PH 301

ENGINEERING OPTICS

Lecture_Optical Detectors_29

Infrared was discovered in 1800 by Sir William Herschel as a form of radiation beyond red light. Infra is Latin prefix for below.

There are four basic laws of IR radiation: Kirchhoff's law of thermal radiation, Stefan-Boltzmann law, Planck's law, & Wien's displacement law.

Division of IR radiation

Region	Wavelength range (μm)
Near infrared (NIR)	0.78 – 1
Short wavelength IR (SWIR)	1 – 3
Medium wavelength IR (MWIR)	3 – 6
Long wavelength IR (LWIR)	6 – 15
Very long wavelength IR (VLWIR)	15 – 1000

Thermal Detectors

- Thermal detector is a resistive element which measures electromagnetic radiation by absorbing it & converting it into heat.
- Thermal detectors contain a small active element on which radiation is focused.
- By blackening & insulating the element & by minimizing size of element temp change & detector response are maximized.
- Temp change is approximately inversely proportional to exposed surface area of element.
- As intensity of radiation increases the temp change on element of detector increases.

Types of Thermal Detectors

1. **Thermopiles** : Thermocouple
2. **Thermistors** : Pyroelectric detector
3. **Pneumatic devices** : Golay Cells

Merits

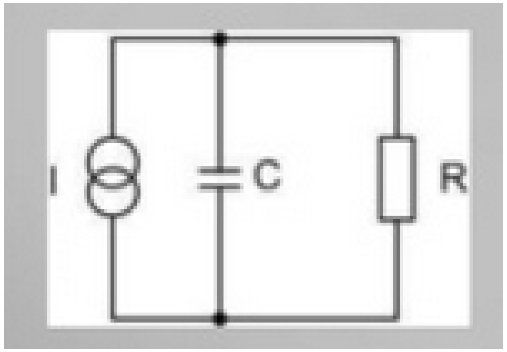
- **Used for wide wavelength range**
- **Linearity in response is seen**

Demerits

- **Slow response time**
- **Lower sensitivity**

Thermal detectors are of low manufacturing costs in comparison to photon detectors. Quality of these detectors was greatly improved after introduction of micromachining technology.

Uncooled arrays of these detectors working in IR region (thermovision cameras) are commercially available.



Electrical scheme for a thermal detector

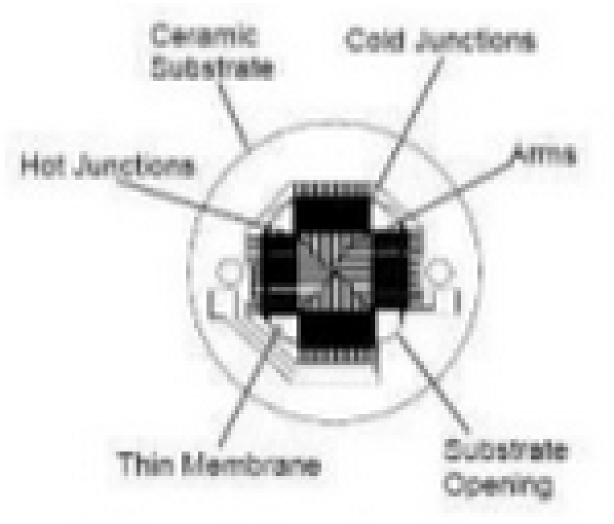
Thermopile Detectors

❖ An electronic device that converts thermal energy into electrical energy.

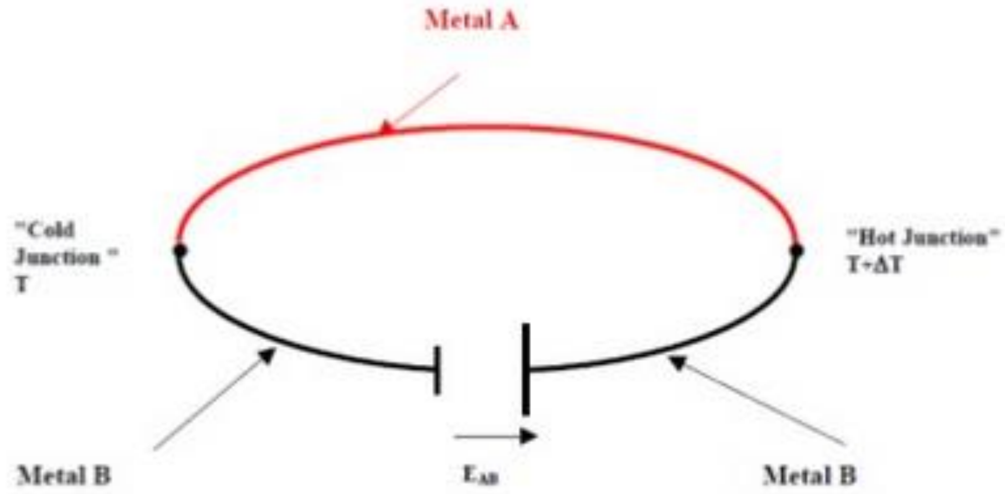
❖ It is composed of several thermocouples connected usually in series, or less commonly, in parallel.

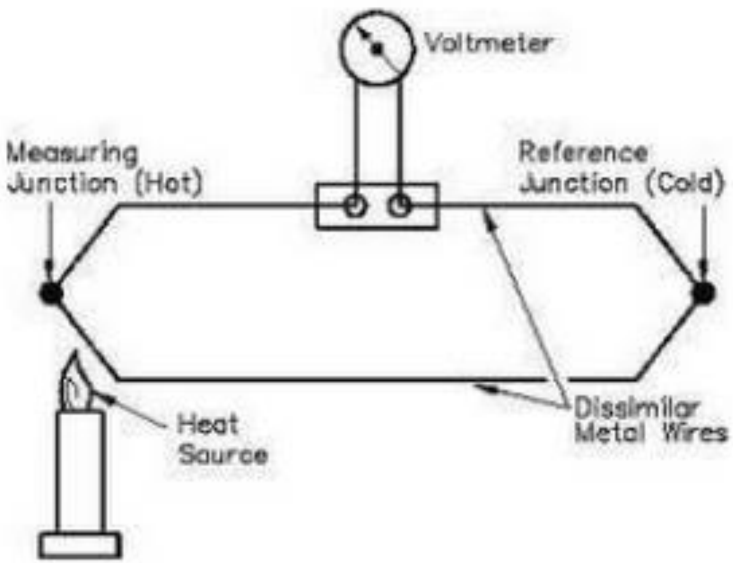
❖ It operates by measuring temp differential from their junction point to point in which thermocouple output voltage is measured.

❖ Thermopile detectors consist of an array of thermocouple junctions linked in series as differential pairs. These differential pairs form hot & cold junctions.



Circuit of thermocouple

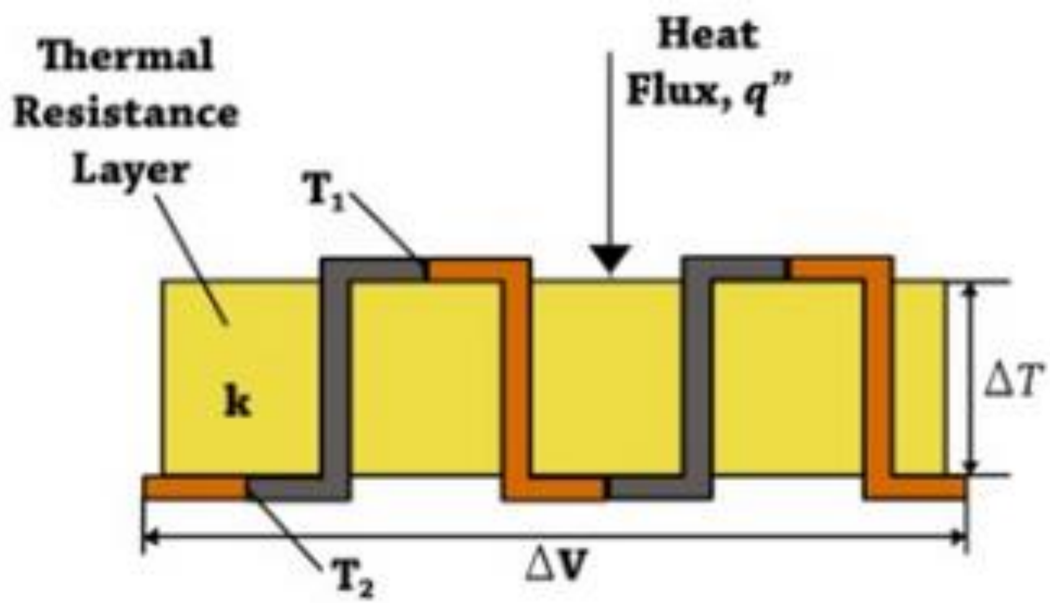




Thermocouple

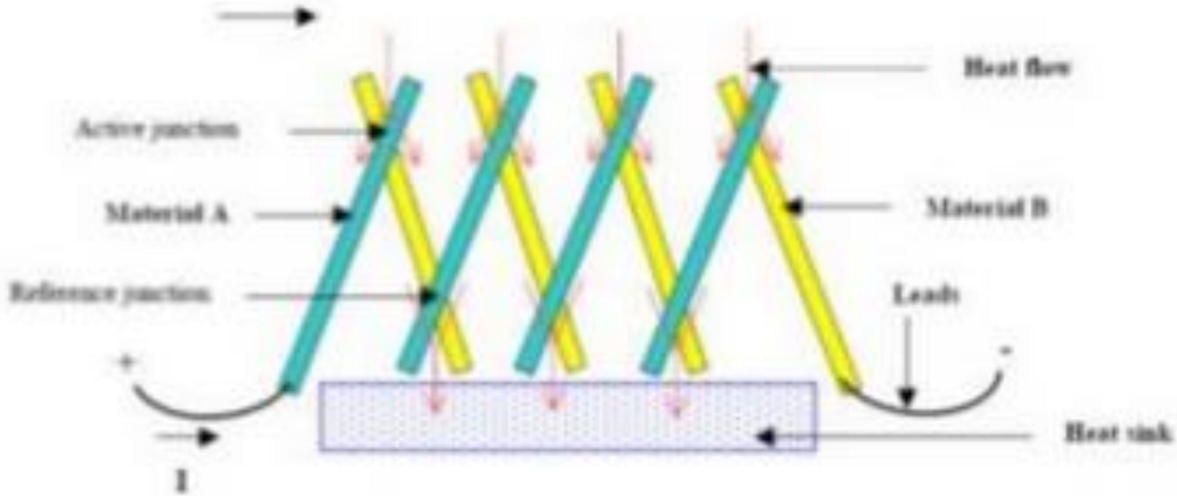
- **Two dissimilar metals like bismuth & antimony.**
- **Two ends are called Hot junction & Cold junction.**
- **Surface at junction of wires is coated with black metallic oxide.**
- **IR radiation falls on hot junction by heat source change in temp at junction between metallic wires causes an electric potential to develop between wires.**
- **Potential difference between unjoined ends of wires is amplified & measured.**
- **Cold junction is not exposed to IR.**

Differential Temperature Thermopile (Two Thermocouple)



- With two sets of thermocouple pairs connected in series.
- Two top thermocouple junctions are at temp T_1 while two bottom thermocouple junctions are at temp T_2.
- Output voltage from thermopile ΔV is directly proportional to temp differential ΔT or T_1 - T_2, across thermal resistance layer & no. of thermocouple junction pairs.
- Thermopile voltage output is also directly proportional to heat flux q, through thermal resistance layer.

Thermopile (several thermocouples)



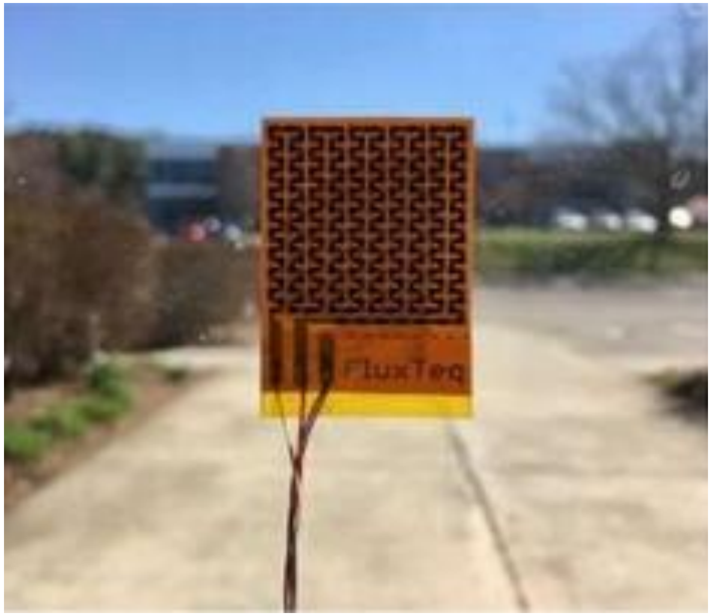
- **Thermopiles do not respond to absolute temp, but generate an output voltage proportional to a local temp difference or temp gradient.**

- **Thermopiles are used to provide an output in response to temp as part of a temp measuring device, such as IR thermometers widely used by medical professionals to measure body temp, or in thermal accelerometers to measure temp profile inside sealed cavity of sensor.**

Applications of Thermopile Detectors

- **Non-contact temp measurements in process control & industry**
- **Hand-held non-contact temp measurements**
- **Thermal line scanners**
- **Tympanic thermometers IR radiometry refringent leak detection**
- **Automotive exhaust gas analysis of HC, CO_2, & CO.**
- **Commercial building HVAC & lighting control**
- **Security human presence & detection**
- **Blood glucose monitoring**
- **Horizon sensors for satellites, aircraft, & hobbyist applications**
- **Medical gas analysis such as blood alcohol breathalyzers, incubator CO, CO_2, & anaesthetic**
- **Aircraft flame & fire detection**
- **Hazard detection including flame & explosion.**

Applications



- Thermopiles are also used to generate electrical energy from, for instance, heat from electrical components, solar wind, radioactive materials, laser radiation or combustion.

- The process is also an example of Peltier effect (electric current transferring heat energy) as the process transfers heat from hot to cold junctions.

Thermistors

- Thermistors are devices that have an electric resistance that is higher temp dependent.
- Materials used are sintered oxide Cobalt, Manganese, & Nickel
- A constant potential is applied across thermistor & difference in current flow between an illuminated thermistor & a non-illuminated thermistor is measured using a differential operational amplifier.
- As temp of mixture increases, its electrical resistance decreases.
- It should be operated at a frequency of less than 12Hz.

Pyroelectric Detectors

- **It contains a noncentrosymmetric crystal, which exhibits an internal electric field along polar axis.**
- **Pyroelectric effect depends on rate of change of detector temp rather than on temp itself.**
- **These detectors operate with a much faster response time & make choice of Fourier Transform Spectrometers.**
- **Materials used in pyroelectric detectors are:**

  - Triglycine sulfate (TGS)

  - Deuterated triglycine sulfate (DTGS)

  - Lithium niobate ($LiNbO_3$)

  - Lithium tantalate ($LiTaO_3$)

Bolometers

- **It is a device for measuring power of incident electromagnetic radiation via heating of a material with a temp-dependent electrical resistance. It was invented in 1878 by American Astronomer Samuel Pierpont Langley.**
- **Used to detect as well as measure microwave energy radiation & heat.**
- **It works by using a temp-sensitive resistive element where resistance changes through temp.**
- **Most frequently used resistive elements are Barretter & Thermistor.**

Bolometer working

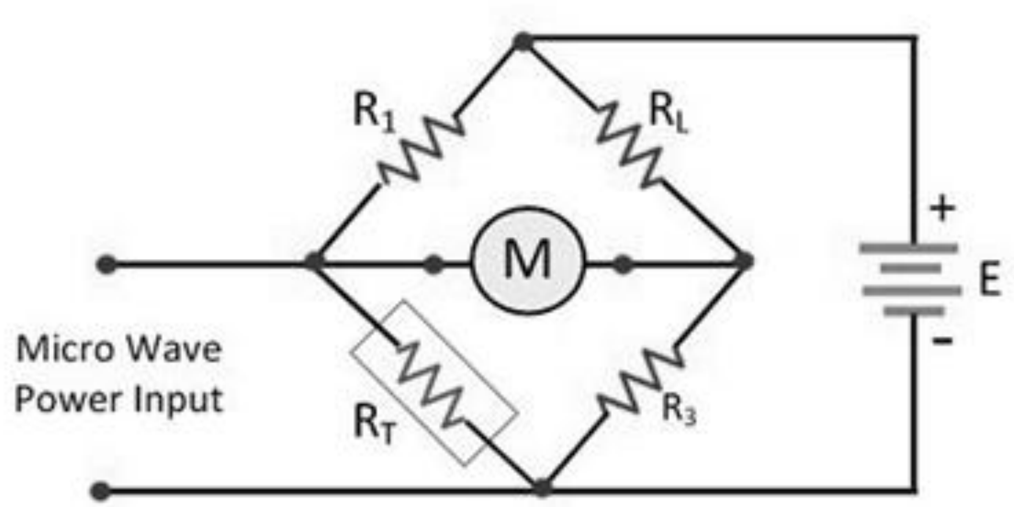
- A bolometer includes an absorptive part that is made up of a slight metal layer. Connection of this part can be done through a thermal reservoir with the help of a thermal link.
- Once radiation hits absorptive part, then its temp will change. So compared with reservoir temp, this temp is high because of radiation absorption.
- Thermal time constant of intrinsic can be equivalent to heat capacity ratio among absorptive element as well as reservoir.
- Therefore, temp change is measured directly through a resistive thermometer that is connected to absorptive part. Sometimes, absorptive parts resistance is used for computing change in temp.

Bolometer circuit

- Arrangement of circuit can be done in a bridge form, where one arm includes temp-sensitive resistor.

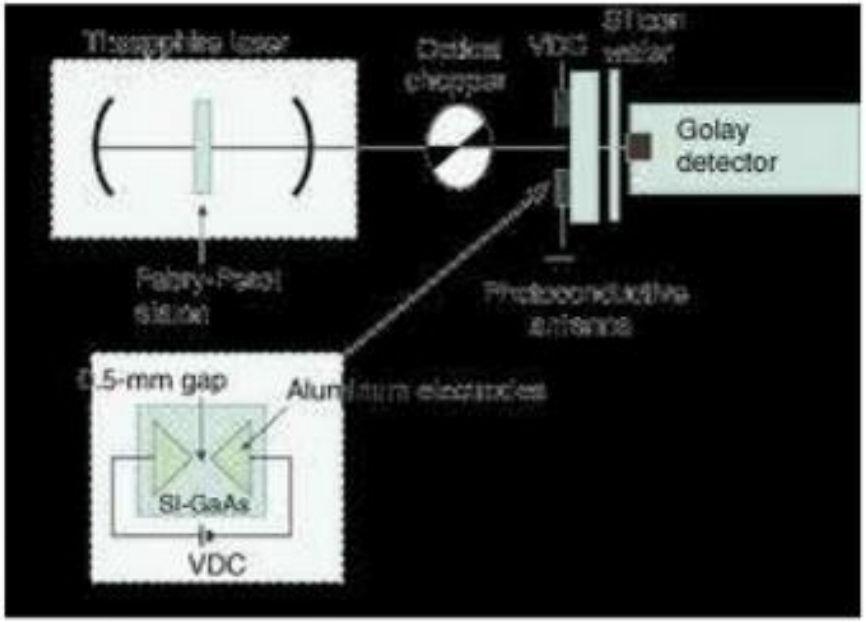
- Arrangement of this resistor can be done in a microwave energy field where power can be measured.

- This resistor absorbs measurand power because heat generates within it. This generated heat can change resistance of an element. Change in resistance can be measured by bridge circuit.

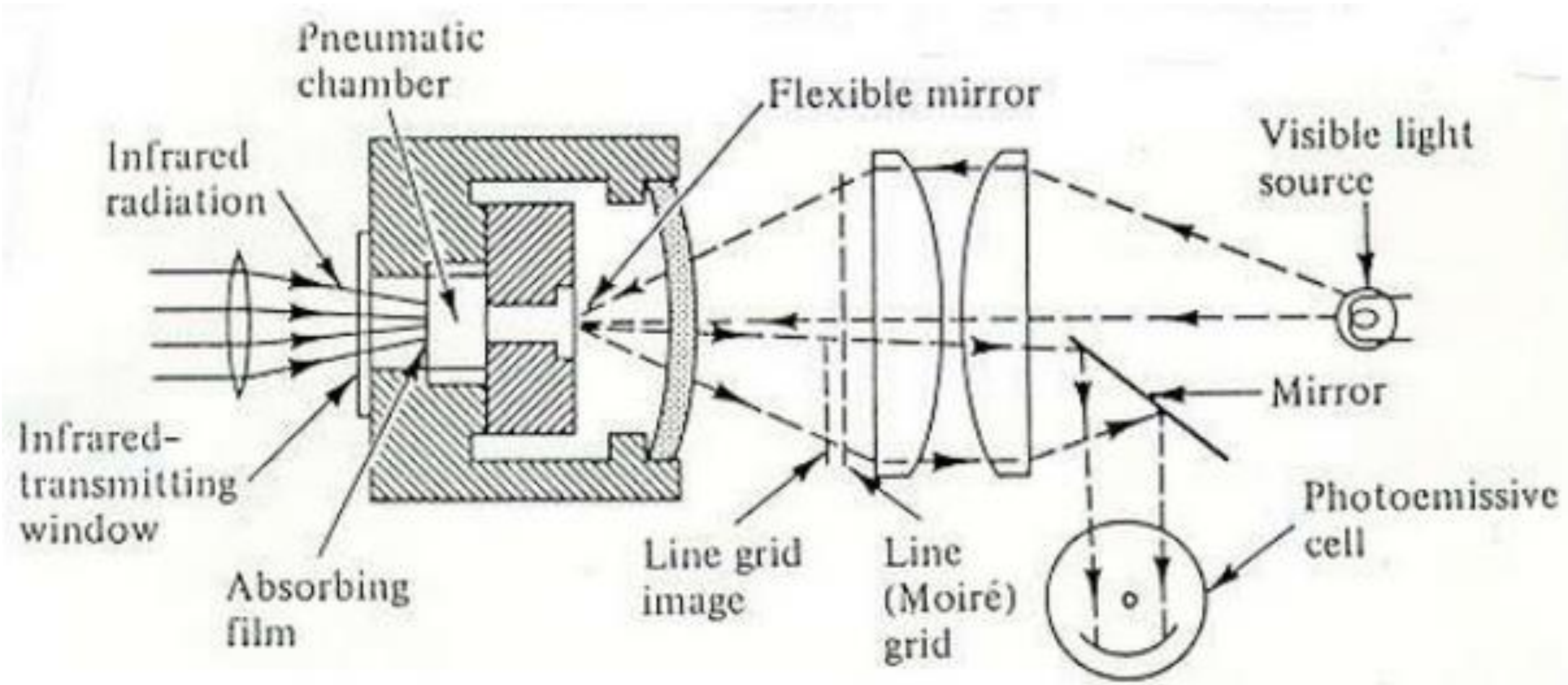


Golay Cell

1947



- **Golay cell consists of a small metal cylindrical closed by a rigid blackened metal plate.**
- **Pneumatic chamber is filled with xenon gas.**
- **At one of a cylinder a flexible silvered diaphragm & at other end IR transmitting window is present.**



- When IR radiation is passed through IR transmitting window the blackened plate absorbs the heat, which causes expansion in gas.
- Resulting pressure of gas will cause deformation diaphragm. This motion of diaphragm detects how much IR radiation falls on metal plate.
- Light is made to fall on diaphragm which reflects light on photocell.
- Response time is 20ms.

Metal Bolometers: **These have a linear change in resistance with temp.**

$$R = R_0[1 + \gamma(T - T_0)]$$

$$\alpha = \frac{\gamma}{1 + \gamma(T - T_0)}$$

This coefficient always decreases with temp, & burnout does not occur. The coefficient is approximately equal to the inverse of temp, & is therefore never high.

Semiconductor Bolometers: **These have an exponential change of resistance with temp.**

$$R = R_0 e^{\beta/T}$$

$$\alpha = -\beta/T^2$$

Value of *β* depends upon the particular material. These detectors can burn out. Two basic types exist: (1) those that are used at low temperatures & (2) those that are used at about room temperature .

Superconducting bolometers: These make use of extremely large thermal coefficient of resistance at the transition temperature.

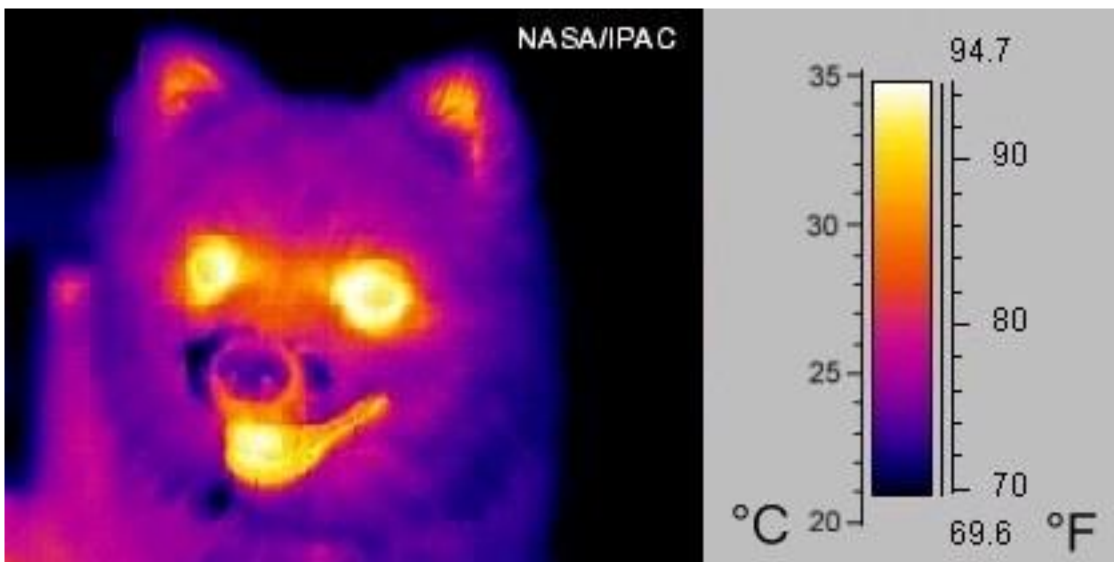
Originally they needed to be controlled very carefully, or a small change in ambient conditions (on the order of 0.01 K) could cause an apparent signal of appreciable magnitude.

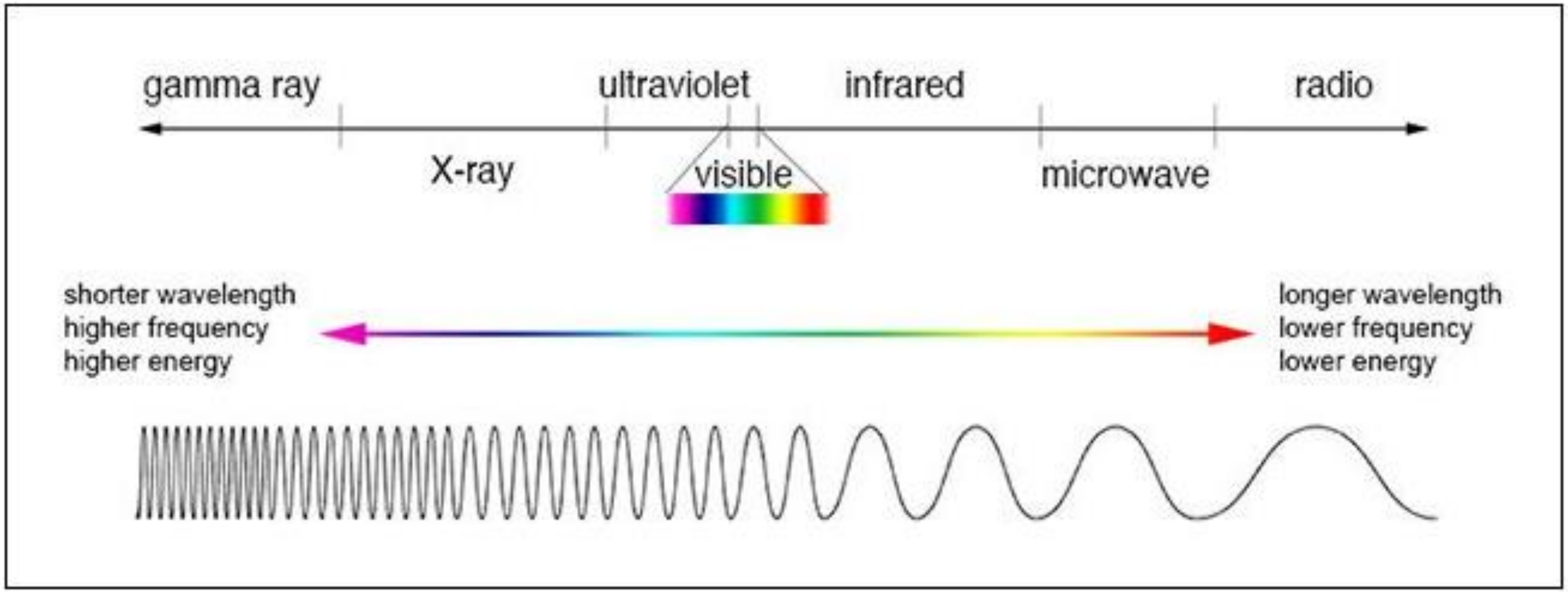
Carbon Bolometers: These are a form of semiconductor bolometer that have been largely superseded by germanium bolometers. They are made of small slabs of carbon resistor material, connected to a metal heat sink by way of a thin mylar film. Although their responsivities are comparable to germanium bolometers, their noise is several orders of magnitude higher.

Thermographic camera

- A thermographic camera also called IR camera or thermal imaging camera or thermal imager is a device that creates an image using IR radiation. They are sensitive to wavelengths 1 μm to 14 μm.

- Practice of capturing & analyzing data such camera provide is called thermography.


NASA/IPAC
35
30
25
20
°C
94.7
90
80
70
69.6
°F



The hotter an object is, the more IR radiation it produces. Thermal cameras can see this radiation & convert it to an image that we can see with our eyes.

- **All objects emit a certain amount of black body radiation as a function of their temp.**

- **Generally speaking, the higher an object's temp, the more IR radiation is emitted as black body radiation. It even works in total darkness because ambient light level does not matter.**

- **A major difference with optical cameras is that focusing lenses can't be made of glass, as glass blocks long-wave IR light. Typically, spectral range of thermal radiation is from 7 - 14 μm.**

- **Special materials such as Germanium, Calcium fluoride, Crystalline silicon or newly developed special type of chalcogenide glasses must be used.**

- **Except for Calcium fluoride all these materials are quite hard & have high refractive index (Ge, *n* = 4) which leads to very high Fresnel reflection from uncoated surfaces (up to more than 30%).**

- **For this reason most of lenses for thermal cameras have antireflective coatings. Higher cost of these special lenses is one reason why thermographic cameras are more costly.**

- **For use in temp measurement, brightest (warmest) parts of image are customarily colored white, intermediate temperatures reds & yellows, & dimmest (coolest) parts black.**

- **A scale should be shown next to a false color image to relate colors to temperatures.**

- **Their resolution is considerably lower than that of optical cameras, mostly only 160 × 120 or 320 × 240 pixels, although more expensive cameras can achieve a resolution of 1280 × 1024 pixels.**

- **In uncooled detectors, temp differences at sensor pixels are minute; a 1°C difference at scene induces just a 0.03°C difference at sensor.**

- **Pixel response time is also fairly slow, at the range of tens of milliseconds.**

Cooled IR Detectors

- Typically contained in a vacuum-sealed case & cryogenically cooled. Cooling is necessary for operation of used semiconductor materials. Typical operating temps range from 4 K to just room temp.

- Modern cooled detectors operate in 60 K to 100 K range (-213 to -173 °C).

- Without cooling, these sensors will be blinded or flooded by their own radiation.

- Drawback of such cameras are that they are expensive both to produce & to run. Cooling is both energy-intensive & time-consuming. The camera may take several minutes to cool down before it can begin working.

- Materials: Indium antimonide (3-5 μm), Indium arsenide, Mercury cadmium telluride, lead sulfide, lead selenide.

Uncooled IR Detectors

- **They use a sensor operating at ambient temp, or a sensor stabilized at a temp close to ambient using small temp control elements. Modern uncooled detectors all use sensors that work by the change of resistance, voltage or current when heated by IR radiation. These changes are then measured & compared to values at the operating temp of sensor.**

- **They can be stabilized to an operating temp to reduce image noise, but they are not cooled to low temps & do not require bulky, expensive, energy consuming cryogenic coolers. This makes IR cameras smaller & less costly. However, their resolution & image quality tend to be lower than cooled detectors.**

- **Uncooled detectors are mostly based on pyroelectric & ferroelectric materials or microbolometer technology. Materials are used to form pixels with highly temp-dependent properties, which are thermally insulated from environment & read electronically.**

Drone with IR camera

IR Night Vision Camera

Intensifier tubes absorb whatever light they can & amplify it.