Sesnic (1973). The drain current of the FET should be set to optimize the signal-to-noise ratio of the preamplifier.

IV. THE OBSERVATIONS

Observations of bright stars to compare with the UBVRI system (Johnson *et al.* 1966). were carried out at the 84 cm telescope during three consecutive nights in July, 1975. We also attempted to measure the dynamical range of the photometer, in October 1975, by observing two additional nights at the 152 cm telescope.

TABLE 2

BVRI PHOTOMETRIC OBSERVATIONS

(84 cm Telescope)

BS	Spectral Type		V	B-V	V-R	V-I	R-I	N
39	B2	IV	2.81	—0.22	—0.13	—0.34	—0.21	4
45	M2	III	4.78	1.57	1.31	2.45	1.11	4
6347	M3	III	4.98	1.62	1.41	2.67	1.27	6
6355	A3	IV	4.90	0.15	0.09	0.14	0.04	6
6603	K2	III	2.75	1.15	0.83	1.37	0.54	4
6629	A0	V	3.75	0.00	0.05	0.05	0.00	4
7001	A0	V	0.05	0.00	0.01	—0.01	—0.02	3
7891	B9.5	V	4.85	—0.03	0.00	—0.01	—0.02	7
7939	K2	III	4.94	1.18	0.87	1.45	0.58	6
8430	F5	V	3.76	0.46	0.40	0.64	0.24	2
8622	O9	V	4.87	—0.19	—0.09	—0.29	—0.19	4
8632	K3	III	4.45	1.32	0.97	1.58	0.62	4

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An artificial star whose apparent magnitude varies by less than 0ᵐ004 magnitudes per night was used to check stability of the photometer and for positional errors. No systematic deviations were observed and the stability of the photometer was found to lie within 0ᵐ005 per night. Due to the lack of a field lens, the positioning of stars was critical and the centering of stars was done by maximum deflection.

For the July observations, the probable errors of a single observation are given in Table 3. The mean extinction coefficients of the two seasons are presented in Table 4. The photometric system is presented in Table 2. The star names and spectral types are from the Catalogue of Bright Stars (1964 edition). The last column of this table gives the number of observations made on each star. In transforming the ins-

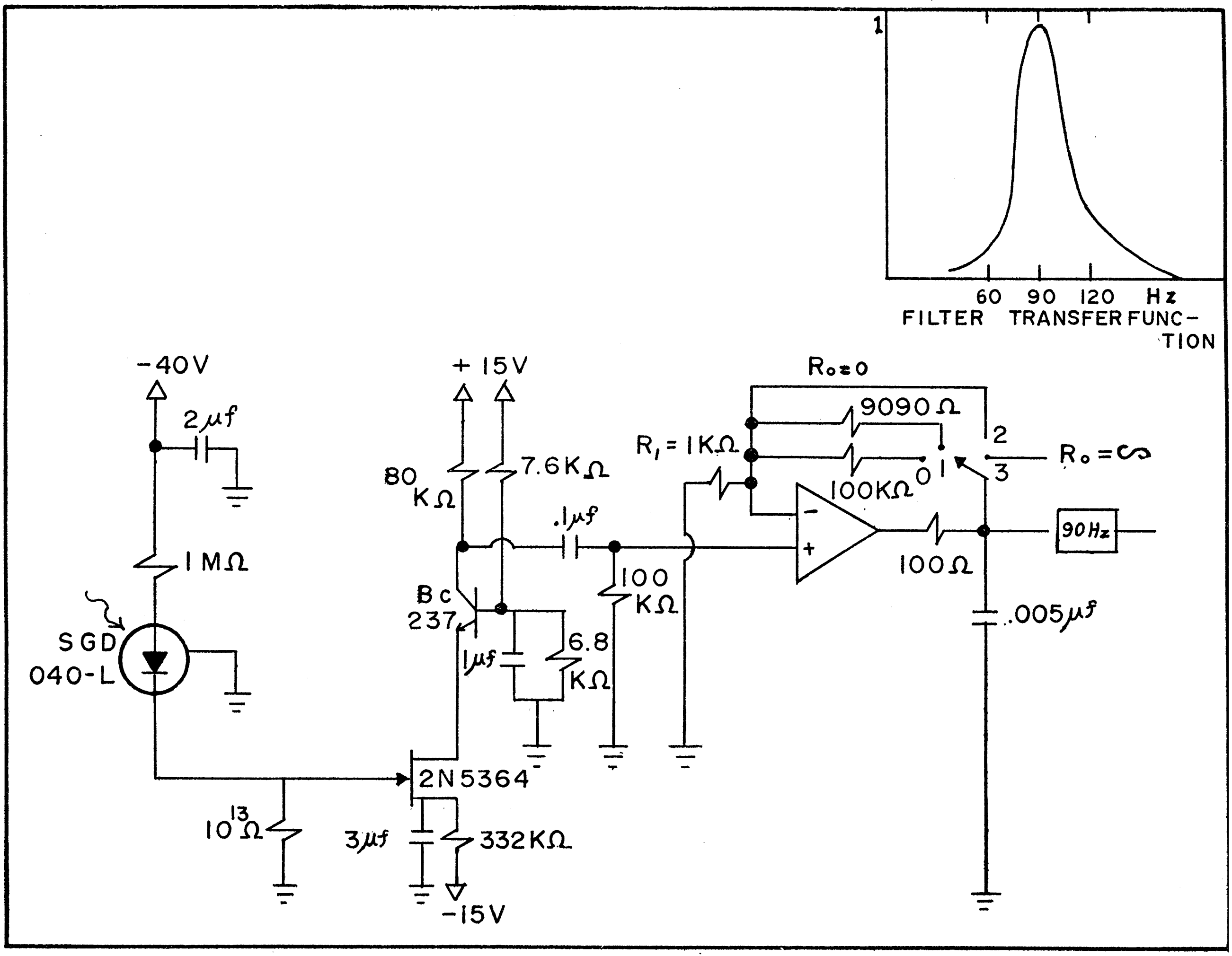

Fig. 2. Preamplifier used for the SGD-040L silicon pinphotodiode.

TABLE 3

PROBABLE ERROR OF A SINGLE OBSERVATION OF A STAR JULY 1975

ε_V	ε_{B-V}	ε_{V-R}	ε_{V-I}	ε_{R-I}
0ᵐ020	0ᵐ025	0ᵐ015	0ᵐ027	0ᵐ025

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TABLE 4

MEAN EXTINCTION COEFFICIENTS

	K_B	K_V	K_R	K_I
JULY	0.316	0.242	0.164	0.124
OCTOBER	——	0.22	0.18	——

TABLE 5

VR OBSERVATIONS
(152 cm Telescope)

	11/12 October		12/13 October	
Name	V	V-R	V	V-R
BS 38	2.85	—0.10	2.88	—0.04
BS 45	4.78	1.27	4.79	1.26
BS 1411	3.87	0.74	3.79	0.72
BS 1412	3.36	0.17	3.39	0.24
BS 1457	0.86	1.28	0.88	1.28
BS 2491	——	——	—1.48	—0.10
P1*	——	——	8.94	0.58
P2*	——	——	13.00	—0.08
P3*	——	——	9.33	0.49
P4*	10.99	0.82	——	——
P5*	15.89	0.23	——**	——**

* Field stars of the Pleiades Cluster.

** Because of noise and seeing, the star could not be measured in the V-bandpass in a 110 sec. integration time. The R-magnitude was $15^{m}.5$. The UV100B detector (Johnson 1977) would have made measures of this star easy.

trumental to the standard system, the best fit for the sample gave the following linear transformation equations:

$$(B\text{-}V)_s = 1.437\ (B\text{-}V)_i - 0.286\ (\pm 0.020),$$
$$(V\text{-}R)_s = 1.101 (V\text{-}R)_i - 0.212\ (\pm 0.033),$$
$$(V\text{-}I)_s = 1.077\ \ (V\text{-}I)_i - 0.431\ (\pm 0.032),$$
$$(R\text{-}I)_s = 1.055\ (R\text{-}I)_i - 0.221\ (\pm 0.034),$$
$$V_s = 1.013\, V_i - 0.063 (B\text{-}V)_s - 3.039\ (\pm 0.025)\ ;$$

where the subscripts s and i stand for the standard (BVRI) and the instrumental systems, respectively. The values in the parentheses are the standard deviations of the transformations.

The observations at the 152 cm telescope were carried out under barely photometric sky conditions, with high-speed winds. A few standard stars were observed in the V and R band-passes. Field stars in the Pleiades Cluster were also observed. Our V magnitude and the V-R color were linearly transformed to the standard system. Stars as bright as $V = -1^{m}48$ and as faint as $V = 15^{m}9$ were measured. The data exhibit large scatter (see Table 5) and are good only for estimating the usefulness of the detector. The transformation equation used to give this estimate was

$$V_s = 1.24\, V_i - 0.31\ (V\text{-}R)_i - 4.52$$

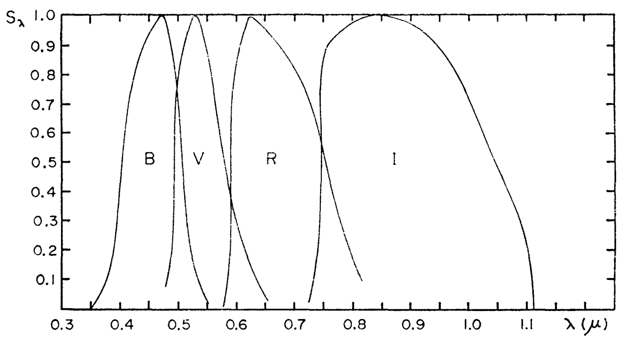

FIG. 3. Normalized response curves of the photometric system.

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V. DISCUSSION AND CONCLUSIONS

Semiconductor technology has made enormous progress; silicon diodes as light detectors for astronomical purposes can be competitive to photomultipliers in many respects, at lower costs. Photometry in wide and intermediate bandpasses over a wide spectral range $(0.3 - 1.1\mu m)$ can be made with such devices. Michelson Fourier spectroscopy is also possible (Johnson 1976). Because the same detection techniques are used, they are an excellent complement to infrared detectors in the shorter wavelength range of the spectrum, with a good matching of the systems at $1\mu m$.

It is clear from Table 1 and the transformation equations for the July observational period that better matching of the filters to the BVRI system is necessary.

Two photometers are under construction at the Instituto de Astronomía of the Universidad Nacional Autónoma de México: one using a selected UV-enhanced silicon photodiode (EG+G UV100B), to be used in broad and intermediate band photometry, and the other using an InSb and another UV-enhanced silicon diode.

We wish to express our thanks to Dr. Mario Martínez for his collaboration in the initial phase of this work.

REFERENCES

Craig, G. B., and Sesnic, S. S. 1973, *Investigations of Field Effect Transistors at Cryogenic Temperatures,* Management Information Services, Detroit, Michigan.

Johnson, H. L. 1977, *Rev. Mex. Astron. Astrof.,* in press

Johnson, H. L. and Mitchell, R. I. 1962, *Comm. Lunar and Planetary Lab.,* **1**, 73.

Johnson, H. L., and Mitchell, R. I., Iriarte, B., and Wisniewski, W. Z. 1966, *Comm. Lunar and Planetary Lab.,* **4**, 99.

King, I. 1952, *A. J.,* **57**, 253.

Low, F. J., and Ricke, G. H. 1974, *Methods in Experimental Physics,* **12**, ed. L. Marton (New York: Academic Press), Chap. 9.

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