Technical Report RSC-05

INFRARED DETECTORS: SPECIAL INTEREST BIBLIOGRAPHY WITH ABSTRACTS

compiled by
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September 1969

supported by
National Aeronautics and Space Administration
NASA Grant ~~NsG 239-62~~ NGL-44-001-001

TEXAS A&M UNIVERSITY
REMOTE SENSING CENTER
COLLEGE STATION, TEXAS

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The Remote Sensing Center, Texas A&M University, conducts several projects utilizing infrared systems and/or data. Sensor studies for these predominantly geoscience oriented programs are conducted to support the data interpretation and analysis activities. A study of infrared detectors lead to the following compilation of related literature. The listing deals with significant publications since 1959. The detailed bibliography of literature prior to 1959 was published by W.L. Wolfe, Proceedings of the I.R.E., Vol. 47, No. 9, September 1959.

The listing is organized into eight sections: Detectors, Cooling, Noise, Optics, Apparatus, Technology, Books, and Special References. No attempt has been to present a comprehensive literature review. The material listed meets the objective of providing a thorough background of infrared detectors as employed in remote sensing applications.

DETECTORS

Anson, M. and deSoyza, A.A., "A Low-Noise Amplifier for Indium Antimonide Infrared Detectors," The Journal of Scientific Instruments, September 1968. Vol. 1, pp 952-4

An amplifier is described for use with indium antimonide photoconductive detectors such as the cooled Mullard ORP13. Field effect transistors are used to give a high input impedance, 5MΩ, and low noise, 30 nv $Hz^{-\frac{1}{2}}$ at 1kHz. When the amplifier is used with such an infra-red detector the low 1 kHz spot noise figure of 0·2 dB is obtained. The bandwidth of 1Hz to 70 kHz is ideal for systems with mechanical chopping of the infra-red radiation. The amplifier is stabilized against variations in supply voltage and temperature.*

Astheimer, R.W. and Schwarz, F. "Thermal Imaging Using Pyroelectric Detectors," Applied Optics, Sept. 1968, Vol. 7, pp. 1687-95.

The pyroelectric detector is a new radiation detector that employs the temperature sensitivity of electrostatic polarization as the sensing principle. Electrically, the detector behaves as a capacitance on which a charge appears when thermally irradiated. This detector has a number of features that make its use attractive for thermal imaging. It does not require cooling, and no biasing voltage is needed. Being electrically capacitative, the noise decreases with frequency, and consequently it has a useful signal/noise ratio at frequencies far above that corresponding to its thermal time constant. Also, these characteristics suppress 1/f type amplifier noise and permit good performance at very low frequencies. A new thermal imaging device or thermograph has been developed to exploit these properties. This is a scanning radiometer that scans a 10^{o} X 10^{o} field in 30 sec with a 0.1^{o} X 0.1^{o} instantaneous element, thus giving 10,000 picture elements. It uses a 7.6-cm diam germanium objective lens and has a noise equivalent temperature of 0.1^{o}C. The thermal image is presented as either a black to white tonal picture or a color picture on Polaroid film. Examples of its use for nondestructive testing purposes are given.*

Bratt, P.; Engeler, W.; Levinstein, H.; MacRae, A.; and Pehek, J, "A Status Report on Infrared Detectors," Infrared Physics, 1961, Vol. 1, pp 27-38.

Infrared photon detectors may be placed into two categories: intrinsic and impurity activated detectors. Intrinsic detectors include film detectors PbS, PbSe, PbTe, and single crystal detectors InSb

and InAs. Their spectral response generally rises linearly to the spectral peak, then drops sharply. Typical PbS detectors operated at room temperature have a long wavelength threshold at 3 μ and a detectivity of 10^{11} cm $c/s^{\frac{1}{2}}$ W^{-1} at 2 μ, their spectral peak. Time constants are of the order of 100 μsec. PbSe and PbTe detectors when operated at liquid nitrogen temperature have a detectivity of about 2 X 10^{10} cm $c/s^{\frac{1}{2}}$ W^{-1} at their spectral peak between 4 and 6 μ. Time constants vary between 20 and 100 μsec. InSb detectors, when cooled to liquid nitrogen temperature, have a spectral peak in the vicinity of 5 μ and a detectivity of about 4 X 10^{10} cm $c/s^{\frac{1}{2}}$ W^{-1}. Their time constants are of the order of 1 μsec.
Impurity activated detectors include Ge and Ge-Si single crystals with impurities such as Au, Cu, Zn, Sb. The spectral response of Ge with the peak at 1·5 μ and a cut-off at 1·8 μ is superimposed on the response characteristic of the impurity. Gold extends the response to 9 μ, Cu to 30 μ, Zn to 40 μ, and Sb to 120 μ. When these detectors are cooled until they are background limited, their detectivity is about 2 X 10^{10} cm $c/s^{\frac{1}{2}}$ W^{-1} at spectral peak. Time constants of Ge: Au and Ge: Zn detectors are less than 0·1 μsec. Evaluation of the theoretical limit of detectivity indicates that most currently available single crystal detectors approach the theoretical limit to within a factor of two-three; average film detectors, however, differ by a greater amount.*

Brown, M.A.C.S. and Kimmitt, M.F., "Far-Infrared Resonant Photoconductivity in Indium Antimonide," Infrared Physics, 1965, Vol. 5, pp 93-97.

A narrow-band photoconductive effect has been observed in indium antimonide in a high magnetic field at 4·2°K. The resonant frequency of this effect depends on the magnetic field strength and measurements have been made between 1000 and 26 μm with fields up to 75kG. At the shorter wavelengths fine structure is observed in the photoconductivity. The resonance is attributed to transitions between impurity states bound to conduction band Landau levels. Good agreement between existing theories and the observed results give a conduction band effective mass of $m^* = 0 \cdot 0148\ m_o$.*

Brown, M.A.C.S., et. al, "Time Constants of Some Fast Photodetectors Measured Using an Indium Arsenide Laser" Journal of Scientific Instruments, 1967, Vol. 44, pp. 419-21.

Apparatus is described which, using a mercury wetted relay pulser and an epitaxial indium arsenide diode laser, will produce light pulses with a rising edge of about 1 nsec. This fast edge has been used to measure the time constant of some commercially available photodetectors.*

Camac, M. and Feinberg, R.M. "High Speed Infrared Bolometer," The Review of Scientific Instruments, September 1962, Vol. 33, pp. 964-72.

A new type of heat transfer gauge that operates in the presence of highly ionized plasmas and in strong electric and magnetic fields has been developed. The principle of its operation is to use a thin opaque surface as the heat transfer element. Aerodynamic and radiative heating is applied to one side of this layer, while measurements are made of the change of the infrared emission from the other side. This system is essentially a bolometer. Since the gauge is initially at room temperature, the predominant radiation from the opaque layer is in the infrared band from 5 to 30 μ. Changes in the temperature of the element are determined by the variation in its infrared emission. The opaque layer is made thin enough so that the temperature of the front surface can be determined in less than 0.1 μsec. This paper describes the components of the heat transfer system and the methods for calibrating the gauge for heating pulses of long and short duration. Gauge calibrations by heat pulses from shock heated air are presented, and the response time of the gauge to short heat pulses is evaluated.*

Galloway, D.G., and Tolbert, C.W., "Germanium Bolometer Detector of Millimeter Wavelength Thermal Energy," The Review of Scientific Instruments, May 1964, Vol. 35, pp. 628-30.

This paper describes the construction and evaluation of a K_a band bolometer receiver using a highly temperature-resistance dependent (at 4.2°K) doped germanium bolometer of Texas Instruments, Inc. The receiver noise equivalent power (NEP) of approximately 10^{-9}W and input bandwidth exceeding 12 Gc has a rms signal level indicating uncertainty equivalent to 90 C° per cycle of output filtering. Evaluation of the germanium bolometer as a millimeter wavelength radiometer detector was performed at K_a band to utilize existing apparatus and to facilitate fabrication of the receiver. With the increased sensitivity anticipated for smaller bolometer elements, short millimeter and submillimeter wavelength scaled models of the receiver appear promising as detectors for radio telescopes.*

Gibson, A.F. et al, "Photoconductivity in Indium Antimonide at 10.6 Micrometers Wavelength," British Journal of Applied Physics, Feb. 1, 1968, Ser. 2 Vol. 1, pp. 149-54.

Photoconductivity has been observed in indium antimonide at 10·6 μm wavelength using a high-power Q-switched laser as a source, and is ascribed to a two-photon absorption process. Variation in photoconductivity over the temperature range 30-300°K has been studied and comparison with the response at 5·3 μm indicates that the laser radiation substantially reduces the carrier lifetime in indium antimonide.*

Giggey, G.F., "Photoconductive Detectors for Infrared Measurements," Electronic Industries, November 1965, Vol. 24, pp. 118-21.

This paper provides a descriptive and chart analysis of the major types of detector effects. The photoconductive effect is expounded as the most advantageous. Various extrensic germanium detectors are described. Cooling using a dewar and the stirling cycle is briefly described.

Glass, A.M., "A Fast Sensitive Infrared Radiation Detector," Bell Laboratory Records, January 1969, Vol. 47, p. 33.

Bell Laboratories recently constructed a new detector for use in the near to far infrared range. A single crystal detector of strontium barium niobate (SBN) uses the pyroelectric effect. It has a better response and smaller time constant than other existing pyroelectric detectors.

Goodwin, D.W. and Jones, R.H., "Far Infrared and Microwave Detector," Journal of Applied Physics, October 1961, Vol. 32 pp. 2056-7.

Most detectors have their detectivity limited by radiation noise. Detectivity is increased by limiting the bandwidth which causes a loss of flexibility. The author explains how the utilization of a semiconductors' cyclotron resonant frequency will confine detection to a narrow tunable band. An extrensic germanium detector is used as an example.

Grimes, C.C., et al, "Josephson - Effect Far-Infrared Detector," Journal of Applied Physics, July 1968, Vol. 39; pp. 3905-12.

Superconducting point contacts, bridges, and tunnel junctions are all capable of carrying a zero-voltage current; i.e., no voltage appears across the device until the current exceeds a finite critical value. The critical value of the zero-voltage current is changed when microwave radiation is incident on such a junction. Thus such a device can be used as a detector of radiation. Experiments have been carried out demonstrating that this detection mechanism extends well into the far-infrared, is highly sensitive, and has inherently high speed. These experiments demonstrate the existence of the Josephson effect at frequencies up to and beyond the superconducting energy gap, and show that over this range of frequencies, Josephson junction detectors exhibit both high sensitivity and high speed when compared with other helium-temperature far-infrared detectors.*

Hill, D.W. and Powell, T., "Frequency Response Characteristics of Some Condenser Microphone Infrared Detectors," The Journal of Scientific Instruments, 1967, Vol. 44 pp. 731-35.

The frequency response characteristics for interrupted infra-red radiation are described for four condenser-microphone type detectors as used in nondispersive infra-red gas analysers. Three of the detectors are of conventional dimensions. The fourth is a subminiature type, and its use is described with a field-effect transistor amplifier. It is shown that markedly increased optical modulation frequencies can be used with infra-red pneumatic detectors, without radical reductions in output signal, if the dimensions of the device are drastically reduced. This has been accounted for on theoretical grounds. The frequency responses obtained are examined and shown to correlate adequately with mathematically predicted profiles. Low frequency attenuation is explained on the grounds of thermal conductivity effects and leakage paths across the transducer diaphragm, whereas a high frequency maximum for one detector is shown to arise from Helmholtz resonation due to the chamber configuration.*

"Infrared Detector Responsive to Picowatt," Electrical Engineering, August 1962, Vol. 81, pp. 630-1.

This article briefly describes Minneapolis-Honeywell's infrared detector tube. It utilizes photoconductive indium antimonide element.

"Infrared Materials - Detectors, Analysts, and Monitors," Materials in Design Engineering, October, 1965, Vol. 62, pp. 108-111.

Although many infrared materials are available, each has its own properties and optical characteristics that best suit it for a particular application. This article tells what materials are available, what their properties are, and where they can be used.*

Jacobs, S.F., "Characteristics of Infrared Detectors," Electronics, April 1960, Vol. 33, pp. 72-3.

Four Distinct Types of infrared detector are in general use: thermal, photoconducting (PC), photovoltaic (PV) and photoelectromagnetic (PEM). The operating principle of each is summarized in table.*

Jamieson, J.A., "Detectors for Infrared Systems," Electronics, Dec. 2, 1960, Vol. 33, pp. 82-4.

Over the past few years there has been a great increase in the use of infrared systems, particularly by the military, to detect small amounts of radiant power from the hot exhausts of jet aircraft, rockets and other targets. To meet the needs of the designer of such systems a variety of radiation detectors have been developed and a number of these have now reached the stage of manufactured stock components. Table I has a compilation of representative data on detectors that are important in military applications.*

Kovit, B., "Infrared Detectors," Space/Aeronautics, November 1961, Vol. 36, pp. 104-123.

This article is a state-of-the-art report on infrared detectors. It contains several articles on individual types of detectors. Several charts provide the properties of numerous detectors. Theoretical and descriptive information conderning infrared technology and detectors is presented.

Lauriente, M.; Higby, R.F.; Bagrowski, J.; and McNally, F.X., "Sophisticated Detector Design for Increased Infrared Sensitivity," Infrared Physics, 1962, Vol. 2 pp. 103-109.

The potential for improving the performance of infrared surveillance systems by incorporating sophisticated detector design is discussed herein. This potential lies in improved background discrimination and incident energy utilization. Progress has been made toward realizing such improvements as the result of thin-film techniques. The principle involved in the discrimination technique is analogous to the bridge-type bolometer circuit used to cancel out ambients. This principle has been implemented by transforming these bridge circuits into elements of microscopic dimensions. The distributed network and high resolution make this concept conducive to thin-film circuitry. Material problems encountered such as the compatibility of dielectric and photoconductor are discussed with recommendations for further research.*

Ludlow, J.H., "Infrared Radiation Detection by the Pyroelectric Effect," Journal of Scientific Instruments, 1967, Vol. 44, pp. 694-6.

> The method of using the pyroelectric effect to detect infra-red radiation is described. The performance of the detector shown at the Physics Exhibition is discussed (noise equivalent power 10^{-8}W, effective response time 2 μsec) and its uses with far infra-red lasers and interferometers mentioned.*

Moore, W.J. and Shenker, H., "A High Detectivity Gallium - Doped Germanium Detector for the 40-120 Micron Region," Infrared Physics, 1965, Vol. 5, pp 99-106.

> Gallium-doped germanium with low levels of compensating impurities has been found to be a fast, efficient detector of far infrared radiation. A peak detectivity, D* (104μ, 390 cps, 1 cps), as high as 3·1 X 10^{11}cm-cps$^{1/2}$-W^{-1} (NEP = 8 X 10^{-13}W-cps $^{-1/2}$) has been achieved. Calculation of the expected Nyquist and generation-recombination noise indicates that this detectivity is within a factor of about 2·4 of the ideal detectivity for the background condition used.*

Morten, F.D. and King, R.J.E., "Photoconductive Indium Antimonide Detectors," Applied Optics, June 1965, Vol. 4, pp. 659-663.

> The manufacture of InSb photoconductive detectors is briefly described. A simplified design theory is given, followed by a description of typical performance between room temperature and 77°K. The practical embodiment of photocells is described, together with the design of arrays of detector elements.*

Morton, G.A., "Infrared Detectors," R.C.A. Review, March 1965, Vol. 26, pp 3-21.

> In applications requiring great sensitivity and high speed of response, infrared photoconductive detectors have proved very effective. The photoconductor employed depends upon the wavelength of interest. For the very near infrared (long wave limit λ_m = 1.8 μ), germanium junction photodiodes are used. At somewhat longer wavelengths (λ_m ~ 3.5 μ), lead sulfide and indium arsenide have suitable responses. For still longer wavelengths (λ_m ~ 7μ), PbTe, PbSe, and InSb are the most frequently used photoconductors. Except for relatively low sensitivity InSb junction devices, detectors employing these materials require liquid nitrogen cooling. Extrinsic photoconductors constituted of appropriately doped germanium are used

for longer wavelengths. These can be made with a wide range of long-wave limits covering the spectrum to beyond 100 μ depending upon the activator employed. Such cells require considerable cooling to reduce thermal excitation of carriers. The sensitivity of these detectors depends upon their cooling, the level of background radiation, and the configuration of the detector. Methods of calculating the sensitivity, cooling requirements, and performance characteristics are discussed and illustrative examples given.*

Peters, D.W., "An Infrared Detector Utilizing Internal Photoemission," I.E.E.E. Proceedings, May 1967, Vol. 55, pp. 704-5.

An infrared detector utilizing internal photoemission as a detection mechanism is demonstrated. The detector consists of a metal-semiconductor contact with photoemission taking place over the associated Schottky barrier. Quantum efficiency and bias effects are investigated.*

Phelan, R.J. Jr. and Dimmock, J.O., "Imaging and Storage with a Uniform MOS Structure," Applied Physics Letters, Dec. 1, 1967, Vol. 11, No. 11, pp. 359-61.

Radiation sensitive characteristics of a uniform InSb-metal-oxide-semiconductor (MOS) structure have been used to detect images. By rapid optical scanning this structure with visible light of 0.63 μ we have detected infrared images due to 5-μ radiation. In addition information can be read-in and stored (or "photographed") by using 1-μ radiation, nondestructively read-out with 5-μ radiation, and erased with 0.25-μ radiation.*

Phelan, R.J., Jr. and Dimmock, J.O., "InSb MOS Infrared Detector," Applied Physics Letters, Jan. 15, 1967, Vol. 10, pp 55-58.

Infrared photovoltaic response and high quantum efficiency have been observed in a large-area InSb, metal-oxide-semiconductor structure. Spectral measurements indicate that the response is due to the generation of electron-hole pairs in a depletion region of the n-type InSb at the InSb-oxide interface. Pulsed current measurements yield a clear diode characteristic and the overall results are equivalent to what one would expect to obtain from a photodiode in series with a MOS capacitor.*

Putley, E.H., "Solid State Devices for Infrared Detection," The Journal of Scientific Instruments, Dec. 1966, Vol. 43, pp. 857-68.

Infra-red detectors can be divided into two types: those which depend upon heating effects produced by the absorbed radiation (thermal detectors) and those which make use of photoconductive effects. The characteristics of the more important members of both types are discussed. The factors which determine their performance and which affect the choice of the most suitable type for a particular application are considered. Future trends in the development of infra-red detectors are briefly mentioned.*

Rodot, M.; Verie, C.; Marfaing, Y.; Besson, J.; and Lebloch, H., "9B3-Semiconductor Lasers and Fast Detectors in the Infrared (3 to 15 Microns)," IEEE Journal of Quantum Electronics, Sept. 1966, Vol. QE-2, pp 586-93.

Small energy gap semiconductors such as InAs, InSb, and Hg_{1-x} Cd_x Te (where $0.15 \leq \chi \leq 0.40$) allow one to build infrared coherent emitters and fast detectors in a wide wavelength range where practical applications are anticipated (3 to 15 microns, approximately). Some recent achievements of these devices are presented. Previously described indium arsenide junction lasers have been improved. Continuous emission is obtained at $27^{o}K$, at a level of 20 mW. Relaxation oscillations of the emitted coherent radiation have been observed at a frequency of 20 Mc/s. Sub-laser emission has been observed at 3 microns on HgTe-CdTe alloy p-n junction. Coherent emission can be predicted on the basis of the band structure. The intrinsic detectors are faster and can work at higher temperatures than impurity photoconductors. Besides photovoltaic InAs and InSb detectors, we have developed three types of Hg_{1-x} Cd_x Te detectors for the 3 to 12 microns wavelength range: photovoltaic, photoconductive cells, and graded band-gap structures. Theoretical possibilities of this type are discussed and preliminary experimental results for all three are given. For a photoconductive cell whose response peaks at 10 microns a time constant of 70 ns has been measured using an InAs laser as a source.*

Schwarz, Frank, "Infrared Detectors," Electro-Technology, November 1963, Vol. 72 pp. 116-19.

The principles of operation of infrared detection devices can be understood through an examination of their basic mechanism and construction. Spaceborne navigation sensing and measuring systems require infrared devices that combine high sensitivity with speed and reliability --- these new applications are stimulating the development of new detection devices.*

Shapiro, Philip, "Infrared Detector Chart Outlines Materials and Characteristics," Electronics, January 20, 1969, Vol. 42, pp. 91-6.

> Progress has afforded science a multitude of infrared detectors. The properties of 24 commercially available detectors are listed along with the manufacturers. The special detectivities of these detectors are discussed and graphed against wavelength.

Slawek, J.E., Jr., "InSb Detectors for Infrared Systems," Electronics, Jan. 10, 1964, Vol. 37 pp. 49-50.

> The properties of the photovoltaic detector are given in several graphs. A table lists the characteristics and an accompanying diagram depicts the equivalent circuit. Discussion briefly includes design data and cooling.

Smollett, M., "The Properties and Performance of Some Modern Infrared Radiation Detectors," Infrared Physics, 1968, Vol. 8, pp. 3-7.

> Many new types of solid state infra-red detectors have become available in the last few years. The properties and performance of some of the most important and widely used detectors are described.*

COOLING

Beerman, H.P., "Thermoelectric Cooling of Infrared Detectors," American Ceramic Society Bulletin, January 1966, Vol. 45 pp. 2-3.

Thermistor bolometers as well as photoconductive detectors of InSb, PbS, and PbSe were examined for improvement in detectivity as a function of thermoelectric cooling. Improvements in detectivity range from a factor of 2 for thermistor bolometers to 100 for InSb.*

Beyen, W.J. and Pagel, B.R.,"Cooling Requirements for Intrinsic Photoconductive Infrared Detectors," Infrared Physics, 1966, Vol. 6, pp 161-166.

This paper discusses the necessary theoretical cooling requirements for intrinsic photoconductive infrared detectors under the ideal situation, compares these results with experimental observations, and gives the authors' opinions on future promise. We begin by considering what necessarily occurs in a semiconductor material at temperature T, in thermal equilibrium with its surroundings, in the nature of radiative processes as they affect the charge carrier statistics. Our assumption of the ideal case implies nothing else does affect charge carrier statistics.*

Butter, C.D., "Some Properties of Cooled InSb Photoconductive Infrared Detectors," Infrared Physics, 1963, Vol. 3, pp. 207-210.

Measurements of the time constant of cooled photoconductive indium antimonide infrared detectors as a function of bias current have been made. The results and the equipment used to make the measurements are described. D*, noise spectra, and responsivity data of two cooled InSb photoconductive infrared detector elements exhibiting quite different surface appearances, are compared.*

Crouch, J.N., "Cryogenic Cooling for Infrared," Electro-Technology, May 1965, Vol. 75, pp. 96

Many different avenues of cooling are available in reducing system noise. This paper discusses open and closed-cycle cooling systems, microphonics, and cooling requirements. A table lists the operating characteristics of eleven detectors at two operating temperatures.

Farmer, V.M. and Forse, D.P., "Improved Cooling Techniques for Detectors," Infrared Physics, 1968, Vol. 8, pp. 37-47.

The work outlined in Part I of this paper had as an objective the design of a Joule-Thomson cryostat to produce a temperature below 90°K within three seconds. The factors affecting the rate of cooling are considered and the resulting optimised cooler is described.
A cooler using the same principles of construction suitable for cooling an image converter is also described.
In Part II the use of a liquid flow heat transfer system between a detector substrate and the boiling refrigerant gives the effect of a low-pass thermal filter which smooths out unwanted temperature variations whilst maintaining a rapid cool-down time. The technique can be extended to include a number of detector substrates in series from a single heat exchanger. A theoretical analysis of the system is presented together with the performance details of practical examples.*

Gross, S., "Infrared Sensor Cooling by the Joule-Thomson Effect," Infrared Physics, 1966, Vol. 6, pp. 47-56.

Many infrared sensors must be cooled to cryogenic temperatures to operate properly. One important technique is cooling to liquid-nitrogen temperature by the Joule-Thomson effect. This paper gives a thermodynamic analysis of Joule-Thomson cooling systems that use nitrogen gas, and considers continuous-flow and bottled-gas systems. Criteria are established for system optimization and data are given to predict cooling performance. Results show that significant weight and volume improvements over present practice are possible by the proper choice by gas storage and regulation pressures. Cryostat heat exchangers of high efficiency are shown to be essential for sensor cooling in high-temperature environments.*

"Infrared Detection Without Cryogenics," Electronics, Sept. 22, 1961, Vol. 34, pp. 68 + .

Characteristics and a diagram describe a cadmium sulfide crystal detector. Infrared radiation will quench the photoelectric effect in the crystal, due to incident visible light. This system does not require cryogenics. A brief discussion is given on the three major detector photon effects.

Kruse, P.W., "Uncooled IR Detectors for Long Wavelengths, "Electronics, March 25, 1960, Vol. 33, pp. 62-64.

With a spectral response peaking almost at seven microns, the indium-antimonide photoelectromagnetic detector responds to long infrared wavelengths. This uncooled detector permits design of simpler ir systems.*

Stephens, S.W., "Advanced Design of Joule-Thomson Coolers for Infrared Detectors," Infrared Physics, 1968, Vol. 8, pp. 25-35.

Many i.r. detectors require cryogenic cooling for optimum performance. Several methods of cooling are available, one of which is the use of Joule-Thomson liquefiers, which is considered in this paper.*

NOISE

Berger, T. and Brookner, E., "Practical Design of Infrared Detector Circuits," Applied Optics, July 1967, Vol. 6, No. 7, pp. 1189-93.

The practical design of the receiver circuitry for an ir surveillance system is considered. A design procedure for obtaining high signal detectability is presented and illustrated with an explicit example. Filtering circuitry is designed which takes into account the nonwhite noise of the detector cell and the first stage of amplification. The tradeoffs between signal detectability, accuracy, resolution, and background suppression are also discussed.*

Carmichael, G.W., "Some Elementary Statistical Properties of a Modulation Noise Limited Detection System," Infrared Physics, 1964, Vol. 4, pp. 9-12.

Some of the basic statistical properties of the noise generated by a 1/f power spectral density function, introduced into a narrow band amplifier, are set forth. A noise process of this type is often the limiting factor in the sensitivity of an infrared detection system particularly when the uncooled PbS detector is employed.*

Eldering, H.G., "The Theory of Optimum Spectral Filtering," Infrared Physics, 1964, Vol. 4, pp. 231-237.

The optimum spectral filter for maximum signal to background ratio, given the target and background spectra, is shown to be trivial and useless because it is an infinitesimal bandwidth filter. If, in addition, the system noise level is specified, the optimum spectral filter has a square bandpass characteristic. Again the theoretical filter is not physically realizable. Finally rules are developed to determine filter specifications given the limits of filter cut off slopes. Thus it is shown that target spectrum, background spectrum, system noise level, and the state of filter technology must be ascertained to determine the optimum realizable filter.*

Long, D., "Generation-Recombination Noise Limited Detectivities of Impurity and Intrinsic Photoconductive 8-14 Micron Infrared Detectors," Infrared Physics, 1967, Vol. 7, pp. 121-128.

An analysis has been made of the dependences of the detectivities (D*) of impurity and intrinsic photoconductive 8-14μ infrared detectors on temperature for the situation in which only the bulk generation-recombination (gr) noise is important; this case determines the upper limit to the detectivity of a background noise limited detector attainable by narrowing the field of view from the usual 180° angle to approach 0°. Hg-doped Ge and $Hg_{0.8}Cd_{0.2}Te$ are considered as examples of impurity and intrinsic photoconductors, respectively, and it is found that for realistic optimum values of material parameters one can achieve a given D* at a higher operating temperature with the intrinsic photoconductor than with the impurity photoconductor, up to a certain D* level.*

Pagel, B.R. and Petritz, R.L., "Noise in InSb Photodiodes," Journal of Applied Physics," October 1961, Vol. 32, pp. 1901-04.

Experimental investigation of noise generation in InSb infrared photodiodes is reported. Minimum noise occurs when the diode is biased to zero potential. Noise spectra taken on seven photodiodes determined the white noise level above 1 kc. The experimental value of white noise is compared with the noise induced by random fluctuations in background radiation. The photonoise is calculated for an equivalent noise generator. The photoinduced current I_{PH} is measurable directly for zero bias potential. The total measured white noise is of the order of one decibel above the calculated photoinduced noise. Thus the photoinduced noise is the primary source observed, and InSb photodiodes closely approach the ideal case of being background-limited infrared detectors.*

OPTICS

Jenness, J.R., Jr., "Infrared Optics of CTFE," Plastics Technology, December 1961, Vol. 7, pp. 35-6.

Quartz, special glasses and common salt are generally used for infrared optical components. But within limits polychlorotrifluoroethylene works as well and is cheaper.*

Rosendahl, G.R., "Basic theory of Infrared Optical Systems Without and With Auxiliary Lenses," Infrared Physics, 1964, Vol. 4, pp. 29-42.

The optical design of a horizon scanner or a similar optical system can be judged by an "optical performance number", OPN, which should be made as large as possible. OPN is the product of two numbers, O and B, the first of which refers to optical system parameters and the second to the bolometer arrangement and signal evaluation. The optical number, O, applies to (a) systems without auxiliary lenses, (b) hemispheric immersion lenses, (c) aplanatic immersion lenses, and (d) ancillary telescopic systems, while the bolometer number, B, applies to the cases of (e) maximum signal, (f) maximum signal-noise ratio, or (g) maximum slope. The reasoning is based on an assumed aplanatism for the optical system but the effect of aberrations is briefly outlined.*

Worrall, A.J., "Materials for Infrared Optics," Infrared Physics, 1968, Vol. 8, pp. 49-58.

The causes of infra-red absorptions are outlined and the properties, uses, and availability of materials are discussed. The useful range of oxide glasses has been extended out to 7 μ by the aluminate, tellurite, and gallate glasses. Two aluminate glasses are in production. The absorption due to water has been eliminated. Some properties of these glasses are given. Other chalcogenide glasses discussed are arsenic trisulphide glass, with particular reference to anti-reflection coating, and the arsenic-germanium-selenium glasses, which have refractive indices in the region of 3 and a useful transmission range of 1-19 μ depending on composition.
The field of crystals is surveyed briefly covering hot-pressed magnesium floride, the halides and germanium.
Infra-red fibre optics are discussed outlining some design considerations and applications.*

APPARATUS

Adhav, R.S. and Kemp, J.G., "Infrared Radiometer, "Journal of Scientific Instruments, 1963, Vol. 40, pp. 26-7.

A radiometer, to integrate high intensity infra-red radiation throughout a hemisphere, is described. It consists of a hemispherical black-body receiver, with an attached thermocouple. The receiver is supported with a mica ring and mounted in a recess of a water-cooled brass cylinder. The radiometer has a time constant of eight seconds and a sensitivity of 2·5 mv $w^{-1}cm^{2}$.*

Beerman, H.P., "Infrared Radiation Detector,"Bulletin of the American Ceramic Society, August 1967, Vol. 46, pp. 737-40.

The concept of a pure capacitance type infrared radiation detector is very attractive. Such materials as triglycine sulfate (TGS), triglycine fluoberyllate (TGFB), lithium sulfate, Rochelle salt, barium titanate and lead zirconate titanates (PZT) are compared as to pyroelectric effect. Several applications using characteristics of the pyroelectric detector are shown.*

Belsey, D.C. and Gabriel, W.P., "A Direct Indicating Infrared Radiation Meter," Journal of Scientific Instruments, 1963, Vol. 40, pp. 526-28.

The instrument measures the intensity of radiant heat. It is used in testing the performance of commercial radiant heaters such as the domestic gas fire or overhead electric radiator. The detector element is a lead sulphide cell that is exposed for about 1/20 second by a shutter similar to one found in a simple camera. The indication is given immediately on the dial of a moving-coil meter, so individual measurements are very speedy. The instrument is much quicker and easier to use than the conventional thermopile.*

Bernard, B., "Industrial Infrared Radiometer," Radio-Electronics, November 1961, Vol. 32, pp. 68-73.

Infrared Radiometers are now being used for industrial applications. The meter's components are described in respect to operation.

Bivans, E.W., "Scanning Radiation Pyrometer," Instruments and Control Systems, July 1965, Vol. 38, pp. 115-18.

This paper views the Infrascan from a system's viewpoint. Medical applications, with illustrations, are discussed. Emissivity is described and explained theoretically.

Borley, C.R. and Guildford, L.H., "A 100 Line Thermal Viewer," Infrared Physics, 1968, Vol. 8, pp. 131-34.

The paper describes a thermal viewer being built at M.R.L. using a line array of 100 InSb, 77°K, 250 μ square detector elements. Object plane scanning is used in the horizontal direction only at 20 frames per second, each element scanning one line in the scene. The field of view is 260 mrad. (15°) horizontally and 100 mrad. (6°) vertically. The cell outputs are pre-amplified and multiplexed at 1·5 MHz sampling rate to feed a C.R.T. display. An angular resolution of 1 mrad. and a temperature resolution of 0·3°C are aimed at.*

"Chopperless Infrared Sensors Developed," Aerospace Technology, January 15, 1968, Vol. 21, pp. 44-45.

Barnes Engineering Co. has developed a chopperless radiometer for NASA's Earth Resources Test Satellite. A brief description of the radiometer and its capability is given.

Hard, T.M., and Lord, R.C., "A Double Beam, High Resolution Spectrometer for the Far Infrared," Applied Optics, April 1968, Vol. 7, pp. 589-98.

A far ir spectrometer has been constructed with an Ebert-Fastie monochromator of 1.8-m focal length plane gratings 19 cm X 13 cm, and slit height of 10 cm. The source optics of the evacuable instrument are double beam, with an electronic system of recording the ratio of the radiant powers in each beam. A commercial bolometer of gallium-doped germanium cooled with liquid helium serves as the detector. Details of the operation of the instrument are given, and the results obtained are illustrated with the spectra of gaseous polyatomic molecules.*

Hexter, R.M. and Hand, C.W., "Infrared Spectroscopy at 20,000 Scans per Second," Applied Optics, Nov. 1968, Vol. 7, No. 11, pp. 2161-65.

Improvements in a rapid scan ir spectrometer used for flash photolysis-kinetic spectroscopy are described. The scanning mechanism now regularly operates at a repetition rate of 20,000 scans/sec; the photolysis flash has a half-time of 7.5 μsec, with energy up to 2940 J, and at 1500 J it yields 5 X 10^{18} quanta/flash; the spectroscopic light source operates with a brightness temperature of 2400 K. The relationship between spectral resolution and scanning speed is quantitatively discussed.*

"Infrared Camera," Engineer, April 16, 1965, Vol. 219, p. 700.

This article presents the Swedish AGA Company's "Thermovision" infrared camera. A brief description of its operation and its clinical applications is given.

Langford, M.J., "British Infrared Television," Industrial Photography, August 1967, Vol. 16, pp. 16, 56.

A summary of the properties of several infrared systems is discussed. Several problems and uses of some systems are presented.

Leftwich, R.F., "Detectors That See Red," New Scientist, December 15, 1966, Vol. 32, pp. 630-33.

What they see, in fact, is the invisible infrared radiation given off by any body whose temperature is above absolute zero. Highly sensitive equipments developed for military and space purposes are now finding applications from process control to fish location, from fault-finding to research on insects.*

Leftwich, R.F., "Infrared," Machine Design, September 16, 1965, Vol. 37, pp. 154-59.

Infrared devices have experienced improvements and found new uses. Diagrams of Barnes Co. instruments are shown. Principles of detection of heat flow in materials are discussed. The infrared radiometric microscope and its applications are described.

"Low-Cost Thermography Is Here," The Iron Age, September 26, 1968, Vol. 202, pp. 76-77.

Non-destructive testing and preventive maintenance now utilizes thermography. The Barnes Engineering Co.'s T-6 infrared camera is electronically diagramed and has its performance described.

"Non-Contact Pyrometer for Moderate Temperatures," Industrial Electronics, June 1965, Vol. 3, pp. 282-84.

An instrument for measuring temperatures in the range 200-1,000°C is described. The measurement is effected by comparing the radiation at two different wavelengths in the infra-red region.*

Pullan, H., and Swarbrick, R., "The Spectrotor, a Selective Infrared Detector of High Sensitivity," The Review of Scientific Instruments, March 1965, Vol. 36, pp. 388-91.

Considerable improvement in the performance of background-limited infrared detectors can be obtained over a restricted range of wavelengths by using a cooled filter to reject a large fraction of the background radiation. This principle has been applied in a portable device containing a series of narrow-band and interference filters which, on external command, can successively be brought into use. In this way exceptional detectivity can be realized over a number of separate wavelength regions. Detectivities in excess of 10^{11} cm/W have been obtained in the 5 to 6 μ region of the spectrum, using filters of 0.6 μ half-width together with a copper-doped germanium detecting element cooled by liquid helium contained in an internal reservoir. Sharper or longer wavelength filters would give still higher detectivity.*

Strasser, J.A., "NASA Receives French Infrared Detector," Aerospace Technology, February 26, 1968, Vol. 21, pp 43-44.

NASA has received a high-speed mercury cadmium telluride unit, apparently also available to the Russians, which is expected to be used in deep space communications. Characteristics not classified are given for this and other Hg Cd Te detectors.*

Thomann, H. and Frisk, B.,"Measurement of Heat Transfer with an Infrared Camera," The Journal of Heat and Mass Transfer, 1968, Vol. 11, pp. 819-26.

In the present paper the application of an infrared camera to heat-transfer measurements in a hypersonic wind tunnel is described.

The technique is closely related to the one using temperature sensitive paints or melting coatings. The main advantages of the present method are: (1) it is easy to apply as the model surface need not be treated with paint etc.; (2) the same model can be used again, as soon as it has cooled down; (3) smooth model surface; (4) good accuracy of the temperature measurement. Results are given for heat-transfer measurements on a paraboloid at M = 7 and compared with other measurements. Good agreement is found.*

Young, R.S., "A New Infrared Radiation Pyrometer," Journal of Scientific Instruments, 1967, Vol.44, pp. 988-92.

A new and sensitive type of infra-red radiation pyrometer has been designed and constructed, one form of which is specifically designed for measuring the temperature of aluminum extrusions in the 400-500°C range, with reduced dependence on the surface emissivity variations of the material. The basic instrument has two novel features. Firstly, it uses optical negative feedback from a semiconductor lamp to its lead sulphide photocell detector in order to give it overall stability, and secondly it uses an efficient infra-red cut-off filter, a water cell, to improve the power law relationship of received energy to temperature, so reducing the effects of emissivity variation. For the temperature measurement of aluminium and its alloys these variations are reduced to about half those encountered with a normal lead sulphide photocell pyrometer. The basic pyrometer is adaptable from narrow to wide angle working (0:75 in. viewing diameter at 7 ft, upwards) and will cover a range of temperatures from less than 300°C upwards, depending on the optical system. Without water cell filtering the minimum measuring temperature on low emissivity aluminium is less than 70°C.*

TECHNOLOGY

Apple, W.R., "Infrared Nondestructive Inspection - A Status Report," Journal of the ASTM, Materials Research and Standards, May 1969, pp. 10-13 + .

This paper summarizes the usefulness of thermal NDT with respect to detecting unbonded surfaces. Diagrams display proceedures and techniques used to test bonds. A description of basic theory and test results is included.

Chatterjee, S.K., "Infrared Radiation and its Applications," The Institution of Engineers (India), Jan. 1967, Vol. ET-2, pp. 47-66.

This paper discusses the fundamental principles of infra red radiation and detection. The transmission properties of infra red radiation through the atmosphere are briefly reviewed. The sensitivity of an infra red system and the maximum range that can be attained are also discussed on the basis of the existing theories.*

Griffin, D.D.,"Infrared Techniques for Measuring Temperature and Related Phenomena of Microcircuits," Applied Optics, September 1968, Vol. 7, pp. 1749-56.

A flexible ir system affords several ways to approach the investigation of temperature, dependent phenomena on small geometry targets. The appropriate technique will generally depend upon the objective of the particular investigation. Procedures for determining thermal time response, temperature mapping, and thermal image generation are demonstrated by example.*

"Infrared Technology," Engineering, June 1968, Vol. 205, pp. 1027-30.

Infrared radiation differs from visible radiation only in its wavelength, which is longer. This outline is confined to the use of wavelengths between 0.75 and 14 microns. It includes synopsis information about infrared emission, transmission, detection, and applications.

Kelton, G., et al.,"Infrared Target and Background Radiometric Measurements - Concepts, Units and Techniques," Infrared Physics, 1963, Vol. 3, pp. 139-169.

This report discusses concepts, units, and techniques for making and describing measurements of radiation from targets and backgrounds. It is a thorough discussion, written by 16 authors.*

Neuringer, L.J., "Infrared, Fundamentals and Techniques," Electrical Manufacturing, March 1960, Vol. 65, pp. 101-128.

This article contains a thorough discussion on infrared phenomenon. Subjects include radiation theory, optics, radiation interaction with various types of materials, detectors, techniques, and applications. Numerous graphs, tables, and diagrams are included to aid the reader.

Sach, H.L., "Infrared Physics," Argonne National Laboratory; 2nd Symposium on Physics and Non-Destructive Testing, 1961, pp. 163-186.

Continuous, remote measurement of the radiant emission from heated surfaces offers the capability for detection of flaws or voids internal to a specimen. The buildup of surface temperature gradient and departure from norm in the vicinity of internal flaw regions is discussed with emphasis on laminated structures and defects in metal to thermal insulator bonds.
The performance requirements for infrared instrumentation with measurement capabilities suited for this task are outlined and special attention given to practical aspects of the problem. An experimental technique and some recent promising results are presented.*

Saul, Robert, "Infrared Measurements and Techniques," Electro-Technology, October 1964, Vol. 74, pp. 112 + .

This paper presents the various qualities which describe power quantity and detection performance. Block diagrams are used to show detector components and to depict methods of measuring frequency response and N.E.P. Methods of evaluating data are briefly discussed.

Wank, M.R., "Application Pointers for Infrared Thermometry," Instrumentation Technology, January 1969, Vol. 16, pp. 43-45.

Design simplifications and built-in ruggedness of infrared thermometers have resulted in their widespread use in industrial

processes. But users should be aware of several interfering factors that can render IR temperature readings unreliable. The author discusses four such factors -- color differences, emissivity variations, ambient temperature effects, and heat-source interference -- and suggests what to do about them.*

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Bellamy, L.J., Advances in Infrared Group Frequencies, Barnes and Noble, New York, 1968.

Bramson, M.A., Infrared Radiation: A Handbook for Applications, Plenum Publishing Co., New York, 1966.

Hadni, Armond, Essentials of Modern Physics Applied to the Study of Infrared, Academic Press Inc., New York, 1968

Holter, M.R., et al., Fundamentals of Infrared Technology, MacMillian Co., Riverside, N.J., 1963.

Houghton, J.T. and Smith, S.C., Infrared Physics, Oxford University Press, New York, 1966.

Jamieson, J.A., et al., Infrared Physics and Engineering, McGraw-Hill, Manchester, N.J., 1963.

Kruse, P.W., et al., Elements of Infrared Technology: Generation, Transmission, and Detection, John Wiley and Sons, Salt Lake City, Utah, 1962.

Simon, Ivan, Infrared Radiation, Van Nostrand, Princeton, N.J., 1966.

Wolfe, W.L. (ed.), Handbook of Military Infrared Technology, U.S. Govt. Printing Office, Washington, D.C., 1965.

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"Non-Destructive Testing" _Applied Optics_, Sept. 1968, Vol. 7, No. 9, pp. 1667-1878.

Proceedings of the Symposium on Remote Sensing of Environment, Ann Arbor, Michigan, 1963-1968.

Remote Multispectral Sensing in Agriculture, Laboratory for Agricultural Remote Sensing, Purdue University, Sept. 1968, Vol. 3.

"Special Issue on Remote Environmental Sensing," _Proc. of I.E.E.E._, April 1969, Vol. 57, No. 4, pp. 371-742.

"Special Issue on Infrared Physics and Technology" _Proc. of the I.R.E._, September, 1959, Vol. 47, No. 9, pp. 1413-1700.

Symposium on Infrared Components, Techniques, and Systems, Royal Radar Establishment, Great Malvern, England, 1967.