New infra-red detectors using indium antimonide


[Paper first received 10 January, and in final form 20 March, 1957]

The paper describes the properties of InSb detectors, at room temperature, using the photo-conductive process, and experimental work on sensitive p-n junction detectors, cooled to 90° K, used as photo-voltaic cells.

INTRODUCTION

Photo-effects in InSb have been reported extending to wavelengths around 7·5 μ at room temperature, and sensitivity in InSb p–n junctions has been reported extending to wavelengths around 5·8 μ. The purpose of this paper is to describe in more detail the properties of room temperature InSb detectors using the photoconductive process, and to describe experimental work on sensitive p–n junctions cooled to 90° K. In a recent note, Hilsum and Ross, have described room temperature detectors using the photo-magnetic effect.

ROOM TEMPERATURE PHOTOCONDUCTIVE DETECTORS

These take the form of thin strips of InSb, of area about 8 × 0.5 mm which have leads soldered at each end, and which are mounted on a varnished metal support. The starting material is single crystal InSb prepared by the pulling technique from previously zone-refined compound. The strips are prepared by first slicing the crystal using a wire-saw, grinding the slices to dimensions 8 × 1 × 0·2 mm followed by a final electrolytic polish.

A suitable polarizing voltage is applied across the strip, which is illuminated with modulated radiation. The resultant changes in resistance of the strip are then observed as an alternating photoconductive current. The resistances are typically between 50 and 500 Ω and in order to make use of the full signal/noise ratio developed in the detector it is customary to use a step-up transformer to increase the noise voltage from the detector to a level greater than the noise in the input stage of a conventional valve amplifier.

The performance of one such detector, operated with an applied voltage of 2·5 V, is shown as a graph of minimum detectable energy* (m.d.e.) against wavelength in Fig. 1.

The noise in the detector which limits the sensitivity is substantially Johnson noise, at least for low applied voltages. For higher voltages, Joule heating of the detector limits its sensitivity, the sensitivity falling by about 2% for each degree rise in temperature. It will be seen from Fig. 1 that the detector roughly responds equally to equal numbers of photons incident upon it anywhere within its spectral range.

Measurements of carrier lifetime in this material suggest that the response time should be about 4·10⁻⁸ s. Observations of the signal obtained when the detector was illuminated by a pulsed spark having a rise time of 2·10⁻⁷ s were indistinguishable from the signals obtained from the same source using a photomultiplier tube. This is taken as evidence that the response time is at least less than 2·10⁻⁷ s.

The sensitivity of this detector is one to two orders of magnitude less than that of good radiation thermопiles operated at frequencies of about 5 c/s. However, in many applications the extremely fast response (20 Mc/s) may more than outweigh its lower sensitivity. For any experiment where high sampling rates are desired, or where transient phenomena are to be observed, these are the most suitable room temperature detectors for wavelengths beyond the PbS limit of ~3μ. Transistor amplifiers could be used, working directly from the strip resistance of say, 100 Ω, with quite small loss in signal/noise, at modulation frequencies in excess of 1–2 kc/s.

InSb detectors have an additional advantage over most existing photoconductive cells, other than chemically deposited PbS cells (see, for example, Milner and Watts), in that they are stable in air over periods of, at least, many months and they require no envelope. It is thus a simple matter to use detector strips of the dimensions described to build any desired array of detectors to match any optical problem. From the point of view of flexibility of design, photoconductive detectors have this advantage over photomagnetic detectors since in order to maintain adequate magnetic fields, each photomagnetic detector requires a separate polarizing magnet.

COOLED P–N JUNCTION DETECTORS

Essentially similar devices to that previously reported by Mitchell and co-workers have been prepared and their properties will be described since they seem potentially useful infra-red detectors.

The InSb junctions were prepared by first melting material of known excess carrier concentration on to the end of a

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* The m.d.e. is here defined as that amount of radiation incident upon the detector which will give a signal/noise ratio of unity, unit bandwidth being assumed in the electronic circuit. It will be quoted as watts/cycle.

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single crystal seed with excess carriers of the opposite type and fewer in number. On reversing the direction of motion of the freezing plane, a single crystal is formed containing the junction. Both seed and melt were held in a silica boat coated with carbon black. The crystal was then sliced so that each slice contained the junction as shown in Fig. 2. The dimensions are roughly as shown, after a final electrolytic etch.

Most of the measurements were made with the slice mounted in a demountable metal Dewar system arranged so that the junction could be illuminated either with a uniform flux from a tungsten lamp, or with a micro-illuminator described elsewhere. Whilst the junction temperature was nominally 90° K, it is possible that it was in fact some 10° higher than this. Some slices have been mounted in conventional glass Dewar vessels as used for PbTe cells.

The junctions were used as photo-voltaic cells and measurements have been made of the m.d.e. as a function of wavelength, and the distribution of sensitivity across the surface in the neighbourhood of the junction. Some showed a slow variation of sensitivity with time; the cause of this variation is not understood, but may be associated with the condensation of residual vapours in the Dewar cell.

In Fig. 3, graphs of m.d.e. against wavelength are shown for three of these detectors and compared with a typical PbTe cell, assuming that the m.d.e. of a PbTe cell is proportional to the square root of its sensitive area. Assuming this proportionality, the m.d.e. for the PbTe cell quoted by Moss is an order of magnitude less than that shown in Fig. 3.

The area quoted for a p-n junction cell is defined as the specimen width multiplied by that distance along the surface within which illumination with a fine light spot produces a signal greater than $e^{-1}$ times the maximum signal. For the case of an ideal junction, this distance is the sum of the carrier diffusion lengths on either side. In practice this simple pattern may be modified by surface channels. Distributions have been observed suggesting this type of channel, and also in some cases double peaks of unexplained origin have been found. Two typical distributions are given in Fig. 2.

These detectors have resistances of about 1 to 10 kΩ as compared with the 1 to 100 MΩ associated with PbTe cells, a much more convenient impedance from the point of view of associated electronic circuits. The noise observed is in general up to ten times greater than the expected Johnson noise. The source of this excess noise has not been studied, but it has been found to increase rapidly with the application of reverse bias to the junction.

The response time of these junction devices is again very short, at most $2 \times 10^{-7}$ s as determined from the pulsed spark method.

ACKNOWLEDGEMENTS

Acknowledgement is made to the Controller, H.M. Stationery Office, for permission to publish this paper.

REFERENCES

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