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A PROPOSED METHOD OF INFRA-RED DETECTION BASED ON THERMAL CONVERSION OF RADIATION

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Synopsis

A new method of i.r. detection is proposed, based on the change in Planck radiation of a black strip when it is heated by the radiation to be measured. The application of a photo-conductive cell is proposed for the detection of the Planck radiation which occurs in the near i.r. region at room-temperature. Some informative calculations on the detection limit will be given, showing that the expected results are good when compared with that of bolometers etc.

Photo-conductive cells of the type PbS may have a useful sensitivity which is 100 times better than that obtained with bolometers or thermo-elements [1]. It is even reported that at room-temperature the sensitivity of these cells approaches the fluctuation of the Planck radiation [2]. However, the spectral region of their response has (up till now) been limited to wavelengths below 10 micron.

Here a method will be proposed in order to make the useful sensitivity of photo-conductive cells in the spectral region beyond 10 micron better than that of bolometers. This method is based on thermal conversion of far infra-red radiation into near infra-red radiation to which photo-conductive cells are sensitive. This conversion can be realized by the change in Planck radiation which occurs when a black strip is heated by irradiation through (far infra-red) radiation.

This method can be of practical interest since Planck radiation at room-temperature occurs for a good deal at wavelengths to which photo-conductive cells are sensitive. The method is expected to be advantageous since the Nyquist noise in the heated strip does not play a part here. It is wellknown that this noise limits the useful sensitivity of bolometers [3] [4]. It is true, photo-conductive cells show fluctuations which are characteristic for semi-conductors, but by cooling and modulation of radiation at sufficiently high frequency this fluctuation has proved to be easily eliminated. When the time-constant of the black strip to be irradiated is long, this modulation should be applied to the secondary radiation incident on the cell.

The results of some informative calculations will be reported here for a rather idealized case, in which the double-blackened strip is irradiated on one side by the radiation to be measured and on the other side faces closely the sensitive layer of the photo-conductive cell which has the same area as the strip. The cell is assumed to be cooled by a cooling element at its back-part, as usual. The surroundings are assumed to be at room-temperature, as usual. Also the black strip is supposed to be, on the average, at this temperature (which may be realized by a heating current through the strip, which compensates the radiation loss of the strip to the cooled cell). The radiation emitted by the cell and possible losses owing to modulation of the radiation (which are about a factor 2) are disregarded here. The quantum-efficiency of the cell is supposed to equal unity in the considered spectral region.

The following notation will be used: a = coefficient of total heat-transport from the strip to its surroundings; a_1 = coefficient of heat transport by radiation from the strip to its surroundings; A = area of strip; C = heat-capacity of strip; w = circular frequency of the modulation of the radiation to be measured; T_0 = room-temperature; σ, k, h, c, c_1 and c_2 are the usual constants occurring in radiation theory.

The factor of merit R is here defined as the ratio of the "natural" fluctuations owing to radiation exchange of the receiving side of the strip with the surroundings, to the actual fluctuations measured by the cell when expressed in terms of equivalent input radiation.

First the case is considered that the cell has a uniform response in the spectral region where Planck radiation at room-temperature mainly occurs. If $a \gg a_1$, it was calculated that:

$$R^2 = \tfrac{1}{2} a_1^2 . (aa_1 + a^2 + w^2C^2)^{-1} \simeq \tfrac{1}{2} a_1^2 . (a^2 + w^2 C^2)^{-1}$$

with: $a_1 = 8\sigma A T_0^3$.

If $a = a_1$, this formula does not hold, since in this case allowance should be made for the fact that the strip virtually does not receive radiation from the cooled cell, and for the coherence that exists between the fluctuation of temperature of the strip and the shot-effect fluctuation in the radiation that is absorbed and emitted by the strip. If it is further assumed that $wC \ll a_1$, then one finds by calculation: R = 81 per cent, which is the maximum value.

Another case was considered, in which the cell was supposed to be sensitive only in a restricted range L of wavelengths with λ as mean wavelength. λ is assumed to be situated on the short-wavelength wing of the spectral curve of the Planck-radiation, in agreement with the practical case. Classical statistics may be applied here in stead of the required Bose-Einstein statistics when treating the radiation fluctuation. The formula of Wien is here a good approximation, too.

If again $a \gg a_1$, it was calculated that:

$$R^2 = \tfrac{1}{2} a_1^2 . \{(a^2 + w^2C^2)/P + aa_1\}^{-1}$$

with:

$$P \equiv (2\pi hcc_1/4k\sigma) \, . (L/\lambda) \, (\lambda T_0)^{-5} \exp \, [- c_2/\lambda T_0].$$

If $a = a_1$, this formula does not hold true either, since in this case allowance should be made for the fact that the strip virtually does not receive radiation from the cooled cell. Coherence between the fluctuations as described above is still absent, however. If it is further assumed that $wC \ll a_1$, it can be proved that then:

$$R^2 = \tfrac{2}{3} \, . \left(\frac{4}{3P} + 1 \right)^{-1} \qquad (1)$$

Since at optimum value of λT_0 ($= 0.288$ cm.degree; $\lambda = 10^{-3}$ cm at room-temperature) P equals $0.80 \, L/\lambda$, it holds that in this special case:

$$R^2 = \tfrac{2}{3} \, (1.66 \, \lambda/L + 1)^{-1}.$$

From this it follows that with $L/\lambda = 0.1$, R equals 0.20; with $L/\lambda = 0.5$, R equals 0.40 (compare above).

When formula (1) is applied to the cooled PbTe-cell, for which Fellgett [5]) has reported that the actual fluctuations are only 1.9 times larger than the ultimate limit set by radiation (shot-effect) fluctuation, corresponding to room-temperature, and filling in reasonable values for $\lambda = 4.10^{-4}$ cm and $L/\lambda = 0.5$, an actual value of $R = 24$ per cent may be expected if modulation losses are disregarded. With cells with a more extended range of spectral response better results might be obtainted.

Furthermore it can be shown by calculation that if an electric current is supplied to the strip, the resistance of which has a dimensionless temperature-coefficient n, an additional increase in temperature may be obtained when the strip is irradiated. This effect is based on an electric feed-back, caused by the fact that the electric energy dissipated in the strip depends on its resistance, and by that on its temperature, which alters upon irradiation.

This additional increase in temperature favourably affects the discrimination of the signal to be measured against the noise that is not correlated with the temperature fluctuations.

For thermistor material with $n = -10$, the factor of additional increase is calculated to be 10, if the strip is connected directly to a d.c. voltage which heats the strip with 30°C.

When a heating current is supplied to the strip, the so-called $I\mathrm{d}V$-effect — which was hypothetically assumed by Becking [4]) in order to explain the fluctuation phenomena with a bolometer — may cause that the Nyquist noise of the strip still plays a part. According to this effect the spontaneous voltage fluctuation $\mathrm{d}V$ due to the Nyquist noise cause a fluctuation in the heat-dissipation equal to $I\mathrm{d}V$, when I is the current which is supplied to the strip from an external source. By calculation it can be shown that this effect does not exceed the natural radiation fluctuations, so that its influence is fairly restricted in our case.

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