Photonik
Ingenieurbüro
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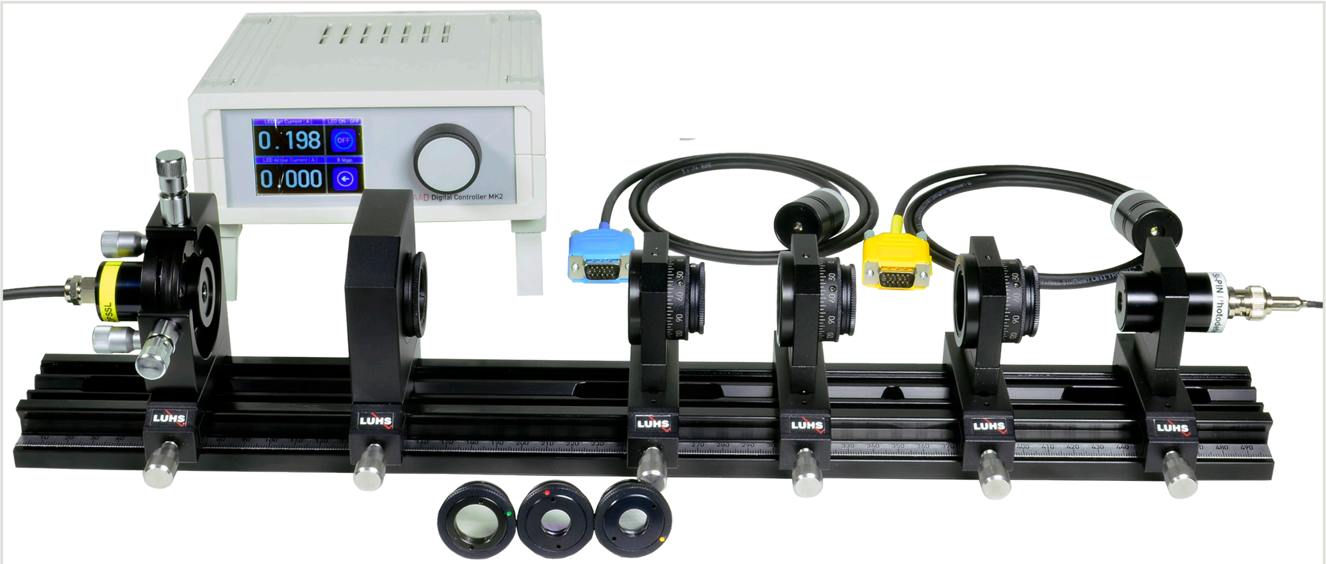
PE-0200 Polarisation of light



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1.0 Introduction

In the year 1809, Etienne Malus discovered the polarization of light by reflection and stated a law which describes the intensity distribution of polarized light as a function of the relative orientation of a polarization analyser. At that time his findings were in contradiction to the presumption of light waves being longitudinal rather than transversal. His discovery had far reaching consequences for the wave theory of light, and his unambiguous experimental results launched a big debate, among the leading scientists about the wave properties of light. Finally, as a compromise light was conceded to have transversal as well as longitudinal character. Two years later Dominique Arago investigated a sample of quartz and discovered its optical activity, a property of many natural and also synthetic materials. Later on, Augustine Fresnel could explain the effect of optical active materials on light by introducing the phenomenon of circular birefringence. In this series of experiments the polarization state of the light sources in use is determined. Furthermore, polarized light is used to prove the Malus' and Fresnel's Laws with respect to their states on polarization. The influence of crystal wave plates and optically active materials on polarization is studied.

2.0 Fundamentals

2.1 Characteristics of light

Light, the giver of life, has always held a great fascination for human beings. It is therefore no coincidence that people have been trying to find out what light actually is for a very long time. We can see it, feel its warmth on our skin, but we cannot touch it. The ancient Greek philosophers thought light was an extremely fine kind of dust, originating in a source and covering the bodies it reached. They were convinced, that light was made up of particles. As humankind progressed and we began to understand waves and radiation, it was proved that light did not, in fact, consist of particles but that it is an electromagnetic radiation with the same characteristics as radio waves. The only difference is in the wavelength. We now know that the characteristics of light are revealed to the observer depending on how he sets up his experiment. If the experimenter sets up a demonstration apparatus for particles, he will be able to determine the characteristics of light particles. If the apparatus is one used to show the characteristics of wavelengths, he will see light as a wave. The question we would like to be answered is: What is light in actual fact? The duality of light could only be understood using modern quantum mechanics. Heisenberg showed, with his famous “uncertainty relation”, that strictly speaking, it is not possible to determine the place x and the impulse p of any given occurrence at the same time

$$\Delta x \cdot \Delta p_x \geq \frac{1}{2}\hbar$$

If, for example, the experimenter chooses a set up to examine particle characteristics, he will have chosen a very small uncertainty of the impulse px. The uncertainty x will therefore have to be very large and no information will be given on the course of the occurrence. Uncertainties are not given by the measuring apparatus, but are of a basic nature. This means that light always has the particular property, the experimenter wants to measure. We can find out about any characteristic of light as soon as we think of it. Fortunately the results are the same, whether we work with particles or wavelengths, thanks to Einstein and his famous formula:

$$E = m \cdot c^2 = \hbar \cdot \omega$$

This equation states that the product of the mass m of a particle with the square of its speed c corresponds to its energy E. It also corresponds to the product of Plank’s constant $h = \hbar \cdot 2\pi$ and its radian frequency $\omega = 2\pi \cdot \nu$. In this case ν represents the frequency of luminous radiation.

In our further observations of the fundamentals, we will use the wave representation and describe light as electromagnetic radiation. All types of this radiation, whether in the form of radio waves, X-ray waves or light waves consist of a combination of an electrical field $\vec{E}$ and a magnetic field $\vec{H}$. Both fields are bound to each other and are indivisible. Maxwell formulated this observation in one of his four equations, which describe electromagnetic fields

$$\nabla \times \vec{H} \approx \frac{\partial \vec{E}}{\partial t}$$

According to this equation, every temporal change in an electrical field is connected to a magnetic field (Fig.1).

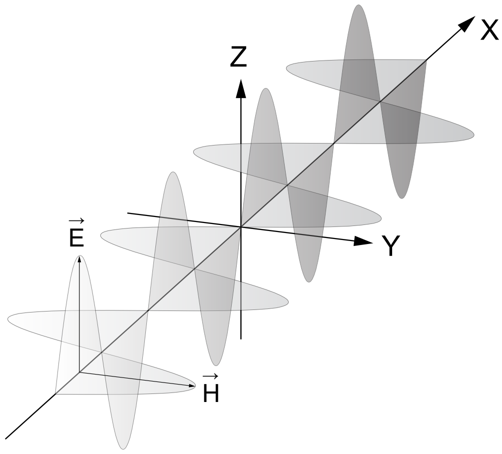


Fig. 1: Light as electromagnetic radiation

Due to the symmetry of this equation, a physical condition can be sufficiently described using either the electrical or the magnetic field. A description using the electrical field is preferred since the corresponding magnetic field can be obtained by temporal differentiation. In the experiments (as presented here) where light is used as electromagnetic radiation, it is advantageous to calculate only the electrical fields since the light intensity is:

$$I = \frac{c \cdot \varepsilon}{4\pi} \cdot \left|\vec{E}\right|^2 .$$

This is also the measurable property as perceived by the eye or by a detector. The speed of light is c in the respective medium and ε is the corresponding dielectric constant. Since we are comparing intensities in the same medium, it is sufficient to use

$$I = \left|\vec{E}\right|^2$$

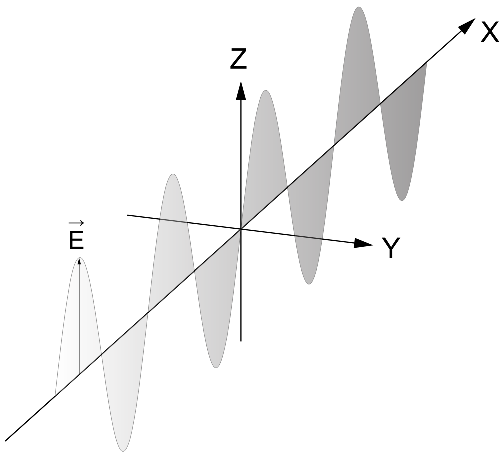


Fig. 2: In this experiment we need only consider the electrical field strength $\vec{E}$

The experimental findings agree to the theory of electromagnetic radiation if the temporal behaviour of the field strength of the light $\vec{E}$ is a harmonic periodic function. In its simplest form this is a sine or cosine function. An amplitude E_0 and a wavelength λ should be used in the definition of this kind of function. Let us begin with the equation:

$$E_X = E_0 \cdot \sin\left(\frac{2 \cdot \pi}{\lambda} \cdot x\right) , \qquad \textbf{(1)}$$

which we will elaborate and explain further.

Theory

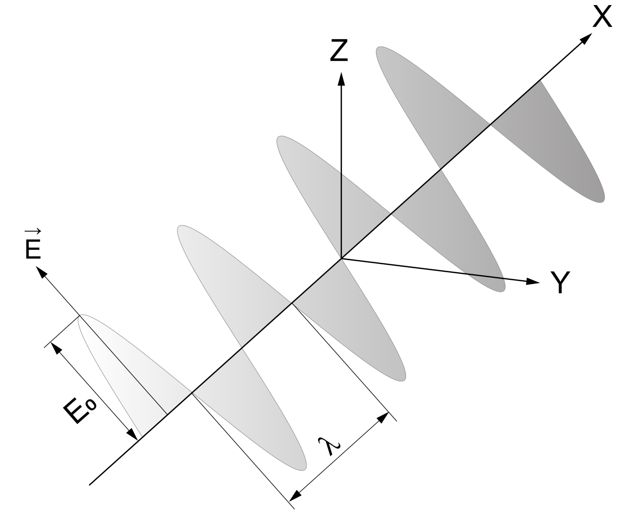


Fig. 3: Amplitude and wavelength

In the above figure the light wave no longer oscillates in the Z-direction as in Fig.2 but at a certain angle to the Z- or Y-axis. The X-axis has been chosen as the direction of propagation of the wave. We still require information on the direction in which the electrical field strength E_x oscillates to complete the description of the wave. Strictly speaking, the field E_x oscillates vertically to the direction of propagation X. However, we have to give information regarding the Z- and Y-axis. This leads to the term 'Polarisation' and Direction of Polarisation. In Figs. 1 and 2 we used linearly polarised light with a polarisation direction in Z and in Fig.3 we used a different direction. We will now introduce the polarisation vector P, which is defined in the following Fig.4. We look into the light wave in the direction of the X-axis for this purpose.

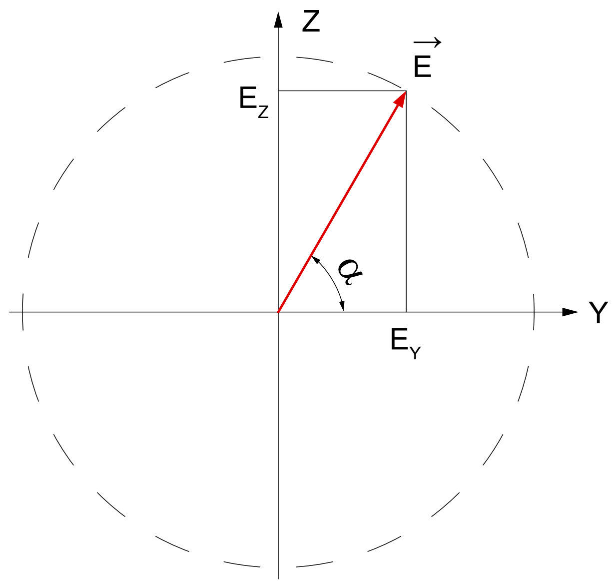


Fig. 4: Definition of the polarisation vector

We observe a wave propagating in the X-direction and oscillating at the electrical field amplitude E_0 under an angle of α to the Y-axis. The amplitude E_o is separated into its components, which oscillate in the Z- or Y-direction. We now write $\vec{E}$ to indicate, that the electric field strength is now made up of individual components.

$$\vec{E} = E_x \cdot \vec{e}_x + E_x \cdot \vec{e}_y$$

In this case $\vec{e}_z$= (0,1) and $\vec{e}_y$= (0,1) are the unit vector in the Z- or Y-direction in the ZY-plane. The unit vectors have the property of $|\vec{c}_z|$=1 and the scalar product $\vec{c}_y \cdot \vec{c}_z$=0. The equation (1) can be generalised to:

$$E_X(Y,Z) = \left(E_0^Y \cdot \hat{e}_Y + E_0^Z \cdot \hat{e}_Z\right) \cdot \sin\left(\frac{2\pi}{\lambda} \cdot x\right)$$

At this point we come across a fundamental principle in classic wave theory, i.e. the principle of superimposition. A big word for the simple statement:

Every wave can be represented as the sum of individual waves.

In our example we had separated the wave as shown in Fig.4 into two individual waves, i.e. one that oscillates in the Z-direction and another in the Y-direction. We could just as well say, that the wave is created by the superimposition of these two individual waves. The word ***interference*** can also be used to mean superimposition. In this context the wave is formed by the interference of two individual waves.

For the time being, let us return to the polarisation vector. The polarisation vector P is also a unit vector, which always points in the direction of the oscillation of the electrical field E_x

$$\hat{P} = \frac{\hat{E}_0}{|\hat{E}_0|} = \frac{E_0^Y}{E_0} \cdot \hat{e}_Y + \frac{E_0^Z}{E_0} \cdot \hat{e}_Z,$$

or as is written for vectors

$$\hat{P} = \left(\frac{E_0^Y}{E_0}, \frac{E_0^Z}{E_0}\right).$$

The polarisation vector for a polarisation in the Z-direction (0°) would then be, for example:

$$\hat{P} = (0,1)$$

for a polarisation direction of 45° it would be:

$$\hat{P} = \frac{1}{\sqrt{2}}(1,1).$$

The equation of the wave with any given polarisation direction will thus be

$$\hat{E}_X(Y,Z) = \hat{P} \cdot E_0 \cdot \sin\left(\frac{2\pi}{\lambda} \cdot x\right), \text{ or}$$

$$\hat{E}_X(Y,Z) = \left(E_Y, E_Z\right) \cdot \sin(k \cdot x) \qquad \textbf{(2)}$$

We have introduced the wave number k in the above equation

$$k = \frac{2\pi}{\lambda}.$$

The wave number k has the length dimension^{-1} and was originally introduced by spectroscopists because it was a size that could be measured immediately with their equipment. We are using this definition, because it simplifies the written work.

2.2 Birefringent crystal

Birefringent crystals are indispensable in optics and laser technology. They are used as optical retarder and as tuning elements. At this point we will introduce a formalism describing the interaction between light and birefringent optics in a simple way. This formalism enables us to analyse and represent the way in which various birefringent components work, with regard to computer applications in particular.

2.3 Jones Matrix Formalism

Jones created the basis for this formalism in 1941. We should really be grateful to him. He was probably one of those people who didn't think much of exercises with complex numbers and sin and cos theorems.

The electric field intensity of light is usually represented in the vectorial form:

$$\vec{E} = \vec{E}_0 \cdot \sin(\omega t + \vec{k}\vec{r} + \delta)$$

$\vec{E}_0$ is the amplitude unit vector describing the size and direction (polarisation) of the electrical field

$\omega = 2\,\pi\nu$, ν is the frequency of light
t is the time

$\vec{k}$ is the wave vector, containing the propagation direction and the wavelength λ:

$$|\vec{k}| = \frac{2\pi}{\lambda}$$

$\vec{r}$ is the displacement vector in the system of coordinates of the light wave

$$\delta = \frac{2\pi}{\lambda}|\vec{r}_1 - \vec{r}_2|$$

δ is a constant phase shift with respect either on a fixed coordinate or a fixed frequency

A complete description of a light wave still requires information on the magnetic field of the light wave. However, it needs not be considered for most applications in the field of optics, since the interaction of light with materials that do not absorb, is primarily of an electrical nature and not a magnetic one. Strictly theoretical derivations the magnetic field must fulfil certain conditions for continuity at the boundary surfaces. We do not propose to reflect on this aspect and will therefore not discuss it any further at this point.

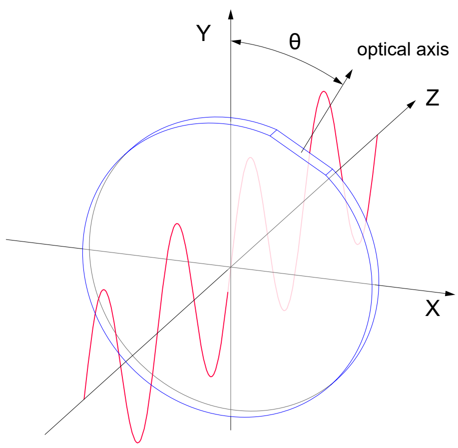


Fig. 5: Passage of a light wave through an optical plate.

The term "optical" is used to indicated that this plate has been manufactured for optical applications and that apart from characteristics specific to the material, the light wave has no outside obstacles (e.g. bubbles, impurities, etc.).
The situation represented in Fig. 5 is typical for the use of birefringent components. It is therefore sufficient to be interested only in the X and Y components of the electrical field E. So, the light wave will be described by:

$$J = \begin{pmatrix} E_x \cdot e^{i\omega t} \\ E_y \cdot e^{i\omega t + \delta} \end{pmatrix} \qquad \textbf{(3)}$$

Since the frequency of the X and Y amplitude will always be the same and for power calculations fast oscillating terms will be neglected, we can simplify (3) to:

$$J = \begin{pmatrix} E_x \\ E_y \cdot e^{i\delta} \end{pmatrix}$$

Let us normalise the power P of the light wave to 1. Then

$$P = E_x^2 + E_y^2 = 1$$

It can easily be deduced that:

$$P = J\,J^{-1}$$

The minus sign in the J exponent means the conjugate complex of J (substitute i by -i). For a light wave that is polarised in the direction of the Y-axis it will be:

$$J = \frac{1}{\sqrt{2}} \cdot \begin{pmatrix} 0 \\ 1 \end{pmatrix}$$

In an analogous representation for a wave polarised in the direction of X the equation would be:

$$J = \frac{1}{\sqrt{2}} \cdot \begin{pmatrix} 1 \\ 0 \end{pmatrix}$$

We know that, based on the validity of the superposition principle of linear optics, any given number of polarised linear waves can be represented by the vectorial addition of two mutually perpendicular individual waves. By adding the two Jones vectors given above we would get linear polarisation of light oscillating at 45 degrees to the X or Y axis.

$$J = J_1 + J_2 = \frac{1}{\sqrt{2}}\begin{pmatrix} 1 \\ 0 \end{pmatrix} + \frac{1}{\sqrt{2}}\begin{pmatrix} 0 \\ 1 \end{pmatrix} = \frac{1}{\sqrt{2}}\begin{pmatrix} 1 \\ 1 \end{pmatrix}$$

If one component has a phase shift δ with respect to the other component, the result will be elliptical polarised light. If the phase shift δ is $\lambda/4$ the result will be the circular polarisation of light.

$$\delta = \frac{2\pi}{\lambda} \cdot \Delta \quad , \quad \Delta = \frac{\lambda}{4} \Rightarrow \delta = \frac{\pi}{2}$$

The Jones vector for this kind of light has the following form.

$$J = \frac{1}{\sqrt{2}} \cdot \begin{pmatrix} 1 \\ i \end{pmatrix} \quad \text{note} : e^{\frac{i\pi}{2}} = i$$

An optical component, which can produce such a phase shift is called "birefringent" or double refractive. An element which works selectively on one component only works as polariser. The difference between the two is that whereas the polariser removes a component, the birefringent plate slows one component down in relation to the other in a way, that the components differ in phase behind the plate. Before giving the Jones matrices for these elements we will explain briefly the way the elements work. A simple model will be used for this purpose. Light will be observed as an electromagnetic oscillation. We consider the optical component as a collection of many dipoles. These dipoles are determined by the type and form of the electron shells which each atom or molecule has. These dipoles are excited by the electromagnetic field of the light and are thus turned out of their equilibrium (susceptibility).The dipoles absorb energy of the light (virtual absorption) and send them out again. However, a dipole cannot send its beam in the direction of its own axis. If a crystal has two kind of dipoles, which are at a particular angle to each other, they can only emit and absorb light within the area of their angles. If the process of absorption and emission is slower in one kind of dipole than in the other there will be a phase shift. Macroscopically it seems as if there were a higher refractive index. A change in the beam direction takes place because of the different dipole directions, i.e. there are two separate beam directions within the component. If a parallel light beam penetrates into this kind of material the result is, indeed, two beams leaving the crystal. Both beams are polarised perpendicularly and have a phase shift between each other.

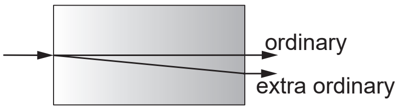


Fig. 6: Birefringent crystal

This phenomenon is called birefringence. These two marked directions of the crystal also have two distinctive refractive indices. One of the two beams appears to violate the Snell's law, it is called extraordinary (eo) and the other behaving normally is called ordinary (o). Crystal quartz and calcite are materials which behave in this way. There are also a series of other crystals but these two have been proved successful in laser technology. Thin plates, used as optical retarder are mostly made out of quartz because it is hard enough for this purpose.
Mica sheets have also been used but they are not suitable for use inside the resonator because of the losses involved. Please note that only crystal quartz has a birefringent behaviour. Quartz that has already been melted (Quartz glass) loses this property. A whole series of laser components are made out of calcite. Short calcite crystals are sufficient to produce the required beam separation, e.g. as with the active Q-switch, because of the great difference between the ordinary and extraordinary refractive indices.
The Jones matrix formalism can now be applied in the description of the interaction of a light wave with such materials. Retarding plates and polariser can be represented as Jones matrices in the same way that a plane wave can be represented as a Jones vector. Polariser which allow X or Y polarised to pass are as follows:

$$P_x = \begin{pmatrix} 1 & 0 \\ 0 & 0 \end{pmatrix} \text{ and } P_y = \begin{pmatrix} 0 & 0 \\ 0 & 1 \end{pmatrix}$$

If the polariser is turned around the beam by the angle θ, P must be treated with the transformation or rotational matrix:

$$R(\theta) = \begin{pmatrix} \cos(\theta) & \sin(\theta) \\ -\sin(\theta) & \cos(\theta) \end{pmatrix}$$

and the result for the turned polariser will be:

$$P(\theta) = R(-\theta) \cdot P \cdot R(\theta) \qquad \text{rotated polariser}$$

A birefringent plate whose optical axis is parallel to the x or y axis has the following Jones matrix:

$$V = \begin{pmatrix} e^{-i\frac{\delta}{2}} & 0 \\ 0 & e^{i\frac{\delta}{2}} \end{pmatrix} \qquad \text{Birefringent plate}$$

It has also to be transformed by the rotational matrix R(θ) in case the optical axis of the crystal was rotated around the angle θ.

$$V(\theta) = R(-\theta) \cdot V \cdot R(\theta)$$

To prevent misunderstandings regarding the optical axes, we must point out that the optical axis of the crystal is the one in which the ordinary refractive index is effective.

As example we consider a vertical polarized light wave passing a λ/2 plate which is rotated by 45° with respect to the polarisation direction of the light wave.
The light wave is described by the Jones vector:

$$J = \begin{pmatrix} 0 \\ 1 \end{pmatrix}$$

The Jones vector of the light wave behind the plate is J':

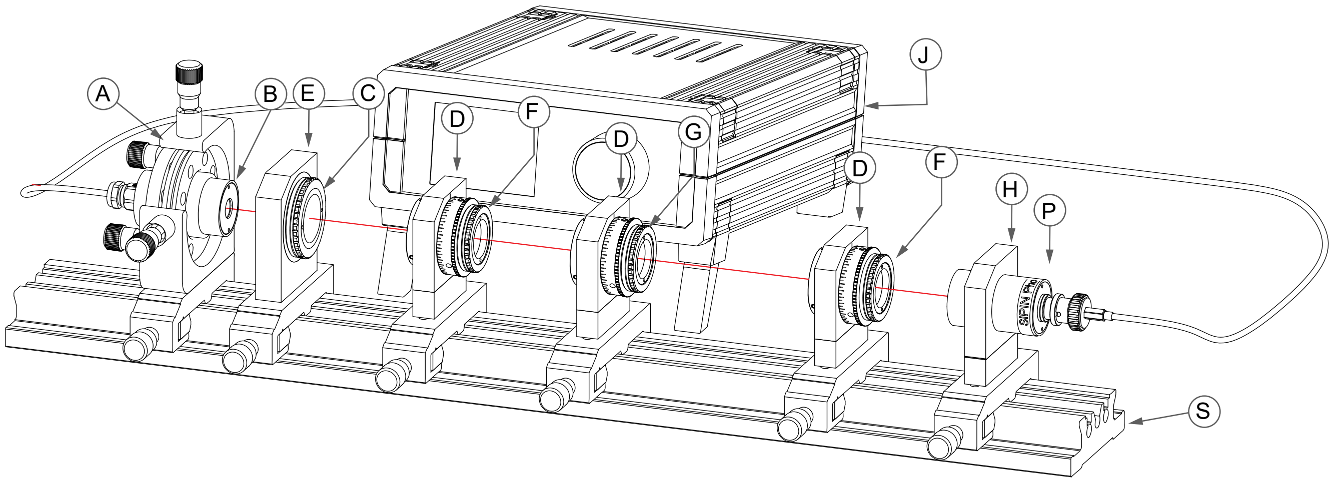
$$J' = V(45°) \cdot J = R(-45°) \cdot V \cdot R(45°) \cdot J$$

$$V(45°) = \frac{1}{\sqrt{2}} \cdot \begin{pmatrix} 1 & -1 \\ 1 & 1 \end{pmatrix} \cdot \begin{pmatrix} -i & 0 \\ 0 & i \end{pmatrix} \cdot \frac{1}{\sqrt{2}} \cdot \begin{pmatrix} 1 & 1 \\ -1 & 1 \end{pmatrix} = \begin{pmatrix} 0 & -i \\ -i & 0 \end{pmatrix}$$

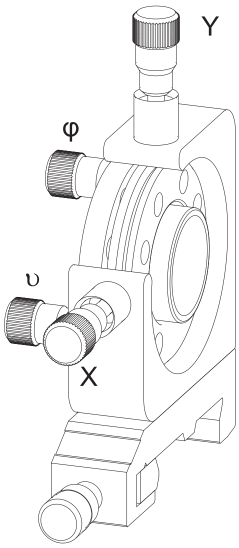
$$J' = V(45°) \cdot J = \begin{pmatrix} 0 & -i \\ -i & 0 \end{pmatrix} \cdot \begin{pmatrix} 0 \\ 1 \end{pmatrix} = -i \cdot \begin{pmatrix} 1 \\ 0 \end{pmatrix}$$

The result shows, that the polarisation of the incident light is rotated by 90°. That is what we expected for a λ/2 plate which is rotated by 45° with respect to the polarisation direction of the light wave.

3.0 Description of the components



Module A: Four axes adjustment Holder



This frequently needed component is ideal for the fine adjustment of lenses, microscope objectives, diode laser, etc. with respect to the optical axis of the rail set-up. The displacement area is 5x5 mm and 10x10 degrees respectively. Different mounts can be attached to the adjustment holder. This model provides a holder for 25 mm cylindrical components. The component is inserted into the adjustment holder and is kept in position by a spring loaded steel ball in the same way as for the lens click mounts. Four precise fine pitch screws of repetitious accuracy allow the translational (X; Y) and azimuthal (υ; φ) adjustment.

Module B: White LED

A white light LED is built into a round housing (C25). The LED is connected via a 15 pin SubD HD connector to the controller MK1. Inside the connector an EPROM contains the data of the LED and when connected to the controller, these data are read and displayed by the controller.

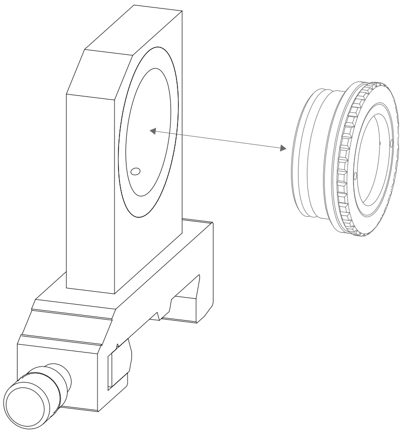
Module B: Blue LED

A blue light emitting LED is built into a round housing (C25). The LED is connected via a 15 pin SubD HD connector to the controller MK1. Inside the connector an EPROM contains the data of the LED and when connected to the controller, these data are read and displayed by the controller.

Green (532 nm) emitting DPSSL

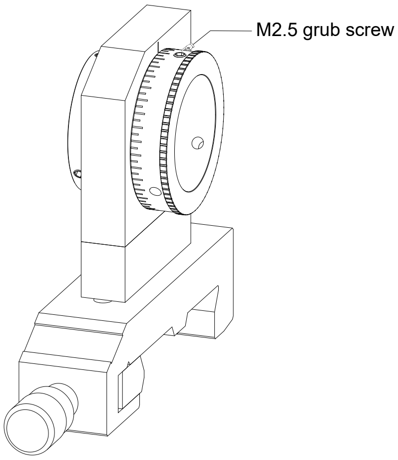
A green (532 nm) emitting DPSSL (Diode Pumped Solid State Laser) is integrated into a C25 housing and is operated with the "DC-0020 LED and Photodiode Controller". The output power is < 5 mW. The diode laser is connected via a 15 pin SubD HD connector to the controller MK2. Inside the connector an EEPROM contains the data of the laser diode and when connected to the controller, these data are read and displayed by the controller.

Module E: Mounting plate C30 on carrier



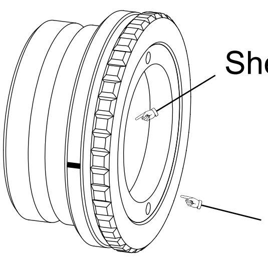
This frequently used component is ideal to accommodate parts with a diameter of 30 mm where it is kept in position by three spring loaded steel balls. Especially C30 mounts having a click groove are firmly pulled into the mounting plate due to the smart chosen geometry. The mounting plate is mounted to a 20 mm wide carrier.

Module D Rotary Polarisation Analyser



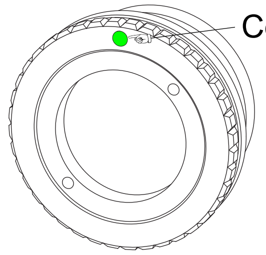
The polarisation analyser or polarizer has a horizontal rotary stage with a 25 mm through hole bore and 360 degree scale with tick marks for each 5 degrees. It is attached to a 20 mm wide carrier. A C25 mount which is set into the rotary stage and is kept in position with three M2.5 grub screws. The module comes with a fitting Allen key.

Module F: Polarizer in C25 mount



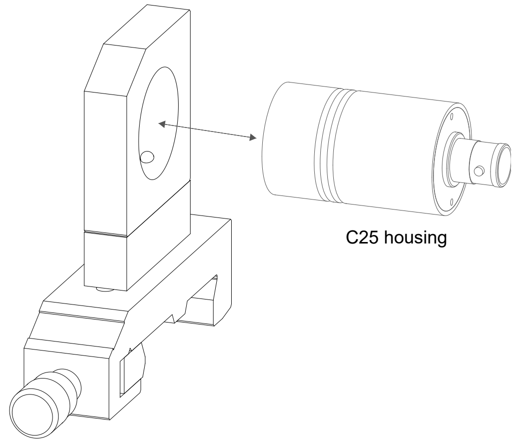
A film sheet polarizer is set into a C25 mount with a tick mark as vertical polarisation indicator. The free opening is 20 mm.

Module G: Optical crystals



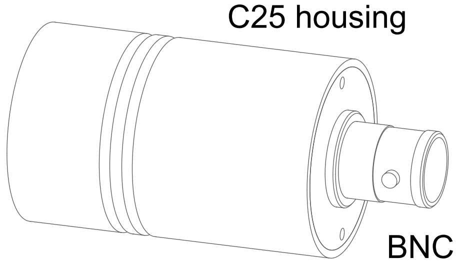
1. Green dot: Mica plate in C25 mount
2. Red dot: Half-wave plate in C25 mount
3. Blue dot: Quarter-wave plate in C25 mount
4. Yellow dot: 3 mm Optical quartz plate in C25 mount

Module H: Mounting plate C25 on carrier



This frequently used component is ideal to accommodate parts with a diameter of 25 mm where it is kept in position by three spring loaded steel balls. Especially C25 mounts having a click groove are firmly pulled into the mounting plate due to the smart chosen geometry. The mounting plate is mounted onto a 20 mm wide carrier.

Module P: Si-PIN Photodetector, BPX61



A Si PIN photodiode is integrated into a 25 mm housing with two click grooves. A BNC connector is attached to connect the module to the MK2 controller. The photodetector module is placed into the C25 mounting plate where it is kept in position by three spring loaded steel balls.

Parameter	Symbol	Value	Unit
Rise and fall time of the photo current at: R_L=50Ω; V_R=5 V; λ=850 nm and I_p=800 µA	t_r, t_f	20	ns
Capacitance at V_R = 0, f = 1 MHz	C0	72	pF
Wavelength of max. sensitivity	λ_{Smax}	850	nm
Spectral sensitivity S 10% of S_{max}	λ	1100	nm
Dimensions of radiant sensitive area	L × W	7	mm^2
Spectral sensitivity, λ = 850 nm	S(λ)	0.62	A/W

Table 1: Parameter of the photodiode BPX61

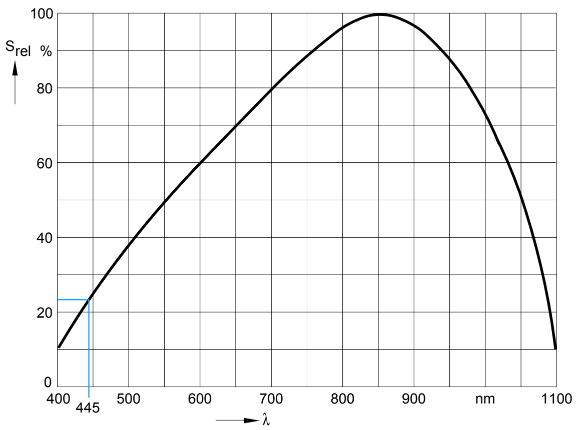


Fig. 7: Sensitivity curve of the BPX61 photodiode

The Mk2 controller contains a digital resistor and provides +5 VDC for the reverse voltage of the photodiode. They are connected to the BNC input (PDIN) as shown in the schematic of Fig. 8. At the output PDOUT of the signal box a signal is present which is given by the following equation:

$$I_c = \frac{U_c}{R_S} = \frac{U_{display}}{R_S \cdot Gain}$$

I_c is the photocurrent created by illuminating the photodiode with light. U_c is the voltage drop across the selected load resistor R_S. $U_{display}$ is the value of U_c displayed on the controllers touch screen multiplied by the selected gain (GAIN). To convert the measured voltage U_c into a respective optical power we use of the spectral sensitivity S(λ) [A/W], which depends on the wavelength of the incident light according to Fig. 7. From the Table 1 we take the value for S(850nm) as 0.62 A/W. To obtain the value for another wavelength, 445 nm for instance, we have to multiply this value with the S_{rel}(445 nm) from Fig. 7 (23% or 0.23).
The detected optical power P_{opt} in W is given as:

$$P_{opt} = \frac{I_c}{S(\lambda)}$$

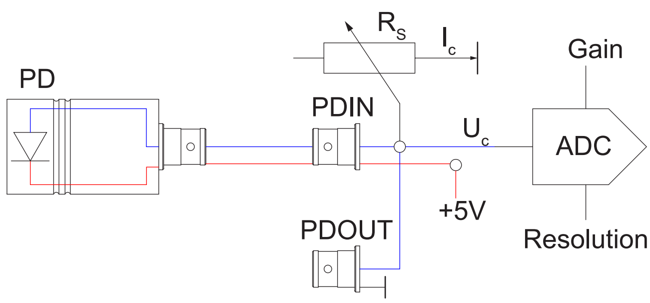


Fig. 8: Photodiode schematic

The photovoltage U_c is internally connected to a high precision ADC from which the microprocessor reads the value of the of U_c and the value of the load resistor R_S and displays their values on the touch screen of the MK2 controller.

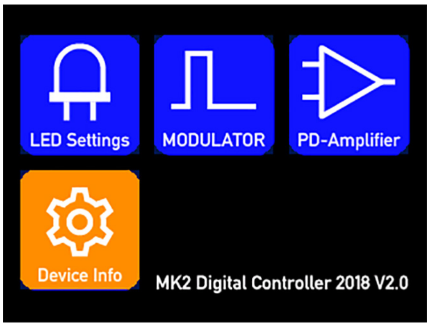
Module J: LED and Photodiode Controller

This microprocessor operated device contains an LED current controller and a photodiode amplifier. A touch panel display allows in conjunction with the digital knob the selection and setting of the parameters for the attached LED or photodiode. The controller reads the operation values of the connected LED or laser from the EEPROM located inside its connector. The device comes with a 230 VAC / 12 VDC wall plug power supply. The device can be controlled and the data read by an external computer via the USB bus.

Fig. 9: The rear of the MK2 controller

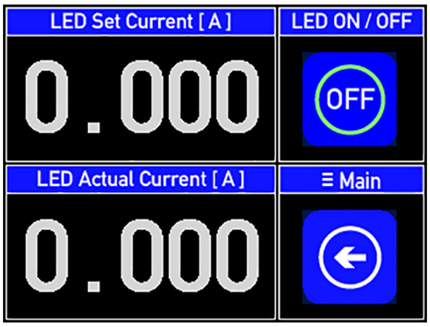
The photodetector is connected via the provided BNC cable to the PD-IN BNC panel jack. The analogue photovoltage is available at the PD-OUT panel jack. The controller is operated by 12 VDC via the provided wall plug power supply. The LED or laser are connected via the 15 pin SubD connector labelled “LED/LD”. When the LED or laser is operated in modulated mode, the reference modulator signal is available at the “MODULATOR” BNC connector.

When the external 12 V is applied and switched on, the controller starts displaying the screen as shown in the figure above.

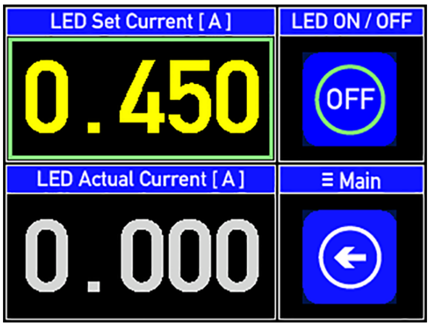


The upcoming interactive screen appears with the selection of 4 buttons:

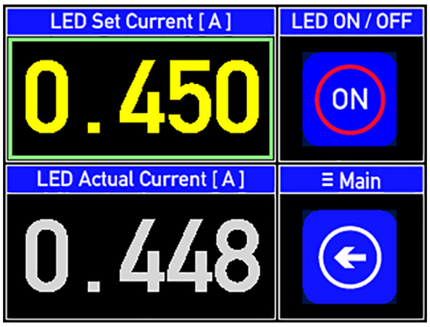
1. LED/Laser current settings
2. Modulation of the LED/laser
3. Photodiode Amplifier
4. Device and LED/laser information



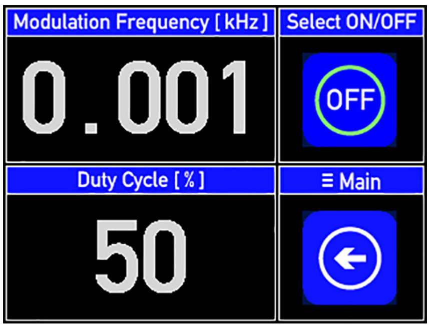
The current settings screen shows the set current as well as the actual current. With the LD ON/OFF touch button the laser is switched on or off. The ≡Main touch button switches back to the main page.



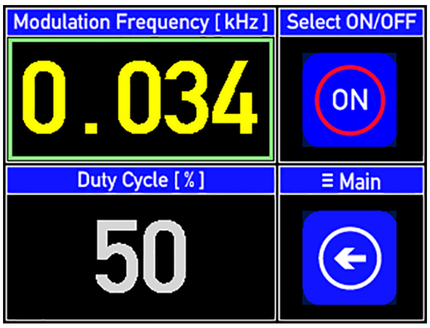
By touching the “LED Set Current” display field it is highlighted. By turning now the knob, the value of the injection current can be set and is immediately applied, provided the LED ON/OFF touch button is activated.



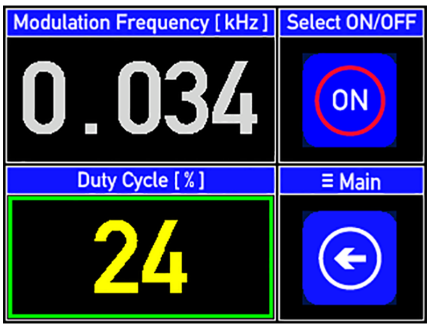
Touching the LED ON/OFF button switches the LED ON or OFF. When switched ON, the actual current is displayed in addition.



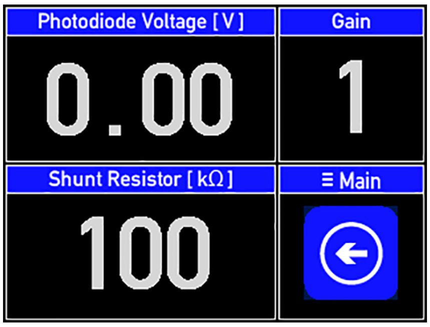
The LED or laser can be switched periodically on and off. This is for a couple of experiments of interest.



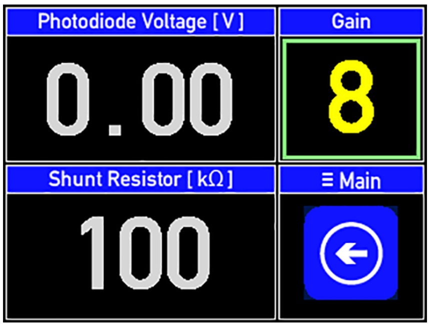
By tapping the display of the modulation frequency the entry is activated. Turning the settings knob will set the desired frequency value. The modulation becomes active, when the Modulator ON/OFF button is tapped.



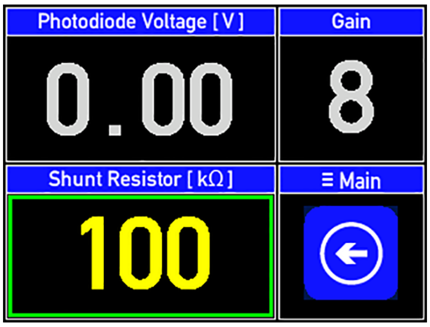
For some experiments it is important to keep the thermal load on the optically pumped object as low as possible or to simulate a flash lamp like pumping. For this reason the duty cycle of the injection current modulation can be changed in a range of 1...100 %. A duty cycle of 50% means that the OFF and ON period has the same length. The set duty cycle is applied instantly to the injection current controller.



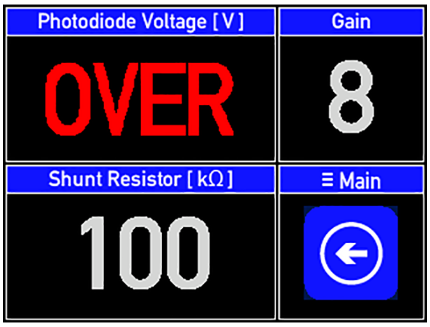
The photodiode page displays the measured photovoltage, the selected shunt resistor and the chosen gain.



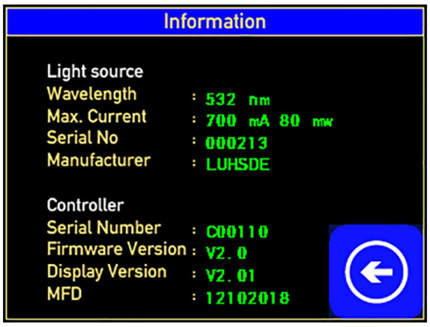
Tapping the gain display field switches the gain from 1, 2, 4 and 8.



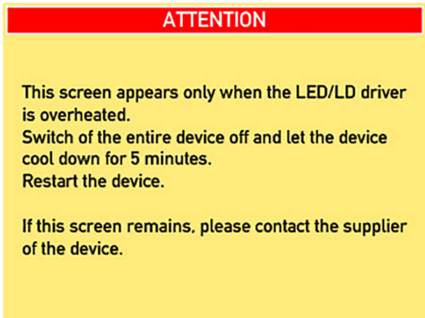
Activating the shunt resistor display field lets one set the shunt resistor by turning the digital knob. The value ranges from 1 kOhm to 200 kOhm.



If the photovoltage exceeds the inter reference voltage of 2.048 V the display shows the overload state. Reduce the gain or the shunt resistor. If the overload state remains although both values are set to minimum values, the injection current should be reduced as well.



The diode laser module is connected via the 15 pin HD SubD jacket at the rear of the controller. The controller reads the EEPROM of the laser diode and sets the required parameter accordingly. This information and some more information about the controller are shown on this screen.



This screen you should never see. It appears only when the chip of the injection current controller is over heated. Switch off the device, wait a couple of minutes and try again. If the error persists please contact your nearest dealer.

This screen appears only, when no LED or laser is connect to the device.

4.0 Measurements

4.1 Measurement of the Light Source

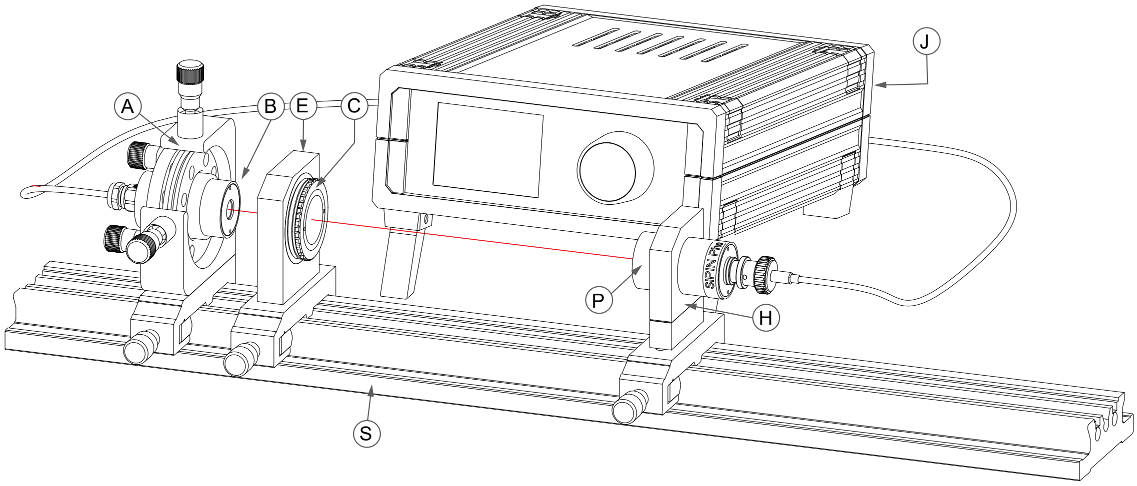


Fig. 10: Setup to measure the optical output power versus the injection current of the LED or DPSSL

As light source either the blue or white LED or the "green" laser (B) is used. The light source is clicked into the four axes kinematic mount (A) and connected to the LED and photodiode controller (J). Each light source has an embedded non-volatile memory into which the property of the light source is stored. The information is processed and displayed by the controller (J) to ensure the operation of the attached light source within its allowed parameter. In addition, the controller contains a pre-amplifier and processing stage for the attached photodiode. The settings are selected by means of the touch screen and set by the precision digital settings knob. The measurements starts with the characterization of the light source as intensity versus injection current and versus the analyser (D+F) angle to check the polarisation of the selected light source.

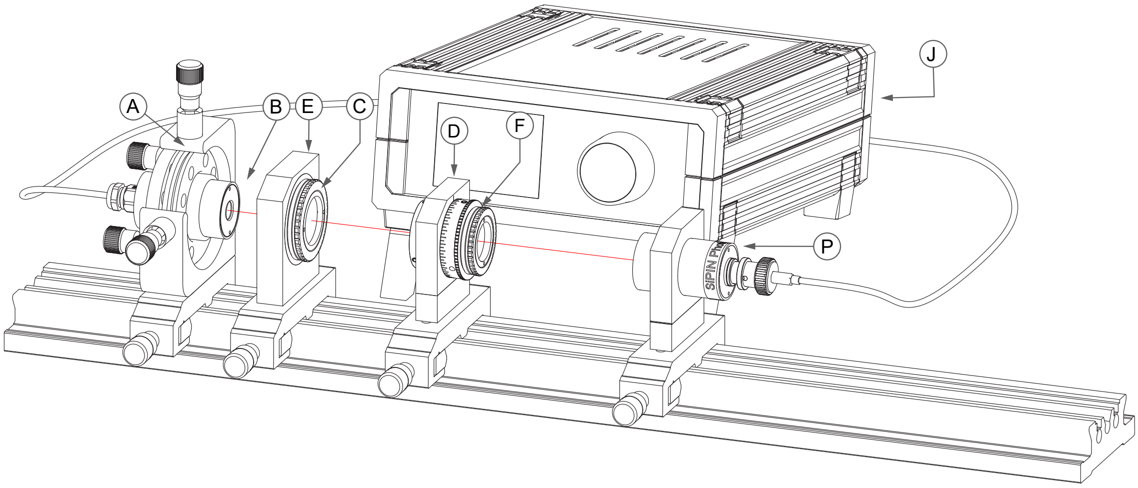


Fig. 11: Setup to measure the polarization of the selected light source.

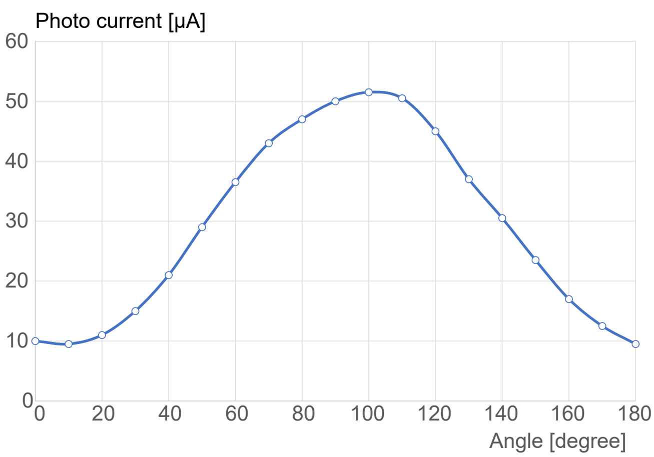
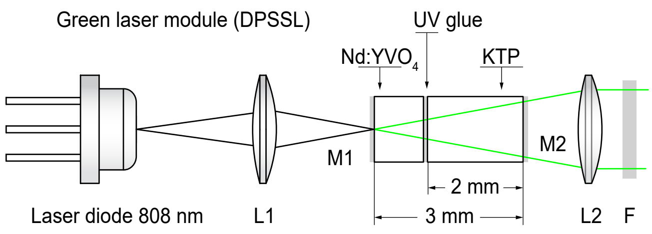


Fig. 12: Polarisation of the green DPSSL

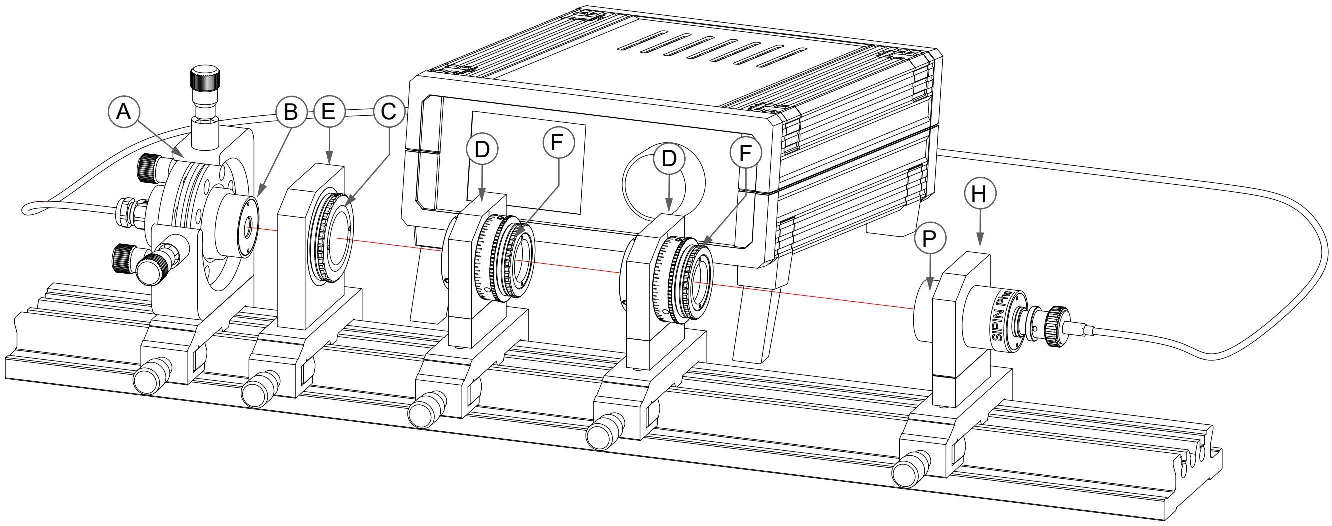
Notes for the green DPSSL:

The KTP cystal generates green emission in both directions. However, the back direction is reflected at the Mirror M1 to enhance the output power. Two beams are leaving collinear the DPSSL with a phase shift to one another. Depending on the thermal length of the crystal compound the phase shift varies resulting in different polarisation states of the green emission. It is recommended to let the DPSSL warm up for 10 minutes before the measurement starts.



Measurements

4.2 Malus' Law and Optical Power Control



The achromat (C) is used to collimate the radiation of the LED to obtain an almost parallel light beam. To make sure that the light is linearly polarized, the first polarizer (D+F) is placed behind the collimator (C) and turned to maximum intensity. The second polarizer (D+F) is used as analyser. The transmitted intensity is measured with the photodetector (P+H) and the controller (J). An angular plot of the intensity yields the verification of the Malus' law. Such an arrangement is often used to control the intensity of a light source when the change of the emission wavelength by the control of the injection current is not desired.

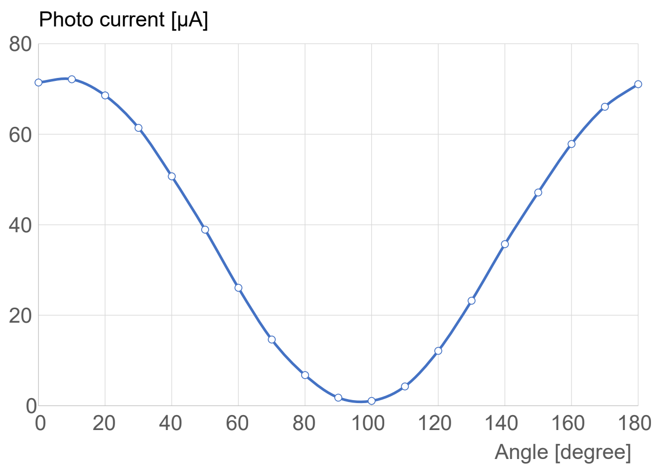


Fig. 13: White LED at 434 mA, gain 1 and shunt resistor 28 k.

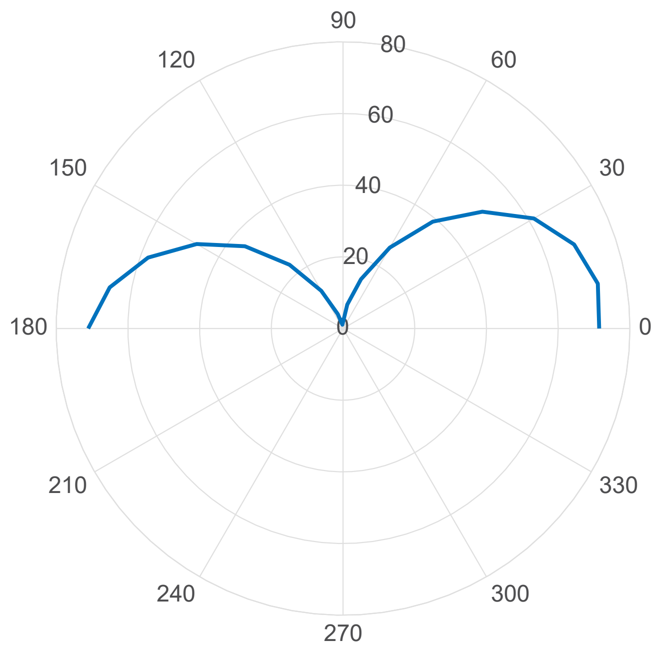
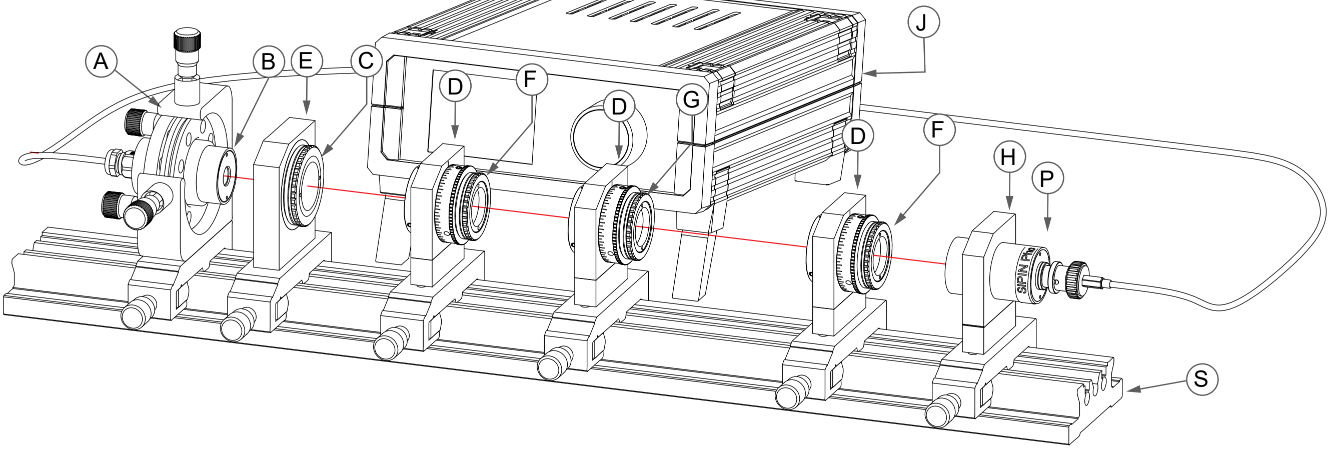


Fig. 14: Same values as Fig. 13, however drawn in polar coordinates

4.3 Polarisation by Optical Activity



To demonstrate the effect of double refraction or birefringence on the polarisation of the transmitted light beam 4 different optical active materials are used (G).

3mm Plate of crystalline quartz (yellow dot)
Quarter-wave plate made from quartz (blue dot)
Have-wave plate made from quartz (red dot)
Plate of natural mica (green dot)

The plates are mounted into a C25 mount and the rotary polarisation analyser provides the corresponding angle scale. The first polariser (D+F) is set to maximum intensity. The resulting linear polarised light of the light source (B) passes the inserted plate (G) and undergoes a phase retardation depending on the kind and orientation of the birefringent material.
The measured results can be plotted either in Cartesian or polar coordinates. The Fig. 15 (calculated) shows such examples in polar coordinates for:

A. Linear polarized
B. Elliptical polarized
C. Circular polarized light

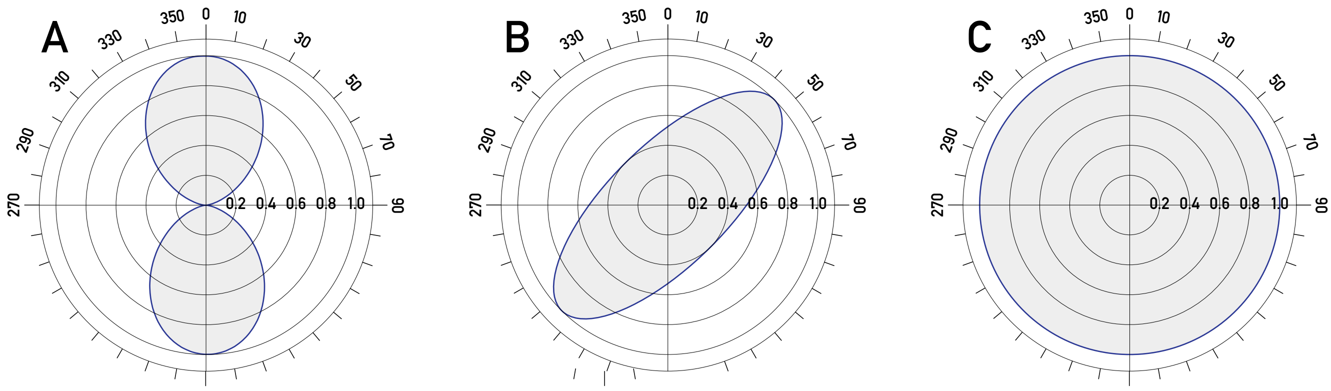


Fig. 15: Different polar diagrams

Measurements