Pulsed diode laser

Objects of the experiment

■ Measuring the repetition rate and the pulse width

■ Measuring the spatial intensity distribution and determine a three dimensional plot of the emission cross section

■ Analysing the polarisation properties

■ Collimating the divergent radiation beam

Safety notes

This experiment uses Lasers. According to EN 60825 they are rated class 3B.

1) 474 5418:

 Laser Class 3B, invisible 908 nm, pulsed, <5 µJ

Safety precautions are necessary. Please check with local regulations. Typically the use requires a safety sign and maybe a warning lamp that is on when the laser is activated and it might also be necessary to do and document a risk assessment. In some places it might be necessary to apply for a license or notify the relevant authorities.

Germany: According to OStrV it is necessary to inform the "Gewerbeaufsichtsamt" and the workers' insurance "Berufsgenossenschaft" 14 days prior to startup.

Misuse of the lasers poses a health risk, especially for the eyes.

Do not operate the devices outside parameters specified in the manual.

People using the laser must be properly trained and students must be supervised.

As a general guidance, the user is advised to:

• Check the laser for damages before use

• Never to look into the beam

• Take necessary measures that no people or animals can accidentally enter the beam area

• Do not direct the beam on reflecting surfaces or into public areas

• Do not work close to the light path with reflecting tools

• Take off all jewelry and wristwatches when working with the laser to avoid reflections

• While placing or removing optical parts in the light path, switch off the laser or cover its exit

• Some of the experiments use invisible laser beams, but still might hurt the eye

• Use laser protection glasses or laser adjustment glasses where necessary

• Supervise students by trained personnel when they work with the laser system

• Use the laser system only as described in the instruction manuals

Principles

Most laser diodes are designed to emit in continuous wave mode with fixed range powers from a few mW up to a few W. These diodes are not designed to exceed these ranges. If so the resonator may be damaged.

Pulsed diode lasers, however, are designed to be overdriven for short periods. To achieve the high peak powers, the duty cycle must be kept very low, typically 0.1%.

For example, a 100 ns pulse is followed by a pause of 100 µs. which means that very short pulses can be used with repetition rates in the kHz range. The maximum pulse lengths that can be achieved are therefore typically in the 200 ns range.

Semiconductor laser

As simple as it may seem, it took about 20 years until people had acquired the necessary technology of coating under extremely pure conditions. It all began in 1962 with the first laser diode, just two years after Maiman had demonstrated the first functional ruby laser. In the course of 1962 three

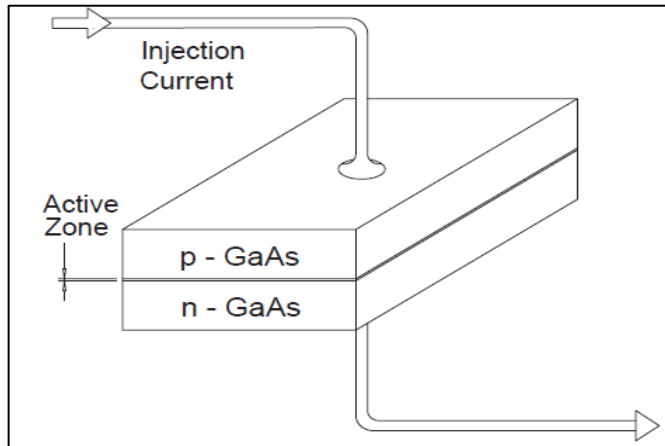different groups reported more or less simultaneously the realisation of GaAs diode lasers.

Fig. 1: Simple laser diode around 1962, working at 70 K and with 100 kA/cm^2 in the pulse mode.

The first laser was basically made of highly doped GaAs (Fig. 1). A threshold current of 100 kA/cm^2 was needed since the GaAs material of those days was not by far as good as it is today regarding the losses within the crystal. Because of thermal conditions the laser could only work at 70 K and in the pulsed mode. In the course of the following years the threshold could be lowered to 60 kA/cm^2 by improving the crystals but only the use of a heterotransition (Bell Labs. and RCA-Labs.) brought the „breakthrough" in 1968. The threshold could be lowered to 8 kA/cm^2 and working in the pulse mode at room temperature was possible (Fig. 2).
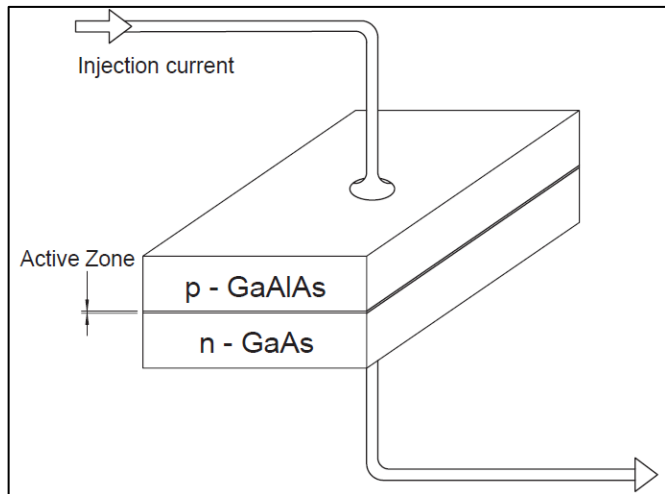

Fig. 2: Simple-heterostructured laser around 1968, working at 8 kA/cm^2 in pulse mode at room temperature.

In this concept a layer of p conducting GaAlAs is brought on the n layer of the pn transition of GaAs. The slightly higher band gap of GaAlAs compared to GaAs ensures that a potential barrier is created between both materials in a way that charge carriers accumulate here and the formation of inversion is increased respectively the laser threshold is remarkably lowered to 8 kA/cm^2.

The next step in development was the attachment of a similar layer on the n-side of the crystal. That way the threshold could be lowered once again in 1970. Now it amounted to about 1 kA/cm^2. Until today nearly all commercially sold laser

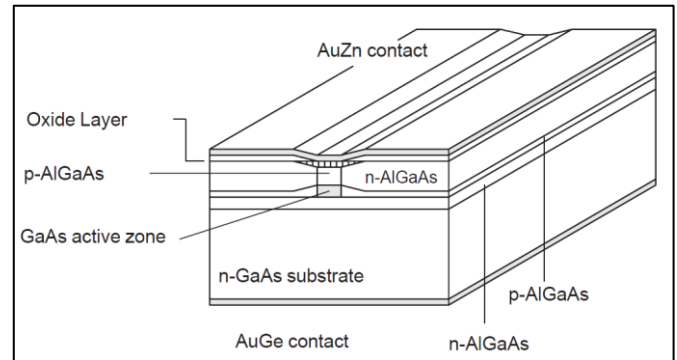diodes are built up on the double hetero structure principle (Fig. 3).

Fig. 3: „Buried" hetero structure. The active zone has been buried between some layers which ensure an optimal beam guidance in the zone.

Pulsed diode Laser

The pulsed laser driver consist of a capacitor with capacitance C and a switch which discharges the charge of the capacitors to the laser. The charging of the capacitor is done between two laser pulses.

In this experiment a hybrid pulsed laser diode is used strained with InAlGaAs/GaAs QW-structures. This guarantees a high power large-optical-cavity laser structure and a Laser aperture 200 µm x 2 µm. The typical pulse width is below 30 ns.

Divergence and intensity distribution

Not only the beam guidance but also the size of the laser mirrors influences the beam geometry. Generally for conventional lasers the mirrors are very large compared with the beam diameter. The laser mirror (crystal gap area of the active zone) of the laser diodes has a size of about 10 µm x 2 µm, through which the laser beam has „to squeeze" itself. Diffraction effects will be the consequence and lead to elliptical beam profiles (Fig. 4).
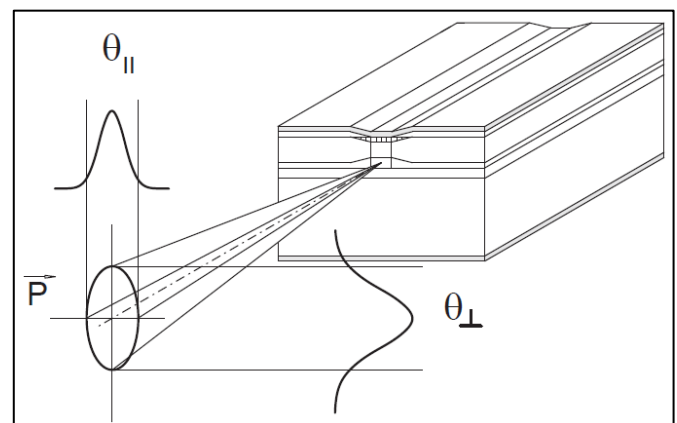

Fig. 4: Elliptical beam profile of a diffraction limited laser diode in the far field (some meters).

The polarisation is parallel to the "junction plane", that is the plane which is passed by the injection current perpendicularly. The divergence angles $\theta_\perp$ and $\theta_{\parallel}$ differ by about 10°-30° depending on the type of laser diode.

If the beams are extended geometrically into the active medium the horizontal beams will have another apparent point of origin as the vertical beams. The difference between the points of origin is called astigmatic difference (Fig. 5). It amounts to about 10 μm for the so called index guided diodes. For the so called gain guided diodes these values are appreciably higher.
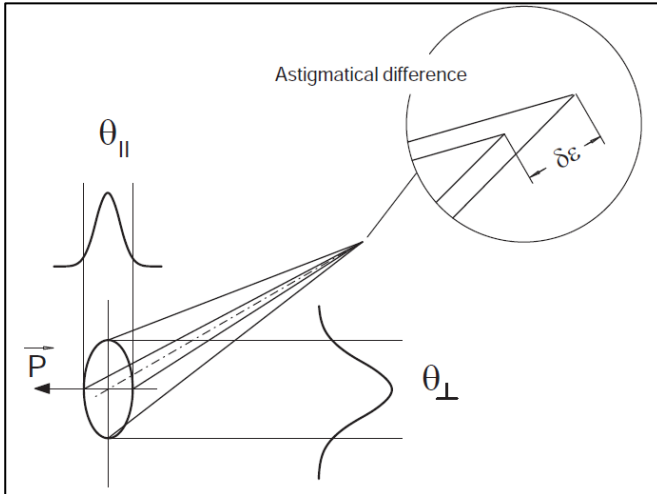

Fig. 5: Astigmatic difference $\delta\varepsilon$

Modern diodes are mostly index guided diodes. This means that the laser beam is forced not to leave the resonator laterally by attaching lateral layers of higher refractive index to the active zone. At the gain guided diodes the current is forced to pass along a small path (about 2-3 μm width).

In this way the direction of the amplification (which is proportional to the current flux) and the laser radiation are determined.

At the gain guided diodes the formation of curved wave fronts within the resonator is disadvantageous since they simulate spherical mirrors. In this case higher injection currents provoke transversal modes which will not appear in index guided diodes because of the plane wave fronts. Laser diodes with intensity profiles following a Gauss curve and a beam profile which is only limited by diffraction are called *Diffraction Limited Lasers* (DFL).

Polarisation

It is understandable that the laser radiation of the diodes has a distinct direction of polarisation, since the height of the exit window is 4 times and the width 12.5 times larger than the wavelength. Because of the fraction of spontaneous emission the light of the laser diode also contains components oscillating in the vertical direction.

The ratio of polarisation, $P_\perp$ to $P_\parallel$, depends on the output power since for higher laser power the ratio of spontaneous to stimulated emission is changing.

Diffraction by a rectangular aperture

Consider the laser beam as a parallel, monochromatic light incident on a single slit of width *b*. As semi-circular wavefronts propagate out from each portion, they will interfere. The resultant intensity depends on the angle θ. A full description of the diffraction pattern is given using Fourier theory.

In optics, the amplitude of the diffraction pattern is given by the Fourier transform of the aperture function, which is a mathematical method of representing the transmission of light from an aperture. The aperture function $f(x)$ for the single slit is given by the so called "top-hat" function and approximates the transmission of light through the aperture.

For the single-slit the aperture function is given by

$$f(x) = 1 \text{ for } -\frac{b}{2} < x < \frac{b}{2}$$

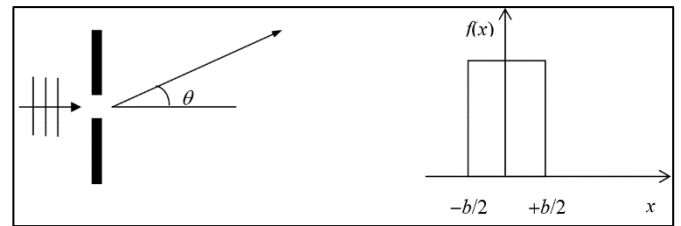$$f(x) = 0 \text{ elsewhere}$$

which is shown in Fig. 6.

Fig. 6: The single slit and its transmission function f(x)

The amplitude $F(k)$ of the diffracted light is given by the Fourier transform of the aperture function

$$F(k) = \int_{-\infty}^{+\infty} f(x)\mathrm{e}^{ikx}\mathrm{d}x$$

where

$$k = \frac{2\pi}{\lambda}\sin\theta$$

k is known as the propagation constant. Note that it has dimensions of inverse length.

θ is the angular distance from the center of the diffraction pattern (see Fig. 6) and λ is the wavelength of the laser.

This leads to an intensity variation given by

$$I(\theta) = I_0[\mathrm{sinc}(\beta)]^2$$

where

$$\beta = \frac{\pi b}{\lambda}\sin\theta$$

Experiments

To visualize the properties of pulsed diode lasers several experiments are presented:

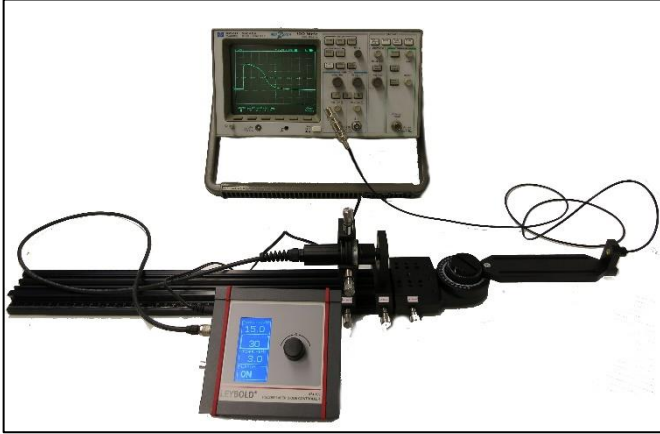### *Experiment 1:*

Measuring the repetition rate and the pulse width

Fig. 7:   Setup for measuring the pulse width.

Setup on the Bench:

1 Pulsed laser diode controller PLDC-01 ....474 309
1 Pulsed diode laser module.............................474 5428
1 Module B- Collimating optics 474 1031
1 Photodetector for pivot arm............................474 6414
1 BNC T – connection piece 501 091
1 BNC shunt resistor 50 Ohm 474 341
1 Profile Rail OCM 650, 500 mm with ruler.......474 5442
1 Triple swivel unit 474 121
1 Adjustment holder, 4 axes, rotary insert,........474 2114
1 Oscilloscope 100 MHz digital, two channel....474 5464

On the bench, the pulsed diode laser is put into the adjustment holder (474 2114). The collimating optics (474 1031) is put on a carrier directly behind the pulsed laser diode. Set the triple swivel unit (474 121) in straight direction (angle = 0°). At the end of the swivel arm the photodetector (474 6414) is placed and connected with the oscilloscope via BNC T – connection piece (501 091) and BNC shunt resistor (474 341).

To run the pulsed diode laser a controller (474 309) is connected to the pulsed diode laser (shown in Fig. 7).

To focus the laser beam exactly on the photodetector an infrared card (4744025) can convert the infrared dot into visible light. Change focus by moving the collimator slightly on the optical bench

The control unit of the laser allows the user to set these three parameters:

- Charge voltage of the capacitor
- Discharge pulse duration
- Repetition frequency

The supply box is powered by a 12 Volt DC power supply connected to mains. During power up, the supply asks for a PIN code, which is supplied on a separate paper.

Dial in the PIN, a short press of the button changes between digits and a long press of the button enters the pin value and unlocks the device when the PIN is correct.

To set the three values, turn the knob until the value to be set is highlighted by a thick white frame (Pulse Width in the image above), press the button for a few seconds, now the value starts to blink.

Pulse width: 30 ns

Repetition rate: 3.0 kHz
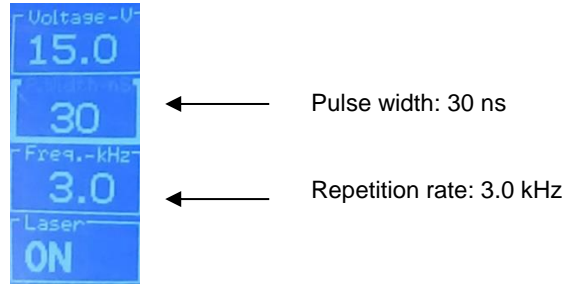
Turning the knob changes the value immediately and another long press of the knob leaves the value setting and changes to the selection of the white frame.

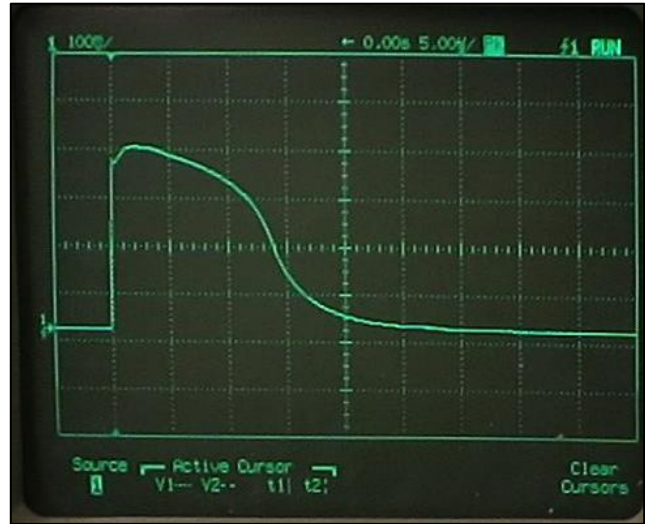To toggle the on/off setting of the laser only a short press of the button is required.

Results:

Fig. 8:   Oscilloscope output. x axis: time in µs. Pulse width 30 ns.

In Fig. 8 the oscilloscope output screen is shown. Note: The indicated width of the pulse is not the pulse width of the laser diode pulse. In fact it is the discharging curve of the capacitance of the photodetector. However it is possible to measure the repetition rate of the pulsed laser diode.
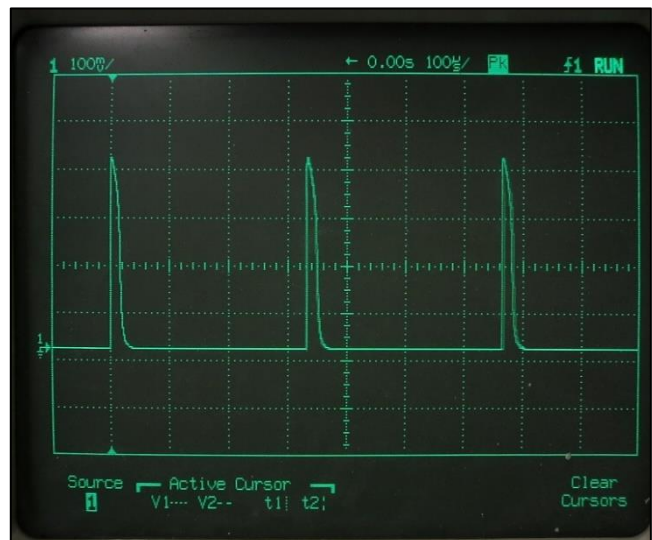
Fig. 9:   Oscilloscope output. Repetition rate: 330 ns.

The difference between two pulses is $t = 330$ ns. This equals to

$$f = \frac{1}{t} = 3.03 \text{ kHz.}$$

Experiment 2:

Measuring the spatial intensity distribution

Setup on the Bench:

1 Photodetector for pivot arm 474 6414
1 BNC T – connection piece 501 091

1 Pulsed laser diode controller PLDC-01 .... 474 309
1 Pulsed diode laser module 474 5428
1 Profile Rail OCM 650, 500 mm with ruler 474 5442
1 Digital multimeter 3 1/2 digits 531 183
1 Triple swivel unit 474 121
1 Adjustment holder, 4 axes, rotary insert, C20 474 2114

On the bench, the pulsed diode laser diode is put into the adjustment holder (474 2114) and as close as possible to the axis of rotation. There are two different possible adjustments for the laser diode: flat and upright (shown in Fig. 11).

Start the triple swivel unit (474 121) in straight direction (angle = 0°). Note: The scale is below the laser.

At the end of the swivel arm the photodetector (474 6414) is placed and connected with the multimeter via BNC T – connection piece (501 091) (shown in Fig. 10).

Run the multimeter in µA position. The measured intensity is the average intensity of the pulsed laser diode relating to an adjusted angle.
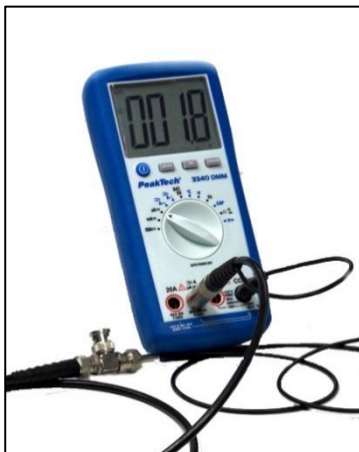

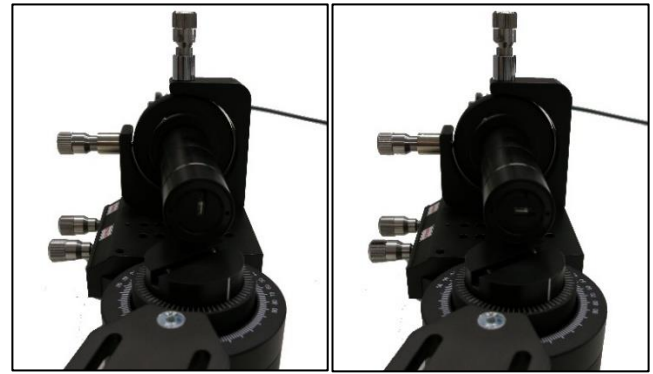Fig. 10:   Multimeter connected with the detector via BNC cable

Fig. 11:   Left: Diode upright. Right: Diode flat

There are certain two ways to place the diodes in the adjustment holder as shown In Fig. 11.
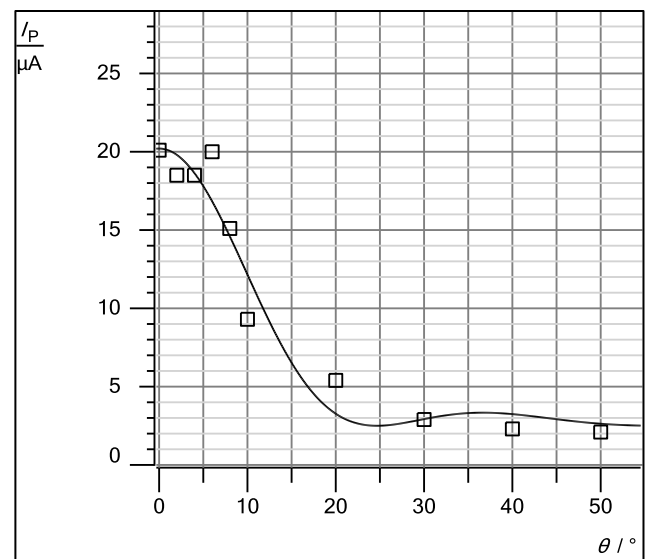

Fig. 12:   Intensity distribution with laser diode in the flat position

In Fig. 12 the measurements with the laser in the flat position and a Frauenhofer fit via CASSY Lab is shown. Some of the points are not perfectly fit to the curve. That depends on the arrangement in the diode. Several emitters are arranged side by side and causes different diffractions. The fit parameter of the intensity distribution and the mean wavelength $\lambda = 908$ nm lead to a single-slit width of

$$b = 2.18 \text{ µm}$$

This value is close the value compared to the value of the exit aperture given by the data sheet.

The measurement with the laser in upright position is shown in Fig. 13. There is also a Frauenhofer fit via CASSY Lab. The fit parameter of the intensity distribution and the mean wavelength $\lambda = 908$ nm lead to a single-slit width of

$$b = 3.88 \text{ µm}$$

This is not the correct value given by the data sheet due to the arrangement of the diodes. The laser emitter consists of several individual diodes next to each other.

Each one of them has the dimensions calculated here from the diffraction pattern, but the whole arrangement is a few 100 µm wide, which is the dimension specified in the datasheet.
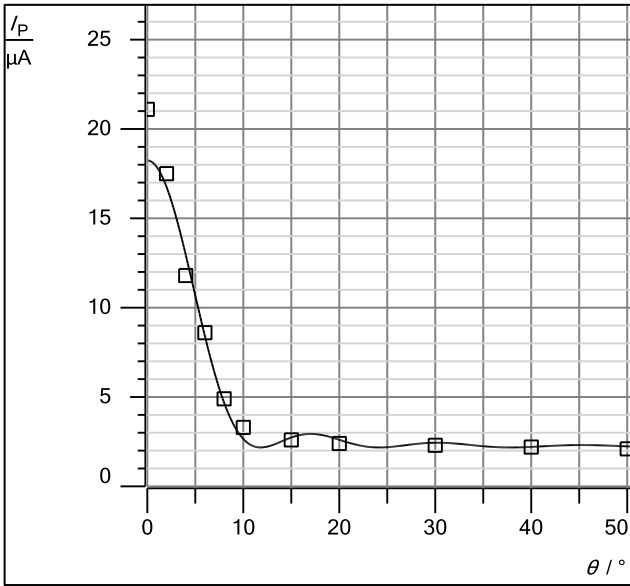
Fig. 13:   Intensity distribution with laser diode in the upright position

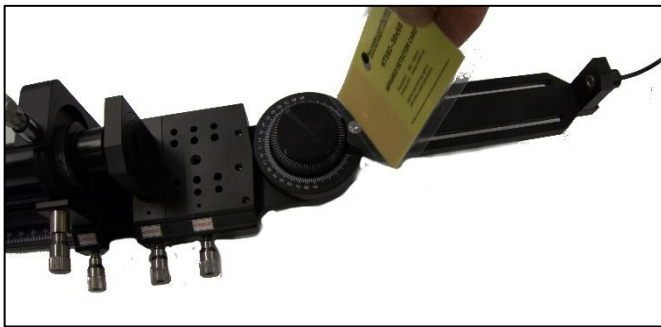## Experiment 3:

Collimating the divergent radiation beam

Fig. 12:   Finding the pulsed laser diode beam using the IR converter screen.

Setup on the Bench:

1 Photodetector for pivot arm............................474 6414
1 BNC T – connection piece 501 091

1 Pulsed laser diode controller PLDC-01 ....474 309
1 Pulsed diode laser module............................474 5428
1 Profile Rail OCM 650, 500 mm with ruler.......474 5442
1 Digital multimeter 3 1/2 digits.........................531 183
1 Triple swivel unit 474 121
1 Adjustment holder, 4 axes, rotary insert, C20 474 2114
1 Module B- Collimating optics on carrier
   MG-65...474 1031

The collimating optics is placed as close as possible to the axis of rotation of the swivel unit. In front of the collimating optics the laser is placed. Adjust the laser in direction of the optical axis and in the same height as the collimating optics and the photodetector. To focus the laser beam exactly on the photodetector an infrared card (4744025) can convert the infrared dot into visible light (shown in Fig. 16.). Therefore move the infrared card from one side to the other and observe the size of the laser dot. Move the collimating optics so that the size of the dot does not change during the movement of the infrared card.

In this setting the three parameters can be chanced individually: Repetition rate, pulse width and voltage.

Results:

a) Repetitions rate
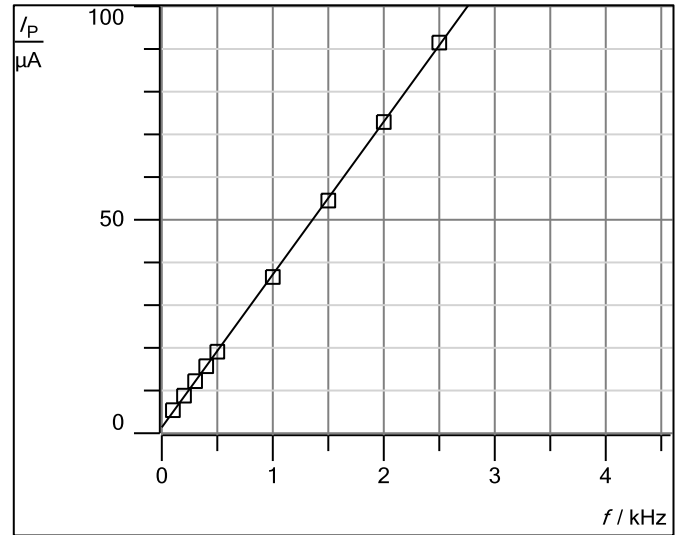At the control panel the following settings has been made:
20 V / 135 ns

Fig. 13:   Measurements of the intensity depending on the repetition rate of the laser diode.

As shown in Fig. 13 the intensity rises linear with the frequency. The more pulses per second the more is the intensity.

b) Pulse width
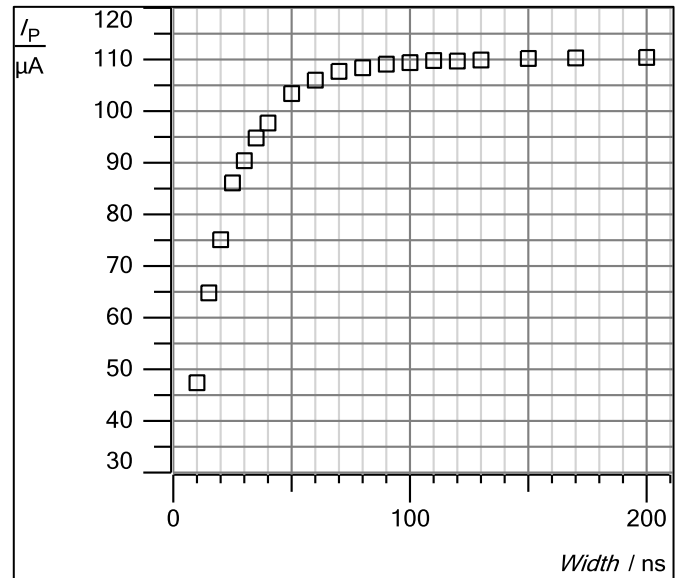At the control panel the following settings has been made:
20 V / 3 kHz

Fig. 14:   Measuring the intensity depending on the pulse width

The intensity reaches a saturation with an intensity about 110 µA and a pulse width about 70 to 80 ns. The reason for the saturation is that the energy storing capacity is full discharged at about 70 to 80 ns so that longer pulses have no effects to the intensity.

c) Voltage
Default settings: 50 ns / 3 kHz
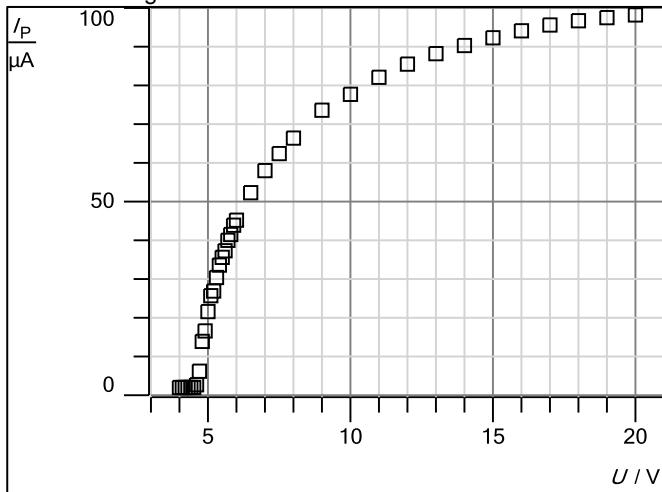
Also in this setting the intensity reaches a saturation at about 19 V.

With a repetition rate of 3 kHz, a 50 ns pulse width and an average photo current of 100 µA the current in one peak is

$$I_{Peak} = \frac{\left(\frac{1}{f}\right)}{50 \text{ ns}} \cdot I_P = 2.2 \text{ A}$$

From the photodetectors datasheet, the responsivity specified is 0.9 A/W, so this small average current indicates a pulse of several watts on the photodetector.

Experiment 4:

Measuring the polarisation properties of the pulsed laser diode.

Fig. 15:   Polarization filter in front of the photodetector.

Setup on the Bench:

1 Photodetector for pivot arm 474 6414
1 BNC T – connection piece 501 091

1 Pulsed laser diode controller PLDC-01 ....474 309
1 Pulsed diode laser module 474 5428
1 Profile Rail OCM 650, 500 mm with ruler.......474 5442
1 Digital multimeter 3 1/2 digits.........................531 183
1 Triple swivel unit 474 121
1 Adjustment holder, 4 axes, rotary insert, C20 474 2114

The setup of this experiment is analogue to Experiment 2. Set the triple swivel unit (474 121) in straight direction (angle = 0°). Place the polarization filter directly in front of the photodetector as shown in Fig. 14.

The pulsed laser diode should lie flat.

Run the multimeter in µA position. The polarization angle can be adjust by turning the polarisation filter.
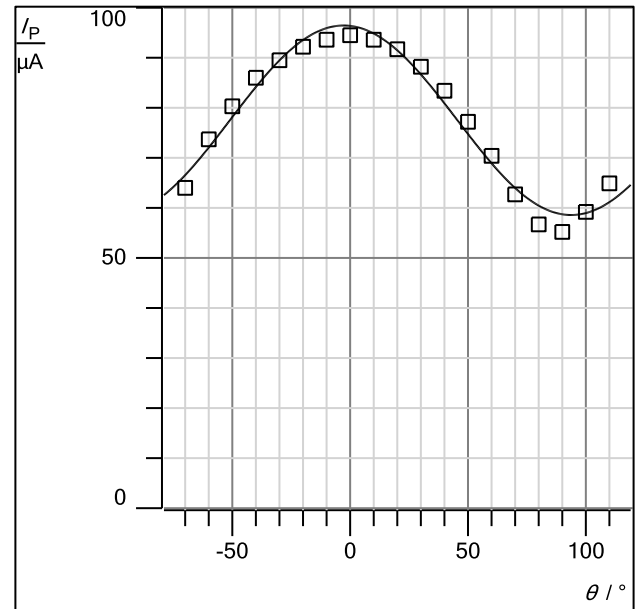
Results:

Fig. 16:   Polarization of the laser diode.

Laser diodes are linearly polarized to the short axis for an elliptical beam. In Fig. 16 you can see the intensity maximum at $\theta \approx 0°$ and it is not perfectly polarized parallel to the short axis.

The second point is that the intensity minimum is not zero at $\theta \approx 90°$. That is because there is spontaneous and stimulated emission of radiation. The spontaneous emission causes the unpolarized part. As shown in fig 16. there is a lot of unpolarized radiation because in short pulses there is no time to equilibrate.

Apparatus

1 Photodetector for pivot arm 474 6414
1 IR converter screen 0.8 – 1.6 µm 474 4025

1 BNC T – connection piece............................. 501 091

1 BNC shunt resistor 50 Ohm 474 341

1 Pulsed laser diode controller PLDC-01 .... 474 309
1 Pulsed diode laser module 474 5428
1 Profile Rail OCM 650, 500 mm with ruler 474 5442
1 Digital multimeter 3 1/2 digits 531 183
1 Module B- Collimating optics on carrier
   MG-65 .... 474 1031
1 Triple swivel unit.. 474 121
1 Adjustment holder, 4 axes, rotary insert, C20 474 2114
Required Options:
1 Oscilloscope 100 MHz digital, two channel ... 474 5464
Optons:
1 Laser power meter LabMax-TO TP-0042

1 Laser energy sensor head 300 nJ - 600 µJ... TP-0050