

Scanning Near-field Optical Microscope

AlphaSNOM



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Warnings and Safety Instructions

To prevent electrical shock do not remove the cover. Unplug power cord and all other electrical connections and consult qualified service personnel when servicing or cleaning. Operate only under dry conditions and in the specified temperature range. For laboratory use only. Use only a power supply that meets all specifications given in the Technical Data chapter.

Please read and follow the warnings and safety instructions in the following chapters of this operating manual. Pay special attention to the Laser Safety Guidelines below.

The piezo translators, amplifiers and controllers described in this manual are high voltage devices, capable of generating high output currents. They may cause serious or even lethal injuries if used improperly. Never touch any part that might have a connection to the high voltage output. Working with high voltage devices requires adequately educated operating personnel.

In case of failure, refer to your local distributor or WITec. Users are cautioned not to attempt to access, open, modify, or service unless outlined herein or otherwise directed by the technical support staff from WITec.

Take special care when connecting products from other manufacturers. Follow the General Accident Prevention Rules. Clean only with a dry cloth.

Make sure not to look into the light exit opening of the halogen illuminator and do not point it at other persons.

Laser Safety Guidelines

Laser light, because of its special properties, poses safety hazards not associated with light from conventional sources. The safe use of lasers requires that all laser users, and everyone near the laser systems, are aware of the dangers involved. The safe use of the laser depends upon the user being familiar with the instrument and the properties of coherent, intense beams of light.

Direct eye contact with the output beam from a laser will cause serious damage and possible blindness.

The greatest concern when using a laser is eye safety. In addition to the main beam, there are often many smaller beams present at various angles near the laser system and the microscope. These beams are formed by specular reflections of the main beam at polished surfaces such as lenses or beamsplitters. While weaker than the main beam, such beams may still be sufficiently intense to cause eye damage.

Laser beams are powerful enough to burn skin, clothing or paint. They can ignite volatile substances such as alcohol, gasoline, ether and other solvents, and can damage light sensitive elements in video cameras, photomultipliers and photodiodes. The laser beam can ignite substances in its path, even at some distances. The beam may also cause damage if contacted indirectly from reflective surfaces. For these reasons, and others, the user is advised to follow the precautions below.

Observe all safety precautions in the operating manual. Extreme caution should be exercised when using solvents in the area of the laser. Limit access to the laser and the microscope to qualified users who are familiar with laser safety practices and who are aware of the dangers involved. Never look directly into the laser source or scattered laser light from any reflective surface. Never sight down the beam into the source. Maintain experimental setups at low heights to prevent inadvertent beam-eye encounter at eye level. As a precaution against accidental exposure to the output beam or its reflection, those using the system should wear laser safety glasses as required by the wavelength being generated. Avoid direct exposure to the laser light. The intensity of the beam can easily cause flesh burns or ignite clothing. Use the laser in an enclosed room. Laser light will remain collimated over long distances and therefore presents a potential hazard if not confined. Post warning signs in the area of the laser beam to alert those present. Advise all those using the laser of these precautions. It is good practice to operate the laser in a room with controlled and restricted access.

Laser safety glasses can present a hazard as well as a benefit; while they protect the eye from potentially damaging exposure, they block light at the laser wavelength, which prevents the operator from seeing the beam. Therefore use extreme caution even when using safety glasses.

Certification

WITec certifies that this product met its published specifications at the time of shipment. The device was tested as shipped.

Warranty

This WITec product is warranted against defects in materials and workmanship for a period of one year from date of shipment. During the warranty period, WITec will, at its option, either repair or replace products which prove to be defective.

Limitation of Warranty

The foregoing warranty shall not apply to defects resulting from improper or inadequate maintenance by the Buyer, Buyer supplied products or interfacing, unauthorized modifications or misuse, operation outside of the environmental specifications for the products, or improper site preparation or maintenance.

WITec does not warrant the Buyer's circuitry against malfunctions that result from use of the PFM unit. In addition, WITec does not warrant any damage to the PFM unit that occurs as a result of using the Buyer's circuitry or other products.

No other warranty is expressed or implied. WITec specifically disclaims the implied warranties of merchantability and fitness for a particular purpose.

Disclaimer of Responsibility

WITec does not assume any responsibility for the use of any circuitry described in this manual. WITec reserves the right to change the product specifications and the functionality, or the manual itself, at any time without prior notice.

Furthermore, WITec assumes no responsibility or liability for any misinformation, errors, or general inaccuracies that may appear in this manual.

Important

Warnings and safety instructions are marked with a red bar. Please read carefully and follow these warnings for your own safety. Please take special care when connecting high voltage outputs and handling optical fibres guiding laser radiation. Working with high voltages and laser radiation requires adequately educated operating personal.

Instructions

Instructions for the operation of the system are marked with a blue bar.



fig. 1: System overview with ScanCtrl SPM controller

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Chapter 1

BRIGHT-FIELD MICROSCOPY

Reflected-light bright field imaging is the easiest and most common far-field optical microscopy technique.

In addition to so-called direct beam bundles, indirect bundles which are diffracted and scattered at the specimen details, are of major importance for image fidelity. The greater the portion of these indirect bundles (aperture), the more the microscope image will be true to the object, according to Ernst Abbe (1840 - 1905).

The bundled illumination light coming from the white-light source ((1) in Fig. 1.1) is reflected from the colour-neutral beam splitter (2) in the black dovetail slider, and then focused by the objective (3) onto the sample surface (4). The objective gathers the reflected or indirect beam portions and -together with the tube lens (5)- produces the intermediary image which can then be viewed or documented objectively.

To make use of the entire optical capability of the microscope and the objective in particular, the luminous-field diaphragm and the aperture diaphragm should be set in accordance with the regulations for Köhler illumination. Adjustment of the Köhler illumination is described the next section.

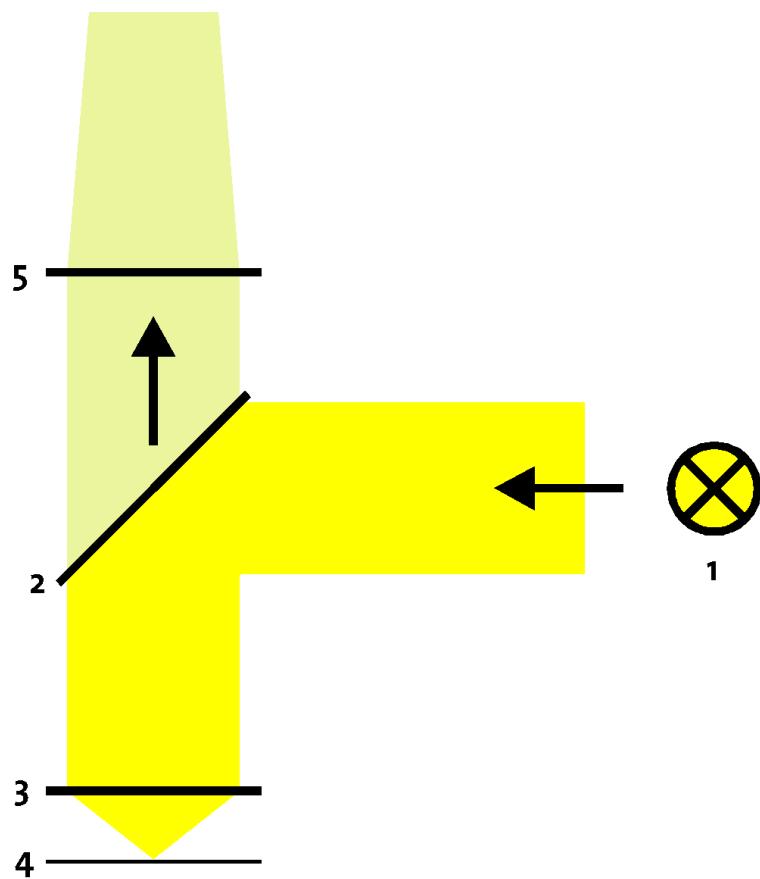


fig. 1.1: Beam path for white light illumination

1.1 Getting Started: Bright-field microscopy

The following chapter describes the settings for conventional far-field reflected-light bright field microscopy with Köhler illumination:

1. Switch on the controller.
2. Power up the computer and start ScanCtrl Spectroscopy Plus, as well as VideoCtrl.
3. Switch on the white light illumination and set the illumination to the required level. Your system is either equipped with a super-bright white LED or a halogen illumination system. The lifetime of a halogen lamp decreases rapidly with increasing voltage. Therefore, reduce the illumination to minimum if the lamp is not needed.
4. Using the pushrod, slide the prism to direct the beam to the eyepiece colour video camera.
5. Move the reflector slider to the illumination position. The beamsplitter is usually mounted in the left chamber of the three position slider.
6. Place a high-contrast reflective specimen on the microscope stage.
7. Using the turret, rotate a low magnification objective into position.
8. Observe the image of the eyepiece colour video camera on the computer monitor using the VideoCtrl Software. Use Channel 1 to switch the video input to the eyepiece colour video camera.
9. Focus on the sample with the Z-focusing-stage by using the Focus Up or Focus Down buttons of the remote control. The focussing speed can be adjusted between about $0,01 \mu\text{m}/\text{s}$ (potentiometer fully counter-clockwise) and $300 \mu\text{m}/\text{s}$ (potentiometer fully clockwise).
It is very difficult to focus on flat and clean surfaces such as a silicon sample. The best way to do this is using bright field illumination. Close the luminous-field diaphragm (10) to a value of 1 – 3. Make sure to move in the 50 : 50

beam splitter to illuminate the sample. Approach the sample until the edge of the field stop appears focused. At this point, the sample is also in focus. This is due to the fact that the field stop is positioned at the back focal plane of the objective. If the field stop is not in the middle of the field of view, move it to this position with the centering screws. If possible, move the objective away from the specimen to avoid a collision between the objective and the specimen.

10. Move the aperture diaphragm to the centre position (approximately half open) by pulling out the pushrod.

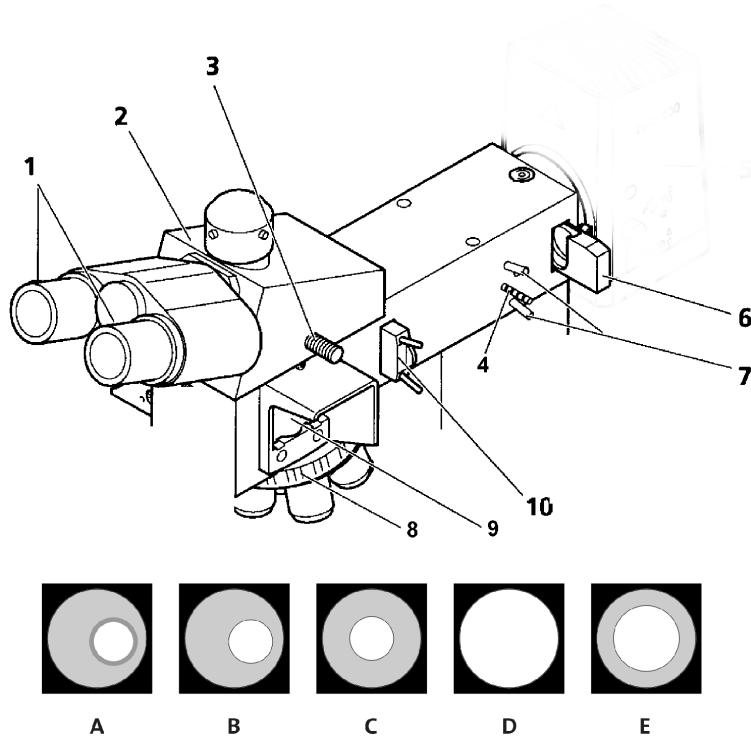


fig. 1.2: Adjusting the Köhler illumination

11. Adjust the setting wheel (10) to reduce the diameter of the luminous-field diaphragm until it is visible in the field of view (A).
12. Use the Z-focusing-stage to refocus on the edge of the luminous-field diaphragm (B) and use the screws to centre the luminous-field diaphragm in the field of view (C).

13. Open the luminous-field diaphragm until it just disappears behind the edge of the field of view (D).
14. To set the aperture diaphragm (4) (image contrast), **BE SURE THAT ALL LASERS ARE TURNED OFF**, then remove the dust cover of the free tube of the binocular assembly and look into the tube with your naked eye.
15. Centre the aperture diaphragm using centre screws (7) and set the pushrod to 2/3 of the exit pupil diameter of the objective for specimens of medium contrast (E). In most applications, this setting of the aperture diaphragm provides optimum contrast at almost full resolution and is therefore the best compromise.
16. Finally, refocus on the specimen via z-focusing-stage and match the image brightness with the potentiometer of the power supply according to the specimen.

Since field size and objective aperture are altered after every objective change, the setting of the luminous-field diaphragm (10) and the aperture diaphragm (4) described above must be repeated.

Do not use the aperture diaphragm for the adjustment of the image brightness, but rather use the illumination control of the white light source or an attenuation filter inserted in the filter slider (6).

1.2 Beam path for bright-field microscopy with operation in reflection

- 1** microscope illumination
- 2** lens system
- 3** beamsplitter (50 : 50) housed in the reflector slider
- 4** dichroic mirror ($T > 95\% @ \lambda = 325 - 850\text{nm}$; $R > 95\% @ \lambda = 980\text{nm}$)
- 5** objective lens system
- 6** cube beamsplitter (50 : 50)
- 7** tube lens ($f=163,5\text{mm}$)
- 8** sliding prism (100 : 0) used for directing the beam either to the eyepiece colour video camera (26) or to the detector (9)
- 10** sample
- 26** eyepiece colour video camera

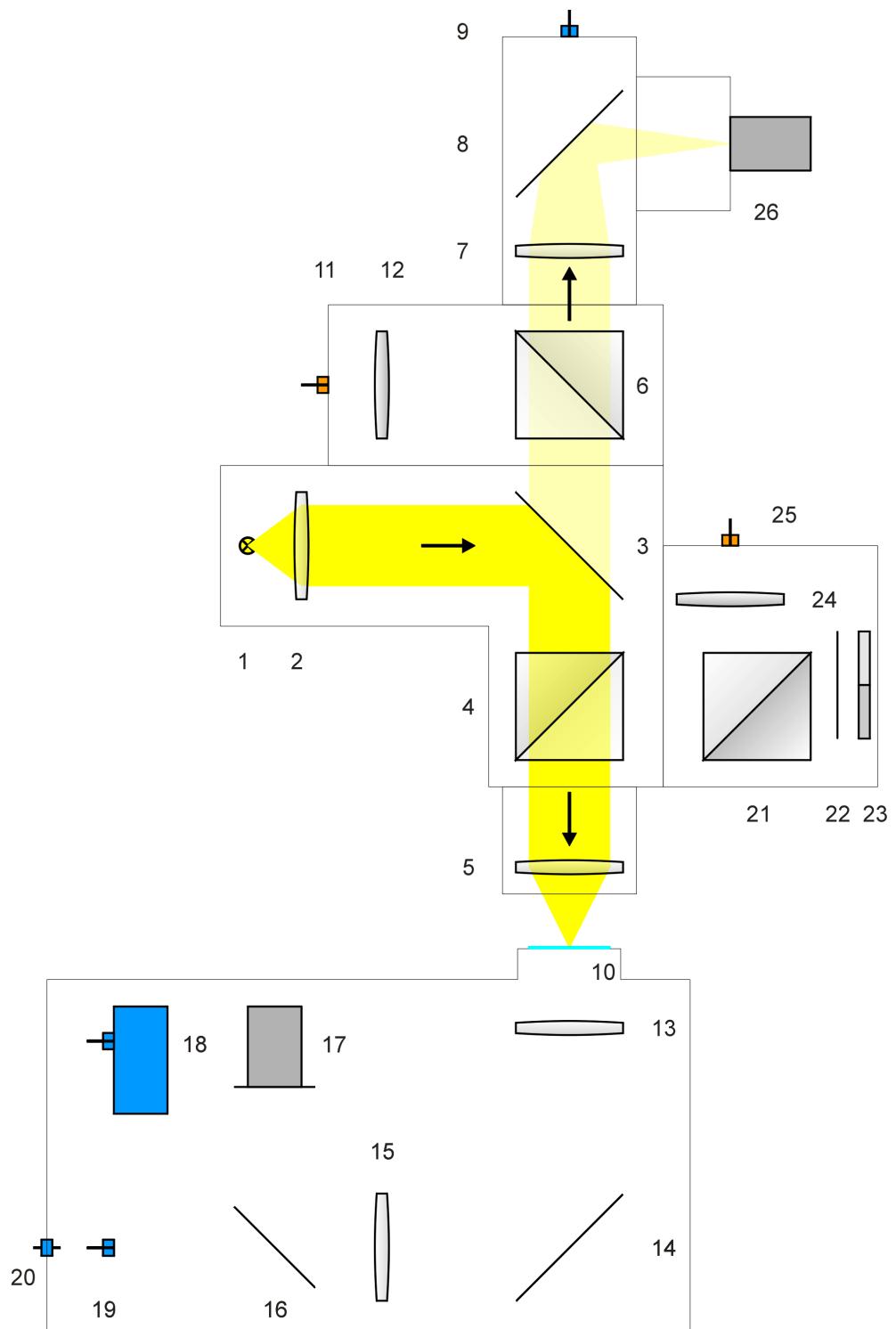


fig. 1.3: Beam path for bright-field microscopy with operation in reflection

1.3 Beam path for bright-field microscopy with operation in transmission

- 1** microscope illumination
- 2** lens system
- 3** beamsplitter (100:0) housed in the reflector slider
- 4** dichroic mirror ($T > 95\% @ \lambda = 325 - 850nm$; $R > 95\% @ \lambda = 980nm$)
- 5** objective lens system
- 10** sample
- 13** collection objective lens system
- 14** mirror
- 15** tube lens ($f=125mm$)
- 16** flip mirror
- 17** high sensitive b/w video camera

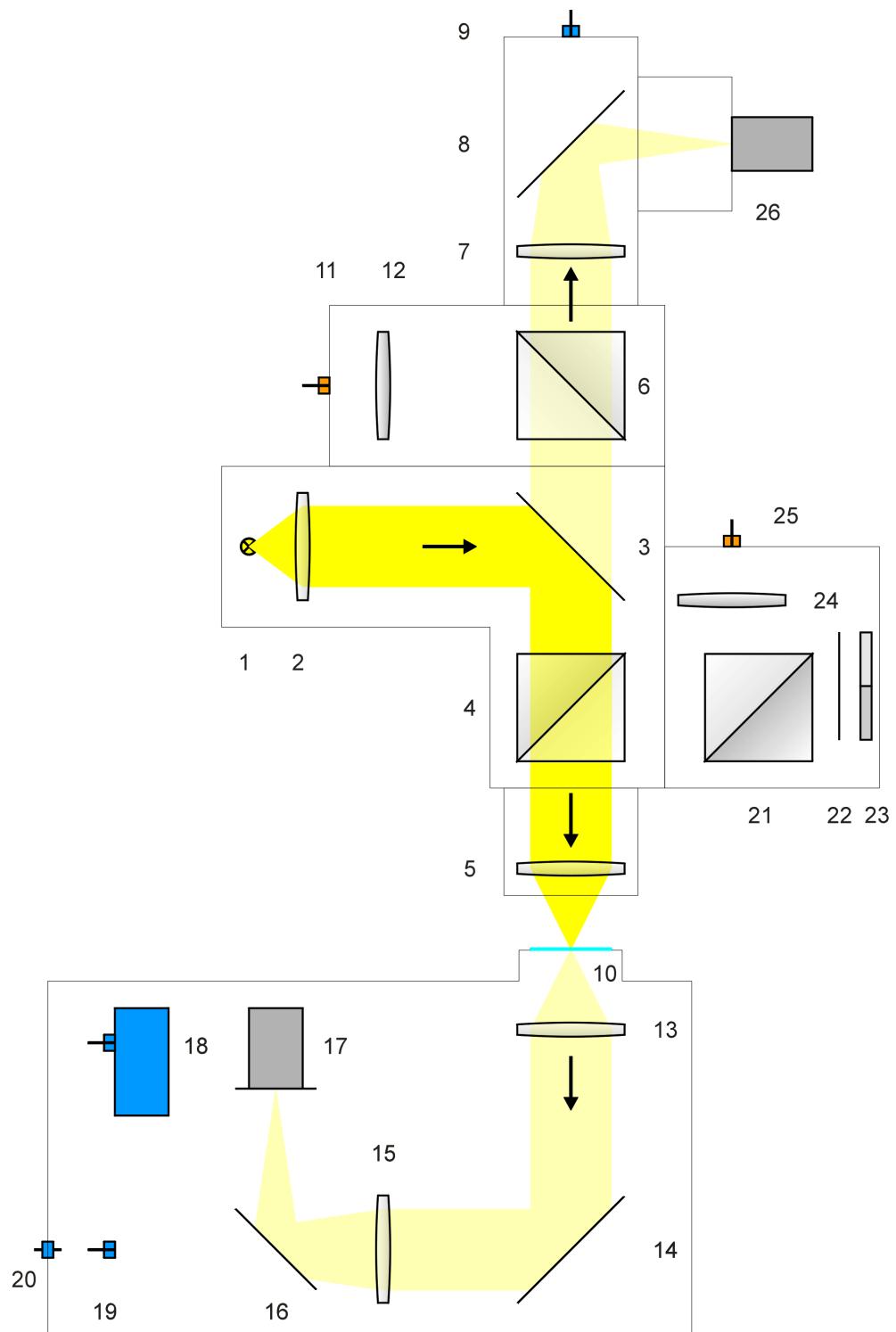


fig. 1.4: Beam path for bright-field microscopy with operation in transmission

Chapter 2

CONFOCAL MICROSCOPY

Confocal microscopy requires a point source (usually a laser), which is focused onto the sample. The reflected (or fluorescence) light is usually collected with the same objective and focused into a pinhole in front of the detector. This ensures that only rays from the image focal plane can hit the detector, which strongly increases image contrast and, with proper selection of pinhole size, slightly increases resolution.

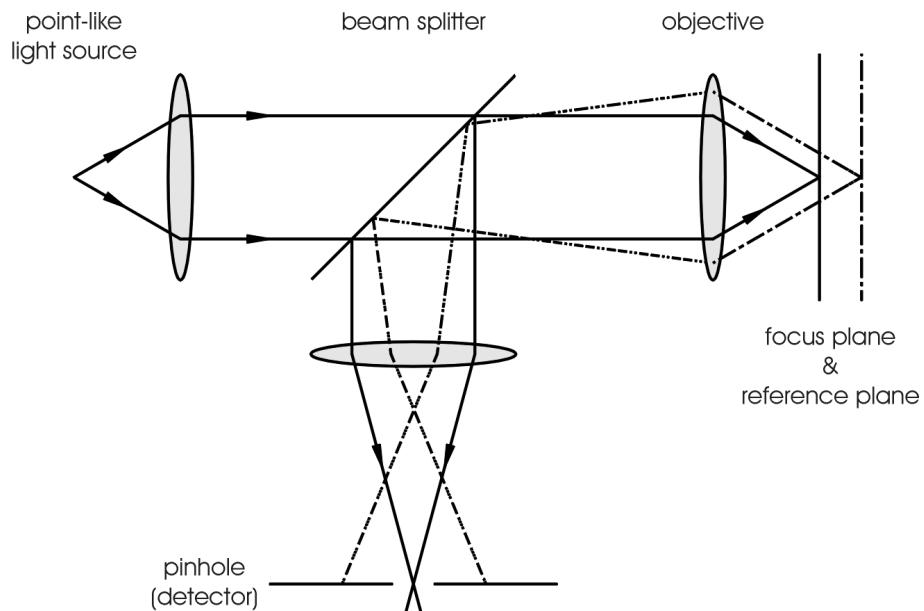


fig. 2.1: Principal setup of a confocal microscope

In the AlphaSNOM, the laser light is delivered via a single-mode optical fibre. This type of fibre transmits only a single transversal mode (Gaussian beam), which can be focused to a diffraction limited spot. The core of a multi-mode optical fibre acts as a pinhole for confocal microscopy. The laser is raster-scanned across the sample by scanning the sample in all axes and the image is acquired line by line.

Using fibres for beam delivery and signal pick-up is very convenient, because bulky lasers and detectors can be placed far from the detecting microscope.

With the AlphaSNOM the following confocal modes are possible:

- confocal microscopy in reflection
- confocal microscopy in transmission
- confocal fluorescence microscopy in reflection (using additional filters)
- confocal fluorescence microscopy in transmission (using additional filters)
- confocal Raman microscopy (using the Raman upgrade)

To take full advantage of the lateral and depth resolution possible with confocal microscopy, the size of the pinhole (core diameter of the multi-mode fibre for detection) must be properly chosen.

The optimum pinhole diameter depends on the optical properties of the microscope objective along with the wavelength employed and can be calculated using the following formula:

$$D \leq \lambda \cdot v \cdot M / (NA \cdot \pi)$$

where λ is the wavelength of the laser, M and NA are the magnification and the numerical aperture of the microscope objective.

v is given in optical coordinates and should be 2,5 for best depth resolution and 0,5 for maximum lateral resolution. If $v < 0,5$ is chosen, the lateral resolution will be $\sqrt{2} \gg 1,4$ times better than for conventional microscopy. However, in this case most of the light reflected from the sample does not reach the detector, so one

sacrifices efficiency.

Make sure that you use the microscope objectives in the proper way. All objectives supplied as standard are corrected for the use with a cover slip.

There are four numbers printed on each objective. The first number gives the magnification in the image plane (at the position of the colour video camera (26) or the multi-mode fibre (9)). The second number is the numerical aperture ($NA = n \cdot \sin \alpha$), which describes the resolving power of the objective. The objectives are infinitely corrected, meaning that the beam is parallel inside the microscope and they will give best results only when a cover slip of $0,17\text{ mm}$ thickness is placed between objective and sample.

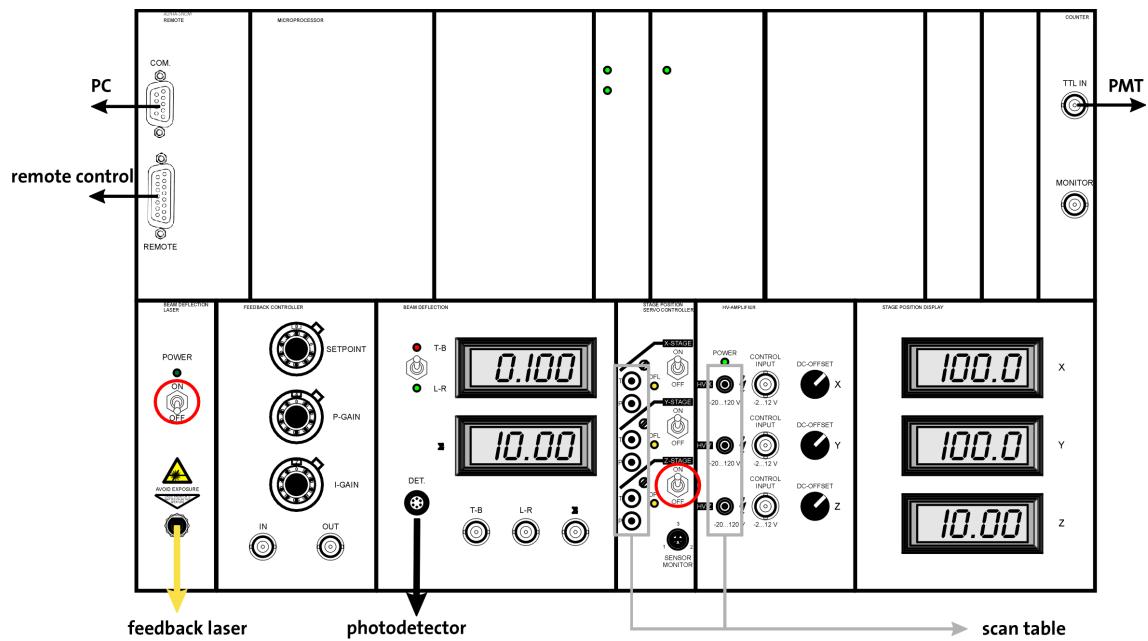


fig. 2.2: Wiring diagram for confocal microscopy

2.1 Getting Started: Confocal microscopy

The following chapter describes how to obtain a confocal image in reflection mode. This is the standard mode in confocal microscopy.

If you have a fluorescing sample, insert an appropriate filter to block the excitation laser. The AlphaSNOM also allows confocal microscopy in transmission, when you are interested in the local absorption properties of your sample.

2.2 Step by step alignment for confocal microscopy in reflection

1. Switch on the controller.
2. Power up the computer and start ScanCtrl Spectroscopy Plus, as well as VideoCtrl. Select Confocal mode by clicking on HARDWARE OPTIONS-METHOD.
3. Switch on the servo control for X, Y and Z of the capacitively controlled piezo stage and make sure that the feedback input at the Z stage used for AFM/SNOM operation is disconnected. Adjust the offset potentiometer, until the Z stage shows a reading of about $10 \mu\text{m}$.
4. Mount your sample on the scanning stage.
5. Rotate the microscope turret until an appropriate objective is in the working position. Make sure you use the microscope objective in the proper way. All objectives supplied as standard are corrected for use with a cover slip.
6. Switch on the white light source and set the illumination to the required level. Your system is either equipped with a super-bright white LED or a halogen illumination system. The lifetime of a halogen lamp decreases rapidly with increasing voltage. Therefore, reduce the illumination to minimum if the lamp is not needed.

7. Push in the pushrod of the sliding prism to direct the beam to the colour eyepiece video camera.
8. Move the reflector slider to the illumination position. The beamsplitter is mounted in the left position of the three position reflector slider. Therefore, move the reflector slider to the right.
9. Observe the image of the eyepiece colour video camera on the computer monitor using the VideoCtrl Software. Use Channel 1 to switch the video input to the eyepiece colour video camera.
10. Focus on the surface of your sample with the Z-focusing-stage by using the Focus Up or Focus Down buttons of the remote control. The focussing speed can be adjusted between about $0,01 \mu\text{m}/\text{s}$ (potentiometer fully counter-clockwise) and $300 \mu\text{m}/\text{s}$ (potentiometer fully clockwise). If possible, move the objective away from the specimen to avoid a collision between the objective and the specimen.
It is sometimes very difficult to focus on flat and clean surfaces. The best way to do this is to use the bright field illumination. Close the luminous-field diaphragm (10) to a value of 1–3. Make sure to move in the 50 : 50 beam splitter to illuminate the sample. Approach to the sample, until the edge of the field stop appears focused. At this point, the sample is also in focus. This is due to the fact that the field stop is positioned at the back focal plane of the objective. If the field stop is not in the middle of the field of view, move it to this position with the centering screws.
11. Switch on the excitation laser at low power.
12. Reduce the bright field illumination, move out the 50 : 50 beam splitter and fine-focus the microscope until the excitation laser is focused on the sample. You will observe several spots on the video screen, but only one of them changes during focusing. The other spots are reflections inside the microscope and do not reach the sample. Make sure that the other spots are as small as possible. If they appear out of focus, rotate the micrometer screw at the fibre input of the microscope until they are perfectly focused. This ensures that the excitation laser is parallel inside the microscope.

13. If you did a complete alignment recently, you can jump to point 19.
14. Remove the multimode fibre and place a white card (e.g. a business card) a few millimeters above the SMA connector.
15. Pull out the pushrod to direct the beam to the SMA connector. Try to localize the laser beam on the namecard. If necessary, increase the laser intensity.
DO NOT LOOK INTO THE SMA CONNECTOR.
16. Turn the micrometer screws to center the beam in the SMA connector. You might recognize several laser spots, but only one of them changes during focusing. Reinsert the multimode fibre.
17. Try to see the laser beam at the end of the multimode fibre. Use the namecard again.
DO NOT LOOK INTO THE FIBRE.
18. Adjust the micrometer screws at the SMA connector to maximize the laser power at the multimode fibre. It might be necessary to adjust focus and repeat this several times.
19. Reduce the laser power and connect the multimode fibre to the SMA feedthrough on the left side of the microscope body (20). Make sure that the detector (18) is connected to the SMA feedthrough (20).
20. Ensure that the laser power is not too high before you switch on the detector. Remember, the photon counting PMT (or APD) used in the AlphaSNOM is an extremely sensitive device which can easily be destroyed by excessive light when powered up.
21. Activate MEASURE-ADJUST in ScanCtrl Spectroscopy Plus.
22. Watch the oscilloscope reading on the monitor and make fine corrections with the micrometer screws at the SMA fibre connector and the microscope fine focus control, until the maximum count rate is achieved. Make sure the counter board and the detector are not overloaded. One should not operate the PMT (or APD) at more than 10^6 counts/sec for an extended period of time.

The integration time in the ADJUST mode is taken from your scan parameters. Choosing 1 second per line and 200 pixels per line will result in an integration time of 5 ms. For this setting, the count rate (counts/pixel) should not be above 5000.

23. You may now begin your measurement.

2.3 Beam path for confocal microscopy in reflection

- 5** objective lens system
- 6** cube beamsplitter (50:50)
- 7** tube lens ($f=163,5\text{mm}$)
- 9** SMA fibre connector optical output (pinhole)
- 10** sample
- 11** FC fibre connector optical input
- 12** achromatic lens system
- 18** single photon counting detector (PMT or APD)
- 20** SMA fibre connector feedthrough

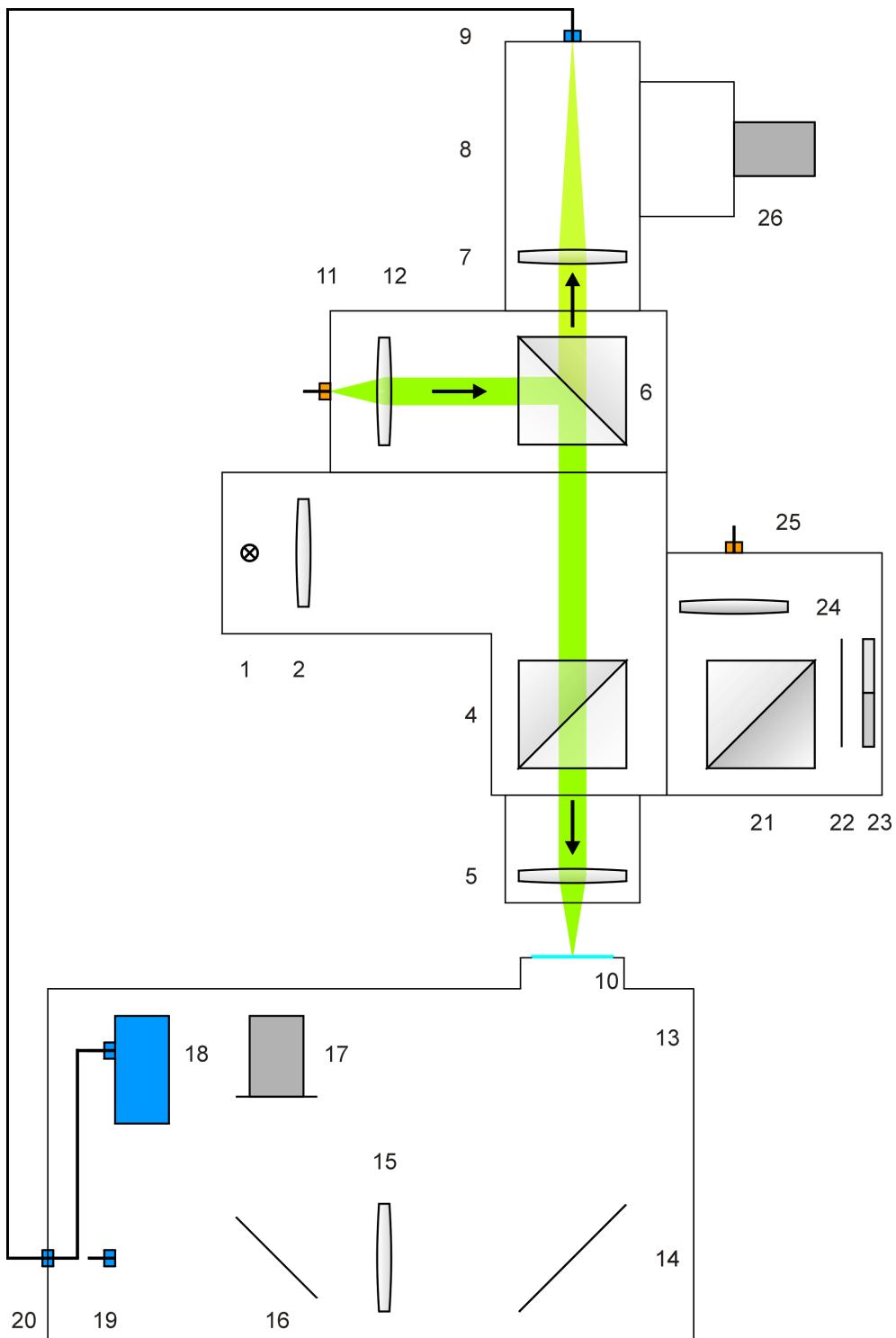


fig. 2.3: Beam path for confocal microscopy in reflection

2.4 Step by step alignment for confocal microscopy in transmission

1. Switch on the controller
2. Power up the computer and start ScanCtrl Spectroscopy Plus, as well as VideoCtrl. Select Confocal mode by clicking on HARDWARE OPTIONS-METHOD.
3. Switch on the servo control for X, Y and Z of the capacitively controlled piezo stage and make sure that the feedback input at the Z stage used for AFM/SNOM operation is disconnected. Adjust the offset potentiometer, until the Z stage shows a reading of about $10 \mu m$.
4. Mount your sample on the scanning stage.
5. Rotate the microscope turret until an appropriate objective is in the working position. Make sure you use the microscope objective in the proper way. All objectives supplied as standard are corrected for use with a cover slip.
6. Switch on the white light source and set the illumination to the required level. Your system is either equipped with a super-bright white LED or a halogen illumination system. The lifetime of a halogen lamp decreases rapidly with increasing voltage. Therefore, reduce the illumination to minimum if the lamp is not needed.
7. Push in the pushrod of the sliding prism and direct the beam to the colour eyepiece video camera.
8. Move the reflector slider to the illumination position. The beamsplitter is mounted in the left position of the three position reflector slider. Therefore, move the reflector slider to the right.
9. Observe the image of the eyepiece colour video camera on the computer monitor using the VideoCtrl software. Use Channel 1 to switch the video input to the eyepiece colour video camera.

10. Focus on the surface of your sample with the Z-focusing-stage by using the Focus Up or Focus Down buttons of the remote control. The focussing speed can be adjusted between about $0,01 \mu\text{m}/\text{s}$ (potentiometer fully counter-clockwise) and $300 \mu\text{m}/\text{s}$ (potentiometer fully clockwise). If possible, move the objective away from the specimen to avoid a collision between the objective and the specimen.

It is sometimes very difficult to focus on flat and clean surfaces. The best way to do this is to use the bright field illumination. Close the luminous-field diaphragm (10) to a value of 1–3. Make sure to move in the 50 : 50 beam splitter to illuminate the sample. Approach to the sample, until the edge of the field stop appears focused. At this point, the sample is also in focus. This is due to the fact that the field stop is positioned at the back focal plane of the objective. If the field stop is not in the middle of the field of view, move it to this position with the centering screws.

11. Switch on the excitation laser at low power.
12. Reduce the bright field illumination, move out the 50 : 50 beam splitter and fine focus the microscope until the excitation laser is focused on the sample. You will observe several spots on the video screen, but only one of them changes during focusing. The other spots are reflections inside the microscope and do not hit the sample. Make sure that the other spots are as small as possible. If they appear out of focus, rotate the micrometer screw at the fibre input of the microscope until they are perfectly focused. This ensures that the excitation laser is parallel inside the microscope.
13. Fine adjust the collection objective, until the excitation beam is in focus and centred in the circle of the VideoCtrl window. Use Channel 2 to switch the video input to the video camera in the transmission path.
14. Reduce the intensity of the excitation laser, until the spot is barely visible on the monitor. Ensure that the laser power is not too high before you switch on the detector. Remember, the photon counting PMT (or APD) used in the AlphaSNOM is an extremely sensitive device which can easily be destroyed by excessive light when powered up.

15. Activate MEASURE-ADJUST in ScanCtrl Spectroscopy Plus.
16. Watch the oscilloscope reading on the monitor and make fine corrections with the micrometer screws at the SMA fibre connector and the microscope fine focus control, until the maximum count rate is achieved. Make sure the counter board and the detector are not overloaded. One should not operate the PMT (or APD) at more than 10^6 counts/sec for an extended period of time. The integration time in the ADJUST mode is taken from your scan parameters. Choosing 1 second per line and 200 pixels per line will result in an integration time of 5 ms. For this setting, the count rate (counts/pixel) should not be above 5000.
17. You may now begin your measurement.

2.5 Beam path for confocal microscopy in transmission

5 objective lens system

6 cube beamsplitter (50:50)

10 sample

12 achromatic lens system

13 objective lens system

14 mirror

15 tube lens ($f=125\text{mm}$)

16 flip mirror

18 single photon counting detector (PMT or APD)

20 SMA fibre connector

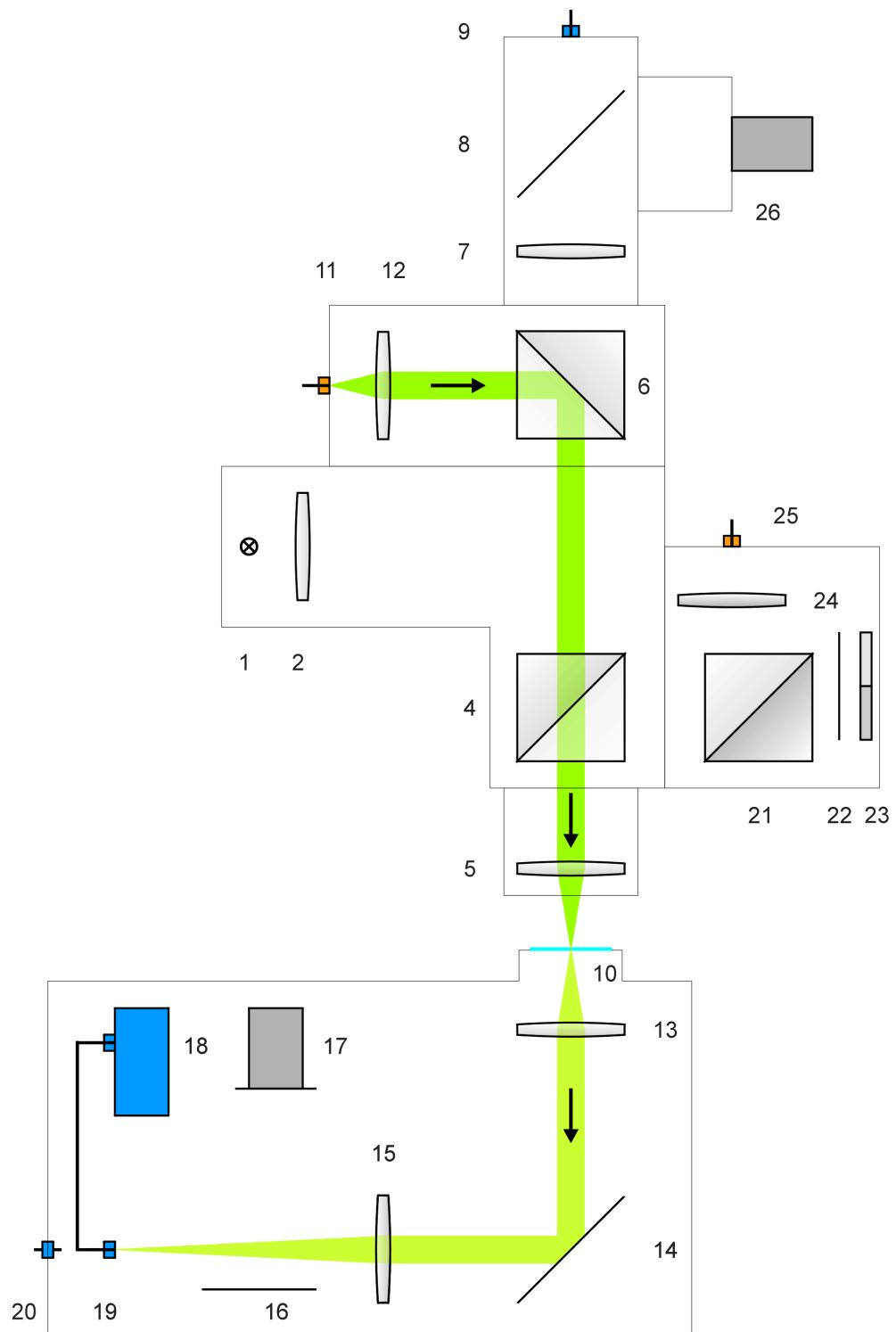


fig. 2.4: Beam path for confocal microscopy in transmission

Chapter 3

SCANNING NEAR-FIELD OPTICAL MICROSCOPY

The resolution in classical (as well as confocal) microscopy is limited by the wavelength of the excitation light. This was investigated in detail by Abbe around 1890. According to him, at least the first diffracted order of an object (e.g. a grating) has to be captured by the lens system to resolve the object in image space. This is the reason for the importance of the numerical aperture for the resolution of an optical system.

In a perfect lens system with circular aperture, the image of a point object will be an Airy-pattern. On integrating the irradiance one finds that 84% of the light arrives within the central spot and 91% within the bounds of the second dark ring.

If one brings two point objects close together so that the maximum of the first Airy pattern is at the first minimum of the second, we are still able to resolve the two spots. This is the Rayleigh limit and the resolution defined by this (arbitrary) criterion is:

$$\Delta x = 0,61 \cdot \frac{\lambda}{NA}$$

where λ is the wavelength of the light and $NA = n \cdot \sin \alpha$ the numerical aperture of the lens system while n is the index of refraction of the surrounding medium.

The maximum NA for commercially available objectives is about 0,95 when working in air and about 1,4 for oil immersion objectives (sample immersed in oil).

From this formula one can see that the maximum resolution is

- $2/3 \cdot \lambda$ for conventional microscopy in air
- $1/2 \cdot \lambda$ for confocal microscopy in air
- $1/2 \cdot \lambda$ for conventional microscopy using immersion oil
- $1/3 \cdot \lambda$ for confocal microscopy using immersion oil

These values are only valid for optimum conditions, e.g. thin samples. The only way to overcome the diffraction limit is to observe very close to the sample in the near-field regime (observer-sample distance $\lambda/5$).

The idea was first proposed by SYNGE in 1928. He suggested using a metal plate with holes much smaller than the wavelength of light, to illuminate this with light from the back side and scan this plate in close proximity across a sample. If the plate-sample distance is much smaller than the diameter of the holes, the resolution is limited by the diameter of the light source (holes) and not by the wavelength of light.

It was not possible at that time to prove this idea and it took until 1972 before ASH and NICOLLS could verify the theory with electromagnetic waves in the microwave range (3 cm wavelength, $0,5\text{ mm}$ resolution $\Rightarrow \lambda/60$). The first results in the optical regime were obtained by POHL and BETZIG (1986), who used pulled optical fibres and shear-force feedback for distance control.

The AlphaSNOM goes a step further and uses microstructured, cantilever sensors and beam deflection feedback (well known from AFM) for distance control. To take advantage of the high resolution obtainable with SNOM, one should consider the following points:

The maximum resolution is given by the aperture of the sensor, but this resolution is only possible in the near-field. Therefore, the distance between tip and sample should be less than the radius of the aperture ($< 50\text{ nm}$ for a 100 nm aperture), otherwise the resolution decreases. This resolution can only be obtained at the surface of a sample (one can not look inside the sample as in confocal microscopy). As a result of the small distance between tip and sample there is always an interaction between topography features and light emitted by the aperture, which gives rise to artifacts. The user should always be aware that these artifacts might be present. On the other hand, the importance of these artifacts should not be

exaggerated.

A careful comparison of the optical image with the simultaneously obtained topographical image can help to identify artifacts. If one finds an optical feature at exactly the same position as a topographical step, one should be sceptical. Particularly if the change in optical contrast is only a few percent of the overall intensity.

If there is a topographical step, the distance between tip and sample changes as does the coupling of the electrical field (near-field) between them, which may cause a change in detected intensity.

Usually, the optical aperture is slightly shifted ($50 - 150\text{ nm}$) from the point of contact. This is due to the fact that the mechanical contact is somewhere at the rim of the optical aperture. The hollow aperture is surrounded by a $100 - 150\text{ nm}$ thick layer of aluminium providing the mechanical contact. Therefore, a genuine optical contrast should show a shift between the optical and topographical images of $50 - 150\text{ nm}$.

The preferable mode for near-field optical microscopy is transmission. In this mode, the light transmitted through the transparent (or fluorescing) sample is collected by the detector and topography artifacts are usually a minor problem.

In reflection mode, the light transmitted through the aperture and reflected from the sample surface is collected with auxiliary optics. In this mode, topography-induced artifacts are most likely and can even dominate the image. The reflection mode is usually used when the sample does not transmit the excitation light. In this case, the light transmitted through the aperture must cross the extremely small gap between tip and sample. If the tip is scanned across a topography step, it is very likely that the detected light intensity would change and gives rise to topography-induced artifacts. Here again, a careful comparison between topography and optical images is very helpful in distinguishing actual sample features from artifacts.

With the AlphaSNOM, the following near-field optical modes are possible:

- near-field transmission
- near-field fluorescence transmission (using additional filters)
- near-field reflection (with the reflection mode upgrade)
- near-field reflection fluorescence (with the reflection mode upgrade and additional filters)
- confocal Raman reflection (using the Raman upgrade)

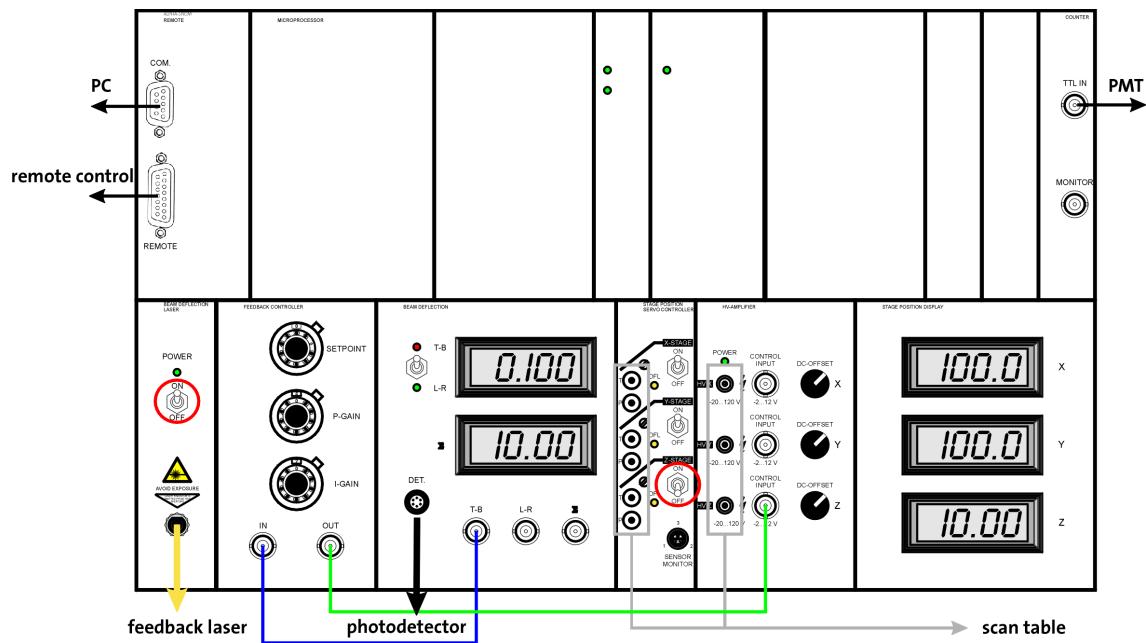


fig. 3.1: Wiring diagram for SNOM

3.1 Getting Started: SNOM operation

The following paragraph provides a short description of the adjustments necessary to obtain a SNOM measurement. For a more complete understanding, the reader is referred to the technical chapters. Please read and follow the warnings and safety instructions in this operating manual.

The feedback and excitation lasers are factory-aligned. The excitation laser is aligned with the optical axis of the upper microscope, while the beam deflection laser is somewhat shifted. Its focus hits the SNOM cantilever at a distance of about $50 \mu\text{m}$ from the excitation laser. This guarantees that no beam deflection light can pass through the SNOM aperture when the cantilever is aligned for maximum transmission of the excitation laser.

A readjustment of either beams should not be necessary in normal operation.

3.2 Step by step alignment for SNOM operation in transmission

1. Switch on the controller and the feedback laser module.
2. Power up the computer and start ScanCtrl Spectroscopy Plus, as well as VideoCtrl. Select SNOM mode by clicking on HARDWARE OPTIONS-METHOD.
3. Switch on the servo control for axes X and Y of the capacitively controlled piezo stage. Make sure that the servo control is switched **off** for the Z-axis and the feedback output is connected to the CONTROL INPUT input of the Z-axis. Turn the potentiometer for the Z-OFFSET completely counter-clockwise.
4. Use a glass cover slip as a sample.
5. Remove the endcap of the SNOM objective, which holds the cantilever.

6. Rotate the microscope turret until the SNOM objective is in the working position.
7. Focus on the upper surface of the cover slip with the Z-focusing-stage by using the Focus Up or Focus Down buttons of the remote control. The focussing speed can be adjusted between about $0,01 \mu\text{m}/\text{s}$ (potentiometer fully counter-clockwise) and $300 \mu\text{m}/\text{s}$ (potentiometer fully clockwise). If possible, move the objective away from the specimen to avoid a collision between the objective and the specimen. If you have already done the alignment, focus on your sample instead.
It is sometimes very difficult to focus on flat and clean surfaces. The best way to do this is using bright field illumination. Close the field stop to a value of 1 – 3. Be sure to select the 50 : 50 beamsplitter (3). Approach the sample until the edge of the field stop appears focused. At this point, the sample is also in focus. This is due to the fact that the field stop is positioned at the back focal plane of the objective. If the field stop is not in the middle of the field of view, move it to this position with the centering screws.
8. Use the remote hand controller to move the collection objective in X,Y, and Z until you see the field stop focused and in the centre of the VideoCtrl window. Use Channel 2 to switch the video input to the video camera in the transmission path. This procedure aligns the optical axis of the collection objective with the optical axis of the microscope. Note: Even at a reading of 1 for the field stop (field stop as small as possible), the illuminated field on the detection monitor will be larger than the field of view.
9. Switch on the excitation laser at low power.
10. Switch to Channel 1 in VideoCtrl to observe the image of the colour eyepiece camera. Reduce the bright field illumination, move out the 50 : 50 beam splitter and fine-focus the microscope until the reflection of the excitation laser is focused on the sample. You will observe several spots on the video image, but only one of them changes during focusing. The other spots are reflections inside the microscope and do not hit the sample. Make sure the other spots are as small as possible. If they appear out of focus, turn the micrometer screw

at the fibre input of the microscope until they appear perfectly focused. This makes sure that the excitation laser is parallel inside the microscope.

11. Switch to Channel 2 in VideoCtrl to observe the image of the transmission path. Fine-adjust the collection objective until the excitation beam is in focus and centered in the middle of the circle in the video image.
12. Note the position of the collection objective as shown on the MICROSCOPE CONTROLLER window in ScanCtrl Spectroscopy Plus.
13. Move the microscope up and switch on the bright field illumination again.
14. Attach a SNOM-cantilever to the endcap and mount it to the SNOM-objective, then rotate it into the working position and focus the cantilever by turning the focusing ring.
15. Loosen the endcap slightly and turn it until the cantilever points downward on the monitor. Make sure that the video camera is correctly oriented. The video eyepiece has a white mark which should point downwards. If everything is correct, the cantilever points towards the front of the microscope. Fix the endcap in place.
16. Move the cantilever in XY direction with the micrometer screws, until the excitation laser is pointing into the pyramid at the end of the cantilever. The focus of the beam deflection laser can then be seen about $50\ \mu m$ above the pyramid.
17. Turn the T-B and L-R adjustment screws on the front of the microscope until you maximum the Σ -signal. The adjustment is perfect if the Σ -signal shows a reading between $2,5\ V$ and $12\ V$, depending on the cantilever you are using.
18. Adjust the L-R signal close to Zero (within $\pm 100\ mV$).
19. Adjust the T-B signal to about $0,100\ V$ ($\pm 50\ mV$).
This ensures, that the reflected beam hits the segmented photodiode close to the center. If the Σ -signal is below $1,5\ V$, the Auto-Approach function is disabled.

20. On the Feedback-Module, adjust the Setpoint to about 0, 2, Proportional Gain to about 4, 0 and Integral Gain to about 2, 0. With these settings, the Z-position of the scan table should display 1 – . – – which means the stage is fully extended.
21. Move the microscope down by using the Focus Down button of the remote control until the cantilever is close to the sample, but be careful to not hit the sample.
22. Press the Auto-Approach Start(SNOM) button (MICROSCOPE CONTROLLER window in ScanCtrl Spectroscopy Plus). The microscope will move down until the cantilever contacts the sample. At this point, the display will read: Tip is in contact. The microscope will then move further down until the Z-position display of the piezo-stage shows approximately $15 \mu m$.
If the initial distance was more than $100 \mu m$, the focusing stage will stop before the tip is in contact with the surface and the display will read: No surface found!. In this case check Setpoint, T-B, R-L, and Σ -signal as well as the Z-position of the scan stage. If everything is ok, press the Auto-Approach button again to start the approach again. In every cycle, the focusing stage will descent at most $100 \mu m$ and then stop if there is no contact. When the tip reaches the sample, the T-B signal will jump to the setpoint value, e.g. $200 mV$, if the knob shows a reading of 0, 2.
If you hear a noise from the stage during contact, the feedback is too aggressive. In this case, reduce I and P-Gain until the noise stops.
23. After a successful approach, move the microscope slowly up, until the cantilever snaps out of contact (setpoint value changes back to roughly 0, 100 and Z-stage shows 1 – . – –). Reset the position reading and move up an additional $20 \mu m$.
24. Slide in the 50 : 50 beamsplitter and increase the white light illumination. Carefully move the collection objective up without touching the sample. Looking at the video image of the collection objective (Channel 2 in VideoCtrl), you should be able to see the shadow of the cantilever and the pyramid. Focus onto the tip of the pyramid. If you are not able to see the tip of the pyramid,

focus onto the edge of the cantilever and then move the collection objective approximately $10\text{ }\mu\text{m}$ down.

25. Slide out the 50 : 50 beam-splitter and reduce the white light illumination to minimum. Increase the excitation laser and fine-adjust the cantilever until you see some of the excitation light transmitted through the aperture. Focus the collection microscope on this spot.
26. Make fine adjustments of the cantilever position and the focussing micrometer of the excitation laser (located at the fibre input), until transmission is maximized.
27. Repeat steps 18 and 19.
28. Press the Auto-Approach Start(SNOM) button and wait until the stage stops at a Z-position of about $15\text{ }\mu\text{m}$. The image of the transmitted light should stay in focus, because the upper and the lower objective move down parallel. If necessary, make small X- and Y-corrections with the remote hand controller until the spot is in the centre of the circle on the monitor. Reduce the laser power until it is barely visible on the monitor.
29. Click on the Adjust button in the Acquisition Control window of ScanCtrl Spectroscopy Plus.
30. Watch the oscilloscope reading and make fine corrections in X, Y and Z of the collection objective until the count rate is maximized. Make sure the counter board and the detector are not overloaded. One should not operate the PMT (or APD) at more than 10^6 counts/sec for an extended period of time. The integration time in the ADJUST mode is taken from your scan parameters. Choosing 1 second per line and 200 pixels per line will result in an integration time of 5 ms. For this setting, the count rate (counts/pixel) should not be above 5000.
31. You may now begin your measurement.

3.3 Beam path for transmission mode SNOM

- 4** dichroic mirror ($T > 95\% @ \lambda = 325 - 850nm$; $R > 95\% @ \lambda = 980nm$)
- 5** objective lens system
- 6** cube beamsplitter (50:50)
- 10** sample
- 11** FC fibre connector optical input
- 12** achromatic lens system
- 14** mirror
- 15** tube lens ($f=125mm$)
- 16** flip mirror
- 18** single photon counting detector (PMT or APD)
- 19** SMA fibre connector
- 21** cube beamsplitter (50:50)
- 22** edge filter
- 23** segmented photodiode
- 24** achromatic lens system
- 25** FC fibre connector optical input
- 27** cantilever

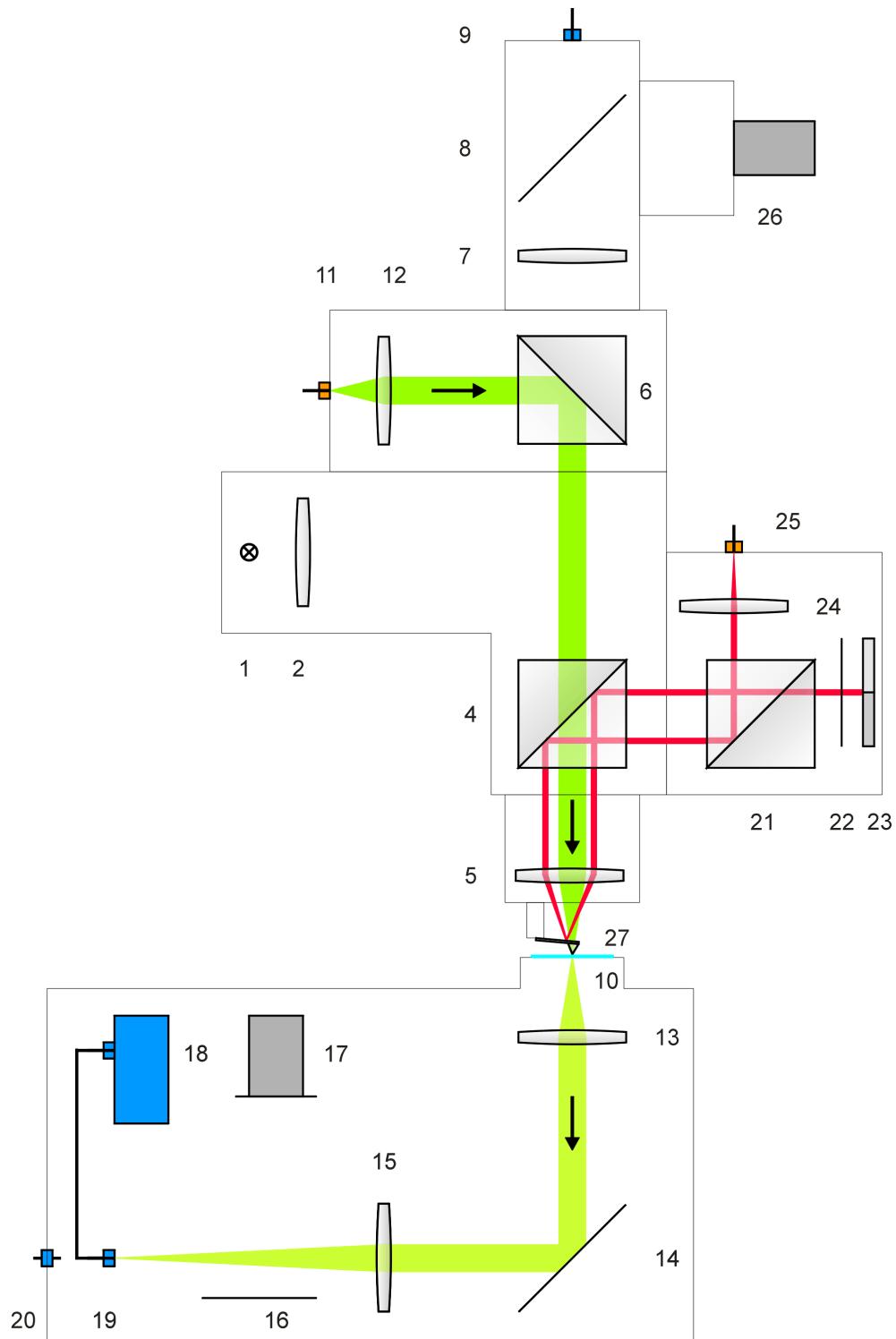


fig. 3.2: Beam path for transmission mode SNOM

3.4 Step by step alignment for SNOM operation in reflection

1. Switch on the controller and the feedback laser module.
2. Power up the computer and start ScanCtrl Spectroscopy Plus, as well as VideoCtrl. Select SNOM mode by clicking on HARDWARE OPTIONS-METHOD.
3. Switch on the servo control for axes X and Y of the capacitively controlled piezo stage. Make sure that the servo control is switched **off** for the Z-axis and the feedback output is connected to the CONTROL INPUT input of the Z-axis. Turn the potentiometer for the Z-OFFSET completely counter-clockwise.
4. Use a glass cover slip as a sample.
5. Remove the endcap of the SNOM objective, which holds the cantilever.
6. Rotate the microscope turret until the SNOM objective is in the working position. Focus on the upper surface of the cover slip with the Z-focusing-stage by using the Focus Up or Focus Down buttons of the remote control. The focussing speed can be adjusted between about $0,01 \mu\text{m}/\text{s}$ (potentiometer fully counter-clockwise) and $300 \mu\text{m}/\text{s}$ (potentiometer fully clockwise). If possible, move the objective away from the specimen to avoid a collision between the objective and the specimen. If you have already done the alignment, focus on your sample instead.

It is sometimes very difficult to focus on flat and clean surfaces. The best way to do this is using bright field illumination. Close the field stop to a value of 1 – 3. Be sure to select the 50 : 50 beamsplitter (3). Approach the sample until the edge of the field stop appears focused. At this point, the sample is also in focus. This is due to the fact that the field stop is positioned at the back focal plane of the objective. If the field stop is not in the middle of the field of view, move it to this position with the centering screws.

7. Use the remote hand controller to move the collection objective in X,Y, and Z until you see the field stop focused and centered monitors field of view. This procedure aligns the optical axis of the collection objective with the optical

axis of the microscope. Note: Even at a reading of 1 for the field stop (field stop as small as possible), the illuminated field on the detection monitor will be larger than the field of view.

8. Switch on the excitation laser at low power.
9. Switch to Channel 1 in VideoCtrl to observe the image of the colour eyepiece camera. Reduce the bright field illumination, move out the 50 : 50 beam splitter and fine focus the microscope until the reflection of the excitation laser is focussed on the sample. You will observe several spots on the video screen, but only one of them changes during focussing. The other spots are reflections inside the microscope and do not reach the sample. Make sure the other spots are as small as possible. If they look out of focus, turn the micrometer screw at the fibre input of the microscope until they appear perfectly focused. This makes sure that the excitation laser is parallel inside the microscope.
10. Switch to Channel 2 in VideoCtrl to observe the image of the transmission path. Fine adjust the collection objective until the excitation beam is in focus and centered in the cross hairs on the monitor.
11. Note the position of the collection objective as shown on the MICROSCOPE CONTROLLER window in ScanCtrl Spectroscopy Plus.
12. Move the microscope up and switch on the bright field illumination again.
13. Attach a SNOM-cantilever to the endcap and mount it to the SNOM-objective, switch it into the working position and focus the cantilever by turning the focusing ring.
14. Loosen the endcap slightly and turn it until the cantilever points downward on the monitor. Make sure that the video camera is correctly oriented. The video eyepiece has a white mark which should point downwards. If everything is correct, the cantilever will point toward the front of the microscope. Fix the endcap in place.
15. Move the cantilever in XY direction with the micrometer screws until the excitation laser is pointing into the pyramid at the end of the cantilever. The

focus of the beam deflection laser can then be seen about $50\ \mu m$ above the pyramid.

16. Turn the T-B and L-R adjustment screws on the front of the microscope until you maximum the Σ -signal. The adjustment is perfect if the Σ -signal shows a reading between $2,5\ V$ and $12\ V$, depending on the cantilever you are using.
17. Adjust the L-R signal close to Zero (within $\pm 100\ mV$).
18. Adjust the T-B signal to about $0,100\ V$ ($\pm 50\ mV$).
This ensures that the reflected beam hits the segmented photodiode close to the center. If the Σ -signal is below $1,5\ V$, the Auto-Approach function is disabled.
19. On the Feedback-Module, adjust the Setpoint to about 0,2, Proportional Gain to about 4,0 and Integral Gain to about 2,0. With these settings, the Z-position of the scan table should display 1 – . – – which means the stage is fully extended.
20. Move the microscope down by using the Focus Down button of the remote control until the cantilever is close to the sample, but be careful to not hit the sample.
21. Press the Auto-Approach Start(SNOM) button (MICROSCOPE CONTROLLER window in ScanCtrl Spectroscopy Plus). The microscope will move down until the cantilever contacts the sample. At this point, the display will read: Tip is in contact. The microscope will then move further down until the Z-position display of the piezo-stage shows approximately $15\ \mu m$.
If the initial distance was more than $100\ \mu m$, the focusing stage will stop before the tip is in contact with the surface and the display will read: No surface found!. In this case check Setpoint, T-B, R-L, and Σ -signal as well as the Z-position of the scan stage. If everything is ok, press the Auto-Approach button again to start the approach again. In every cycle, the focusing stage will descent at most $100\ \mu m$ and then stop if there is no contact. When the tip reaches the sample, the T-B signal will jump to the setpoint value, e.g. $200\ mV$, if the knob shows a reading of 0,2 .

If you hear a noise from the stage during contact, the feedback is too aggressive. In this case, reduce I and P-Gain until the noise stops.

22. After a successful approach, move the microscope slowly up, until the cantilever snaps out of contact (setpoint value changes back to roughly 0,1 V and the Z-stage shows 1 – . – –). Reset the position reading and move up an additional 20 μm .
23. Slide in the 50 : 50 beamsplitter and increase the white light illumination. Carefully move the collection objective up without touching the sample. Looking at the video image of the collection microscope (Channel 2 in VideoCtrl), you should be able to see the shadow of the cantilever and the pyramid. Focus onto the tip of the pyramid. If you are not able to see the tip of the pyramid, focus onto the edge of the cantilever and then move the collection objective 10 μm down.
24. Slide out the 50 : 50 beam-splitter and reduce the white light illumination to a minimum. Increase the excitation laser and fine adjust the cantilever until you see some of the excitation light transmitted through the aperture in the monitor. Focus the collection microscope on this spot.
25. Make fine adjustments of the cantilever position and the focusing micrometer of the excitation laser (located at the fibre input), until transmission is maximised.
26. Repeat steps 18 and 19.
27. Move the microscope up and replace the cover slip with your sample.
28. Select Channel 3 in VideoCtrl to observe the video image of the reflection mode.
29. Approach the surface with the cantilever again, until the distance is only a fraction of a millimeter.
30. Move the reflection microscope in X, Y, and Z directions until you see the light emitted from the cantilever (and eventually its reflection at the sample surface). It might be helpful in the first step to illuminate the cantilever from the

side. Adjust the focus (Y direction) and make corrections in X and Z until the circle on the video image is halfway between the two spots.

31. Make sure that the fibre at the reflection microscope is connected with the SMA feedthrough of the AlphaSNOM body and the PMT.
32. Press the Auto-Approach button and wait until the cantilever contacts the sample and the piezo-stage stops at a Z-position of about $15\ \mu m$.
During approach, the two spots merge and at contact the light transmission suddenly reduces.
33. Check if the spot is located in the circle on the monitor. If not, carefully correct the position of the reflection microscope.
When the tip is in contact, try to avoid any vibrations of the microscope body.
34. Click on the Adjust button in the Acquisition Control window of ScanCtrl Spectroscopy Plus.
35. Watch the oscilloscope reading and make fine corrections with the micrometer screws of the SMA fibre connector until the count rate is maximized. Make sure the counter board and the detector are not overloaded. One should not operate the PMT (or APD) at more than $10^6\ counts/sec$ for an extended period of time. The integration time in the ADJUST mode is taken from your scan parameters. Choosing 1 second per line and 200 pixels per line will result in an integration time of 5 ms. For this setting, the count rate (counts/pixel) should not be above 5000.
36. You may now begin your measurement.

3.5 Beam path for reflection mode SNOM

- 4** dichroic mirror ($T > 95\% @ \lambda = 325 - 850\text{nm}$; $R > 95\% @ \lambda = 980\text{nm}$)
- 5** objective lens system
- 6** cube beamsplitter (50 : 50)
- 10** sample
- 11** FC fibre connector optical input
- 12** achromatic lens system
- 18** single photon counting detector (PMT or APD)
- 20** SMA fiber connector feedthrough
- 21** cube beamsplitter (50 : 50)
- 22** edge filter
- 23** segmented photodiode
- 24** achromatic lens system
- 25** FC fibre connector optical input
- 27** cantilever
- 28-32** reflection microscope
- 28** achromatic lens
- 29** achromatic lens
- 30** cube beamsplitter (50 : 50)
- 31** SMA fiber connector optical output
- 32** high sensitivity b/w video CCD camera

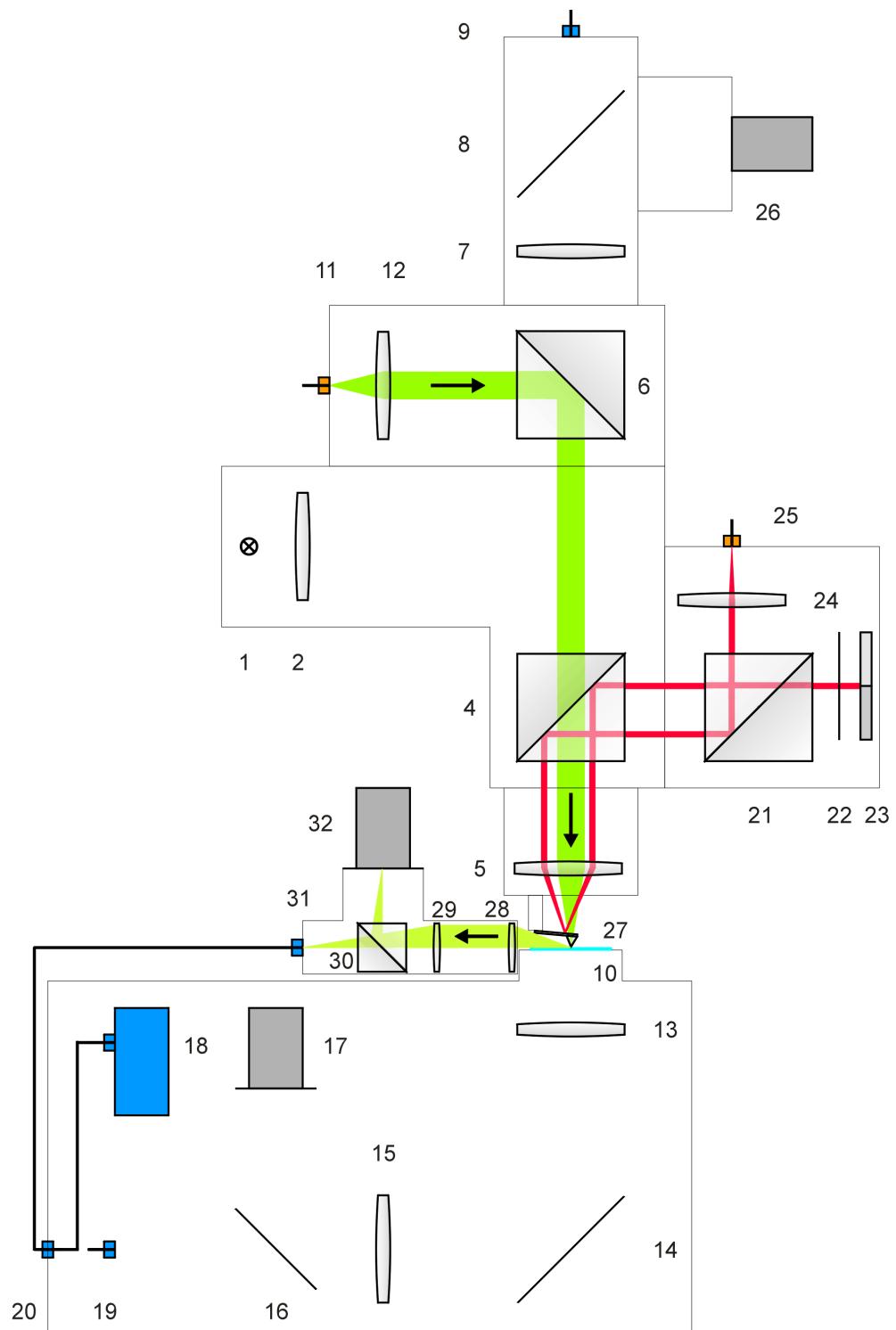


fig. 3.3: Beam path for reflection mode SNOM

Chapter 4

ATOMIC FORCE MICROSCOPY

The lateral topography resolution obtainable with AFM-cantilevers is usually restricted to the diameter of the AFM-tip. If a SNOM-cantilever is used for topography measurements, the lateral resolution will be in the order of 300 nm . This is due to the fact, that the SNOM-aperture has a diameter of $50 - 100\text{ nm}$ surrounded by about 100 nm of aluminium. A small protrusion close to the aperture can enhance the resolution on flat samples, but this protrusion will usually affect the optical resolution, if it is larger than about the diameter of the aperture.

Therefore, if a high topographical resolution is needed the use of standard AFM-cantilevers will lead to better results.

Nearly all commercial AFM-cantilevers can be used in the AlphaSNOM, but due to the shape of the holder we recommend the use of NANONSENSORS cantilevers. Due to the relatively small angle between cantilever and sample, especially when using a highly reflecting sample, the use of reflex coated cantilevers might be important to reduce effects due to interference between light reflected at the cantilever and the sample.

The following AFM modes are (currently) possible with the AlphaSNOM:

- Contact Mode
- AC Mode (with the AC Mode extension)
- Magnetic Mode (with the AC Mode extension)
- Pulsed Force ModeTM (with the PFM extension)

Please ask WITec if you have a special application and need a measurement mode not listed above.

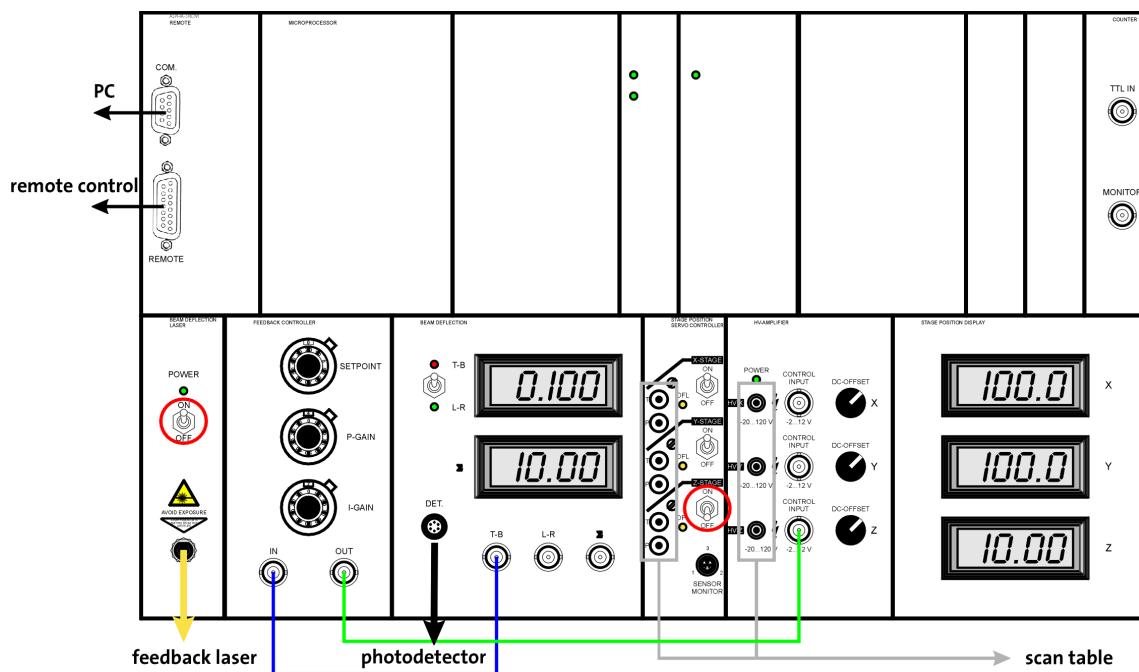


fig. 4.1: Wiring diagram for AFM

4.1 Getting Started: AFM operation

The following paragraph gives a short description about the adjustments necessary to obtain measurements in contact mode. For a more complete understanding, the reader is referred to the technical chapters. Please read and follow the warnings and safety instructions in this operating manual.

The feedback mechanism for AFM operation is the same as for SNOM operation (optical beam deflection feedback). Therefore, some parts of the alignment procedure are identical. There is no excitation laser in AFM mode, so the optical alignment is easier.

Wiring is the same as for SNOM operation, except that the PMT is not needed.

4.2 Step by step alignment for AFM operation

1. Switch on the controller and the feedback laser module.
2. Power up the computer and start ScanCtrl Spectroscopy Plus, as well as VideoCtrl. Select AFM mode by clicking on HARDWARE OPTIONS-METHOD.
3. Switch on the servo control for axes X and Y of the capacitively controlled piezo stage. Make sure that the servo control is switched **off** for the Z axis and the feedback output is connected to the CONTROL INPUT input of the Z axis. Turn the potentiometer for the Z-OFFSET completely counter-clockwise.
4. Mount your sample on the scan table.
5. Remove the endcap of the SNOM objective, which holds the cantilever.
6. Attach an AFM-cantilever to the endcap and mount it to the SNOM-objective, switch it into the active position and focus on the cantilever by turning the focusing ring.
7. Loosen the endcap slightly and turn it, until the cantilever points downward on the monitor. Make sure that the video camera is correctly oriented. The

video eyepiece has a white mark which should point downwards. If everything is correct, the cantilever will point toward the front of the microscope. Fix the endcap in place.

8. Move the cantilever in X and Y direction with the micrometer screws until you see the reflection of the beam deflection laser on the cantilever. Move the cantilever until the laser spot is close to the end of the cantilever.
9. Turn the T-B and L-R adjustment screws at the front of the microscope until the Σ -signal is maximised. The adjustment is perfect if the Σ -signal shows a reading between 2,5 V and 12 V, depending on the cantilever you are using.
10. Adjust the L-R signal close to Zero (within $\pm 100 \text{ mV}$).
11. Adjust the T-B signal to about 0, 100 V ($\pm 50 \text{ mV}$).
This ensures that the reflected beam hits the segmented photodiode near its center. If the Σ -signal is below 1,5 V, the Auto-Approach function is disabled. If the Σ -signal is above 13 V, the power of the feedback laser is too high.
12. On the Feedback-Module, adjust the Setpoint to about 0,2, Proportional Gain to about 4,0 and Integral Gain to about 2,0. With these settings, the Z-position of the scan table should show 1 – . – – which means the stage is fully extended.
13. Move the microscope down by using the Focus Down button of the remote control until the cantilever is close to the sample, but be careful to not hit the sample. The focussing speed can be adjusted between about $0,01 \mu\text{m}/\text{s}$ (potentiometer fully counter-clockwise) and $300 \mu\text{m}/\text{s}$ (potentiometer fully clockwise).
14. Press the Auto-Approach Start(AFM) button (MICROSCOPE CONTROLLER window in ScanCtrl Spectroscopy Plus). The microscope will move down until the cantilever contacts the sample. At this point, the display will read: Tip is in contact. The microscope will then move further down until the Z-position display of the piezo-stage shows approximately $15 \mu\text{m}$.
If the initial distance was more than $100 \mu\text{m}$, the focusing stage will stop before the tip is in contact with the surface and the display will read: No sur-

face found!. In this case check Setpoint, T-B, R-L, and Σ -signal as well as the Z-position of the scan stage. If everything is ok, press the Auto-Approach button again to start the approach again. In every cycle, the focusing stage will descent at most $100 \mu m$ and then stop if there is no contact. When the tip reaches the sample, the T-B signal will jump to the setpoint value, e.g. $200 mV$, if the knob shows a reading of 0, 2.

If you hear a noise from the stage during contact, the feedback is too aggressive. In this case, reduce I and P-Gain until the noise stops.

15. You may now begin your measurement.

4.3 Beam path for AFM

4 dichroic mirror ($T > 95\% @ \lambda = 325 - 850nm$; $R > 95\% @ \lambda = 980nm$)

5 objective lens system

10 sample

21 cube beamsplitter (50:50)

22 edge filter

23 segmented photodiode

24 achromatic lens system

25 FC fibre connector optical input

27 AFM cantilever

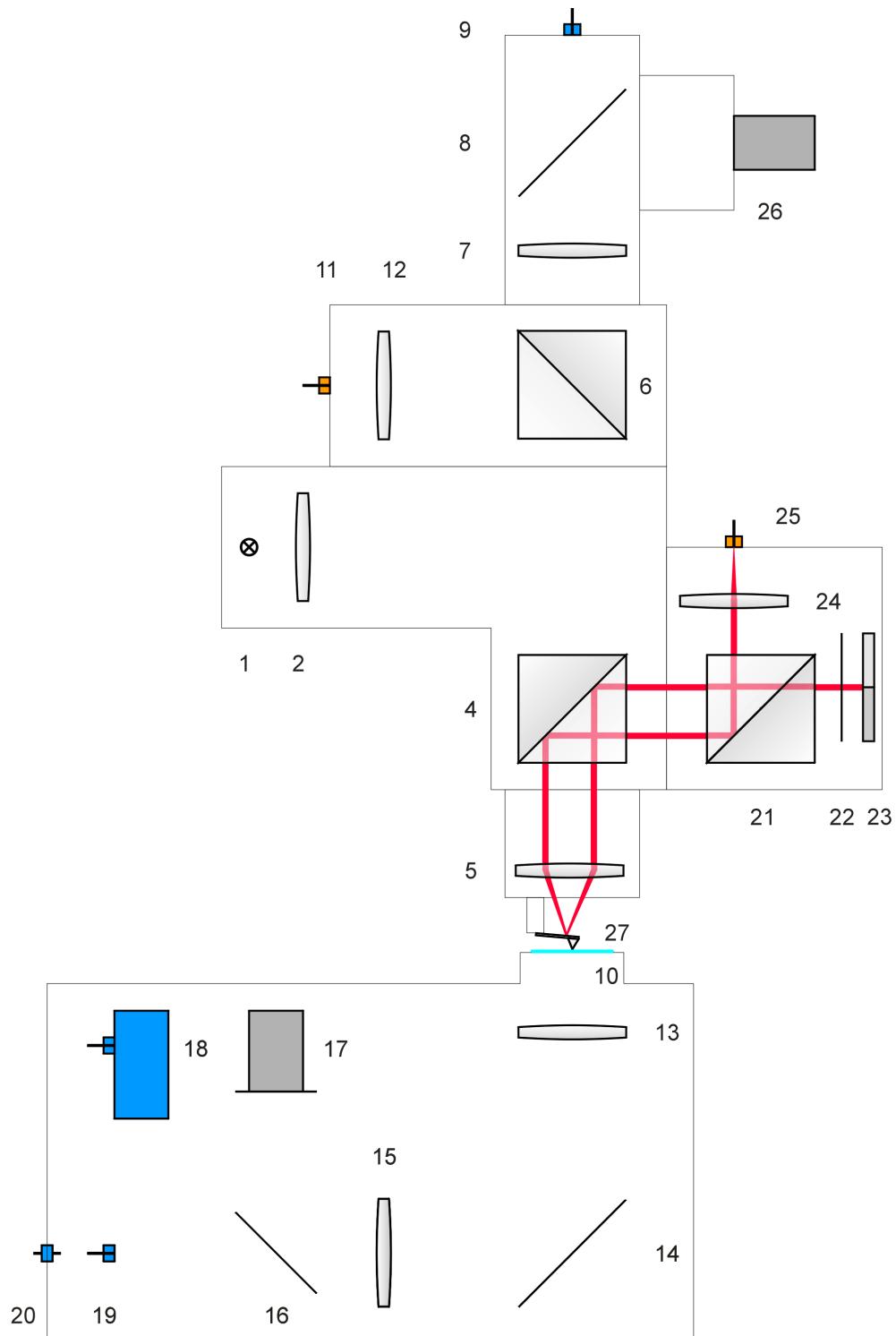


fig. 4.2: Beam path for AFM

Chapter 5

SYSTEM DESCRIPTION

Important

Warnings and safety instructions are marked with a red bar. Please read carefully and follow these warnings for your own safety. Please take special care when connecting high voltage outputs and handling optical fibres guiding laser radiation. Working with high voltages and laser radiation requires adequately educated operating personal.

Instructions

■ Instructions for the assembly of the system are marked with a blue bar.

5.1 BACK-PANEL CONNECTIONS

Connect the two high density cables with the Data Acquisition board located in the PC.

Connect the LEMOSA plug with the Z-stage of the microscope.

Connect the 15 pin Sub-D connector with the Sub-D connector at the backside of the microscope body.

The +5V power output is only needed, if the system is equipped with the SpeckPack option and an external APD.

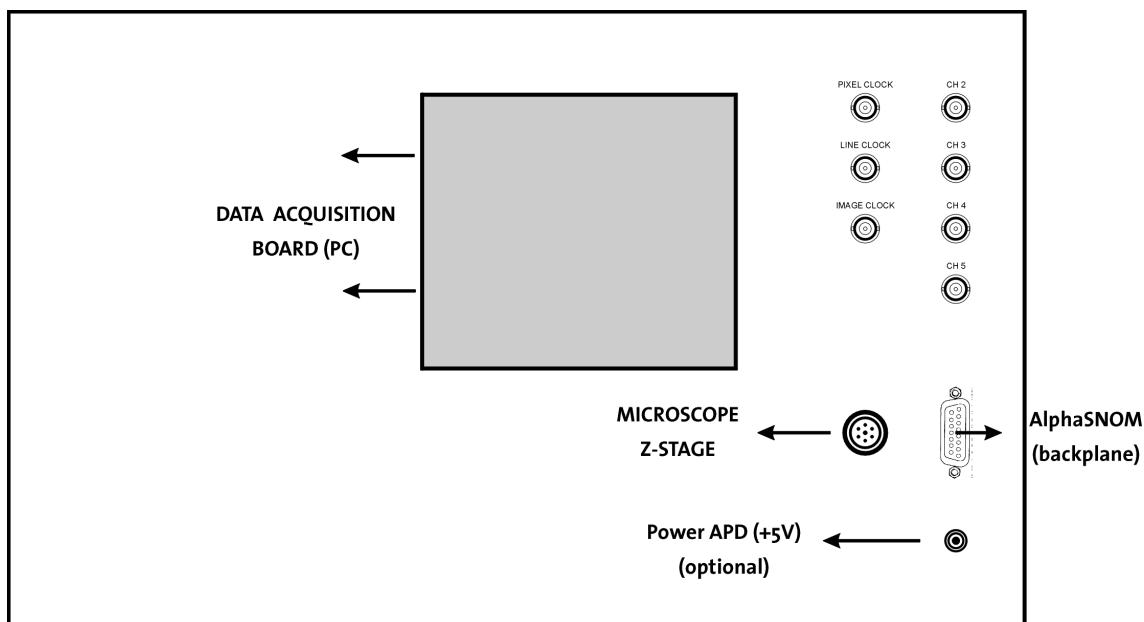


fig. 5.1: Back-panel connections

Do not disconnect the LEMOSA cable at the z-stage of the microscope or at the backplane of the microscope electronics when the power is on. This might destroy the motors and/or electronics.

5.2 X-Y TRANSLATION STAGE FOR SAMPLE POSITIONING

The translation stage for coarse alignment of the sample in X- and Y- direction is mounted underneath the scan table. The precise preloaded dovetail guidance allows a very linear and smooth movement combined with long term stability.

The stage has a travel of 20 mm in both directions. Two drive knobs are used to move the sample (the one in front for the Y-, the right hand side for the X-movement).

Technical Data

travel	20 mm
pitch	$0,25\text{ mm}$
graduation	$5\text{ }\mu\text{m}$
resolution	$<1\text{ }\mu\text{m}$
backlash	$<5\text{ }\mu\text{m}$
max load	400 N
free opening diameter	80 mm

The maximum weight of the sample is determined by the maximum load of the scan table (50 N), not by the x-y translation stage (400 N).

5.3 SCAN STAGE

The AlphaSNOM uses a piezoelectrically driven 3-axis flexure stage to scan the sample for all modes of operation. Integrated low voltage (0 to 100 V, provided by the LVPZT Amplifier Module of the ScanCtrl SPM controller) piezo translators and flexures are employed as the drive and guidance system. The flexures provide zero stiction, friction, and backlash, combined with ultra-high resolution and exceptional guiding precision.

The maximum scan range is $100 \mu\text{m}$ in the X- and Y-directions and $20 \mu\text{m}$ in the Z-direction. A stage with $200 \mu\text{m}$ travel in X and Y is available as an option.

Piezo translators, amplifiers, and controllers described in this manual are high voltage devices, capable of generating high output currents. They may cause serious or even lethal injuries if used improperly. Never touch any part that might be connected to the high voltage output.

Integrated capacitive position feedback sensors provide sub-nm resolution and stability in closed loop operation (in combination with the PZT-Servo Module of the ScanCtrl SPM controller). Each axis has a separate sensor. The closed loop control avoids all of the problems normally associated with piezo translators (hysteresis, creep, non-linearity, aging etc.), offers stable (drift-free) and hysteresis-free movements, high virtual stiffness, and long term positional stability. The capacitive sensors provide the stage with excellent resolution, long-term and thermal stability.

A capacitive sensor consists of a probe and a target plate separated by a thin air gap. The sensor and the target plate form a capacitor. The capacitance, which depends on the plate separation, is compared with an internal reference capacitor. Changes in the distance between the two plates cause a change in capacitance and the resulting signal is related to the deviation from the nominal distance. At the nominal distance, the capacitance of the sensors equals the capacitance of the internal reference capacitor.

closed loop resolution	$x, y \leq 1\text{ nm}, x, y \leq 0, 1\text{ nm}$
closed loop linearity	0,03%
full range repeatability	$x, y : \pm 5\text{ nm}, z : \pm 2\text{ nm}$
stiffness	$x, y : 2\text{ N/m}, z : 15\text{ N/m} (\pm 20\%)$
push/pull force	$x, y : 200/30\text{ N}, z : 50/30\text{ N}$
max. normal load	50N
unloaded resonant frequency	$x, y : 450\text{ Hz}, z : 1100\text{ Hz} (\pm 20\%)$
resonant frequency @500g load	$x, y : 250\text{ Hz} (\pm 20\%)$
resonant frequency @2500g load	$x, y : 140\text{ Hz} (\pm 20\%)$

The scan table has a clear aperture of 66 mm × 66 mm. There are several M3 threaded holes (3,5mm deep) to fix sample holders to the moving part of the scan table.

5.4 REMOTE MODULE

Connect the 9-pin Sub-D connector to the serial port (COM 1) of the PC.

Connect the Remote Hand Controller to the 15 pin Sub-D connector of the Remote Module.

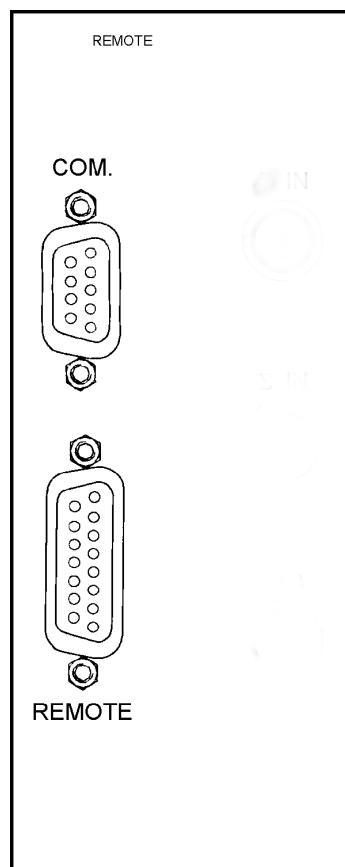


fig. 5.2: Remote Module

The Remote Module is the interface between Computer, Remote Hand Controller and Control Electronics.

5.5 REMOTE HAND CONTROLLER

The Remote Hand Controller has 8 push buttons. The upper two labelled FOCUS UP and FOCUS DOWN are used for focusing in confocal mode and approach in SNOM/AFM mode. Pressing these buttons moves the microscope up and down. The speed can be adjusted between about $0,01 \mu\text{m}/\text{s}$ (potentiometer fully counter clockwise) and $300 \mu\text{m}/\text{s}$ (potentiometer fully clockwise). The lower 6 buttons labelled +X, -X, +Y, -Y, +Z and -Z are used for moving the collection objective which is necessary for focusing the transmitted light onto the detector in confocal or near-field transmission mode. The speed can be adjusted between $0,1 \mu\text{m}/\text{s}$ (potentiometer fully counter-clockwise) and about $500 \mu\text{m}/\text{s}$ (potentiometer fully clockwise).

Be careful not to use the FOCUS UP or FOCUS DOWN buttons when you want to adjust the collection objective, or move the +X, -X, +Y, -Y, +Z or -Z buttons when you want to move the microscope.// As the potentiometer covers a very broad speed range, always check the speed setting before moving the microscope or the collection objective.

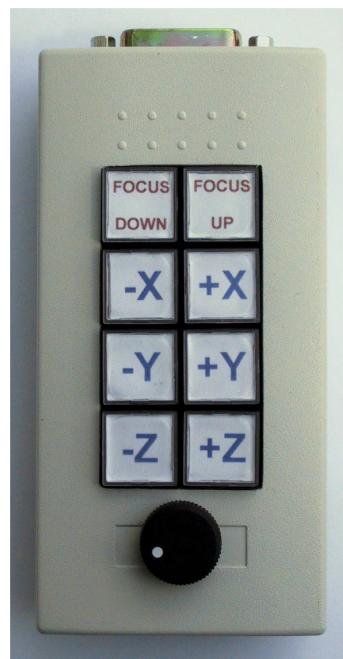


fig. 5.3: Remote Hand Controller

5.6 FEEDBACK MODULE

Connect the IN BNC connector with the T-B output of the Beam Deflection Module. Connect the OUT BNC connector with the CH 3 CONTROL INPUT connector of the LVPZT Amplifier Module.

As a starting value, set the I-GAIN (integral gain) to about 2 and the P-GAIN (proportional gain) to about 5.

Set the SETPOINT to about 0,2.

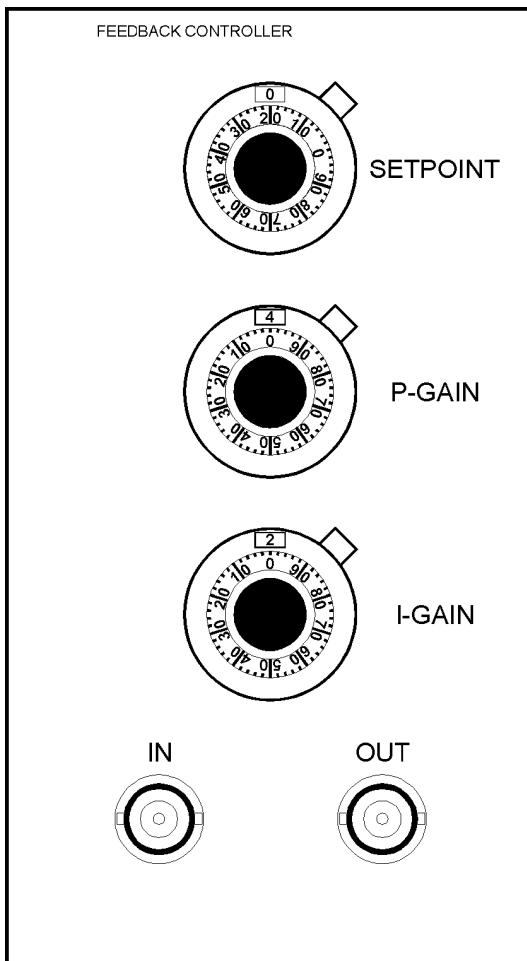


fig. 5.4: Feedback Module

The P-I (Proportional-Integral) Feedback Controller Module compares the input voltage fed into the IN connector with the setpoint voltage, selected by the SETPOINT knob and tries to compensate for differences with a speed, according to the P-GAIN and I-GAIN settings. Increasing these settings increases the speed of the system.

If the feedback loop of an SPM is not optimised, the resulting image will be poor. The gains should be as high as possible to optimise the speed of the feedback circuit. If, however, the feedback gains are too high, the system can oscillate. In this case, high frequency periodic noise appears in the image. This may occur throughout the image or be localised to features with steep slopes.

On the other hand, when feedback gains are too low, the tip cannot track the surface well. This is most obvious on steep edges. In the extreme case, the image loses detail and appears blurred and fuzzy.

A high or low sum signal due to high or low cantilever reflectivity also affects the feedback gain. If the reflectivity of the cantilever and therefore the sum signal is low, higher values of the feedback gain will be required.

For medium sum signals (e.g. 4 V), a P-GAIN value of 4 – 5 and an I-GAIN of about 2 are good initial values.

5.7 BEAM DEFLECTION MODULE

Connect the LEMOSA connector with the Segmented Photodiode Electronics at the front of the microscope.

Connect the T-B BNC connector with the IN connector of the P-I Feedback Controller Module.

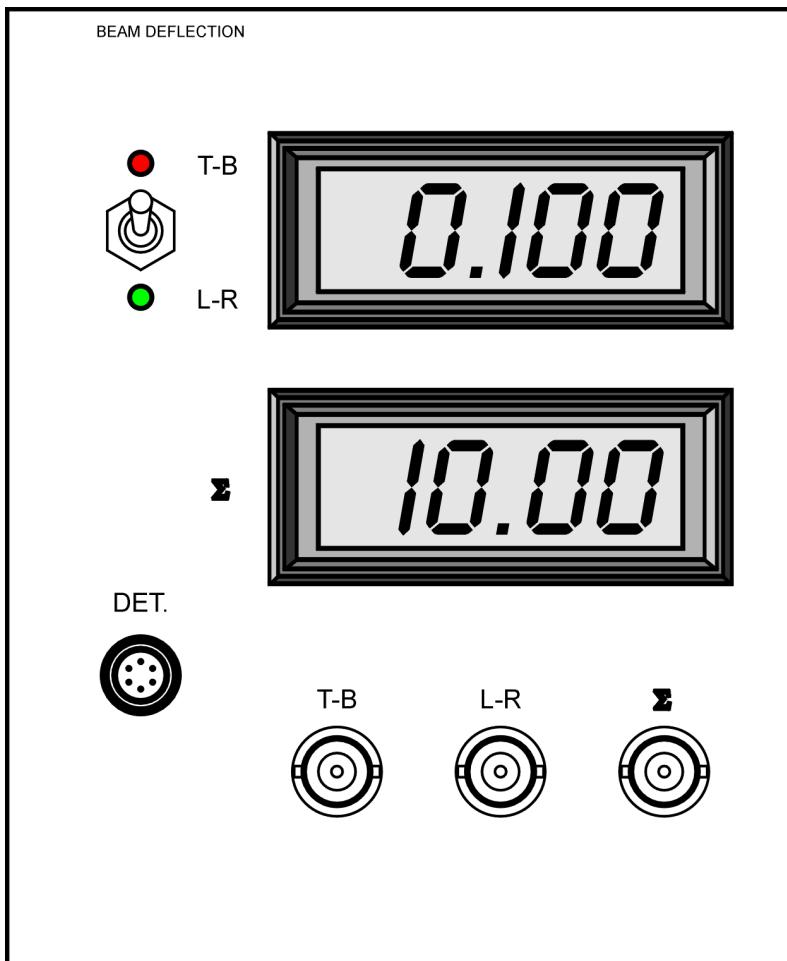


fig. 5.5: Beam Deflection Module

The Beam Deflection Module provides access to the signals of the segmented photodiode used for distance feedback in SNOM/AFM mode. In the microscope, a laser beam is focused onto the cantilever and the reflected signal is directed onto a segmented photodiode. During contact, the lever bends and the position

of the laser beam on the segmented diode changes. An electronic circuit close to the photodiode amplifies the photocurrent and provides a voltage proportional to the signals T-B (top minus bottom), L-R (left minus right) and Σ (sum of all four segments of the diode).

The LEMOSA connector provides the power for the photodiode circuit and feeds the amplified signals to the Beam Deflection Module.

The upper display shows either the T-B signal (switch up, red LED), or the L-R signal (switch down, green LED). The T-B signal is a voltage proportional to the light intensity on the top two segments minus the light intensity on the bottom two segments of the photodiode, whereas the L-R signal is a voltage proportional to the light intensity on the left two segments minus the light intensity on the right two segments. The lower display always shows the Sum signal, which is a voltage proportional to the light intensity on all four segments of the photodiode. The BNC connectors provide flexible access to these three signals.

For SNOM/AFM operation, the position of the cantilever and the photodiode are adjusted so that the Sum signal is maximum (between 2 V and 12 V, depending on the reflectivity of the cantilever), T-B is 0, 1 V, and L-R signal is zero. The T-B output is used for feedback and is therefore connected to the input (IN) of the P-I Feedback Controller Module. The Sum signal indicates whether there is enough light on the photodiode for stable feedback operation. If the Sum signal is too low (below ca. 1,5 V), the Automatic Approach will not start.

The L-R signal can be used to monitor the torsion of the cantilever and is proportional to the friction force between tip and sample. To record the friction force, connect the L-R output to any of the input channels on the backside of the control electronics and enable this channel in the channels menu of the ScanCtrl Spectroscopy Plus software.

5.8 SERVO MODULE

Connect the six cables of the capacitive positioning sensors of the scan table to the servo controller module. Each axis requires two cables: a yellow cable for the target sensor (labelled T), and a brown cable for the probe sensor (labelled P). Axes X, Y, and Z are labelled 1, 2 and 3 respectively. If you mix up probe and target, the sensor system will work, but not as accurately as specified.

For SNOM and AFM operation, switch servo 1 and 2 to the ON position and servo 3 to the OFF position.

For confocal operation, switch all three servos to the ON position.

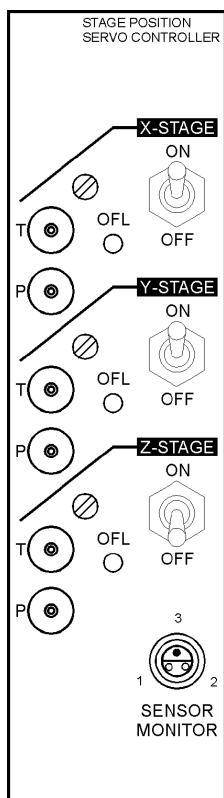


fig. 5.6: PZT-Servo
Module

The PZT-servo module in the WITec AlphaSNOM works in conjunction with capacitive sensors to drive the scan table with extreme precision in closed loop operation.

Piezo driven three axis scanners are widely used in SPM systems. They allow extremely accurate motion in the sub-nm range. The disadvantage of these systems is that piezos suffer from hysteresis and creep. The hysteresis (and therefore the position error) of piezo materials used in SPM can be as high as 20%.

To compensate for the piezo positioning errors, most AFM manufacturers use software correction algorithms. Software solutions in general are relatively simple and inexpensive to implement. Their primary disadvantage is that they compensate only partially for scanner nonlinearities. The corrections are dependent upon scan speed, scan direction, and whether the scanner was centred within its scan range during calibration. As a result, software corrections are most accurate only for scans that reproduce exactly the conditions under which the calibration was performed.

The only way to compensate for all positioning errors is to use hardware correction. This requires a sensor that accurately measures the scanner position and actively compensates for all piezo

errors.

Closed loop position control of piezoelectric driven stages offers stable drift-free and hysteresis-free movements, high virtual stiffness and long-term position stability. The key element for position servo control is the sensor measuring the stage position. The sensor's accuracy determines to a high degree the resolution and quality of the complete position control system. Therefore, high resolution sensors with appropriate evaluation electronics must be used to achieve optimum performance of the position control system. This is especially important when piezo systems with a large scan range are used, as in the WITec AlphaSNOM system. Compared with other sensor types, capacitive sensors provide excellent resolution, long-term and thermal stability.

Capacitive Sensors

The capacitance of a pair of parallel plates, called probe and target plate, depend on their distance from one another. Using this principle for high resolution position detectors requires complex signal processing electronics to satisfy the high demands in accuracy and stability. The probe and target plates, the signal conditioning electronics, and the connecting cables must be matched for best results. The unique integrated linearization system offers extremely high linearity over the full measurement range.

Measurement principle

The sensor probe and target plates form an air-capacitor. Its capacitance, which depends on the separation of both plates, is compared with an internal reference capacitor. Changes of the distance between the sensor plates cause a change in capacitance, which is analyzed by the signal processing electronics.

Resolution

The resolution of a capacitive sensor is limited by electronic noise. The connecting cables (length and path) may also influence the noise. Precision manufacturing and mounting of the sensor plates prevents non-linearities.

The PZT-Servo Controller Module provides a linearization circuit to compensate for heterogeneities in the electrical field. The influence of mechanical errors (plate

parallelism) is also compensated to the first order.

The sensor processing module, in conjunction with the special linearization circuit, ensures very good linearity, low background noise, and excellent long term stability.

Closed loop position control

The Servo Position Control Module includes a position control board that compares the control voltage input and the sensor reference signal to generate an amplifier control signal. The P-I circuit is optimized for fastest response. An additional notch filter suppresses mechanical resonances. A feed-forward circuit is installed for extended dynamic response. This circuit feeds a portion of the control signal directly to the controller output. The advantage is a shorter rise time and therefore a higher cut-off frequency.

For SNOM/AFM operation, the servos for X and Y should be in the ON position, while Z should be OFF. This ensures the most linear motion in X, and Y directions. The Z servo must be OFF, because the Z position is controlled with the Beam Deflection Module. This controls the motion of the Z piezo via the force acting on the cantilever, regardless of any piezo nonlinearities. The exact piezo motion is supplied at the Zoutput BNC of the scan position display module.

For confocal operation, all three servos should be in the ON position. This ensures a linear scan in X and Y direction and avoids drift in Z direction.

The scan table provides a range of $100x100x20\mu m^3$ ($200x200x20\mu m^3$ optional), a resolution of $1,5 nm$ in XY direction and $0,3 nm$ in Z direction. Typical non-linearity is 0,03%.

5.9 LVPZT AMPLIFIER MODULE

For AFM/SNOM operation: Connect the Z control input of the LVPZT amplifier module to the OUT BNC of the feedback controller module and turn DC-OFFSET potentiometer fully counter-clockwise.

For Confocal operation: Disconnect the Z control input of the LVPZT amplifier module and turn C-OFFSET potentiometer until the Z-position reading at the stage position display shows about $10 \mu\text{m}$.

Connect the three PZT-voltage output channels to the scan table.

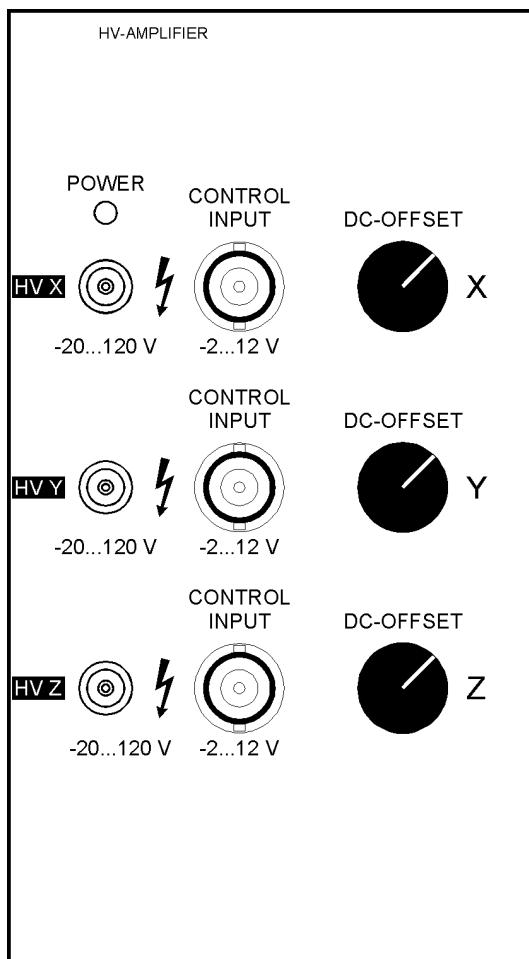


fig. 5.7: LVPZT Amplifier Module

The LVPZT Amplifier Module is a three channel amplifier for low voltage PZTs. The module is designed to work in conjunction with the capacitive sensor feedback module and the three axis scan table.

It contains three independent amplifiers that can provide an average current of 60 mA . It can be used for static and dynamic operations providing a peak current of 140 mA for some ms, allowing fast PZT expansion.

The output voltages can be controlled either manually via 10-turn offset potentiometer, or by analogue input signals. For scanning operation, the DC-OFFSET of channels X and Y should be Zero (turn DC-OFFSET potentiometer fully counter-clockwise). During scanning, the output channels X and Y of the data acquisition board will control the movement of the scan table by delivering a 16 bit analogue output voltage between 0 and 10 V. This voltage is amplified by the LVPZT-Amplifier Module and supplied to the scan table.

5.10 STAGE POSITION DISPLAY MODULE

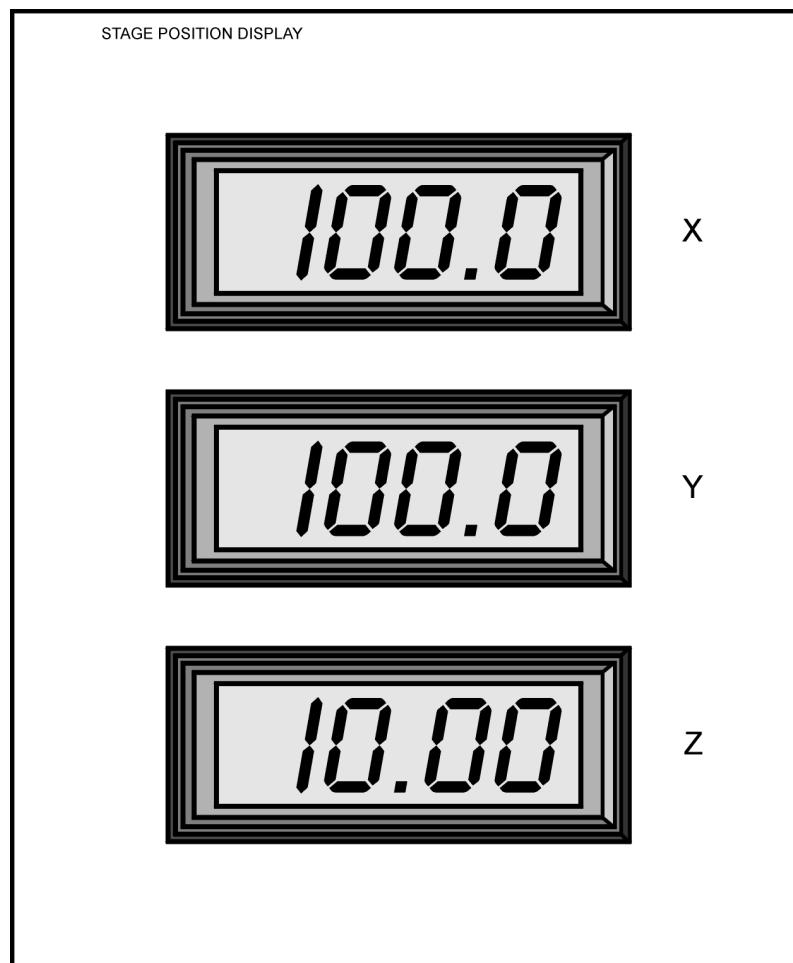


fig. 5.8: Stage Position Display Module

The Stage Position Display Module shows the X, Y, and Z position of the scan table in microns. Scan direction:

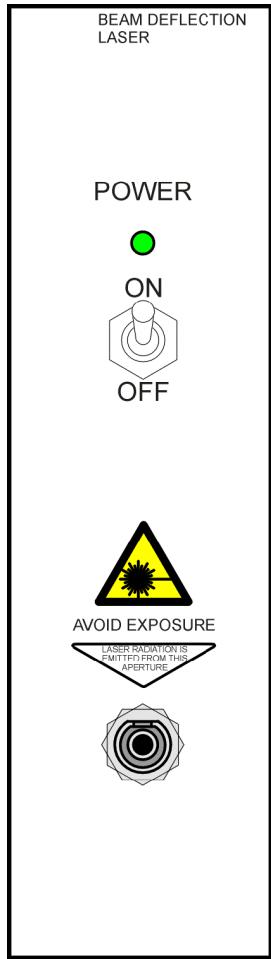
X: from left to right

Y: from front to back

Z: from bottom to top

5.11 BEAM DEFLECTION LASER MODULE

Use the FC-style single mode fibre patch cable to connect the output of the beam deflection laser module to the input of the beam deflection unit of the microscope.



The beam deflection laser module utilizes an internally-pigtailed laser diode that is connected to the front panel FC feedthrough via a single mode optical fibre.

The standard laser wavelength is 980 (± 15)nm. If this wavelength interferes with your experiments, other wavelengths are available on request.

The laser diode can be switched off, for instance when the system is used in confocal mode. The LED indicates whether the laser is turned on or off.

The laser power is factory adjusted.

fig. 5.9: Laser Module

Please read and follow the warnings and safety instructions of the Laser Safety Guidelines in the Appendix of this manual.

WARNING: BE CAREFUL, HARMFUL LASER RADIATION.
DO NOT REMOVE THE FIBRE.
DO NOT STARE INTO THE FC CONNECTOR WHEN THE LASER IS SWITCHED ON.
SEVERE DAMAGE TO YOUR EYES MAY RESULT.
DO NOT STARE INTO THE FIBRE. CLASS 3B LASER PRODUCT.

5.12 CONNECTOR MODULE

The Connector Module is located at the back-plane of the control electronics. Connect the analogue signals you want to measure to any of the signal inputs 2 – 5. The input channels accept voltages between $-10.. + 10\text{ V}$.

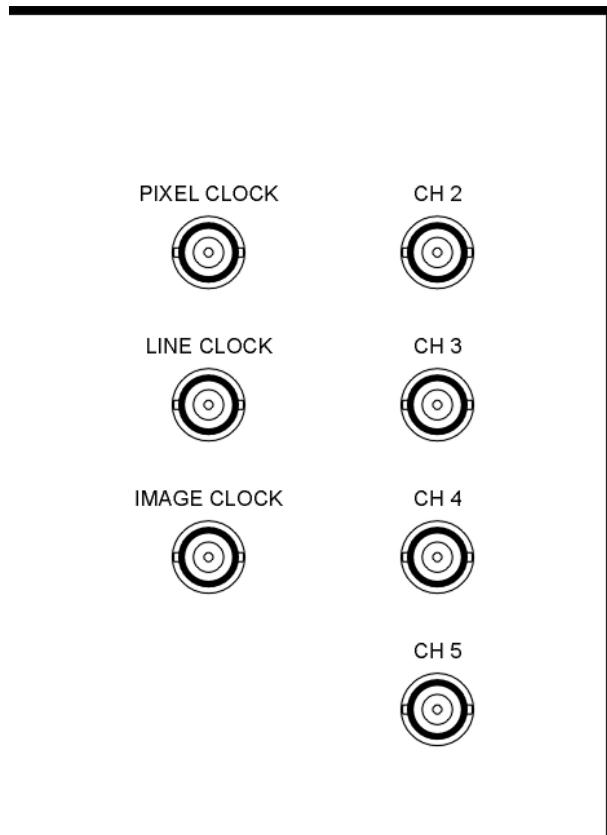


fig. 5.10: Connector Module

The connector module connects the input channels with the data-acquisition board in the PC. Additional to the topography (connected to channel 1 as default in AFM and SNOM operation) and the counter signal (connected to Channel 8 as default in Confocal and SNOM operation), up to 5 external signals can be acquired simultaneously during a scan. The 5 input channels accept voltages between $-10.. + 10\text{ V}$ and are sampled with 16 bit resolution. Make sure to enable the appropriate channel in the software.

Additionally, there are three digital outputs: pixel trigger, line trigger, and image trigger, which can be used to control and synchronise external devices (like a spectrometer) with the scan.

- The PIXEL output delivers a TTL pulse at every pixel.
- The LINE output delivers a TTL pulse at the start of every line.
- The IMAGE output delivers a TTL pulse at the beginning of every picture.

5.13 COUNTER MODULE

Connect the TTL output of the PMT (or optional APD) to the TTL input on the counter module.

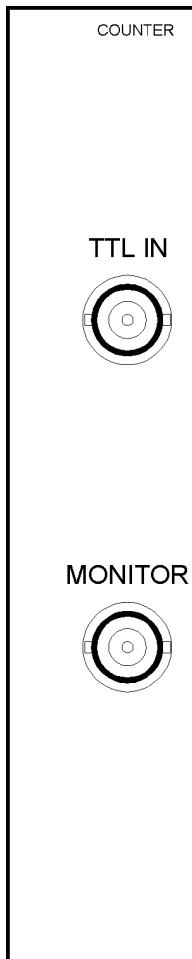


fig. 5.11: Counter Module

The counter module counts TTL pulses delivered by the PMT (or optional APD) to the input BNC connector, and converts them into an analogue output voltage. During a scan, the module is triggered by the internal pixel clock. This ensures that the counting signal is synchronized with the scan.

At the beginning of each pixel trigger, the counter is reset and starts counting. When it gets the next pixel trigger, the counter is stopped and the signal is converted into an analogue output signal. This analogue signal is read into data acquisition channel 8. The system can be equipped with up to three counter modules. When more than one counter module is installed, the analogue output of the additional modules are read to data-acquisition channel 7 or 6 respectively. Each module can be jumpered to channels 5 through 8.

Each counter can be configured to work as a 16 bit ($16\text{bit} = 65536\text{counts} = +10V$) or 12 bit ($12\text{bit} = 4096\text{counts} = +10V$) counter. This is done with two jumpers on the counter module and by choosing the appropriate software setting in the acquisition menu. Setting the counter to 12 bit might be useful to increase precision when detecting very low count rates (usually below 100 counts/pixel). The monitor output connector can be used to view the analogue output voltage on an external oscilloscope for alignment purposes.

WARNING: The counter will only work properly if it receives a pixel trigger. The pixel trigger is only enabled during a scan. For alignment purposes (without scanning), trigger pulses can be generated via the MEASURE-ADJUST menu in ScanCtrl Spectroscopy Plus. If this function is not enabled and you do not perform a scan, there will be no trigger pulses and the module will not count pulses. The output will instead show the last counted signal.

WARNING: Extreme care must be taken to not destroy the PMT/APD with excessive light. The maximum count rate for the PMT/APD is on the order of 10^7 counts/s , but in this range the output will be highly non-linear, the detector will produce excessive heat, and safe operation can not be guaranteed over a long period of time. For safe operation, the detector count rate should not exceed 10^6 counts/s for more than 1 minute. Remember that PMTs (and APDs) are extremely sensitive devices that count single photons with a quantum efficiency of 15% @ 400 nm (80% @ 600 nm). Exposing these detectors to daylight when powered on can easily destroy them. Always make sure that no intense light source (laser) is hitting the detector before activation.

At a trigger rate of 100 Hz, a 10^6 counts/s pulse rate translates to 10.000 counts/pixel , which gives a monitor voltage of 1,526 V ($10V/65.536 \cdot 10.000 = 1,526V$), if the module is configured to 16 bit. If the counter board is jumpered to 12 bit, the counter is 2 times overrun and the output will show 4,414 V ($10.000 - 2 \cdot 4096 = 1808/4096 \cdot 10V = 4,414V$). Therefore, it should be checked whether or not the output voltage of the counter board responds linearly to increasing/decreasing light intensity. When you see large jumps in the output signal, the counter may be overran and therefore starts at zero again.

5.14 OPTICAL MICROSCOPE COMPONENTS

1. microscope illumination
2. lens system
3. beamsplitter (50 : 50), housed in the reflector slider
4. dichroic beamsplitter ($T > 95\% @ \lambda = 325 - 850\text{nm}$, $R > 95\% @ \lambda = 980\text{nm}$)
5. objective lens system
6. cube beamsplitter (50 : 50)
7. tube lens ($f=163,5\text{mm}$)
8. sliding prism (100 : 0)
9. SMA fibre connector optical output
10. specimen
11. FC fibre connector optical input
12. achromatic lens
13. collection microscope
14. mirror
15. tube lens ($f=125\text{mm}$)
16. flip mirror
17. high sensitivity b/w video CCD camera
18. single photon counting detector (PMT or optional APD)
19. SMA fibre connector
20. SMA fibre connector feedthrough
21. cube beamsplitter (50 : 50)

22. edge filter
23. position sensitive photodiode
24. achromatic lens
25. FC fibre connector optical input
26. eyepiece colour video camera
27. cantilever
28. achromatic lens
29. achromatic lens
30. cube beamsplitter (50 : 50)
31. SMA fibre connector optical output
32. high sensitivity b/w video CCD camera

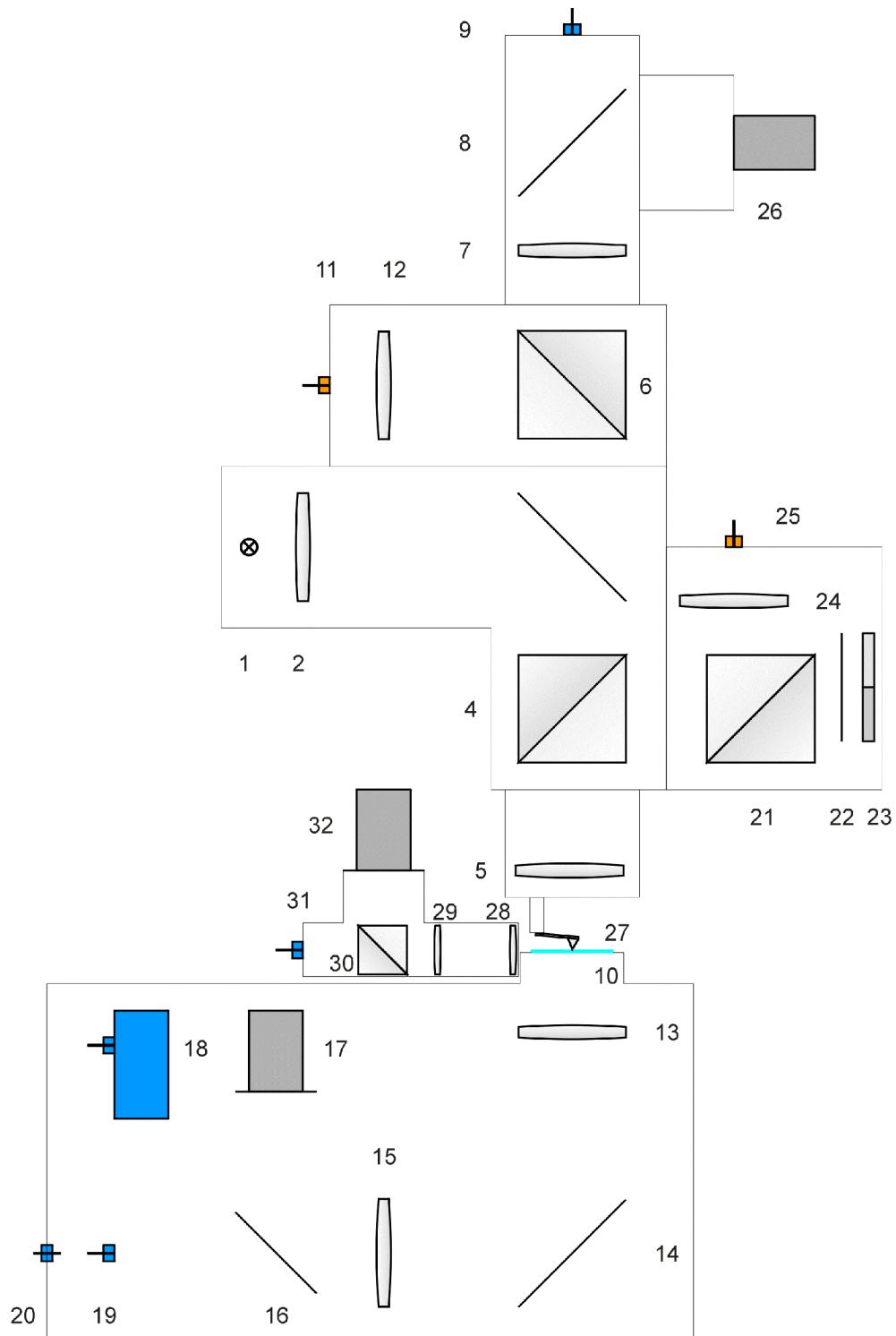


fig. 5.12: Optical components of the AlphaSNOM

5.15 FUNCTION CONTROLS OF THE MICROSCOPE BODY

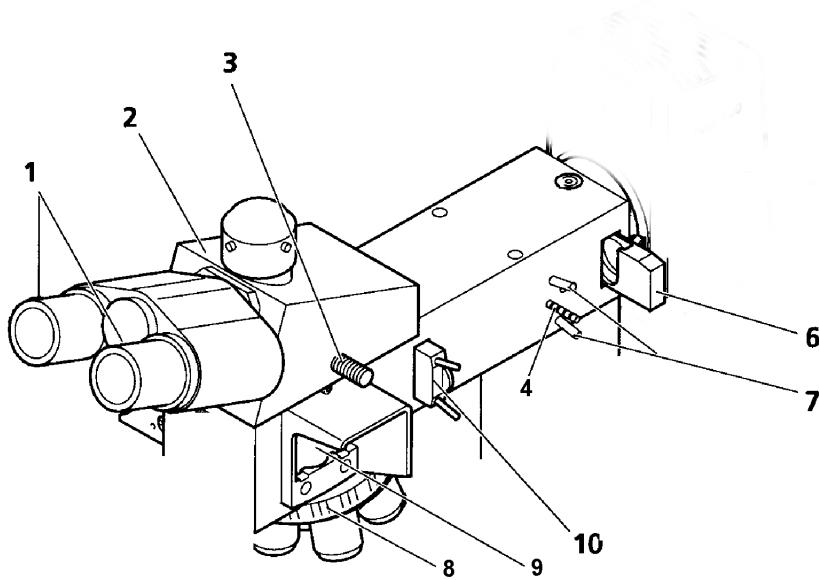


fig. 5.13: Microscope body

1. Tubes for colour video camera replacing the eyepieces (only one is used).
2. Binocular tube.
3. Push-rod for sliding prism, used for directing the light to either the colour camera or the fibre.
4. Push-rod for aperture diaphragm.
5. White light source (not shown).
6. Filter slider.
7. Centering screws for aperture diaphragm.
8. Objective turret.
9. Compartment for reflector slider.
10. Luminous-field diaphragm slider with centering screws and knurled wheel.

5.16 OBJECTIVES

In a typical configuration (configurations may vary) the AlphaSNOM comes with a set of 3 objectives (20x/0,4, ∞ /0,17, WD 3,8mm; 60x/0,8, ∞ /0,17, WD 0,3mm; 100x/1,25, ∞ /0,17, WD 0,18mm) for far-field reflection and one for transmission measurements (60x/0,8, ∞ /0,17, WD 0,3mm). The first number gives the magnification in the image plane (position of the colour video camera (26) or the multimode fibre (9)). The second number is the numerical aperture that describes the resolving power of the objective. The objectives are infinity corrected, which means that the beam is parallel inside the microscope. All objectives supplied as standard are corrected for use with a cover slip. That means they will give good results only when a cover slip of 0,17 mm thickness is used between objective and sample.

The WITec Near-field Objective for AFM/SNOM operation will be described in the next chapter.

To mount the objectives to the microscope, remove the dust covers inserted in the 5-position turret. The turret has M27x0,75 threads, so that new ZEISS objectives will fit without an adapter ring. The NIKON objectives supplied with the AlphaSNOM require the use of the supplied adapter rings (M26x0,75).

The AlphaSNOM works with any objective that is infinity corrected, but using objectives of manufacturers different than ZEISS or NIKON might require special adapter rings. Please contact WITec for additional information.

The magnification written on the objective gives the magnification in the image plane. A 100x objective will magnify a $1\text{ }\mu\text{m}$ spot to $100\text{ }\mu\text{m}$ at the position of the eyepiece camera (26) or the multimode fiber (9).

The magnification in the image plane is obtained by dividing the focal length of the tube lens by the effective focal length of the microscope objective. As every manufacturer uses a slightly different tube lens, the magnification printed on the objective is only correct, if a microscope body of the same manufacturer is used. As NIKON uses a tube lens with $f = 200\text{ mm}$, while ZEISS uses $f = 163,5\text{ mm}$, a 100x NIKON objective has an effective magnification of 82x when

used in a ZEISS microscope body. This difference can be corrected in the options menu of the VideoCtrl software. The magnification of the Near-Field Objective is 8x.

5.17 NEAR-FIELD OBJECTIVE



fig. 5.14: Microscope turret with SNOM-objective

For Scanning Near-field Optical Microscopy, the AlphaSNOM uses the Near-field-Objective. The Near-field-Objective has an 8x magnification and is used to focus the illumination, as well as the beam deflection laser onto the Cantilever-SNOM Sensors. The Near-field-Objective also incorporates a high precision XY-stage used to move the Cantilever-SNOM Sensors into the optical axis.

The micro-machined Cantilever-SNOM Sensors are magnetically fixed at the endcap of the Near-field-Objective.

The Cantilever-SNOM Sensors consist of a silicon cantilever with a hollow SiO_2 tip. Typical dimensions of the cantilever are 150 μm width, 700 μm length and 5 μm thickness. The pyramid has a typical base of 20 μm and a height of 15 μm .

The cantilever is Al-coated and has a nanoscopic hole at the centre of the pyramid which acts as the near-field aperture.

Typical diameter of the near-field aperture for visible wavelength applications is

less than 100 nm . Aperture sizes down to 50 nm and up to several 100 nm as well as different aperture geometries are available on request. Remember that the transmitted light intensity is strongly dependent on the ratio of wavelength to aperture. Reducing the aperture diameter by a factor of only two can reduce the transmitted light intensity by several orders of magnitude.

Please contact WITec if you need different apertures for your specific experiment.

The excitation laser (green in the schematic below) is focused into the back-side of the pyramid of the Cantilever-SNOM Sensor. A small portion of the light tunnels through the Near-Field Aperture and is used for near-field optical microscopy.

Distance control between tip and sample is accomplished using the beam-deflection principal:

A second laser (red in the schematic below) with a different wavelength is focussed onto the cantilever and the reflected signal is detected with a segmented photodiode. The force on the sample is proportional to the bending of the cantilever. If the bending of the cantilever changes, the position of the laser beam on the photodiode changes. This change in position is registered by the electronics and used to correct for the vertical position of the sample. The feedback electronics try to hold the bending of the cantilever (and therefore the force onto the sample) fixed during the scan.

In the standard configuration, the excitation wavelength can be chosen between 400 and 700 nm . To avoid interference with the SNOM measurement the feedback laser has a wavelength of $980 \pm 15\text{ nm}$. If you need to use an excitation wavelength above 900 nm , a beam deflection laser of 980 nm may cause problems with your experiments. For this reason, the AlphaSNOM can be equipped with feedback lasers of different wavelengths (e.g. 635 nm or 785 nm). In this case, please contact WITec to discuss your application requirements.

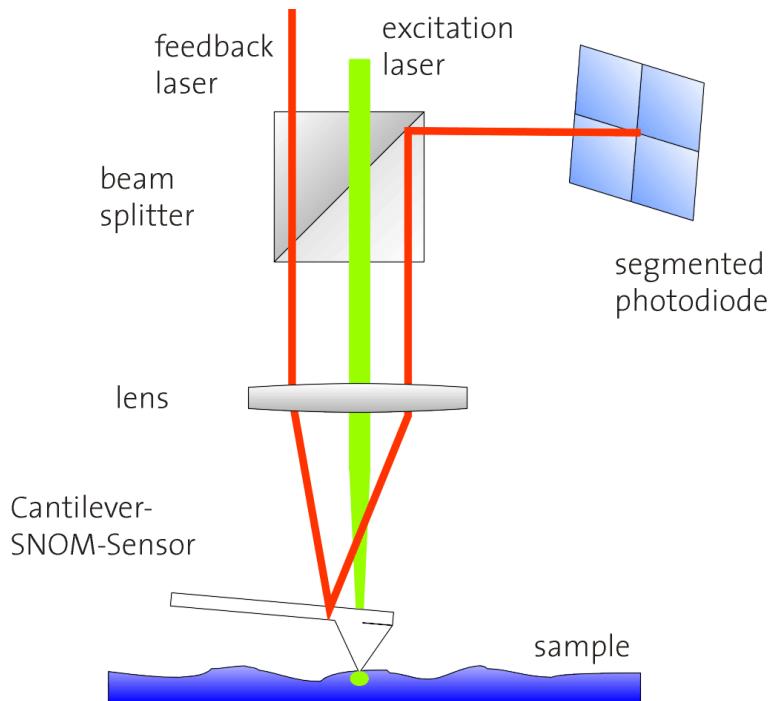


fig. 5.15: Distance feedback with Cantilever-SNOM sensors

The Near-Field Objective allows one to align the tip of a Cantilever-SNOM Sensors in X, Y and Z. In X and Y a two-axis translation stage is used to move the tip with respect to the excitation laser beam.

Focus is adjusted by turning the knurled black ring at Near-Field Objective. Turn the ring until the cantilever appears focused.

In case the XY-stage adjustment screws are in an inconvenient position, loosen the three screws in the adapter ring and turn the complete Near-Field Objective until the adjustment screws are in a more convenient position.

The excitation laser is aligned in the optical axis, while the beam deflection laser is shifted by about $100 \mu\text{m}$ with respect to the excitation laser.

The complete Near-field-Objective is mounted in one socket of the 5-position turret using an adapter ring.

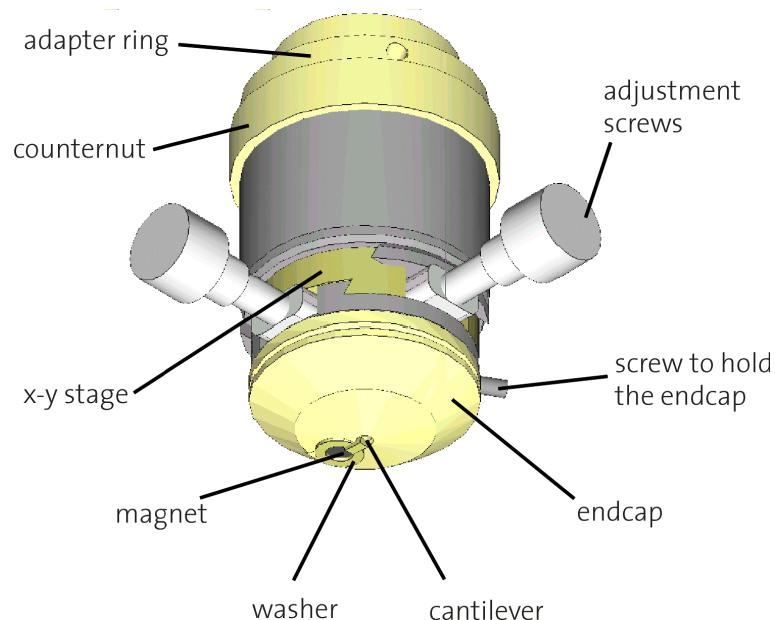


fig. 5.16: SNOM objective

The endcap can be removed from the objective housing for cantilever change by loosening a single set screw. The cantilevers are glued onto washers. The washers are held by the magnet of the endcap. This ensures easy cantilever handling and exchange.

By simply turning the turret of the microscope the operator can easily change from confocal microscopy (using standard microscope objectives) to Scanning Near-Field Optical Microscopy (using the Near-field-Objective) and vice versa. Using standard AFM-cantilevers instead of Cantilever-SNOM Sensors the AlphaSNOM is a fully working Atomic Force Microscope (AFM) with high quality optical access. Besides *Contact Mode*, other AFM modes like *AC-Mode*, *Pulsed Force ModeTM*, *Magnetic Mode* etc. are available as an option.

5.18 BINOCULAR TUBES

The AlphaSNOM has binocular tubes that provide an upright image and a sliding prism (light splitting camera : detector 100 : 0/0 : 100) that directs the light either to the colour eyepiece video camera or the detector (via multimode optical fibre) as a standard feature of the microscope.

For laser safety reasons, a colour video camera is used instead of standard eyepieces. The video camera slides into one binocular tube. The second tube is closed for safety reasons.

The video camera has a small mark which has to point downwards for proper image orientation. This orientation is crucial for SNOM/AFM operation.

NEVER REMOVE THE PROTECTIVE CAP AND LOOK INTO THE LASER BEAM. SEVERE EYE DAMAGE MAY RESULT.

5.19 PHOTOMULTIPLIER

The Hamamatsu H6240 series photon counting photomultiplier (PMT) used in the standard configuration of the AlphaSNOM incorporates a PMT, a high speed amplifier, a discriminator and a high voltage power supply circuit in a single housing. The H6240-01 (used as standard) has a higher sensitivity in the range from 400 – 800 nm (see figure below), but at the cost of a slightly higher dark count rate. The H6240 can be ordered for applications where lowest dark count rate is necessary and detected wavelengths are always below 500 nm (see figure below). The H6240-02 is not recommended due to its high dark count rate (> 400 cps). If higher sensitivity is needed or low signals above 500 nm are to be detected, a photon counting APD can be ordered as an option.

Specifications

Parameter	Description/Value	Unit
Effective Area	4 x 20	mm
Spectral Response Range	185 to 680 (H6240) 185 to 850 (H6240-01)	nm
Dark Counts	30 typ., 80 max. (H6240) 80 typ., 200 max. (H6240-01)	cps
Counting linearity at –10% deviation from linear output	2, 5	Mcps
Pulse Pair Resolution	35	ns
Output Pulse Width	30	ns
Output Logic	TTL, positive	
Input Voltage	+4, 5.. + 5, 5	V DC
Operating Temperature	+5.. + 40	C
Storage Temperature	-20.. + 50	C

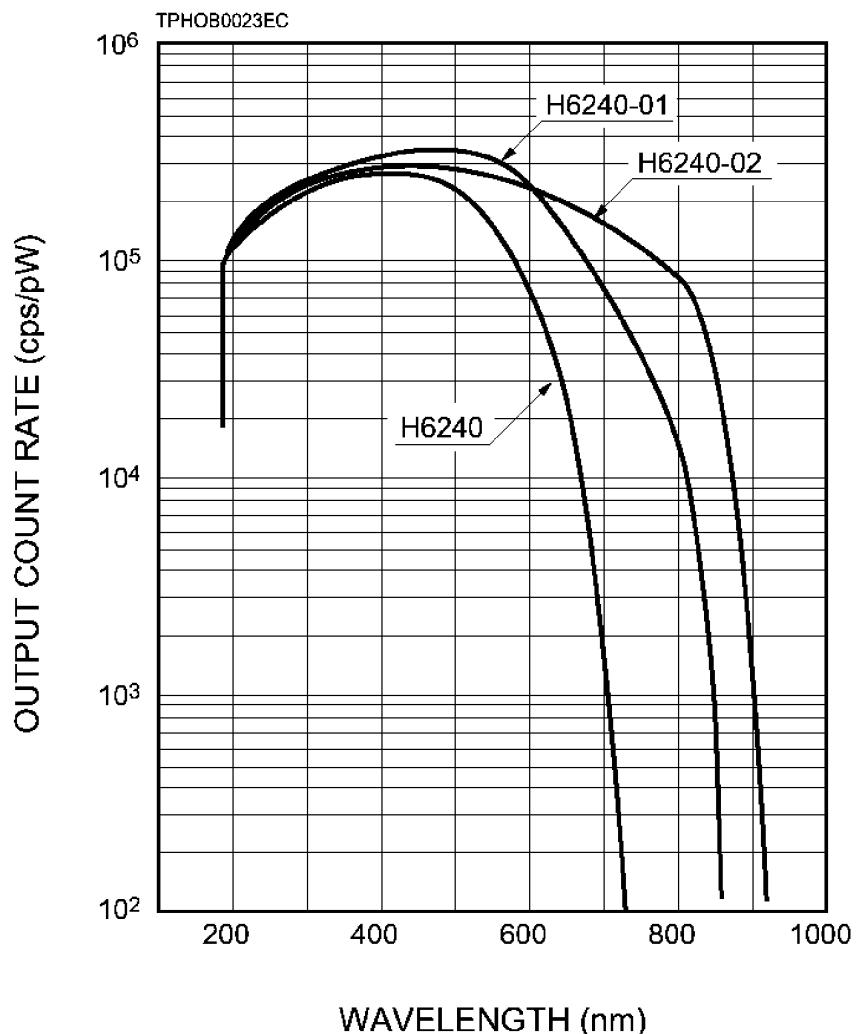


fig. 5.17: Output count rate versus wavelength for H6240 series photon counting photomultipliers

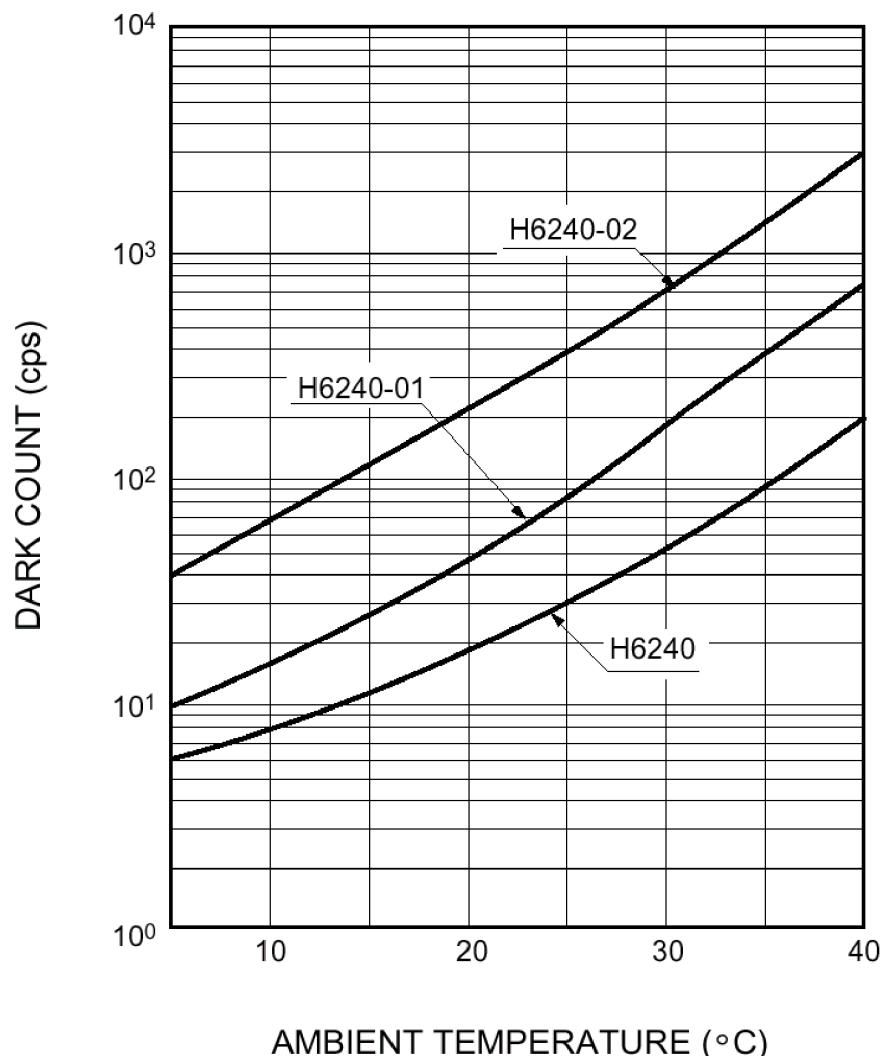


fig. 5.18: Dark count rate versus temperature for H6240 series photon counting photomultipliers

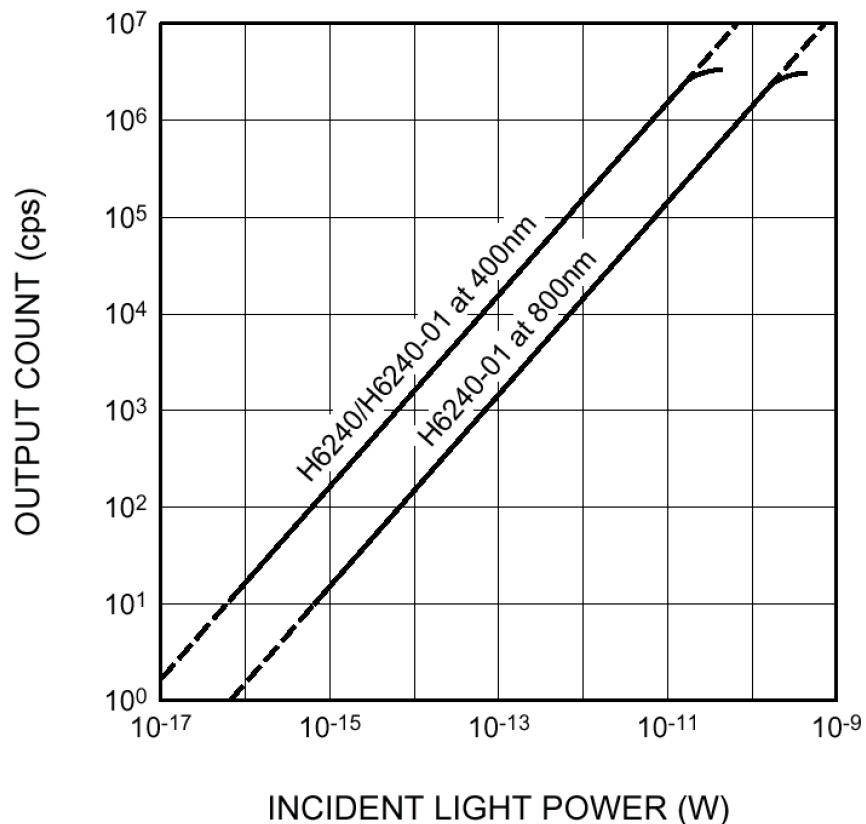


fig. 5.19: Linear/Dynamic Range for H6240 series photon counting photomultipliers

Note: When connecting the photon counting H6240 series PMT to an external commercially available counter with a TTL input, use a $50\ \Omega$ termination resistor or a $50\ \Omega$ feed-through termination.

5.20 AVALANCHE PHOTODIODE (optional)

The SPCM-AQR Avalanche Photodiode Detector (APD) is a self-contained module which detects single photons over the wavelength range from 400 nm to 1060 nm . It utilizes a unique silicon APD which has a circular active area whose peak photon detection efficiency over a $0,17\text{ mm}$ diameter exceeds 55% at 633 nm . This sensitivity and wavelength range easily outperforms every commercially available PMT detector at wavelengths above 500 nm . A photon counting APD is the most sensitive detector in the world at wavelengths between $500 - 1000\text{ nm}$. Therefore, the SPCM-AQR APD is recommended for applications involving extremely low light levels such as single molecule fluorescence detection.

The photodiode is both thermoelectrically cooled and temperature controlled, ensuring stable performance despite changes in the ambient temperature. The SPCM-AQR utilises an improved "active quench" circuit which can count to speeds exceeding 10 million counts per second.

The SPCM-AQR Avalanche Photodiode Detector contains a high voltage power supply. All internal settings are preset. There are no user adjustments. Units which appear defective or have suffered mechanical damage should not be used because of possible electrical shorting of the high voltage power supply.

Saturation

At higher incoming light levels, the count rate levels out and then decreases as light levels continue increasing. The point at which the output rate levels out is called the saturation point. As an extreme example, if the module is exposed to too much light, the count rate will fall to zero. Consequently, in certain applications, some tests should be performed by the operator to ensure that a low count rate is not caused by detector saturation.

Some precaution should be taken to avoid any excessive light level that will damage the SPC module.

Fibre Connector Input

The SPCM-AQR Avalanche Photodiode Detector has a standard FC fibre connector prealigned to the optical detector. An appropriate optical fibre with an FC connector on one end and a SMA connector on the other is included.

Gating Function

A gating function is provided with each module. It is useful when looking for a signal that occurs only within a small time window. Also, in some applications the background light flux is higher than the signal. In this case, the gating option could be used to improve the S/N ratio by opening a window only when the light signal is present. The detector is disabled when a "low" level is applied to the gate input (see specification table for the threshold level).

When the AlphaSNOM detector is switched OFF, only the SPCM gate input is shorted. Power is still applied to the SPCM Peltier cooler and high voltage circuitry as long as the Connector Rack is on.

Dark counts

In the dark the APD generates random counts that follow a Poission distribution. In a Poissonian process the standard deviation (s) is equal to the square root of the average counts. The variation in average dark count rate at a constant case temperature of $25^{\circ}C$ is max. $\pm 1\sigma$.

The APD dissipates a mean power of $2,5 W$, and a maximum power of $10 W$ at high count rates and $40^{\circ}C$. Adequate cooling must be provided by clamping the module to a suitable heat sink via the holes in the module base as it is done in the factory setup of the AlphaSNOM. To achieve the specified performance, the module case temperature must not exceed $40^{\circ}C$.

The APDs are not qualified for shock or vibration other than normal instrumentation environments.

	min.	typ.	max.	unit
supply voltage (1,9 A max., 0,5 A typ.)	4,75	5,0	5,25	V
case operating temperature	5		40	C
case storage temperature	5		50	C
active area (diameter)	0,170	0,180		mm
photon detection efficiency				%
@400 nm	2,0	5,0		
@630 nm	55	70		
@830 nm	40	50		
@1060 nm	1,0	2,0		
dark counts		50	100	cps
single photon timing resolution		300		ps
dead time		40	50	ns
count rate before saturation	10	15		Mcps
linearity correction factor				
@200 kcps		1,01		
@1 Mcps		1,08	1,15	
@5 Mcps		1,40	1,67	
after pulsing probability	0,15	0,30		%
settling time after power up (1% stability)	15	30		s
threshold setting for digital out	0,75	1,0	2,0	V
pulse width		25		ns
gating turn on/off				
disable = TTL low		2	4	ns
enable = TTL high		45	55	ns
Gate threshold voltage				
low level (sink current > 90mA)	0		0,4	V
high level (sink current > 90mA)	3,5		5,25	V

Table 5.1: APD specifications and technical data

Connection to incorrect voltage or reverse voltage may destroy the module.

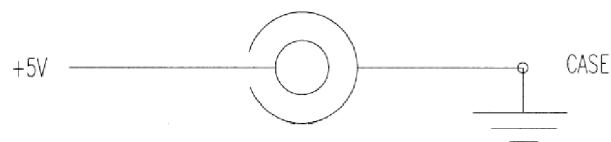


fig. 5.20: APD power connector polarity

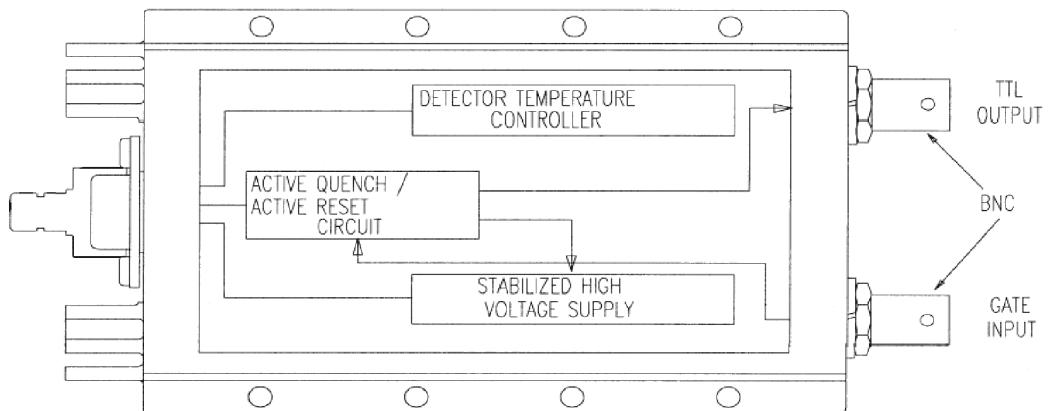


fig. 5.21: APD setup

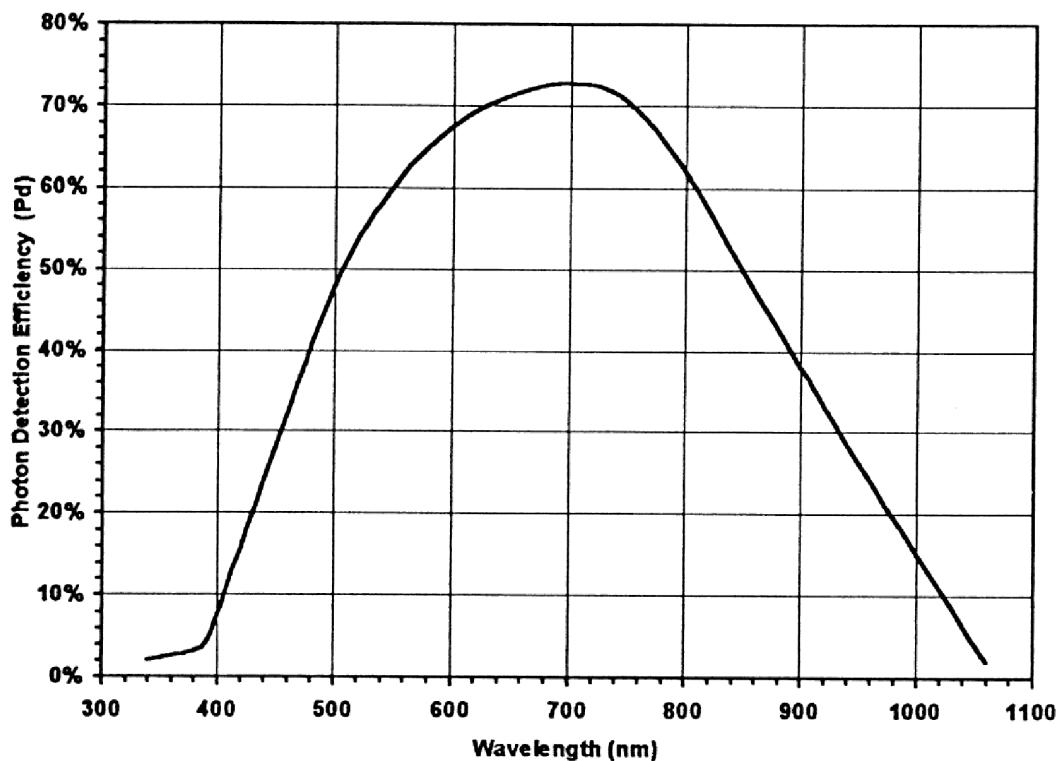


fig. 5.22: APD photon detection efficiency

