

Infrared Detectors Address New Markets

Infrared detection technology improves, opening new opportunities in science and industry.

by Zbigniew Drozdowicz,
Oriol Instruments

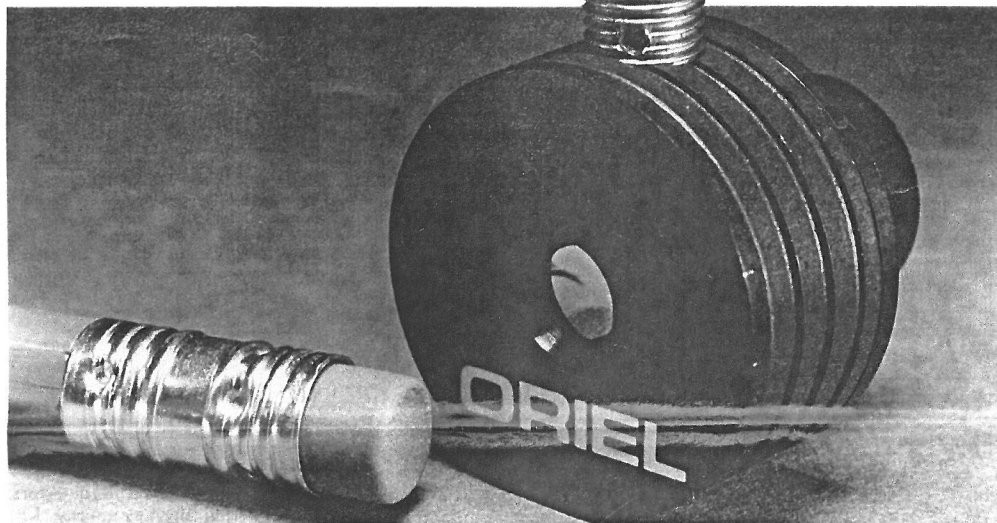


Figure 1. Photoelectromagnetic HgCdZnTe detector.

Blackbody emission peaks near $10\ \mu\text{m}$ at room temperature. That makes the infrared wavelength region rich in information on "hot" and "cool" bodies (your child's temperature is measured these days with an infrared detector, a thermopile, inserted into the ear for just a second). Vibrational transitions of molecules correspond to IR wavelengths, thus opening the entire genre of IR spectroscopy (absorption, fluorescence, Raman, Fourier Transform, and so on). One of the most widely utilized lasers, the CO_2 laser, emits near $10\ \mu\text{m}$. A number of atmospheric "windows" – regions of low absorption – fall into the IR range. These windows are used for various sensing applications to determine atmospheric constituents or the physical characteristics of the atmosphere, such as wind shear.

Infrared radiation received by an infrared system depends on object temperature, the chemical composition of the object, its physical structure, and its geometry. The IR radiation received by a detection system is also affected by propagation through atmosphere. Important knowledge can be obtained from the IR photon flux, merely by utilizing detectors capable of recording this bounty of available information.

It may be interesting to play a little game of numbers: We use our eyes to analyze our surroundings. We could "investigate" another person by sub-

jecting him or her to full sunlight and collecting the scattered and reflected radiation. A simple calculation, based on the solar constant and the 5800-K solar temperature approximation, yields an incident flux of about 5×10^{20} photons per second, within the 400 nm to 700 nm visible band, for a typical body at some intermediate angle of incidence. This is the maximum number of bits of information one could collect, even assuming a person exhibiting 100% reflectivity. However, if we take two people and stand them in front of each other in a dark room, they will exchange up to 2.4×10^{22} infrared photons per second, in the spectral band from $2\ \mu\text{m}$ to $40\ \mu\text{m}$, since each body acts as a source and a receiver in rough thermal equilibrium with the other. Granted, this comparison is one of apples and oranges, but it does point to the fact that even a basically room-temperature body will emit up to 50 times more infrared photon flux than the visible photon flux which may be illuminating it in full sunlight.

Infrared detectors are broadly divided into thermal and photon types. Thermal detectors respond to the temperature change induced by the absorption of radiation. These detectors – bolometers, thermopiles, and pyroelectrics are the most popular examples of the thermal family – have excellent spectral coverage (black coat-

ings are equally absorbing to a wide range of UV to far IR wavelengths) and reasonable sensitivity. Various room-temperature versions of these detectors are used for measuring incident power levels from nanowatts (pyroelectric detectors coupled with a lock-in amplifier) to kilowatts (water-cooled thermopiles). Special versions of pyroelectric detectors have been used up to gigahertz bandwidths. However, the need to allow for heat flow before an

A number of atmospheric "windows" – regions of low absorption – fall into the IR range.

electrical signal can be generated makes thermal detectors best suited for low frequency applications – DC to 10 Hz for thermopiles, DC to 1 kHz for thermistor bolometers, and 10 Hz to 10 kHz for pyroelectrics. Thermal detectors are also frequently used to measure pulses of radiation, even in the femtosecond regime, but they will only provide information on the total pulse energy

and not on its temporal shape.

The use of photon detectors becomes necessary when higher speed or detectivity is required. These detectors generate a single increment of response (a photoelectron) as a direct consequence of each photon absorbed, and thus are not subject to the delays and inefficiencies of heat flow. They are, however, subject to strong spectral variation of their responsivities by the very nature of the photon absorption process. We all remember that hc/λ defines photon energy, where h is Planck's constant, c

The use of photon detectors becomes necessary when higher speed or detectivity is required.

is velocity of light, and λ is the wavelength of the photon. Because of this $1/\lambda$ dependence, it takes five times as many 10- μm photons as 2- μm photons to deliver a particular amount of radiant power (flux). Accordingly, absorption of a 1-nW flux of 10- μm photons will produce about a five times larger response than absorption of a 1-nW flux of 2- μm photons.

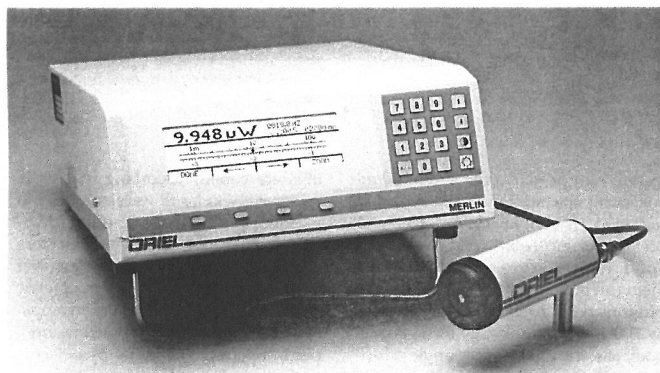


Figure 4. Optically immersed, TE-cooled HgCdZnTe detector with a Merlin™ DSP lock-in system.

All photon detectors are also subject to a long wavelength cutoff, corresponding to the wavelength above which incident photons do not have enough energy to kick electrons into the conduction band. This cutoff wavelength is fixed by nature for the intrinsic binary devices such as InSb, PbS, or PbSe, and is broadly composition-tunable for the ternary and quaternary systems like HgCdTe and its derivatives. Operating temperature also affects this cutoff wavelength, but to a lesser degree. Photon detectors cover the IR region up to about 20 μm . HgCdTe and HgCdZnTe can be composition-tuned to provide peak responsivity at wavelengths from 4 μm to 12 μm and beyond. The long wavelength compositions provide useful response to beyond 20 μm ; the upper limit depends

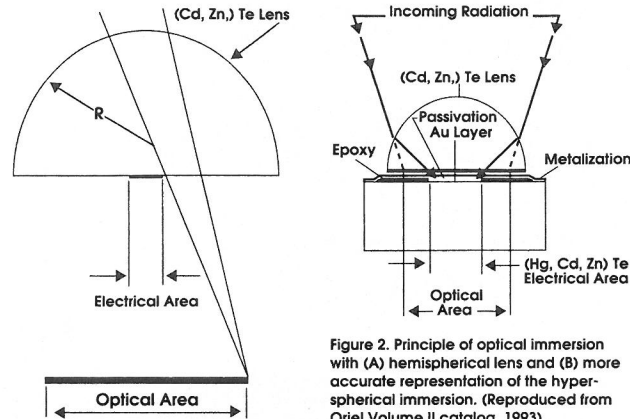


Figure 2. Principle of optical immersion with (A) hemispherical lens and (B) more accurate representation of the hyper-spherical immersion. (Reproduced from Oriel Volume II catalog, 1993).

Table 1: Optical Immersion Gains

Value	Hemisphere		Hyperhemisphere	
	n	(=2.7)	n ²	(=7)
Linear size	n	(=2.7)	n ²	(=7)
Area	n ²	(=7)	n ⁴	(=49)
Voltage responsivity	n	(=2.7)	n ²	(=7)
Detectivity	n	(=2.7)	n ²	(=7)
Bias power	1/n ²	(=0.14)	1/n ⁴	(=0.02)
Capacitance	1/n ²	(=0.14)	1/n ⁴	(=0.02)
Acceptance angle	180°		42°	
Tolerances	relaxed		stringent	

on the temperature of operation. These detectors' detectivity and speed are also affected by composition changes; longer-wavelength devices are faster, and shorter-wavelength devices have higher values of detectivity. A number of extrinsic, doped, detectors can be used for sensitive detection of longer wavelengths, but will not be discussed here.

Photovoltaic Or Photoconductive?

Photon detectors are typically operated in either photovoltaic or photoconductive modes. A number of different noise mechanisms, related to the statistical nature of the detection and bias processes, affect the performance of photon detectors. Some noise sources can be controlled or eliminated. Thermal generation and

recombination noise is the main culprit for room-temperature IR detectors because the thermal energy, kT , becomes comparable to the bandgap energy. For example, the 0.1-eV bandgap of a 12- μm -cutoff detector is only four times greater than the room temperature kT energy. Cooling, either with a thermoelectric (TE) cooler or a liquid nitrogen (LN_2) dewar, improves the noise performance of IR detectors when the signal-to-noise ratio becomes too low at room temperature. Another significant noise element is produced by bias current and is usually referred to as the $1/f$ noise, since that formula describes its frequency dependence.

The lowest-noise operation, at any particular temperature, is achievable in the photovoltaic, PV, mode through the elimination of the $1/f$ noise associated with the bias current flow.¹ This mode of operation is typical of room-temperature HgCdZnTe devices, where the responsivity is further improved through the use of either photoelectromagnetic or Dember effects. These are the fastest IR photon detectors; 100-ps risetimes are possible in specially selected HgCdZnTe detectors, ideal for CO_2 laser monitoring and similar applications. A typical HgCdZnTe photoelectromagnetic device is shown in Figure 1. It only requires a proper coaxial cable to be connected to an oscilloscope for CO_2 laser monitoring applications from DC to gigahertz frequencies. These devices are optimal for low-frequency operation (down to DC) and very-high-bandwidth operation.

Photoconductive, PC, operation is more typical of cooled detectors. PC

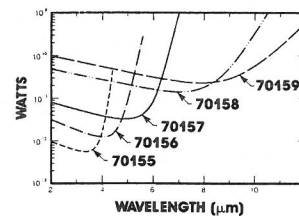


Figure 3. Lowest measurable powers with Merlin™, a digital signal processing (DSP) lock-in spectroradiometric unit.

operation is also quite useful for operating at intermediate frequency ranges at room temperature, when greater dynamic range is required. TE-cooled devices are a happy compromise between the very low-noise capabilities of LN_2 cooling and the very high-noise default condition inherent in room-temperature operation. Noise levels are drastically reduced, compared to the room temperature operation, and linearity range is extended, compared to the LN_2 cooling. The linearity range is extended because, at the noncryogenic temperatures achievable with TE cooling, it takes a much larger photon flux to generate excess carrier concentrations comparable to the equilibrium ones. For that reason, TE-cooled HgCdZnTe detectors make excellent FTIR detectors, as long as the signal levels are not too low. When signal levels fall too far, the less user-friendly LN_2 -cooled devices must be used and their nonlinearities dealt with. TE-cooled HgCdZnTe detectors also find application in accident-avoidance systems for automated factories, where their high speed and sensitivity make them ideal for detecting the presence of people. Atmospheric pollutant sensing, with infrared laser diode emitters, also takes good advantage of the properties of these versatile devices. Heat sensing military and space applications abound and would take volumes to describe in detail.

Detectors can only provide useful information if the measured signal exceeds the grand total of noises in the system. Flux of background photons, when incident on a detector, produces a noise signal due to its statistical nature.¹ This noise is roughly proportional to \sqrt{N} , where N is the number of photons. The great quantity of IR photons, produced by all warm bodies, sets certain absolute limits on the performance of IR detectors. Those detectors in which all other sources of noise are so well controlled that this background photon noise dominates are called BLIP (Background Limited Infrared Photodetectors) devices and define the ultimate in the art of detection. Usually, this performance is achieved at temperatures of liquid nitrogen (77 K) or below, because cryogenic temperatures limit thermally generated electrical noises. Recent advances in materials technology combined with simple optical principles made possible achievement of near-BLIP performance up to about 5 μm with detectors cooled to 220 K with simple TE coolers. Figure 2 illustrates the principle of optical

immersion which allows an electrically small detector to collect photons like an optically large device. The reason for the importance of this optical "trick" can be understood from an equation used to predict the performance of Oriol's HgCdZnTe family of 2 to 16 μm detectors:²

$$D^* = \frac{\lambda}{hc} \left(\frac{A_o}{A_e} \right)^{1/2} \left(\frac{\eta}{t^{1/2}} \right) \left(2(G+R) \right)^{-1/2}$$

where D^* is a commonly used figure of merit of a detector. D^* increases with larger effective optical size of a detector (A_o), for better photon capture, and with smaller electrical size (A_e), for less electrical noise generation. A higher quantum efficiency, η , which is the percentage of incident photons contributing to the electrical signal output, obviously improves D^* . Extra electrical thickness, t , increases noise and decreases D^* . The influence that material thickness, t , has on efficiency merits further consideration: Photons can just pass through, without inducing any response, when the electrical layer thickness becomes comparable to the absorption depth. Adding a reflective layer at the bottom of the detector can double the effective absorption path. Resonant cavity structures can also be used, when detecting laser radiation, to farther increase the effective absorption path in a thin structure.

The last term in Equation 1 represents the generation and recombination

and average power handling capabilities of monolithic devices also far exceed those of composite structures. The index of refraction of (CdZn)Te, 2.7, yields best results with a hyperspherical immersion scheme. Hemispherical immersion should be used when a larger field of view is necessary. Possible detector improvements, due to the two techniques, are listed in Table 1. Some of them apply only to the photovoltaic or photoconductive versions of these devices; bias power, for example, has no meaning for photovoltaics.

Very impressive performance can be achieved with optically immersed, TE-cooled HgCdZnTe detectors. Figure 3 breaks with the tradition of always using D^* for comparisons of detectors.

It shows some typical minimum measurable powers, which we think are more useful for the end user. Figure 3 shows these values for 1-mm optical size detectors used in conjunction with a digital signal processing lock-in amplifier, as shown in Figure 4. A chopper wheel and a TE-cooler controller, not shown in Figure 4, would be needed to present a complete system.

In summary, the IR region contains an abundance of information on our environment. We described here a few of the versatile detectors which can be used to collect this information. Coming attractions in the world of IR photon detectors include TE-cooled PV-mode units, for better low frequency detectivity and longer-wavelength operation

to 16 μm , and three- and four-stage TE-cooled detectors for FTIR and other applications.

References

1. John David Vincent, *Fundamentals of Infrared Detector Operation and Testing*, John Wiley & Sons, 1990.
2. J. Piotrowski, Z. Drozdowicz, and M. Merlen, "New Generation of 3 to 14 μm Laser Radiation Receivers", paper CTuN74, presented at CLEO, Baltimore, Md., May 1993.

Dr. Zbigniew "ZB" Drozdowicz is vice president of research and development at Oriol Instruments, Stratford, Conn.

EDITORIAL EVALUATION

Circle Number on Reader Service Card

I found this article:

Very Useful	Useful	Not Useful
300	301	302

Small Wonder!!

The Smallest Intensified CCD Camera Available Anywhere!



ISS Series

- MICROSCOPY
- SURVEILLANCE
- INDUSTRIAL INSPECTION
- SPACE
- RUGGED ENVIRONMENTS

Now there's an intensified camera that's designed to fit right in with your toughest, tightest low light-level imaging requirements. The self-contained ISS Series measures just 7" from end to end. Yet, it offers 6×10^{-6} fc sensitivity, 450 TV lines of resolution and up to 7 orders of interscene dynamic range.

The ISS Series video sensor can be rotated in 90-degree increments so its output is properly oriented - even if the camera is mounted upside-down. And for hostile, high vibration environments, there's a ruggedized version too. Size up the ISS for your application. It'll fit right in.

XYBION ELECTRONIC SYSTEMS

8380 Miralani Drive San Diego, CA 92126
(619)566-7850 FAX 619 566 2032

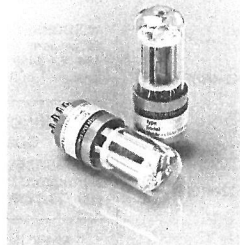


TE-cooled HgCdZnTe detectors also find application in accident-avoidance systems for automated factories.

rates, which create $A_e t(G + R)$ noise, which can be thermally or photon generated. We have little control over the photon generated noise, once experimental conditions are optimized. However, careful material properties control has lead to carrier depleted structures, and thus lower equilibrium ($G + R$) noise rates. High-temperature, room-temperature, and TE-cooled detectors are usually optimized with low p -type doping. Very low n -type doping is typically used for LN₂-cooled detectors.

Monolithic optical immersion of HgCdZnTe detectors, where the active layer is grown on a (CdZn)Te substrate as shown in Figure 2, offers major optical and thermal advantages over the usual methods of using adhesives to bond detectors to germanium lenses. Gone is the total internal reflection effect, because of a lack of optical adhesives with indices of refraction as high as that of germanium, which in turn limits the angular field of view for composite devices. Gone, too, are the spectral limitations caused by the absorptive properties of the adhesive. Peak

A Red Sensitive Side-on Photomultiplier



THORN EMI Electron Tubes have extended their range with a red sensitive side-on photomultiplier, 9785B.

The trialkali photocathode is sensitive to a wide range of wavelengths, particularly in red and near infra-red region, extending to 860 nm. A quartz option, 9785QB, will extend the UV response down to 160 nm. Its special features include fast response with a rise time of 2.0 ns and a low dark current, typically 2.0 nA at 1000 V. The main applications are in Spectrophotometers, Biomedical Instruments and Colour Scanners.

Contact THORN EMI Electron Tubes for all your light detection needs. An ISO 9001 registered company.

THORN EMI Electron Tubes, Bury St., Ruislip, Middx, HA4 7TA, UK. Tel: +44 (0)895 630771. Fax: +44 (0)895 635953

Circle 129

NEW

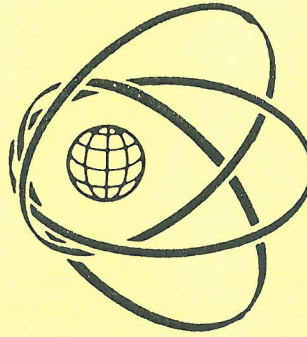
Mini Sensor: Mega Results

State-of-the-art IR Pyroelectric Detector Hybrid

This tiny goliath takes on giant optical applications. It's a sensor for laser power, pulse energy, radiometry, IR gas analysis, FTIR spectroscopy and even horizon-sensing. The sky's the limit! Call today for applications assistance on our colossal line of new P2-series SMT Pyroelectric Sensors:

1-800-366-4340

7470 SW Bridgeport Road Portland, OR 97224 Fax: 503-620-8964



Boston Electronics Corporation

72 Kent Street, Brookline, Massachusetts 02146 USA (617) 566-3821 TELEX 951712 BOSELEC BKLE
(800) 347-5445 Fax (617) 731-0935

UNCOOLED 2 - 12 MICRON PHOTOELECTROMAGNETIC DETECTORS

SERIES PEM

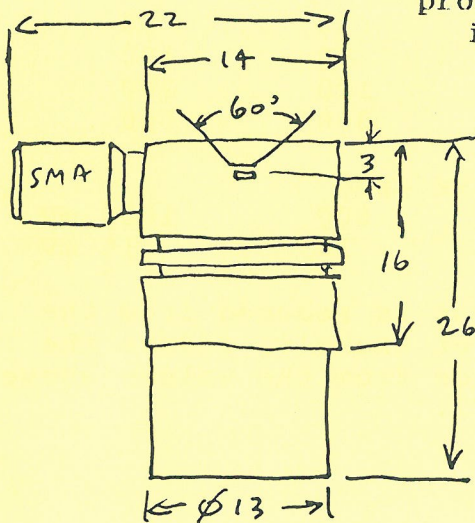
FEATURES

- low cost
- no bias required
- convenient to use
- high output signal
- wide dynamic range
- no flicker (1/f) noise
- bandwidth D.C. to 1 GHz
- custom design upon request
- ambient temperature operation
- lightweight, rugged and reliable
- perfect match to fast electronics

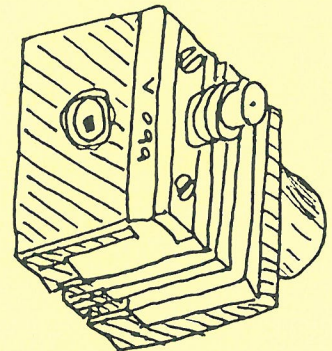
D* (10.6 micron) to $> 1 \times 10^7 \text{ cmHz}^{1/2} \text{ W}^{-1}$

APPLICATIONS

- ideal for pulsed or modulated CO₂ laser detection or monitoring
- suitable for detection of CW 2 - 12 micron radiation
- laser radar, range finding and communications
- laser - matter interaction experiments
- process control in laser technology
- ideal for heterodyne detection
- laser beam diagnostics
- laser metrology
- warning systems



PRELIMINARY
DATA
MAY '90



DESCRIPTION

The PEM-L series detectors are HgCdTe photoelectromagnetic detectors designed for ambient temperature operation in the 2 to 12 micron spectral band. *They are especially cheap to use as they do not require electrical bias.* Due to very short response time and ease of matching them to fast electronics they are ideal for pulsed or modulated CO₂ laser applications in an extremely wide frequency band to 1 GHz. In addition, because no flicker noise (1/f noise) exists in this class of device, they are also suitable for detection of CW radiation.

The new PEM-L series detectors include use of modern rare earth permanent magnets and cobalt steel pole pieces. As a result, the PEM-L series detectors offer improved performance and increased output signals both for CW and single or repeated short pulses; long term stability and linearity over a wide dynamic range. The devices are supplied with SMA connectors. An AR-coated germanium window (10.6 μM) is standard. Other windows or bandpass filters are also available.

SPECIFICATION

CHARACTERISTICS	UNITS	PEM-L-2	PEM-L-3	PEM-L-5
Spectral Range	μm	2	- 12
Response Time	nsec.....	0.2
Detectivity (<i>minimum</i>) (10.6 μm , 1MHz, 1Hz)	$\text{cmHz}^{1/2}\text{W}^{-1}$	2×10^6	3×10^6	5×10^6
Active Area	mm x mm	from 0.1 x 0.1 to 1 x 1		
Resistivity	ohms	from 30 to 80: typically 50		
Responsivity	mV/W			
	for 1 x 1 mm area	20	30	50
	for 0.5 x 0.5 mm	40	60	100
	0.25 x 0.25 mm	80	120	200
	0.1 x 0.1 mm	200	300	500
Saturation output, mV	for 1 x 1 mm active area			
	for pulse input	400	600	1000 mV
	for CW input	6	10	15 mV

NOTE: Saturation output for smaller areas is reduced from the above by the square root of the area. For example, reduce the saturation output of a 0.5 x 0.5 mm device from the values above by the square root of (0.5 x 0.5), or 1/2.



Boston Electronics Corporation

72 Kent Street, Brookline, Massachusetts 02146-7630 USA

(617) 566-3821 (800) 347-5445 FAX (617) 731-0935 TELEX 951712

CO₂ LASER DETECTORS

Product Line Summary

Model	D* x10 ⁶	Resp mV/W	\$\$\$
-------	------------------------	--------------	--------

R004-0*	0.3	3	\$ 550
R005-2.....	1.5....	20	995
R005-3	3.0	50	1,250
R005-4	3.0	80	1,400
R005-5.....	5.0...	100	1,550
R005-6	10.0	120	1,650

versions available as fast as 0.4 nsec. Most popular types.

P005-1*	0.5	5	850
P005-2*	1.0	10	1,095
P005-3*	2.0	20	1,195
P005-4*	3.0	30	1,400.
PEM-L-2	2.0	20	1,295
PEM-L-3	3.0	30	1,550
PEM-L-5	5.0	50	2,150

Photoconductors: These devices require constant current bias @ 30 mA (typical) and exhibit high signal and signal-to-noise. Time constant is 1 nsec with

PEM Mode: These devices require no bias and have 0.2 nsec time constant. They have no ¹/₂ noise so are good from dc to 800 MHz. Versions are available to 3.2 GHz.

PCI-L-1	20.0	200	1,895
PCI-L-2	50.0	500	2,150
PCI-L-3	100.0	1000	2,850

Immersed Photoconductors: Fabricated on the plano surface of a small lens, these devices exhibit larger equivalent optical area than electrical (noise producing) area. This optical gain improves performance significantly.

PC-L-2TE	100	1000	1,895
PCI-L-2TE-1	200	2000	
PCI-L-TE2-2	500	5000	
PCI-L-TE2-3	1000	10000	

TE-cooled Photoconductors: higher performance devices incorporate immersion lenses.

Electronics

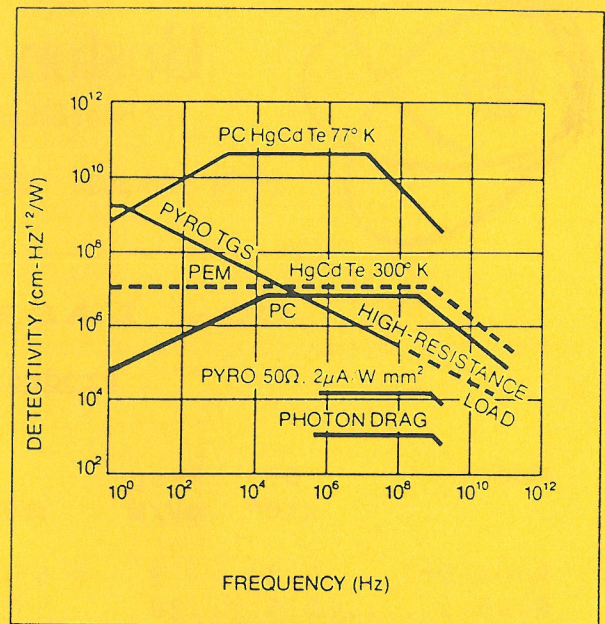
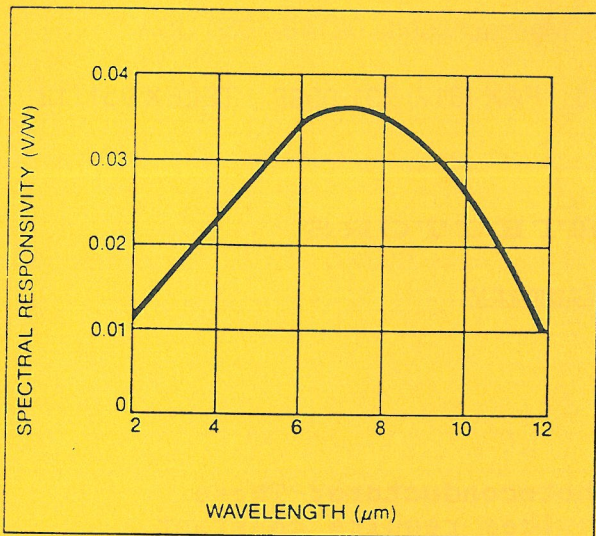
S025..2 channel power supply	\$ 1,095
S026..2 channel power, w/display	1,195
S035..1 channel power & preamp	1,300
S045..4 channel power supply	1,195

Delivery: Stock to 60 days

=====

NOTES: D* and Responsivity values measured at 10.6 μ m and 10⁹ Hz. Responsivity values cited are for 1 x 1 mm active area - other active areas available on request. Items *'d will be discontinued when current stocks are gone. Warranty 12 months.

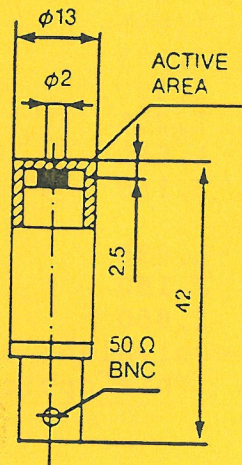
=====



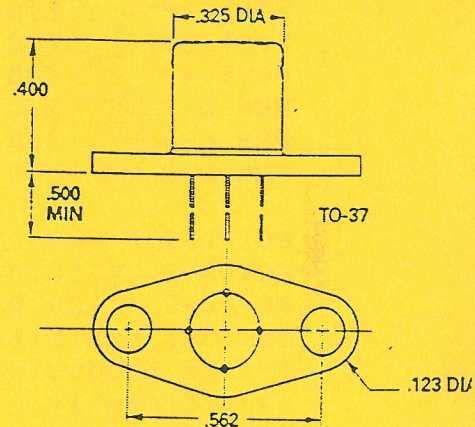
=====
 Warranty: 1
 year
 =====

For more information see
Infrared Physics, Volume
 31, No. 1, January 1991,
 REVIEW Article pages 1 to
 48 titled "NEAR ROOM-
 TEMPERATURE IR PHOTO-
 DETECTORS" by J.
 Piotrowski, W. Galus and
 M. Grudzien.

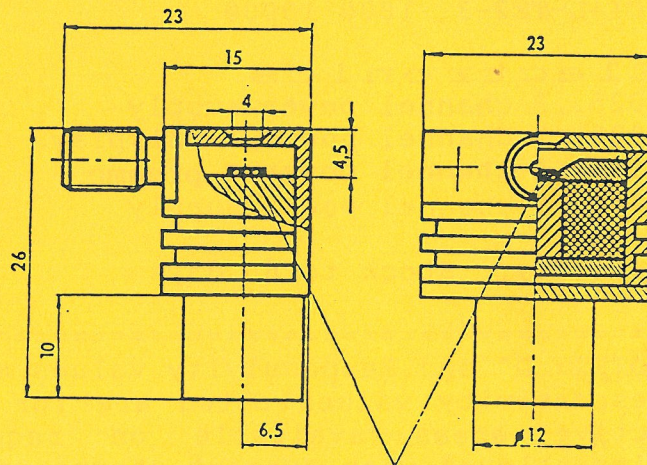
**Boston Electronics
 Corporation**
 72 Kent St. Brookline MA
 02146
 Fax (617) 731-0935 Toll
 Free (800) 347-5445



Standard R005-series package



Standard TE-cooled package



active element
 Standard PEM-mode device package