Sources

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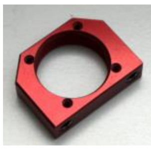
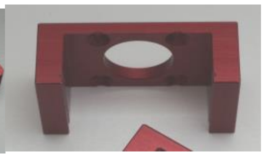
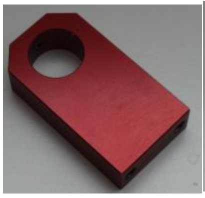
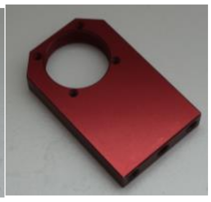
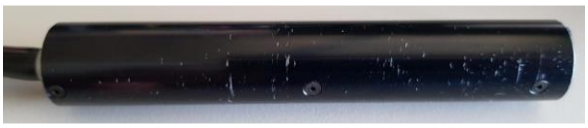
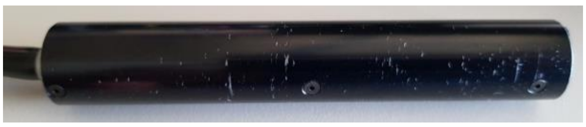
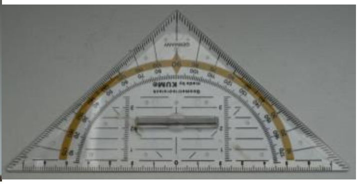
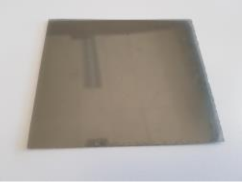
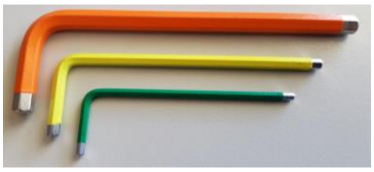
List of material for the TP

1x Board 1x Linear stage	 
1x Camera holder (3 parts)	  
1x Source holder 2x Lens holders	 
1x Laser 1x Led 1x Halogen	     
1x Lens with holder 2x Bare lens	 

1x Lens cap	
1x Ruler 1x Triangle	 
1x Camera	
2x Polarizers	
2x-4x Small screws (triangular head) 4x Large screws	 
4x Large screws with cap 2x Small screws with cap	 
3x Allen keys 1x Screw driver cross 1x Spanner wrench	  

1x Black tape	
2x Retaining rings	

1 Background

Sources

Beside the detector, another important component in all optical system is the light source that illuminates the scene. We cover here three types of sources: halogen lamp, light emitting diodes LED and laser diodes. We are interested in the properties of the source that are important for engineering. For details on their operation, please refer to the specialized literature. (For example: Iizuka, Elements of Photonics Vol. II Wiley 2002).

Here, sources are distinguished by two important properties: the coherence and the brightness of the emitted light.

The degree of coherence is another name for the correlation of a light wave at different times or different positions. A high degree of coherence is needed to visualize interference phenomena and create interference fringes. The degree of coherence depends on the size of the source (emitting area, spatial coherence) and the spectral widths $\Delta\lambda$ of the source (temporal coherence). Highly coherent light is obtained from point-like source emitting over very limited spectral width. An example of such a source is the laser.

The brightness is a visual sensation but is also defined as the power of a source emitted within a unit solid angle by unit source area:

$$B = \frac{P}{A\Omega}$$

Consider sources with equal power P and different geometrical and emission parameters. The solid angle describes the angular emission in the space. A source that is collimated has a very small solid angle for instance. The sources with a small solid angle Ω and a small emitting surface A will appear bright because all the emitted light goes into a defined direction starting from a very small surface, a bright spot! A collimated laser is a good example of such a source. The sources with a large solid angle Ω and a large emitting surface A appear less bright because the emitted light is distributed over large range of directions and has a “diluted” surface. A halogen lamp is a good example for such a source. Its solid angle Ω is almost the complete angular range (maximum solid angle is the whole directional space and has an value of $\Omega = 4\pi$). A light emitting diode LED represents a source having an intermediate solid angle, emitting surface, and spectral bandwidth. As a measure of light quality, we use a combination of brightness B and degree of coherence.

The table below summarizes the different properties for different sources.

source	Operational principle	Spectral width	Solid angle	Emitting surface	quality
Halogen lamp	Black body emitter (heat)	Large, $I_\lambda = \dfrac{2\pi hc^2/\lambda^5}{e^{[hc/\lambda k_B T]} - 1}$	Full angle, $\Omega = 4\pi$	$> 1\ mm^2$	low
LED	Solid state semiconductor device, charge recombination	Medium, >20nm	Half angle $\theta > 30°$, $W = 2p(1 - \cos q)$	$< 1\ mm^2$	medium
Laser diode	Solid state semiconductor device, charge	Fine, <1nm	Half angle $\theta > 30°$, $W = 2p(1 - \cos q)$	$< 0.01\ mm^2$	high

	recombination, monomode				
Gas laser	Gas discharge, high quality resonator	Extremely fine, <1nm	Half angle θ < 1°, $W = 2p(1 - \cos q)$	> 1 mm^2	Very high

NOTE that the table above is not exhaustive. A lot of different sources are available and are difficult to classify in such a simple scheme. One example is a white light laser source that can be extremely well focused but have a very large bandwidth such as a supercontinuum fiber source, that base their operation principle on nonlinear effects.
In what follows we give some details of the source used in the experiment.

Halogen Lamp

The halogen lamp is from International light technologies (www.intl-lighttech.com/). It is a gas filled Argon clear-end lamp driven at its designed voltage of 3.5V. It draws a current of 450 mA and has a light output of 4.5 Lumen (What is lumen?). The color temperature is 2270K. The lamp has a lifetime of 30,000 hours. The **filament measures 1.2 x 0.43 mm^2**. It is a particularly small halogen lamp. Like all halogen lamps, it emits over a very large solid angle. One recognizes the large spectral width of this source that is close to a black body emitter.

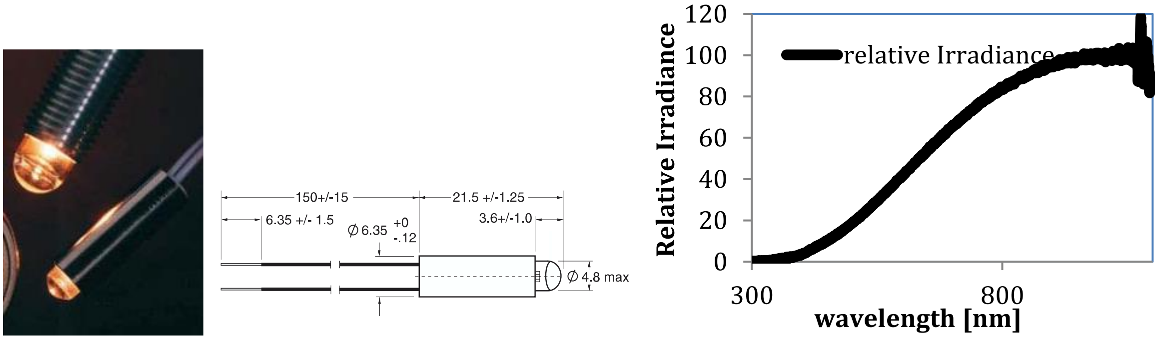


Figure 1. Appearance, dimensions and spectum of the miniaturized halogen lamp from International light technologies. The spectrum is plotted as relative irradiance (calibration mode) and represents the power per wavelength units. Only such an irradiance curve should be compared to a black body emitter.

Light emitting diode LED

The light emitting diode LED is a solid-state light source. The peak wavelengths indicated by the supplier is 660 nm and the spectral bandwidth at FWHM is 30 nm (Full width at half maximum FWHM). The LED is from Everlight (https://www.everlight.com), part number 27-21/R6C-AP1Q2B/3C. The exact chip size that emits light is not given. The table below gives some specifications.

Product	Size (LXWXH mm)	Color	λ_d (nm)/CIE(x,y)	I_V Min./Typ. (mcd)	I_V Max. (mcd)	V_F Min./Typ. (V)	V_F Max. (V)	I_F (mA)
27-21/R6C-AP1Q2B/3C	1.7x1.1x0.6	●Brilliant Red	624	45	112	1.75	2.35	20

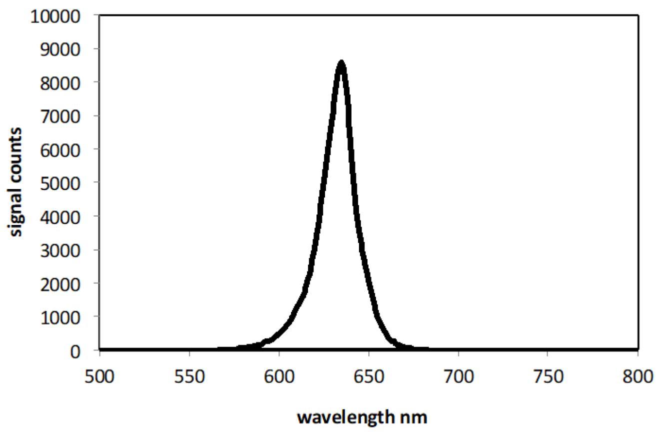


Figure 2 Spectral behavior of the red LED used in the experiments as provided by the supplier.

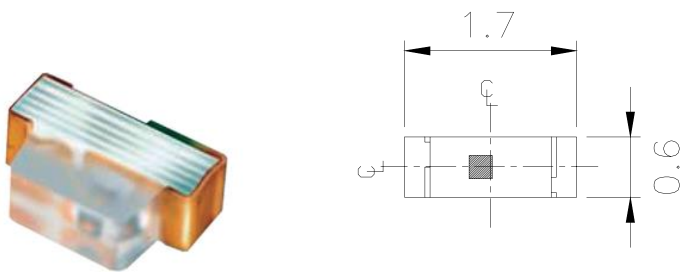


Figure 3. Appearance of the LED, its dimensions, a schematic of its construction as given by the manufacturer. **Note that the emitting area is the black square on the right image.**

Most LEDs emit light along a preferred direction. For the actual LED the viewing angle (2 x θ) is given by the manufacturer as 130°!

Laser Diode

The laser source is a monomode laser diode (model Opnext_Laserdiode-HL6354_EN). Its spectral properties are shown below. The width of the single peak is very narrow, below 0.2 nm full-width half maximum (FWHM). In general, a laser diode has several modes, which separation and width are determined by the geometry of the laser cavity (Fabry-Perot effect!). The laser diode has a very small active zone and this leads to diffraction at the edges and gives a particular angular emission. Because the active zone is not symmetric the emission profile is elliptical.

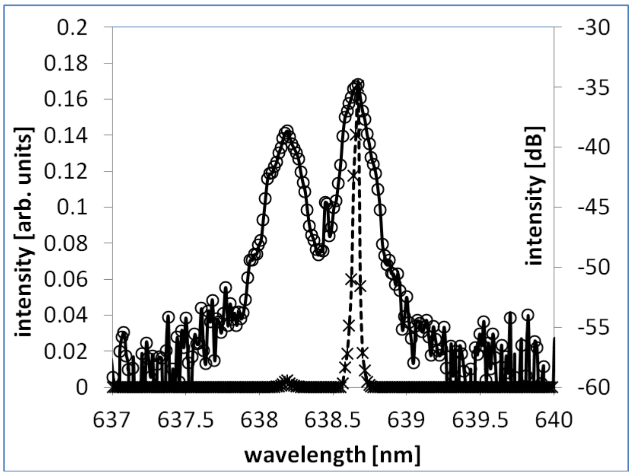


Figure 4. Spectral characteristics of the monomode laser diode measured with an optical spectrum analyzer in linear and logarithmic scale. The logarithmic plot reveals that there are two peaks of different intensity. The laser is thus not strictly monomode. (monomode -> one peak only)

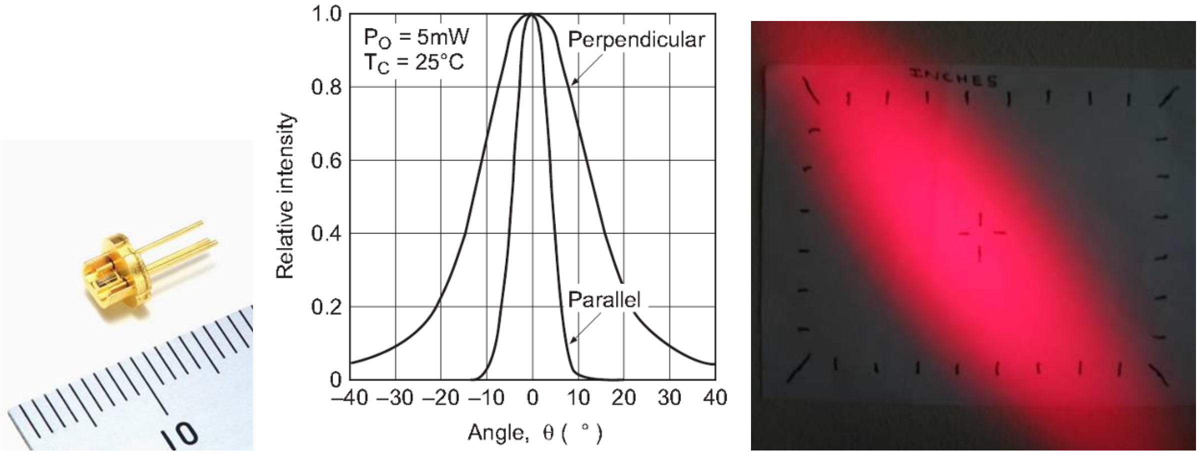


Figure 5. Appearance and emission profile of the laser diode. The emission profile is not symmetric and leads to an elliptical shape in the far field.

The emission properties of sources can be summarized in the graphic below.
The brightness of different sources is summarized below.

Brightness is the power P emitted from a surface A in a solid angle Ω	$B = \frac{P}{A\Omega}$
Halogen source (solid angle Ω=4π)	$B = \frac{P}{A\Omega} = \frac{P}{A4\pi}$
LED (half angle θ, emitting surface A)	$B = \frac{P}{AW} = \frac{P}{A\ 2p(1-\cos q)}$
Laser (diameter 2w, fully coherent, monomode, divergence angle $\theta_{1/e} = \lambda/(\pi w_0)$)	$B = \frac{P}{A\Omega} = \frac{P}{w^2\pi\ \pi(\lambda/(\pi w))^2} = \frac{P}{\lambda^2}$

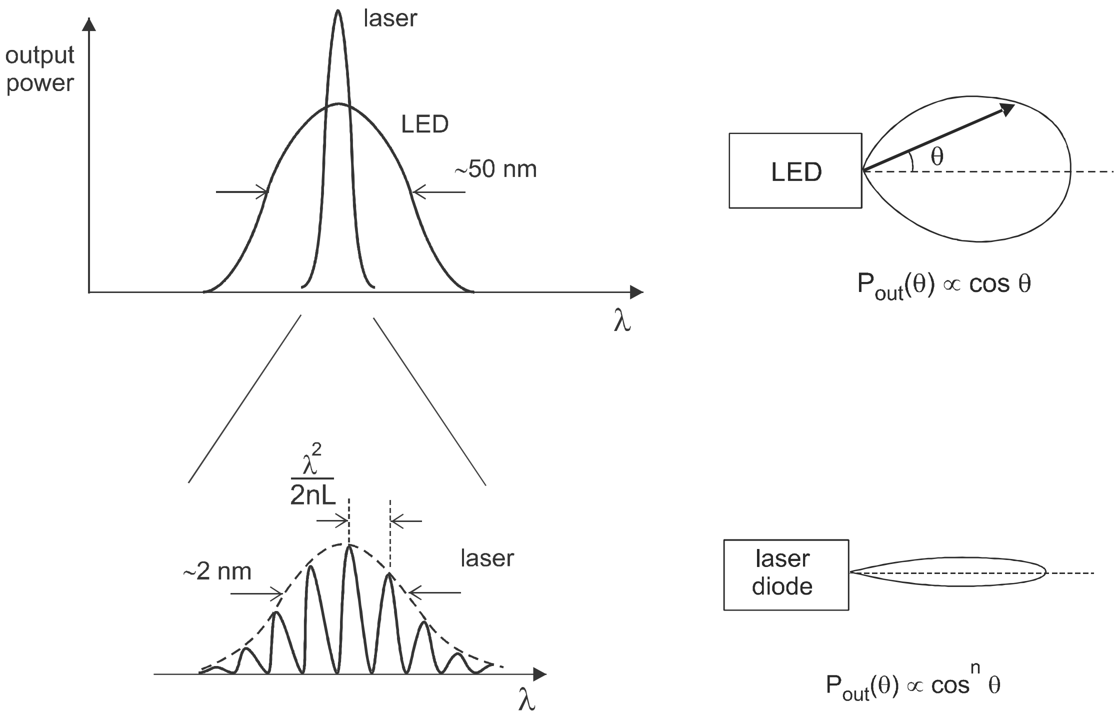


Figure 6. Emission properties of different source Left: spectral emission characteristics. The LED has a broad spectrum. The laser has line spectra. A monomode laser has only one spectral line (or mode). Right. Difference in the directionality of the emitted light. These distributions can be approximated using a power law of cos θ. (after Richard S. Quimby, Photonics and Lasers, An Introduction, Wiley 2006, ISBN-13 978-0-471-71974-8)

4f imaging

In imaging, particular configurations exist. One of these is the 4f configuration as shown below in Fig. 7. If one puts an object at a distance equal to 2 times the focal length, the image will appear at 2 times the focal length behind the lens and will have the same height. Magnification in such a case is one (M=1). The numerical aperture on both sides (given by the angle θ) is also equal as can be easily seen in Fig.7.

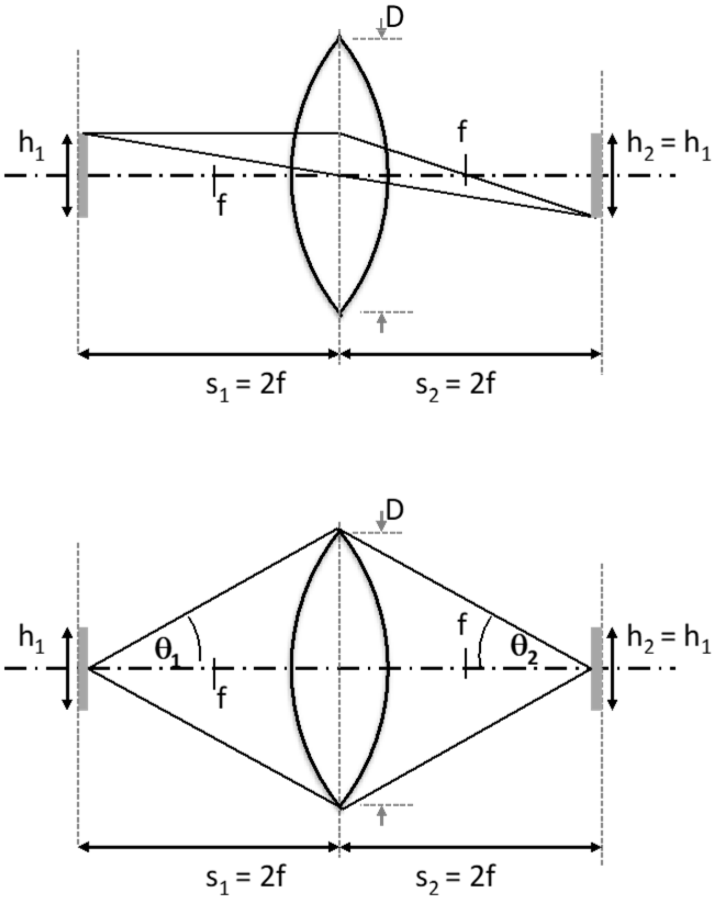


Figure 7. Top: Imaging of an object of height h_1 with a lens governed by the lens equation. The diameter of the lens does not influence the imaging conditions. If the object is put at double the focal length as object distance, magnification becomes one. Below: The situation is completely symmetric and all angles as well as the numerical aperture are the same.

In 4f imaging the total track length (length between object and image) is 4 times the focal length.

Brightness theorem

An important theorem in optics is the brightness theorem. It states that **in an imaging situation** the brightness cannot be increased when going from the object to the image space. To better understand this, we can consider the following situation. An object is put in front of a lens and we image the object with a biconvex lens. We study the magnification and the angles to calculate the brightness. Please refer to the Fig.8 below.
Calculations are based on the assumption that the object is a Lambertian emmitter. A Lambertian emmitter (or surface) has a brightness that does not depend on the angle of observation hence emmits equally into the space. This means one assumes an unform angular radiation form the object. If this is not the case (as for lasers) great care has to be taken for calculation. The brightness B could be written (in a small angle or linear approximation for θ, paraxial approximation) as follows:

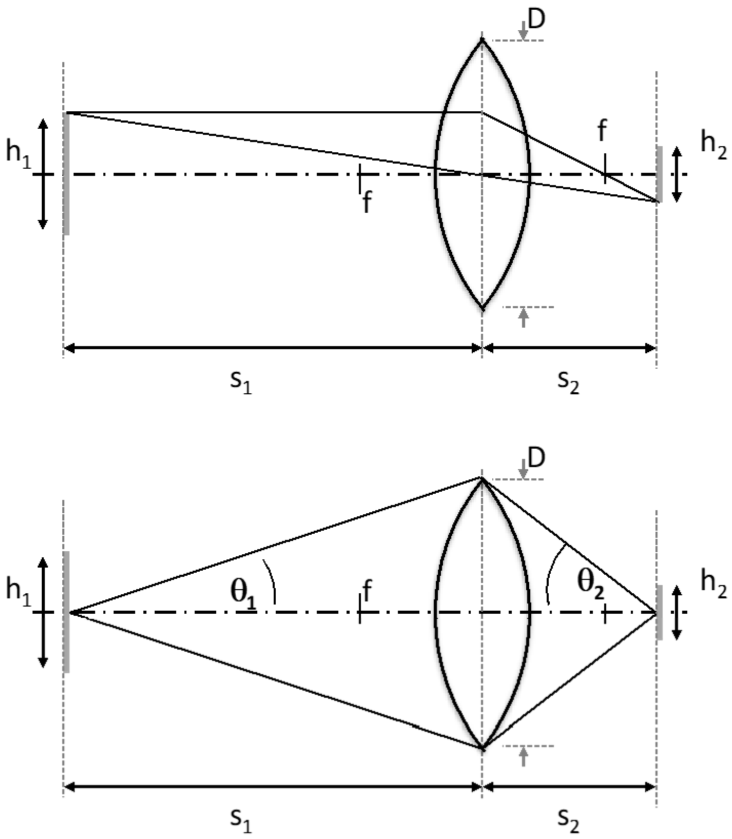


Figure 8. **Top**: Imaging of an object of height h_1 with a lens governed by the lens equation. The diameter of the lens does not influence the imaging conditions. The image has a magnification smaller than one. **Below**: The brightness theorem relates the brightness B = P/(AΩ) of the object and the image. In imaging conditions, the brightness is conserved. The aperture of the lens and the object distance will define the maximum solid angle and hence overall energy collected by the lens.

Object space $$B_1 = \frac{P}{A_1\Omega_1} = \frac{P}{h_1^2\pi\theta_1^2}$$

Image space $$B_2 = \frac{P}{A_2\Omega_2} = \frac{P}{h_2^2\pi\theta_2^2}$$

Under paraxial imaging conditions, the relation between distances and image heights are

$$\frac{h_1}{s_1} = \frac{h_2}{s_2} \quad -> \quad \theta_1 s_1 = \frac{D}{2} = \theta_2 s_2 \quad -> \quad \theta_1 h_1 = \theta_2 h_2$$

Putting all together one finds $$\boxed{B_1 = B_2}$$

It will be interesting to compare several situations. As one can see by comparing Fig. 8 and Fig. 9, with the same lens two imaging conditions can be realized at the same track lengths by just moving the lens position. But what happens with the brightness? This is topic of one experiment.

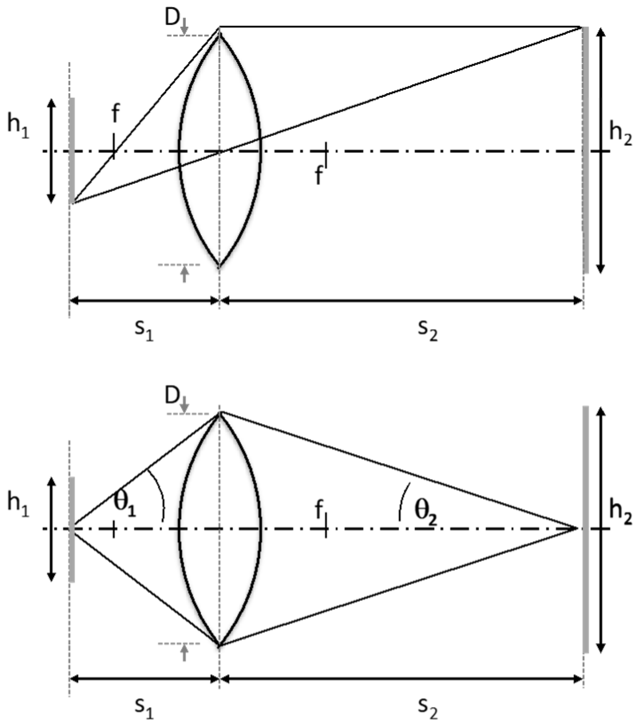


Figure 9. **Top**: Imaging of an object of height h_1 with a lens governed by the lens equation. Compared to Fig 7, the image has a magnification greater than one. **Below**: One sees that the collection angle θ_1 is much larger than in Fig.7 in this case. More light is collected at the object side but the image is larger. As a result, the intensity (power over surface P/A) in the image is not changed.

Note that the conventional technique of finding the image by drawing the middle ray and one ray through the focus point can still be applied although the lens diameter is smaller than the height of the position of the ray!

In the experiment you will measure the dependence of the brightness for different imaging conditions and compare the brightness in several cases.

Spectral properties

For some parts of the experiment, it is important to know the spectral properties of the components used. For example, the camera has a near infrared transmission filter mounted in front of the detector. Its spectral properties are given below.

If this filter is mounted, all light outside the transmission wavelength range is blocked. But if the filter is taken away light in the Near infrared wavelength range (NIR) will enter the detector and contribute to the signal. In this case the color filters (RGB) do not work properly anymore.

IR filter transmission

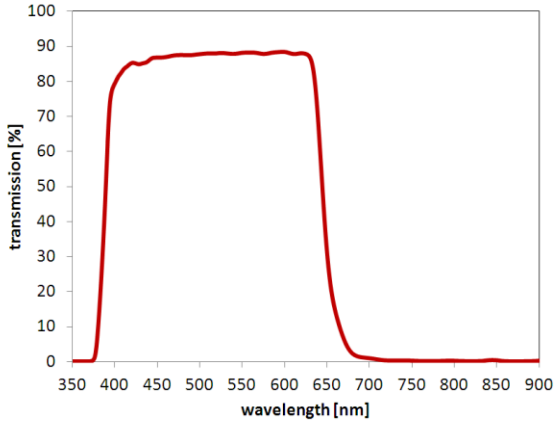


Figure 10 Transmission of the IR filter of the camera. This filter limits the wavelength band to 380 - 680 nm. The transmission band is slightly smaller than the spectral sensitivity of the eye ranging from 380 to 780 nm.

Polarizer extinction ratio (contrast) and transmission

Polarizer are used to change the light level. But the polarizers work only within a certain spectral range when contrast can be generated. The contrast and transmission curves are given below. Above 730 nm for instance the polarizer used here is not operating anymore as a polarizer.

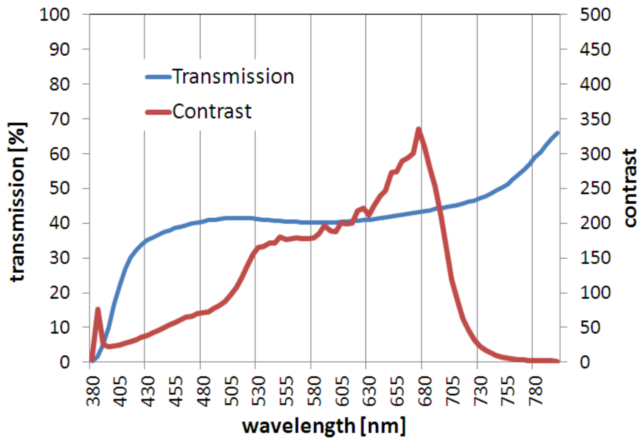


Figure 11 The transmission of the polarizer is high over the whole range whereas the contrast (its functionality) drops at about 700 nm. The intensity cannot be adjusted for wavelength above 700 nm because there is no extinction!

Detector spectral sensitivity

Silicon detectors have certain sensitivity curve. A maximum wavelength is given by the bandgap of the semiconductor and is just below 1200 nm. The sensitivity falls off for smaller wavelength. In reality, these curves are much more complicated and the image below give an example of an idealized (dashed line) and a real (continuous line) sensitivity curve.

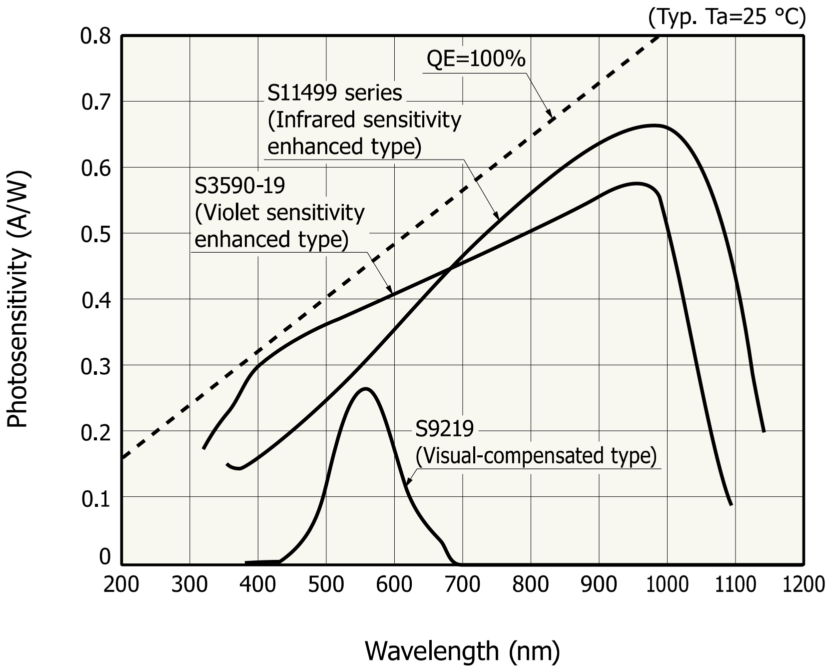


Figure 12. Sensitivity of silicon. The solid line shows the sensitivity according high performance photodidodes from Hamamatsu. The dashed line shows the ideal sensitivity or maximum sensitivity. There is a cutoff wavelength determined by the bandgap of silicon that cuts off the sensitivity sharply around 1100 nm.
[Hamamatsu photonics, document si_pd_kspd0001e.pdf downloaded 2.3.217, https://www.hamamatsu.com/resources/pdf/ssd/si_pd_kspd0001e.pdf]

2 Setup and equipment

2.1 Materials

- The USB camera
- Three different light sources (Halogen, LED, Laser diode), USB driven
- Sheet polarizer for intensity regulation
- Objective lens of the camera
- Double convex lens diameter D=25 mm, f=25.4 mm (Thorlabs, LB1761 - N-BK7 Bi-Convex Lens, Ø1", f = 25.4 mm, Uncoated)
- Plan convex lens in red tube, diameter D=9 mm, f=12 mm (Thorlabs)
- Mechanical setup

2.2 Source size measurement

Sources have different characteristic: Spectral range and spatial extensions. Spectral widths can be measured with a spectrometer. What often are not studied are there spatial characteristics. We want to do experiments on the spatial characteristics like size and radiation pattern of sources.

Objective

- Measure the size of the **emitting element** of the source (chip size or filament) in a 1:1 magnification situation (4f configuration)

Mechanical setup:

The camera will be fixed in the linear stage like this:

Figure13 Mechanical holder to fix the camera. Unscrew the original objective to that the IR filter becomes visible.

You should take away the objective by simple rotation. The objective is the small black piece carrying the lenses. We will use a different lens for imaging in our experiment.
As lens we will use a 25.4 mm (1 inch) diameter lens from Thorlabs with a focal length of 25.4 mm diameter. (LB1761, D=25.4, F=25.4 N-BK7 BI CONVEX LENS MATERIAL: N-BK7).
The positions of the red mounts on the linear stage are not critical. In this TP, we use three different sources. Their datasheet can be found on the web. These sources are USB driven and have the same housing. The light from the LED and the halogen source is linearly polarized by a polarizer sheet fixed in front of the housing.

Figure 14. A set of three Sources USB powered sources is available. From left to right LED (with glued polarizer), Halogen (with glued polarizer), Laser (laser diode is visible).

The sources are mounted in the source mount designed only for this purpose.

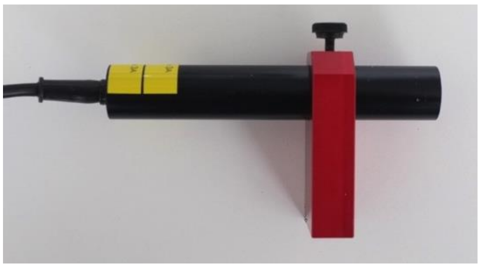


Figure 15 Holder for the source, here a laser with a yellow sticker.

For measurement using the 4f configuration, one sets the object (our sources) at the double of the focal distance of the observing lens. The camera is also set at the double of the focal distance of the observing lens but on then other side of course. The setup looks like this shown below.

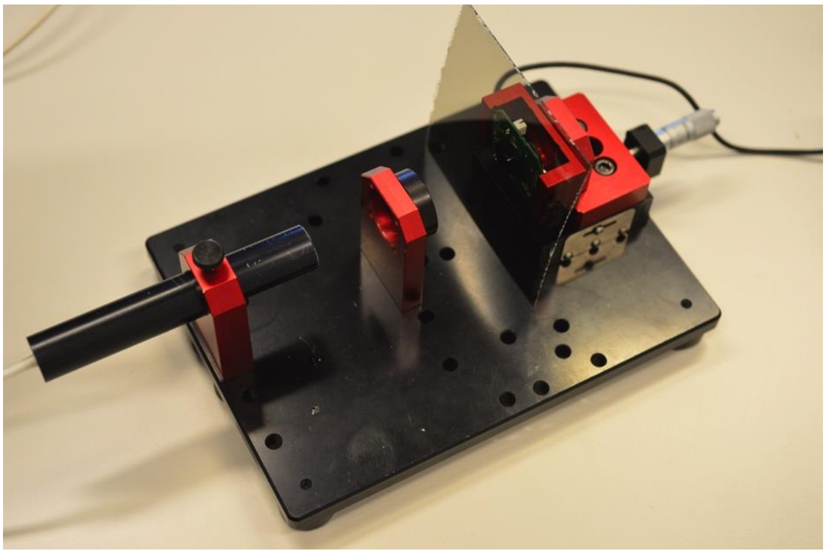


Figure 16 Setup with the source, the camera and a sheet polarizer on the right with the lens in its holder in the middle

The sheet polarizer is used to adjust the light intensity. It is placed in front of the camera or the source. By rotating the source in its mount, the light intensity can be varied (because the sources are polarized or carry themselves a polarizer). The polarizer can be put in front of the camera

or the source and if its orientation is not changed, the intensity adjustment stays valid. The settings of the camera might be also adapted to prevent overexposure.
The first measurement task is to determine the size of the different sources. To do so, we bring the source in a defined position, focus, adjust intensity and take pictures.

One important point is the intensity adjustment to prevent saturation of images. The best working conditions are low gain and fast (small) exposure. Polarizers can be used for additional intensity adjustments. For the halogen bulb and the LED, there are sheet polarizers mounted just in front of the source exit. The laser diode is itself a polarized source. The sources we use in the course are hence polarized in a certain direction and **rotation of the source with respect to a sheet polarizer allows intensity adjustment** (cosine square law when rotated by a certain angle Θ).

To measure use the following procedure:

- Set the linear stage on which the camera is mounted to 5 mm (in the middle)
- Take care that the original objective of the camera is not installed (Fig. 13)
- Mount the sources: Start with the LED
- Take the lens mount it in the holder

Figure 17. The Thorlabs 25 mm lens will be mounted in a holder.

- Put the lens on then optical axis (middle line between camera and source).
- Set the distance between the lens and the camera to be 2 times the focal length of the lens (f=25.4 mm) – you should set the distance at around 5 cm (see below Fig. 18)

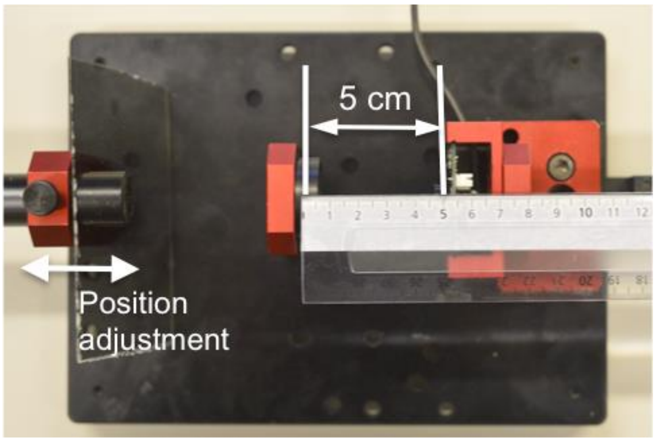
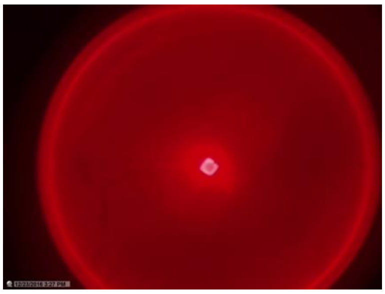


Figure 18. Mount the source as shown in the image. The distance between the camera and the lens should be approximately 2f = 25.4mm x 2= 50.8 mm

- Switch on the source (plug in the USB cable)
- Focus by moving the source gently back and forth (position adjustment), you might need to adjust the height of the camera.
- Adjust the camera settings (lowest gain, play with exposure time)
- Adjust the intensity (insert the sheet polarizer, rotate the source!)
- Focus again by moving the source gently on the optical axis (the line between source and camera is called optical axis), avoid rotation.
- Avoid saturation in the image and camera parameters.
- Fix the source position with the screw and do not move anymore.

Figure 19 below gives you an idea what you might see on the screen while looking for the perfect focusing position.

a)  b) 

c)  d) 

Figure 19. Example pictures of the 4f setting when focussing and adjsuting intensity: a) Source to far away from lens; b) Source to close to the lens, c) Source in focus but two bright; d) Source image in focus and well-adjusted intensity.

Take an image. The source size can be measured in pixels in the image and when multiplied by the pixel size one finds the source dimension.
Measure all sources. Start with the LED already mounted and pass over to the halogen bulb and laser.

- Bring the LED chip into focus
- Adjust intensity
- Take a picture
- Change source respecting the position
- Adjust intensity
- Focus
- Take a picture
- Avoid saturation

Under some circumstances, you might need to use two crossed polarizers. If you cannot get the proper result, please use a second polarizer or contact an assistant.
The result should be similar to the images below.

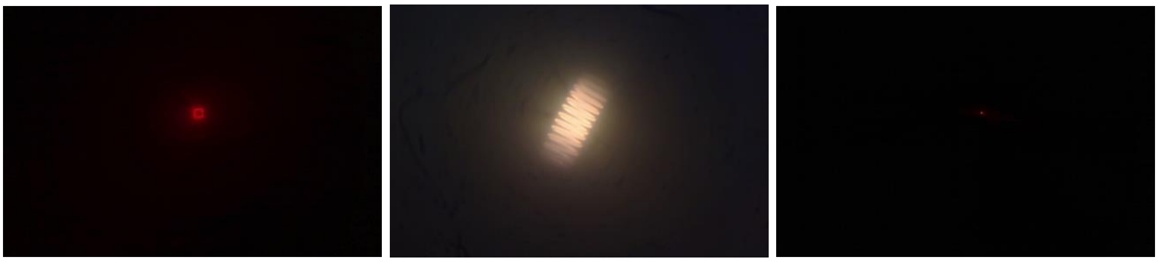


Figure 20 Sources image. From left to right: LED, Halogen, Laser. For the laser two polarizer have to be crossed to reduce its strong intensity!

- Evaluate the size of the three sources (dimensions are known because you know the detector size and pixel size, simply counting pixels allows you to measure the dimension)
- It is very important to **avoid saturation** because it falsifies the size measurement.

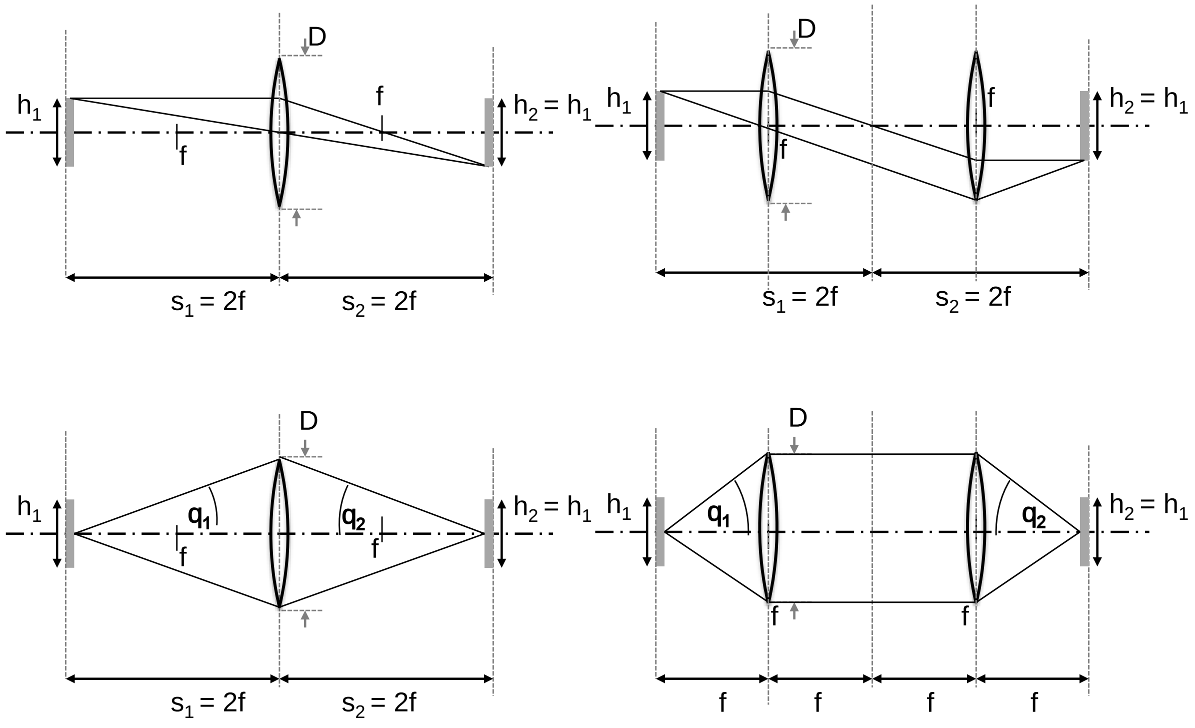
To be done for the report: Present for each source an image in a 4f setting (3 images similar to Fig. 20). Give the approximate dimension in pixel on the detector and in mm in the object space in the table below (image space/magnification=1). Make an error estimation!

Table to be filled out:

Source	Measured size (4f) pixel	Measured size (4f) mm	Error	Datasheet value
Halogen				
LASER				
LED				

2.3 Brightness for different imaging conditions with LED

Next, we would like to see the influence of the solid angle in an optical system on the image intensity. We consider the two situations depicted in the figure below.



A) **B)**

Figure 21. Two configurations that will give the same magnification but have different collection angles θ. In such a situation the angle changes but not the surface.

In A) a single lens is used and the angle θ is half of the angle than for the situation in B). In the arrangement B) with two lenses, the maximum numerical aperture can be realized because we use the shortest distance to object which is equal to the focal length f. Considering that we use the same source which emits uniformly in space, the brightness will be different for both situations. This is because in both cases the magnification is M=1 the image height and the image surface A is the same. The only parameter that influences the brightness is the angle θ. To measure this effect, we perform the following experiment.

Start with the 4f imaging setup.

- Use the LED.
- Position the biconvex lens as shown below at 2f = 50 mm from the detector.
- Adjust the intensity with the polarizer.
- Find an image by moving the source forward and backward.
- Adjust to have a good image of the LED chip!

The setup looks similar to the one below

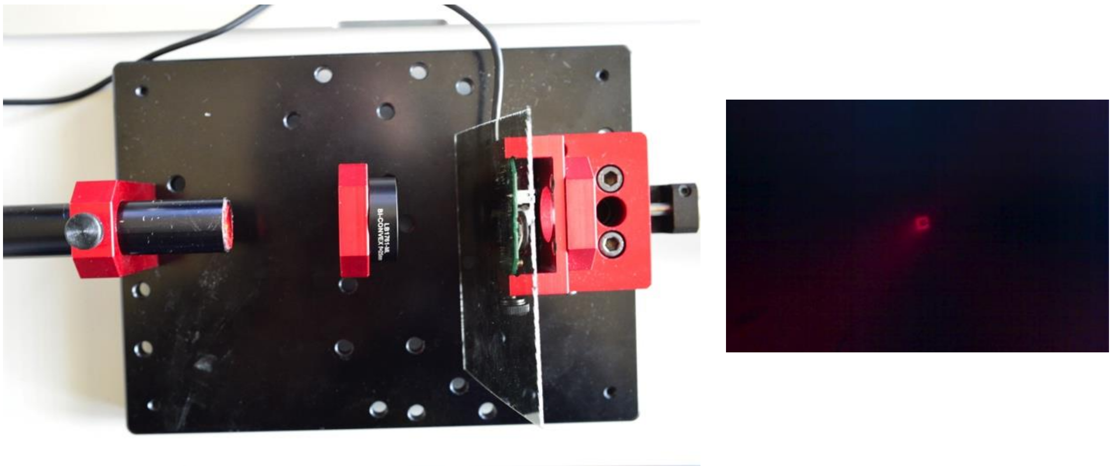


Figure 22. Single lens setup for 4f imaging. The distance between source and camera are fixed now and should not be changed. On the right, the corresponding camera image.

The next step is to build up the double lens system. For that, we use the extra lens in the box.

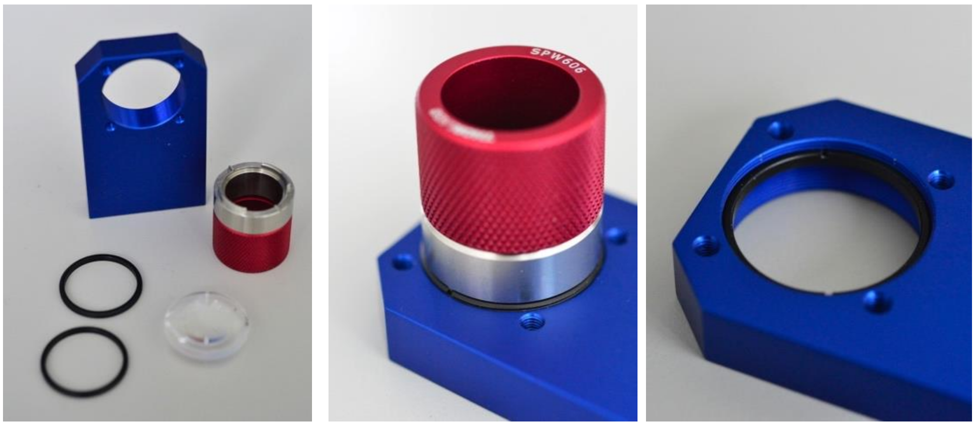


Figure 23. Mounting the lens with retaining rings. Left: the holder (blue), biconvex lens, retaining rings and spanner wrench (red). A first retaining ring is used, the lens is put in and fixed with the second retaining ring from the other side. **Please mount it with care to avoid scratching the lens.**

Figure 24. The second biconvex lens (f=25.4 mm) needed for the double lens arrangement in its holder.

- Move the lens to the focal length position shown below.
- Take care that the lens is positioned on the axis source-detector (optical axis)

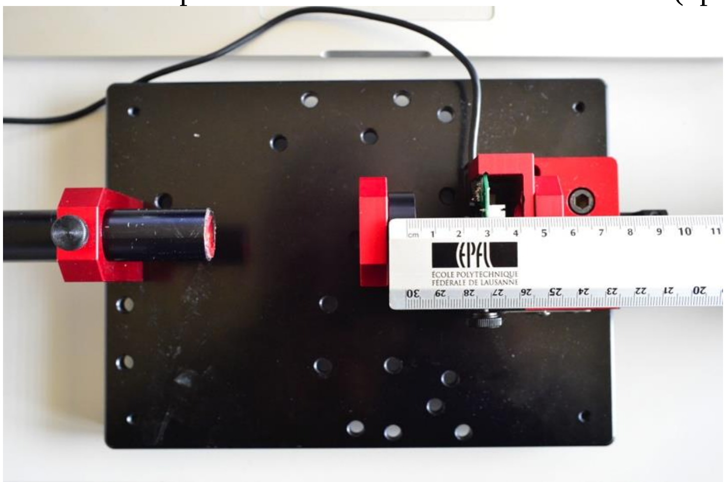


Figure 25. The lens is now 25 mm (one focal length) away from the camera chip (detector).

- Introduce the second lens
- Move the second (blue lens) to find an image

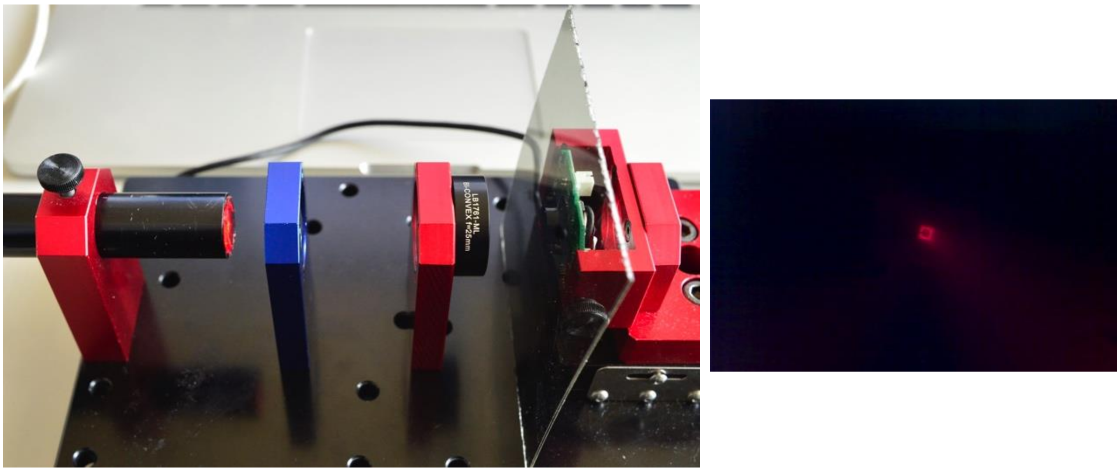


Figure 26. Double lens or infinity setup. The distance between source and camera were fixed before and only the components are moved. On the right, the corresponding camera image.

- Adjust the position of the blue lens without moving other components until you get an image. Take your time to center the image well!
- Adjust intensity to avoid saturation.
- If you move the first lens, you need to start again by setting the first lens at 25 mm from the camera.
- Measure all distances carefully and note them. They will be needed for calculation!

Distance camera first lens (red)	25 mm
Distance lens - lens	…..
Distance second lens (blue) source	…..
Distance source camera	….

- Control and set the exposure and gain

- Avoid saturation
- **Take images without saturation do not change the exposure and gain settings**

In what follows, we establish the single lens 4f imaging to record an image under identical conditions. Then, one can compare the optical power for both situations.

- Remove the second lens (blue)
- Use then first lens to create an image
- **Take images without changing the exposure and gain settings**

Note the parameters

Distance camera first lens (red)	…..
Distance lens - source	…..

Now we have images with identical camera settings that can be compared. The next step is to integrate the signal in the image and compare both values.

- Use the matlab script "Integral_intensity_ROI.m" to evaluate the intensity for both case, choose a Region of interest (ROI) that is small but contains all useful signal

The provided script plots two figures. Figure one below is the whole image. In the image, you can use the zoom button  to choose your region of interest (ROI). You can use the zoomed region to define the pixel numbers you have to use for the RIO definition. An example is given below.

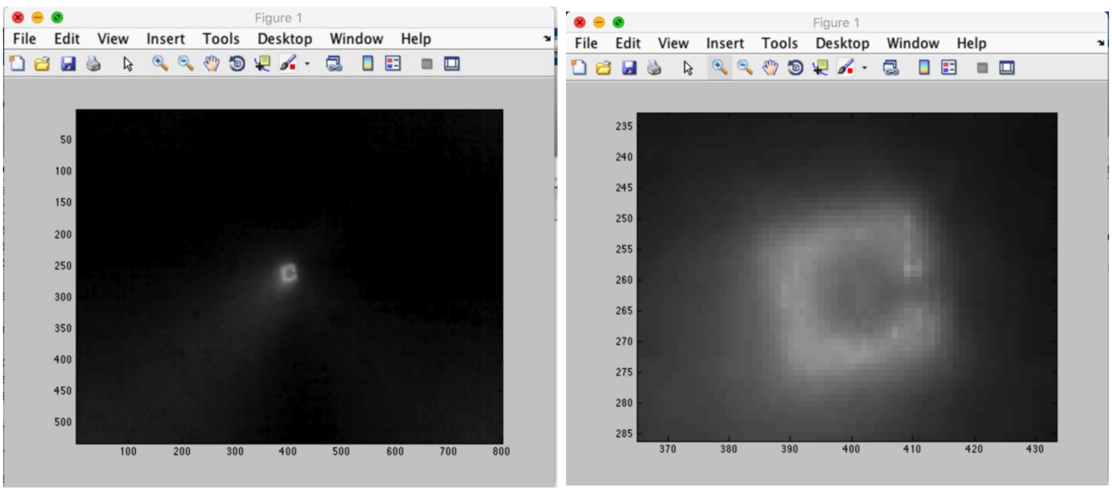


Figure 27. Matlab Figure 1 and the zoom area of a possible region of interest (ROI). In the image crop the RIO will be x(230,290) and y(360,450).

The region of interest is found as vertical (230,290) and horizontal (360,450). These number can be used in the matlab script to define the position of the ROI.

2.4. Spectral matching

It is important to match the spectral sensibility of different components in an optical system. A mismatch can have tremendous effects on the measured quantity. Different characteristics and functionality with respect to the wavelength have to be considered. In our case, we have four main components:

- the emission spectrum of the source
- the spectral sensitivity of the detector
- the sensitivity of the polarizers extinction ratio versus wavelength
- the IR filter transmission spectrum

We will proof spectral influences by making measurements with the Halogen lamp under different conditions. The halogen lamp has a very wide spectrum and emits light all over the sensitivity range of our detector. The IR filter in front of the detector is used to cut the IR components and adjust the sensitivity to the spectral sensitivity curve of the human eye. If one takes the IR filter away, energy in the non-visible part of the spectrum will be seen by the detector and the detector is saturated nearly all the time. It is therefore necessary to reduce amount of light by mechanical shutters. We will make a comparative measurement to illustrate this effect.

Proceed as follows:

- Use the setup as described above and mount the halogen source with a 30 mm source adjustment as shown below in Fig. 28.

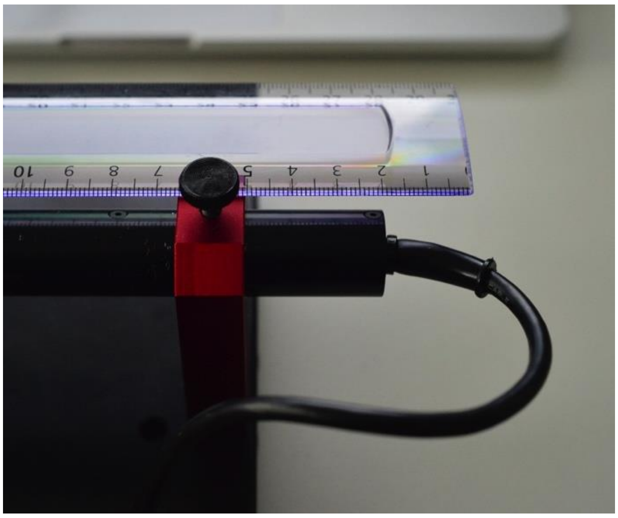


Figure 28. The source is adjusted to stick out approximately 30 mm from its holder.

- Mount the halogen lamp with the lens cap. Make a hole in a piece of black tape and place it in front of the cap. Assure that it is centered and light can go though.

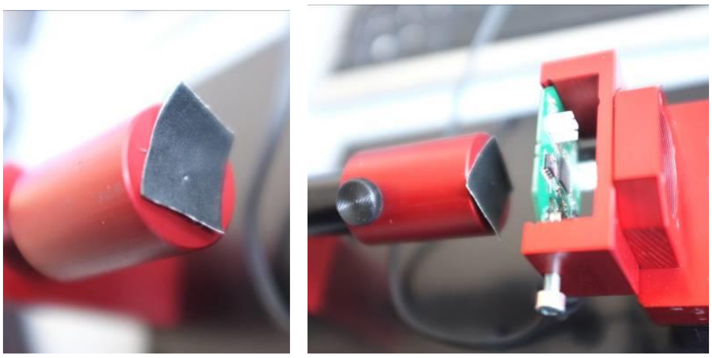


Figure 29. Details for the source mounting. We use method of reducing intensity this to avoid saturation.

- Unscrew the IR filter from the camera (do not lose the screws please)

Your camera body should look like the right image in the Figure 30 below.

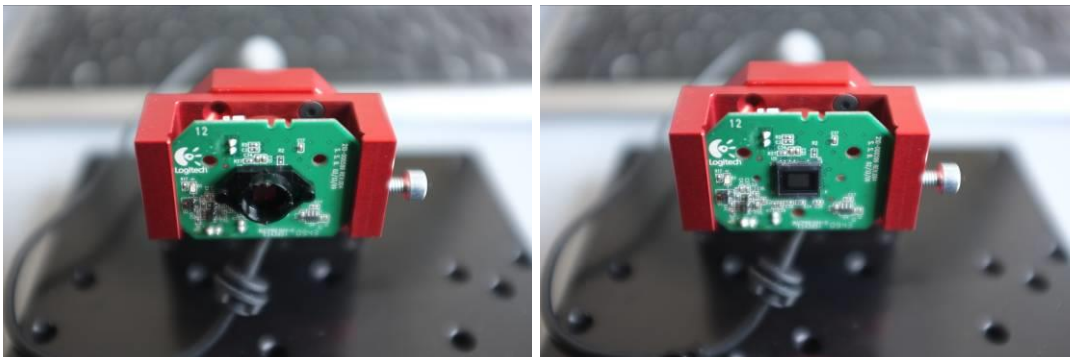


Figure 30. Camera PCB with and without IR filter.

- Switch on the halogen lamp equipped with mechanical shutter (the tape).
- Focus the filament by moving the lens cap.
- Adjust intensity by rotating the lens cap and play with the size of the mechanical shutter (the whole in the tape) to avoid saturation.
- Make an image of the filament

For the case without IR filter the exposure conditions should be minimal. This depends largely on the mechanical shutter. If there is too much light, make the shutter smaller (the hole in the tape needs to be smaller). You might try to use the lens cap rotation with its polarizer to get the intensity down. But this might not work because the polarizer limited efficiency in NIR (wavelengths above 800 nm). You should get exposure conditions and an image similar to this one shown below.

Figure 31. The intensity should be set to avoid saturation and have lowest exposure conditions without IR filter.

Put the IR filter in place **WITHOUT** changing the imaging conditions (position of lamp and lens). Repeat the measurement, adjust the exposure conditions (increase first exposure and then gain) and try to find back the same intensity by **visual inspection**. Your result might look like this:

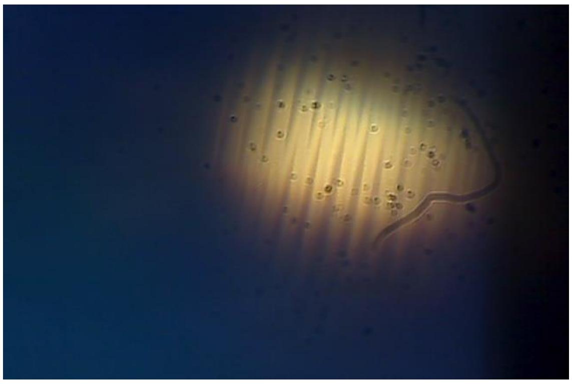


Figure 32. Same as figure above but this time with IR filter. The exposure needs to be adjusted to very high value.

NOTE: It might be necessary to cover the setup with the black tissue to avoid the influence of stray-light (parasitic light from room illumination).