Amateur video camera as a detector of infrared radiation

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Abstract

This paper deals with the possibility of using a common video camera as a detector of near infrared radiation in physical demonstrations. After a brief theoretical description of the physical basis of infrared detection, the set of experiments is presented. Most of the experiments can be done with relatively simple and easily accessible equipment. These experiments are intended for use in physics courses at all educational levels, ranging from basic schools up to universities.

Introduction

Infrared (IR) and ultraviolet (UV) radiation cover the regions nearest to the visible range of electromagnetic radiation. Though both have a recognizable impact on the human body – notably through sunburn and heat – they remain invisible, and hidden from our senses. At present, probably everybody knows that IR and UV radiation exist, or at least believe in their existence. Current environmental problems involving the ozone hole and global climatic changes have made UV and IR radiation two of the most frequently used physics terms in the media. But teaching this aspect of nature undetectable to human senses is more complicated than teaching things that students can see, hear, smell or touch. Making any invisible part of physical reality visible is the simplest and strongest argument for its existence.

All ordinary cameras and video cameras detect light using silicon based CCD or CMOS chips. When any photon is to be detected, it must be absorbed. The same is true for CCD, photographic film, the retina, and so on. This means that the spectral sensitivity of a detector is closely connected with the absorption spectra defined by the mechanism used for detection. In a silicon semiconductor structure, the photon is detected via its absorption by an electron in the valence band, leading to electron excitation to the conducting band. The electron - hole pair created by this excitation is subsequently detected by the CCD or CMOS electronic structure in the shallow below-surface area.

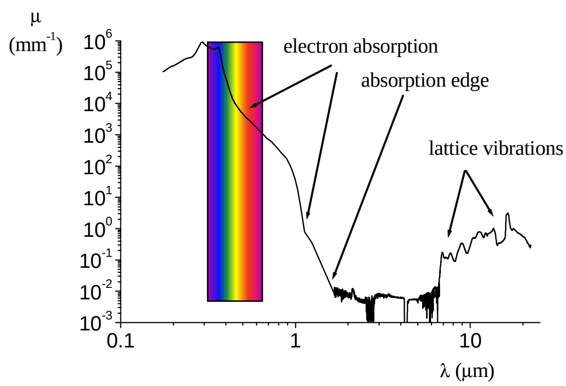


Fig. 1: Absorption coefficient μ of silicon

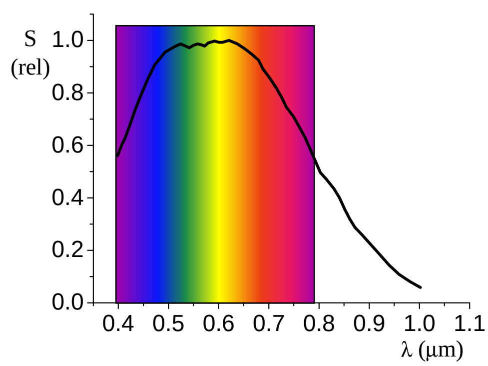


Fig. 2: Sensitivity of silicon CCD chip.

The silicon absorption spectrum is illustrated in Fig. 1. The absorption edge at 1.1μm is given by the width of the energy gap which is equal to 1.1eV. For shorter wavelengths – higher photon energies – the absorption increases extremely rapidly. The absorption half thickness drops from several centimetres at 1.1 μm to the nanometre range in blue light. In the range from 1.1 μm to 7 μm, silicon has a good transparency. In the far infrared region, the radiation is absorbed at lattice vibrations, but this mechanism is useless for photon detection in CCD structure.
The real spectral sensitivity of a CCD chip is slightly different from the spectral absorption of silicon; see Fig. 2. The decrease in sensitivity at short wavelengths – blue light – is due to absorption of this radiation in thin surface layers and in the below-surface volume of silicon itself[1].

It is clear from absorption spectra that the electronic structure of silicon must detect light further towards the IR region. This is not desirable because the main goal is to have a light detector with exactly the same spectral sensitivity as the human eye. If this is not fulfilled, a distortion in the reproduction of colours occurs. This problem is usually solved by adding an IR filter into CCD camera optics, which makes the detection spectrum similar to that of the eye.

Some video cameras come equipped with the possibility of infrared night vision. This mode is named Nightshot® (in Sony cameras) or MagicVu® IR Filtr – 0 lux (in Panasonic cameras). In this paper we will call it IR mode.

When the IR mode is switched on, two things happen

1) IR filter is withdrawn from the optical path and
2) IR light emitting diodes located close to the objective are switched on. This way the camera could see even in complete darkness, illuminating the scene by infrared LEDs[2].

If we disable the IR LEDs, e.g. simply by covering them with black sticky tape, we get a sensitive detector of near IR up to 1.1μm with very good space and time resolution that can be used in a demonstration experiments to make IR light visible.

Description of experiments

Remote control infrared LED

As written above, a combination of CCD chip and infrared filter makes the spectral sensitivity of digital cameras similar to the spectral sensitivity of the human eye. However, it is not exactly the same. This can be simply shown with any infrared remote control. Most IR remote

[1] A photon is detected in CCD only in the case when it is absorbed in the p-n junction. Due to the extremely high absorption of blue light, photons are absorbed in a larger scale before reaching the p-n junction, which leads to a drop of sensitivity in this part of the electromagnetic spectrum.
[2]The colour night vision of most modern cameras, mostly named NightScope, is based on a different principle – increasing the sensitivity by prolongation of the exposure time. Using this mechanism the camera could provide a colour image even at a very low light intensity, but it is much less convenient to IR detection in the experiments described later. If a video camera with IR mode is not available, an ordinary black and white camera from security systems can be used. These cameras are quite cheap and also have a good sensitivity in the near infrared region [1].

controls operate at wavelengths between the ranges of 850 - 950nm, very close to visible light. This radiation is not visible to the eye, but is visible for a CCD camera [2,3]; see Fig. 3.

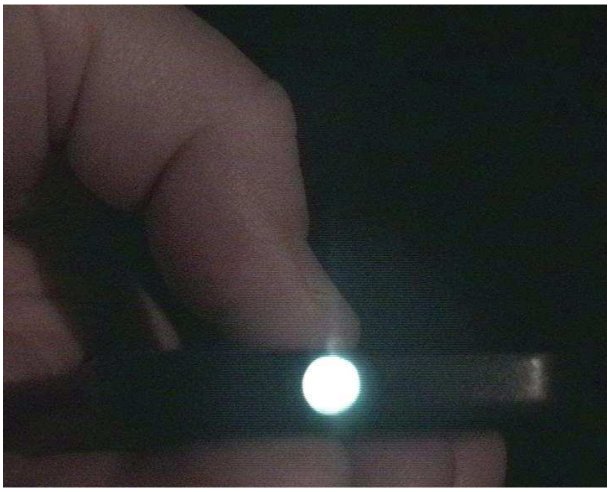
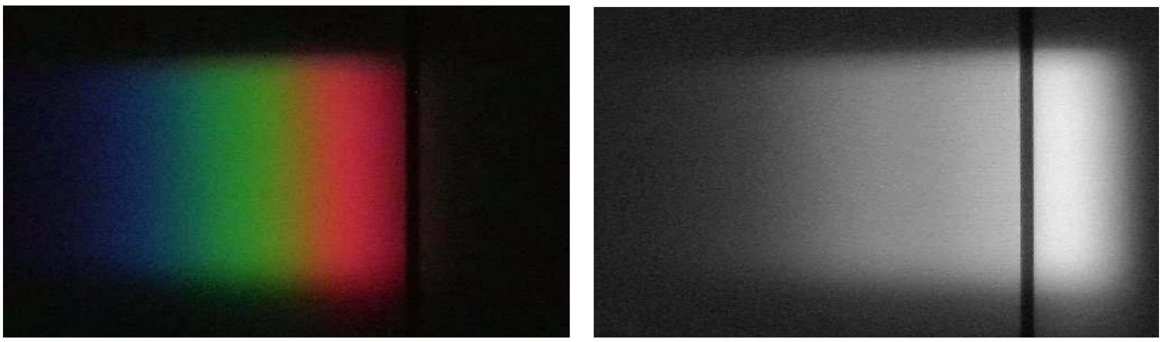


Fig. 3: Flashing infrared light coming from a remote control.

The infrared range of the electromagnetic spectrum

The previous experiment shows that a camera can detect something invisible. How do we know that this is really infrared radiation? Well, it has been stated to us. There exists, however, an easy way to persuade anybody that this invisible radiation actually lies beyond the red part of the spectrum – infrared. Let us make an ordinary prism spectrograph fixed at an optical bench. The visible spectrum is projected on a piece of paper, where we draw a black line at the very end of the red side of visible light (see Fig. 4(a)). It is better to set the manual focus of the camera to avoid focusing problems at low light intensity. When we switch the IR mode on, we get an image as at Fig. 4 (b) where a very bright section of radiation can be seen to the right of the black line. There can be no doubt this is infrared.



(a) (b)

Fig. 4: Spectrum of halogen bulb supplied by nominal voltage (filament temperature approx. 3000°C) as detected by video camera (a) in normal day light mode, (b) in IR mode.

When we change the power supply voltage we can demonstrate shift of the maximum in the spectrum towards longer wavelengths as the temperature decreases (as described mathematically by Wien's displacement law). The spectrum with the same experimental arrangement but with lower voltage supplying a halogen bulb is shown in Fig.5. When we decrease voltage continuously, the disappearance of shorter wavelengths is far more demonstrable with the camera in IR mode than by watching it with the naked eye.

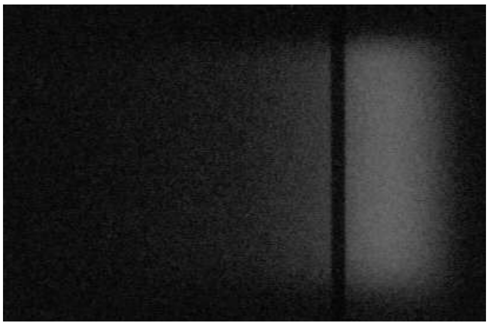
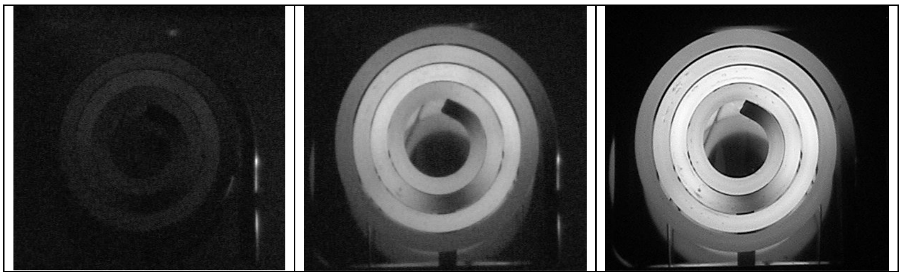


Fig. 5: Spectrum of halogen bulb supplied by decreased voltage (filament temperature approx. 2000 °C) and detected in the IR mode.

Watching at the source of heat

Any material body emits electromagnetic radiation, but only when the surface temperature exceeds about 500˚C we can see a red light of low intensity. With an IR mode camera the infrared radiation can be seen at much lower temperatures, at which our eyes can see nothing.

This experiment requires proper darkness. The plate of an electric cooker is heated up and observed by a camera in the IR mode. Simultaneously students watch the cooker with their own eyes. The temperature of the plate can be measured using any thermocouple gauge. The set of images taken at different temperatures in the IR mode is at Fig. 6. Using infrared vision, a camera can see radiation emitting from a hot surface starting at approx. 350˚C.



350˚C	450˚C	550˚C

Fig. 6: Hot electric cooker plate at different temperatures as seen by video camera in IR mode.

Separating infrared with an absorption filter

Using absorption filters, which absorb visible light more strongly than infrared, we can separate infrared radiation from the whole emission spectrum of a particular light source. Comparing the visible and infrared radiation image, we can get qualitative information about the emission spectra of different light sources and discuss source efficiency, for example.

The main problem is to find a convenient filter. From the physical point of view, silicon is an interesting possibility – the same material that is used for detection in a CCD chip. The absorption is a random process, and there is a non-zero probability that an IR photon comes through the whole silicon plate filter and is absorbed in the silicon CCD. This photon will be detected by a camera, and thus the camera can see through the silicon plate, which is totally non-transparent in visible light (even at thicknesses well below 100µm).

An even better result could be obtained with a GaAs plate with an energy gap of 1.43 eV, which corresponds to an absorption edge at a wavelength of about 0.86µm. The problem is that both silicon and GaAs wafers from semiconductor technology are not easy to obtain, especially if the wafers must be polished on both sides. But in the last few years, the so-called silicon window has appeared on the market as an optic component doing the same job.

Another possibility is using some commercially available IR bandpas or VIS cut filters. RT 830 bandpas could be an example. Lastly, black polyethylene foil e. g. dustbin bag plastic has sufficient transmission in the near infrared range, and could be the simplest and cheapest way.

Some examples with different filters are depicted in Figs. 7 – 10. Two light sources were combined – a candle as an example of a typical IR rich radiation source, and white LED emitting mostly in the visible range. In all the images, the candle and LED lamp are placed in the same position, both lighting as seen in Fig. 7.

Light from white LED is filtered completely by silicon and GaAs wafers. The weak contours to the right of the candle flame are reflections of IR radiation (Fig. 8 (a) and (b)). Surprisingly, light from the candle comes through the silicon wafer even without the IR mode (Fig. 8 (c)). Thus this experiment can be done with any video camera or digital camera.

Fig. 7: Candle and white LED lamp taken at visible light without any absorption filter.

(a) (b) (c)

Fig. 8: Candle and white LED lamp taken in IR mode through (a) Si and (b) GaAs absorption filters. (c) the same scene with Si filter in ordinary day light mode.

The IR bandpas filter RT 830 has an excellent transparency in the IR region, but is not fully absorbent at the visible range. Nevertheless, the drop of intensity from LED in comparison to a candle is clearly seen (Figs. 9 (a) and (b)). The candle flame is overexposed in the IR mode.

(a) (b)

Fig. 9: Candle and white LED lamp with IR bandpas filter RT 830. (a) IR mode and (b) day light mode.

A good and valuable result can even be obtained with black polyethylene foil (Fig.10). While the candle flame is very well seen, white light from the LEDs is hard to distinguish. The main disadvantages of this cheap filter are its non-homogeneity and surface roughness, which result in a distorted image. To get the best picture quality, the foil must be as close to the light sources as possible.

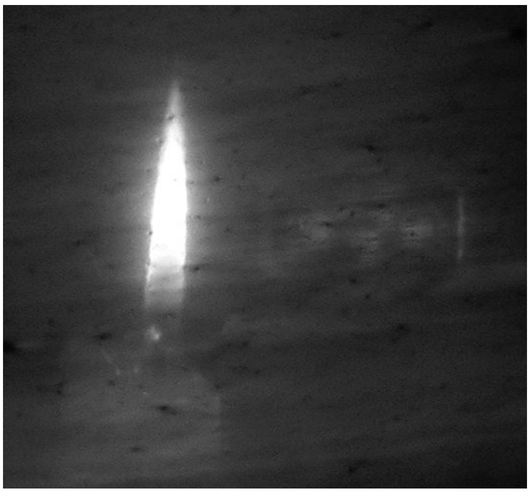


Fig. 10: Candle and white LED lamp with black polyethylene foil in IR mode.

Other types of light sources can be used in this experiment. A tungsten bulb serves as a typical source of high intensity IR and can be compared to LEDs of different colours including ultraviolet and infrared, or for example a fluorescent bulb or tube.

Conclusion

Nearly all of the experiments described above can be performed with simple and relatively easily accessible equipment. Some of them don’t even require full darkness. Due to their visual attractiveness, they can be used at basic schools for demonstrating the existence of infrared radiation. On the other hand, their nontrivial physical background makes them also valuable for university physics courses, namely optics, solid-state physics and electronics.

References

[1] Williams G Phys. Educ. **41** No 4 (July 2006) 317-322
[2] Zetie K Phys. Educ. **41** No 3 (May 2006) 208
[3] Taylor B Phys. Educ. **38** No 6 (November 2003) 494