Titan – Condenser manual

Table of Contents

1   Introduction

This is the user manual for the condenser system of Titan with software version 1.0 (or higher).

Users who do not like reading manuals only need to read Section 2.1. That section discusses how to set the basic modes of the condenser. Sections 2.2 and 2.3 discuss how to make modifications to these settings.

Chapter 3 has been written for users who like to know the optics of the condenser. It sketches the beam paths for all modes and how the paths change when the beam parameters are varied.

Chapter 4 provides background information on parallel illumination. Parallel illumination is characterized by its coherence and by its amount of remaining convergence or divergence. The chapter discusses how these vary with the different condenser modes. This chapter can help the advanced user to optimize his illumination.

Chapter **Error! Reference source not found.** lists the alignment procedures. This chapter is intended as a reference. When the microscope is properly aligned, the user will not need much of this section.

Chapter 6 gives answers to some frequently asked questions. It is worthwhile to read this chapter because it touches some issues which could not be placed in a natural way in the other chapters.

Note: Alignments are not covered in this manual. Pelase refer to the seperate align.pdf file.

2   Titan User Interface

2.1   Beam Settings
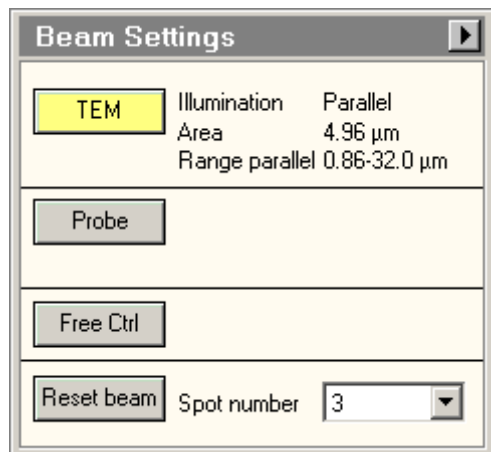
The Beam Settings Control Panel.

The illumination on the microscope is controlled through the 'Beam Settings' control panel and its flap-outs.

TEM
Select this mode if you want to do normal TEM imaging. The size of the illuminated area is indicated to the right of this button. The illuminated area is changed with the Intensity knob on the left hand control pad. The illumination is parallel when the illuminated area is within the range indicated to the right of the 'TEM' button. The area and range are directly proportional to the size of the C2 aperture. For example, when the C2 aperture is changed from 50 um to 100 um, the area and range are doubled.
When the illuminated area is smaller than the minimum of the range of parallel illumination, then the illumination system automatically switches to 'condensing mode'. In this mode, the beam is slightly converging towards the sample.
When the illuminated area is larger than the maximum of the range of parallel illumination, then the illumination system automatically switches to 'spreading mode'. In this mode, the beam slightly diverges towards the sample.
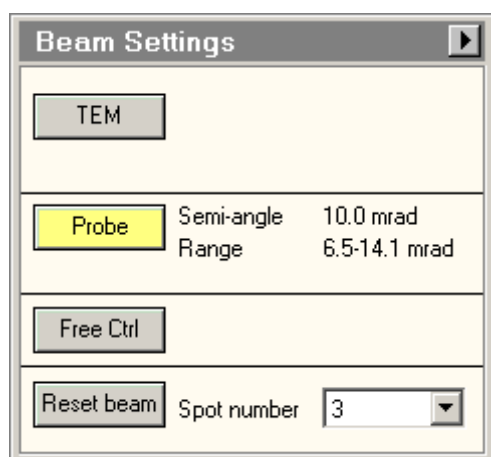
Probe
Select Probe if you want to have a focused probe on the sample, for example for STEM, EDX, EELS, or CBED. The semi-convergence angle of the probe is indicated on the right of this button. The focus of the probe is controlled with the Intensity knob on the left hand control pad (except when the microscope is in STEM mode, then it is usually controlled with the Focus knob on the right hand control panel).

The default semi-convergence of 10 mrad is optimum for most Titans without Probe Cs-corrector. The semi-convergence angle can be varied in the Tune flap-out. The range of convergence angles is indicated on the right of the 'Probe' button. The semi-convergence and range are directly proportional to the size of the C2 aperture. For example, when then the C2 aperture is changed from 50 um to 100 um, the semi-convergence angle and range are doubled.

Free Ctrl
Select Free Ctrl if you want to illuminate the sample in a way that is not covered by the two basic modes TEM and Probe. When the Free control mode is selected, the Free Ctrl flap-out automatically opens. This flap-out contains several more options for adjusting the illumination.

Reset beam
Press Reset Beam to set the user-shift (normally set with the left-hand trackball) and user-defocus to zero. This helps to find the beam when it is lost.

Spot number
The beam current is controlled with the Spot number setting. Spot number 1 has the highest beam current, and spot number 11 has the lowest beam current. With each step, the beam current reduces by about a factor of two.
With a monochromator further spot numbers are available in filtered mode. These spots are selected in the Tune flap-out.

Flap-out
The flap-out button leads to the Tune and Free Ctrl tabs of the Beam Settings Control Panel.

2.2   Beam Settings Tune
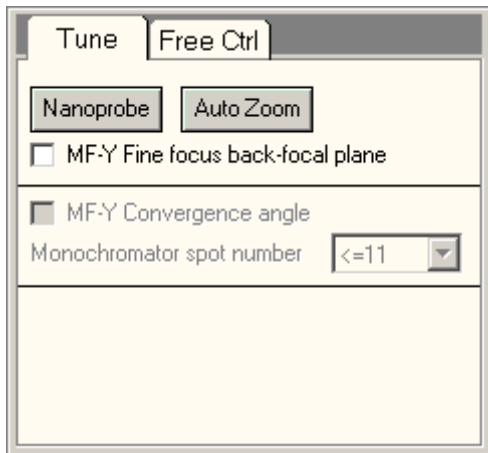
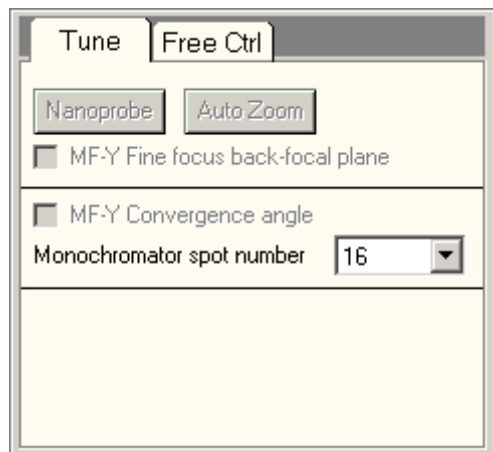*The Beam Settings Tune Control Panel in TEM mode.*

Nanoprobe
By default, the TEM illumination uses the Microprobe setting. Press Nanoprobe to switch the TEM illumination to the Nanoprobe setting (this switches the minicondenser lens off). The minimum and maximum area that can be illuminated with a parallel beam in Nanoprobe are five times smaller than in Microprobe. However, when the illuminated area is outside the range of parallel illumination, so when the illumination system has switched to condensing mode or spreading mode, then the beam converges or diverges five times stronger in Nanoprobe than in Microprobe. Therefore, it is advised not to use Nanoprobe in combination with condensing mode or spreading mode.

Auto Zoom
When Auto Zoom is on, the size of the illuminated area automatically scales with the magnification.

Fine Focus Back-focal Plane
Select MF-Y Fine Focus Back Focal Plane to fine-tune the position of the diffraction pattern at the objective aperture. When selected, the Multifunction-Y knob controls the position of the diffraction plane. In normal use, this needs seldom to be changed.

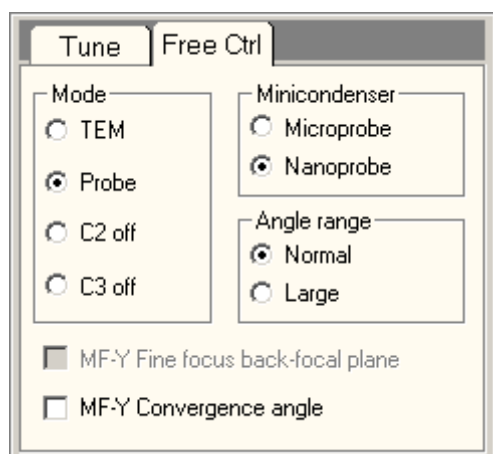*The Beam Settings Tune Control Panel in Probe mode.*

Convergence angle
When MF-Y Convergence angle is selected, the semi-convergence angle of the probe can be varied with the Multifunction-Y knob.

Monochromator spot number
When the monochromator is in Filtered mode, further spot numbers than 11 (up to 17) can be selected. When these spots are to be used, the C3 aperture is used as the beam-defining aperture (instead of C2) and the C2 lens acts optically as an additional C1 lens. The normal C2 function (focusing/defocusing the beam) is switched to C3.

2.3   Beam Settings Free Ctrl

The Beam Settings Free Ctrl Control Panel.

The Free Control flap-out automatically opens when the Free Control mode is selected in the Beam Settings control panel. When the user switches from TEM or Probe to Free Control mode, the illumination does not change. The main difference is that several additional options become available.

When the user switches back from Free Control to TEM or Probe mode, the illumination is set back to fit within the restricted range of options available in these two main modes.

Mode
The mode option controls how the C2 and C3 lens are set. The TEM and Probe modes correspond to the TEM and Probe modes in the main Beam Settings control panel.
In the modes "C2 off" or "C3 off", the second or third condenser lens is set to zero and the condenser column behaves as a two-condenser system (very much comparable to the Tecnai and CM microscopes). Normally, the "C2 off" and "C3 off" modes will be seldom used. They may be helpful to circumvent problems when the condenser lenses have become misaligned for some reason. In the "C2 off" mode, the Intensity knob controls the C3 strength and the C3 aperture must be used to limit the beam. In the "C3 off" mode, the Intensity knob controls the C2 strength and the C2 aperture must be used to limit the beam.

Minicondenser
Normally, the TEM illumination uses the Microprobe setting (minicondenser lens on) and Probe illumination uses the Nanoprobe setting (minicondenser lens off). In Microprobe, the illuminated area and probe size are five times larger than in Nanoprobe. The convergence angle in Microprobe is five times smaller than in Nanoprobe.

Angle range
The angle range option is only available in Probe mode. When the user switches from normal range to large range, the C2 and C3 lenses get strongly excited and an additional intermediate image of the source is created between the C2 and C3 lens. This gives optically more flexibility, resulting in a larger range of convergence angles. This mode is especially suited for LACBED (large angle convergent beam electron diffraction). However, the strong excitation of the C2 and C3 lenses also gives more spherical aberration, especially at small convergence angles where it can contribute up to 0.3 mm to the total spherical aberration of the objective lens. Therefore, in order to obtain a very low convergence angle in probe mode, it is better not to switch to the large angle range, but instead to switch to Microprobe setting.

Fine Focus Back-focal Plane
Select MF-Y Fine Focus Back Focal Plane to fine-tune the position of the diffraction pattern at the objective aperture. When selected, the Multifunction-Y knob controls the position of the diffraction plane. In normal use, this needs seldom to be changed.

Convergence angle
When MF-Y Convergence angle is selected, the semi-convergence angle of the probe can be varied with the Multifunction-Y knob.

3   Optics

The Titan microscope has six lenses in the illuminating system, namely the gun lens, the first condenser lens (C1), the second condenser lens (C2), the third condenser lens (C3), the minicondenser lens (MC) and objective lens (Obj). The main function of these lenses is summarized in the following table.

Function	Name	Lens
Beam current/Probe size	gun lens	gun lens
	spot number	C1-C2 zoom
Beam width/Beam convergence	Aera/Semi-angle	C2-C3 zoom
Parallel beam/focused beam	TEM/Probe	C3
Compensate upper objective lens	Microprobe/Nanoprobe	minicondenser
Probe forming		upper objective lens

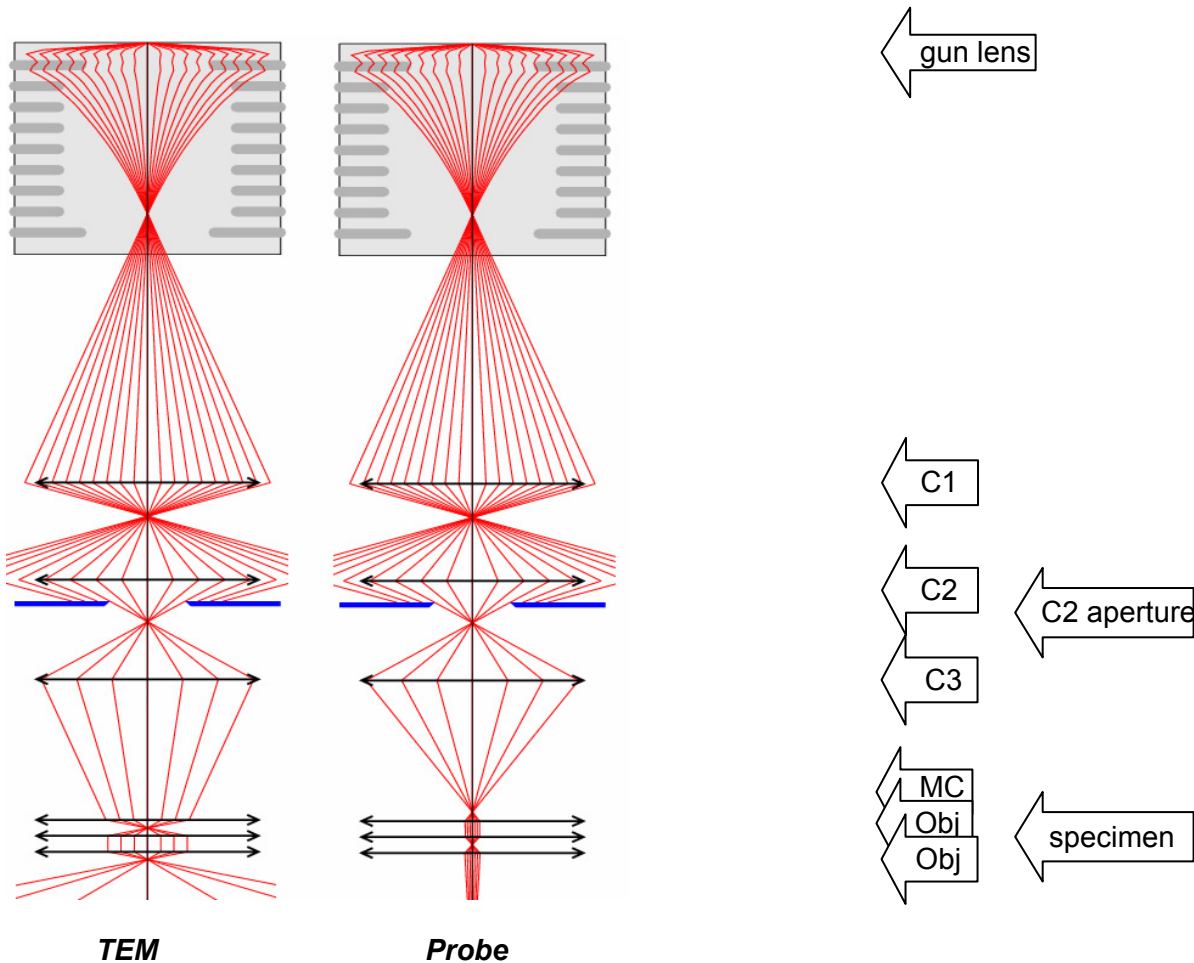## 3.1   TEM/ Probe

TEM   *Probe*
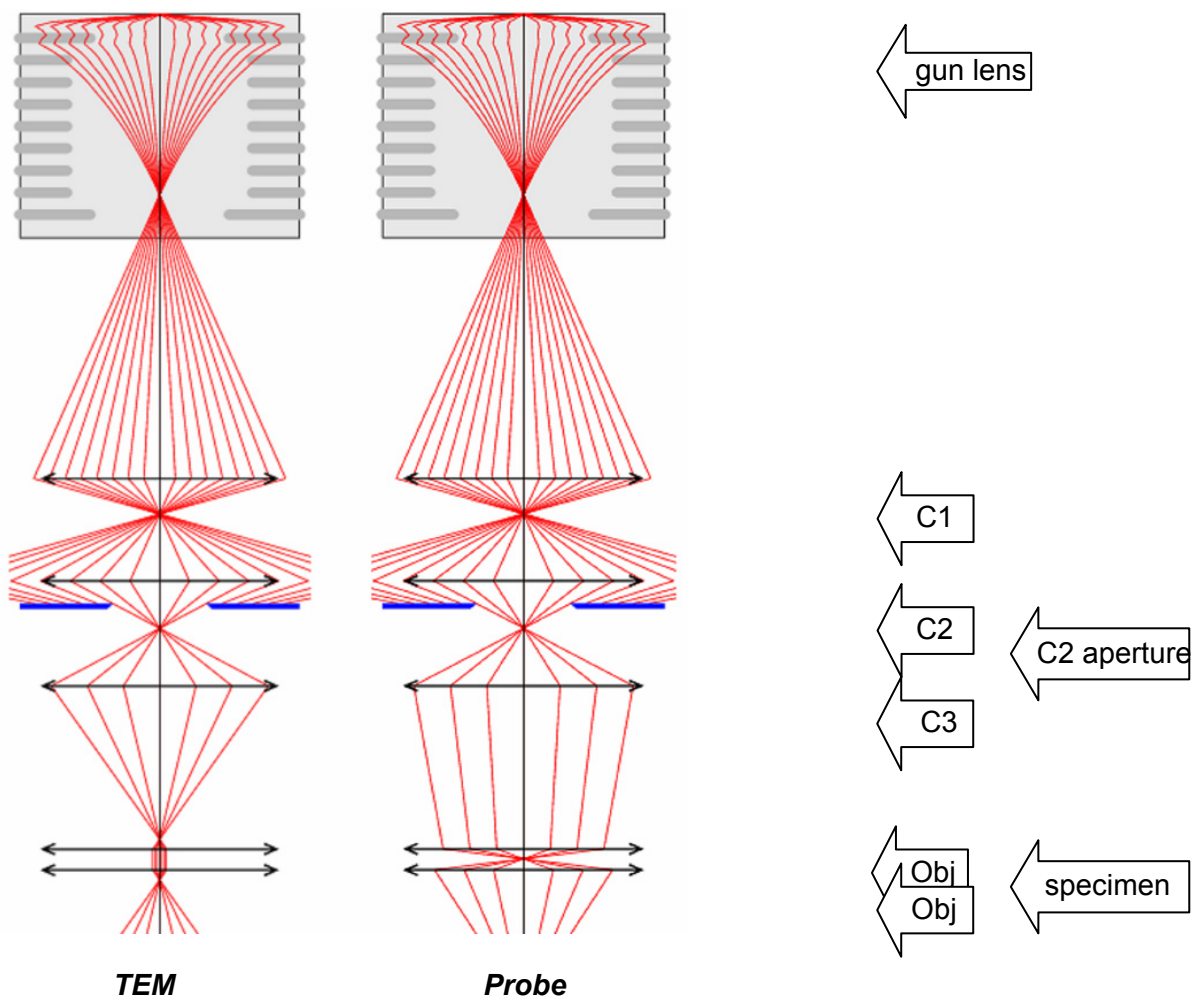
The two basic settings of the condenser column (in nanoprobe).
Left: parallel illumination for TEM. Right: probe illumination for analysis or STEM.

The figure above shows the two basic settings of the condenser column. The first setting is the TEM mode, in which the beam on the specimen is parallel. Here, the C3 lens images the source on the front focal plane of the upper objective lens. The second setting is the probe mode, mainly intended for STEM and for EDX or EELS analysis. Here, the C3 lens forms a beam which enters the upper objective lens roughly parallel.

3.2   Microprobe/ Nanoprobe

The specimen is in the middle of the magnetic field of the objective lens, and therefore the objective lens acts on the beam below the specimen as well as on the beam just above the specimen. These two actions are usually called the upper objective lens and the lower objective lens. The upper objective lens is essential for STEM, but the upper objective lens makes it difficult to get good TEM illumination, especially for very large areas and for very small areas (this is explained in more detail in Section 4.2.4).

In order to improve the TEM illumination of very large areas and of very small areas, a minicondenser lens is added just in front of the upper objective lens. When this lens is switched on, it compensates largely the upper objective lens. This is sketched in the figure below.

TEM   **Probe**

The two basic settings of the condenser column (in microprobe).
Left: parallel illumination for TEM. Right: probe illumination for analysis or STEM.

In TEM mode, the parallelly illuminated area is five times larger when the minicondenser lens is on than when it is off. Similarly, in Probe mode, the convergence angles are five times smaller when the minicondenser lens is on than when it is off. Also, in Probe mode, the focused probe is larger when the minicondenser lens is on than when it is off. For these reasons the setting with minicondenser lens on is called microprobe setting, and the setting with minicondenser lens off is called nanoprobe setting.

TEM mode normally uses the microprobe setting and Probe mode normally uses the nanoprobe setting.

3.3   Gun lens

The gun lens is an electrostatic lens positioned directly behind the field emitter and extractor. The user can choose eight settings for this lens (called gun lens 1 to 8). The figure below sketches the rays for three gun lens settings. Increasing gun lens leads to increased demagnification of the source and to decreased current in the beam. Increasing the gun lens by 1 leads to a reduction of the beam current by approximately 35%.

'gunlens 1'   *'gunlens 5'*   *'gunlens 8'*
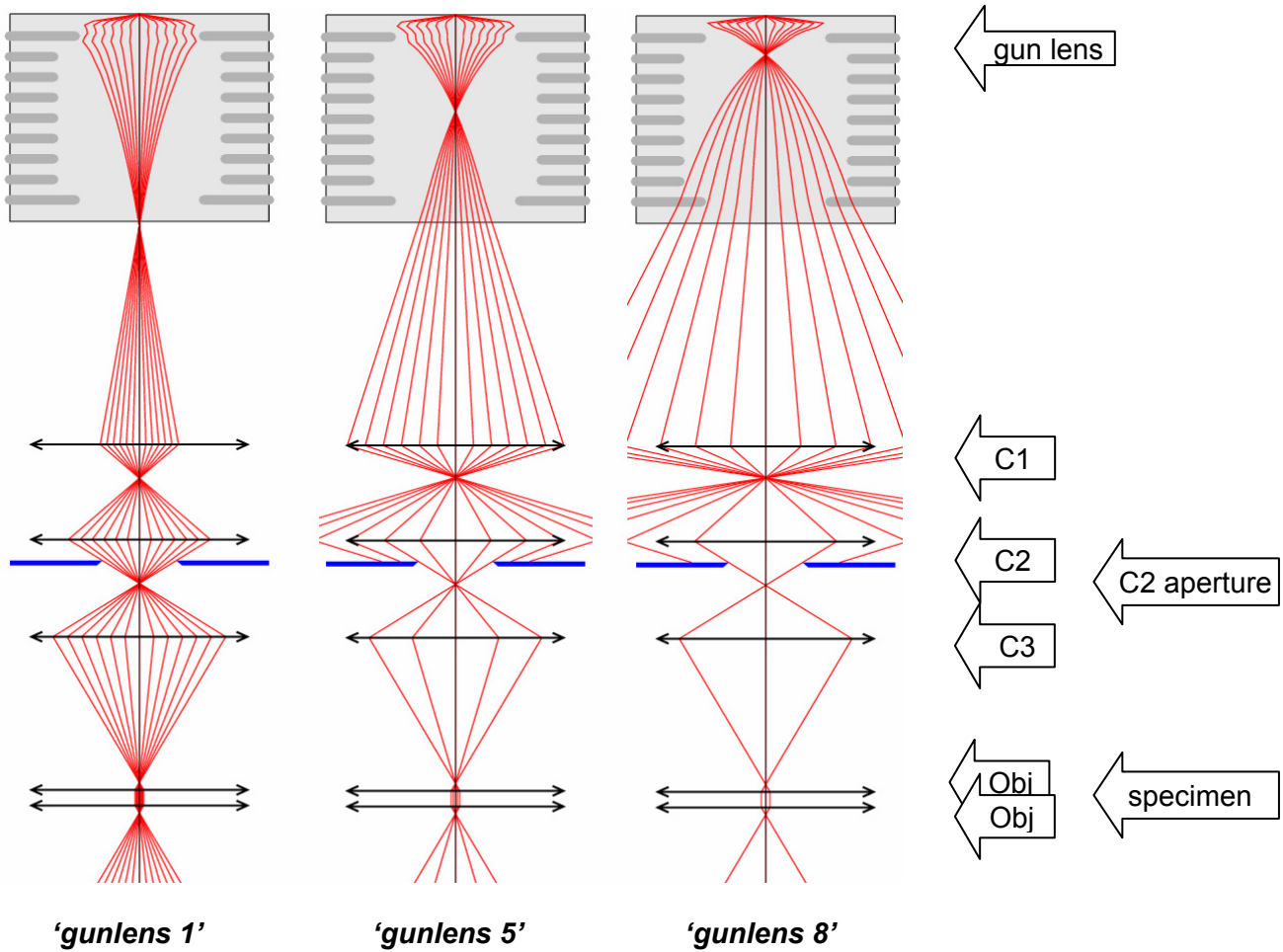
3.4   Condenser zoom

The image distance of C3 is normally fixed, and its value depends on the mode used (TEM/Probe, microprobe/nanoprobe/LM). The gun lens determines the position of the object of C1. Two parameters remain to define the precise state of the condenser column. These are the position of the intermediate source image between C1 and C2, and the position of the intermediate source image between C2 and C3.

It is common to use the name 'zoom system' for two neighboring lenses with an image in between that can be moved up and down without changing the position of the image in front of the first lens or that of the image after the second lens:
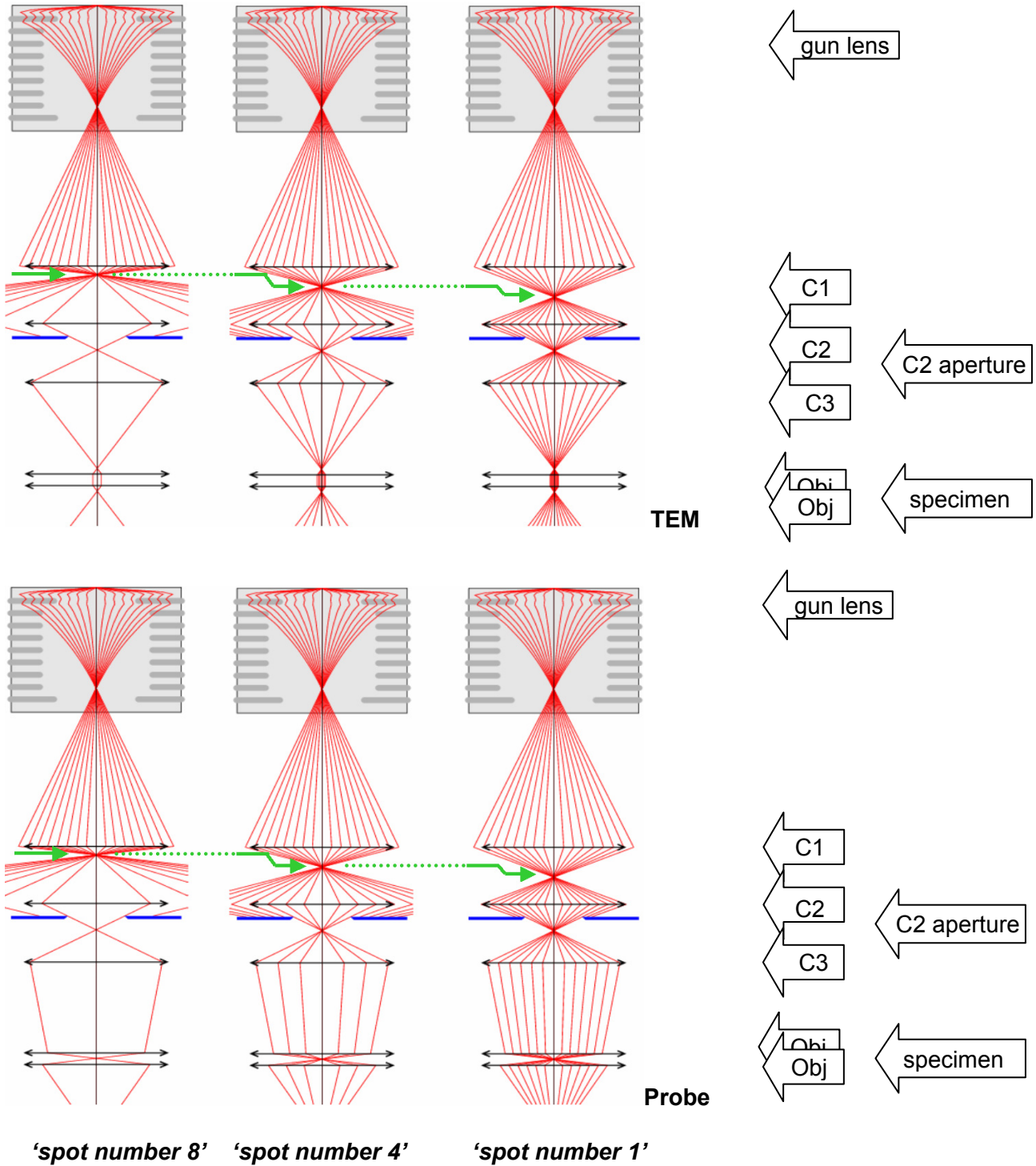

zooming
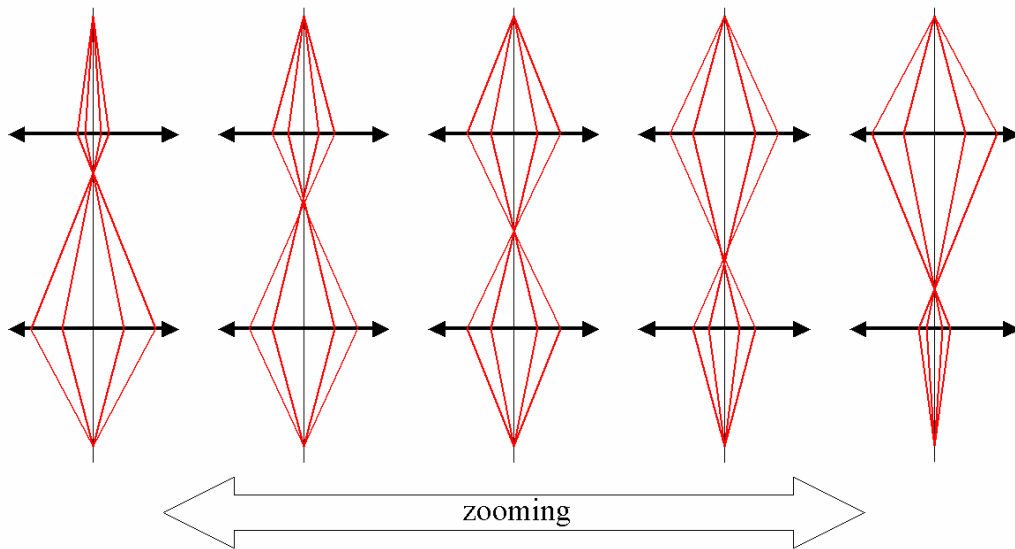
 The Titan condenser system is a double zoom sysem with a C1-C2 zoom and a C2-C3 zoom. The C1-C2 zoom is called the spot number and determines the beam current. The C2-C3 zoom controls the beam diameter in TEM and the probe convergence in STEM. This is summarized in the following table.

|	TEM	STEM
changing position between C1 and C2	varies beam current	varies beam current
changing position between C2 and C3	varies illuminated area	varies convergence angle

3.4.1   Spot number

The user can choose from eleven settings for the image position of the first condenser lens (called spot number 1 to 11). The next two figures give each three sketches for the rays in these different settings for TEM and Probe mode. Increasing 'spot number' leads to increased demagnification of the source and to decreased current in the beam. Increasing the spot number by 1 leads to a reduction of the beam current by roughly 50%.

gun lens

C1

C2   C2 aperture

C3

Obj
Obj   specimen

TEM

gun lens

C1

C2   C2 aperture

C3

Obj
Obj   specimen

Probe

'spot number 8'   *'spot number 4'*   *'spot number 1'*

Changing the position of the intermediate image between C1 and C2 changes the beam current, not the illuminated area or convergence angle.
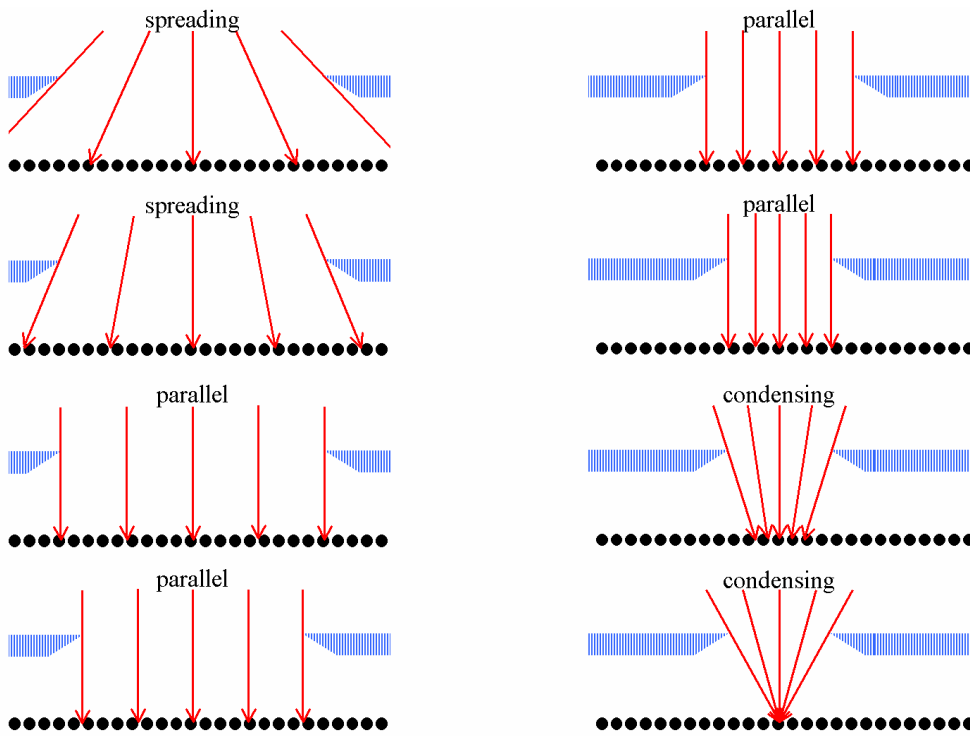
3.4.2   Area zoom

Changing the position of the intermediate image between C2 and C3 changes the diameter of the beam at the C3 lens, and through this, the size of the illuminated area in TEM. The software takes care that C2 and C3 are simultaneously changed such that the beam remains parallel.
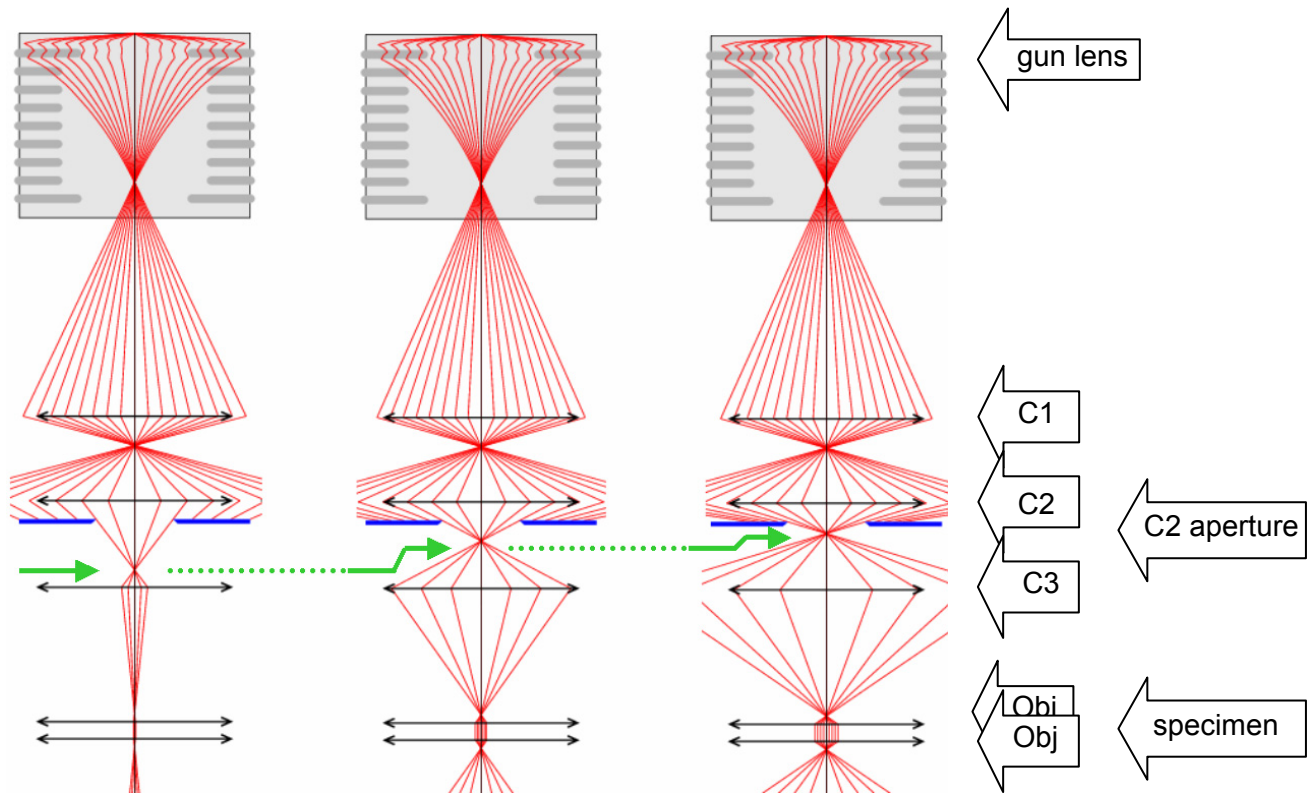
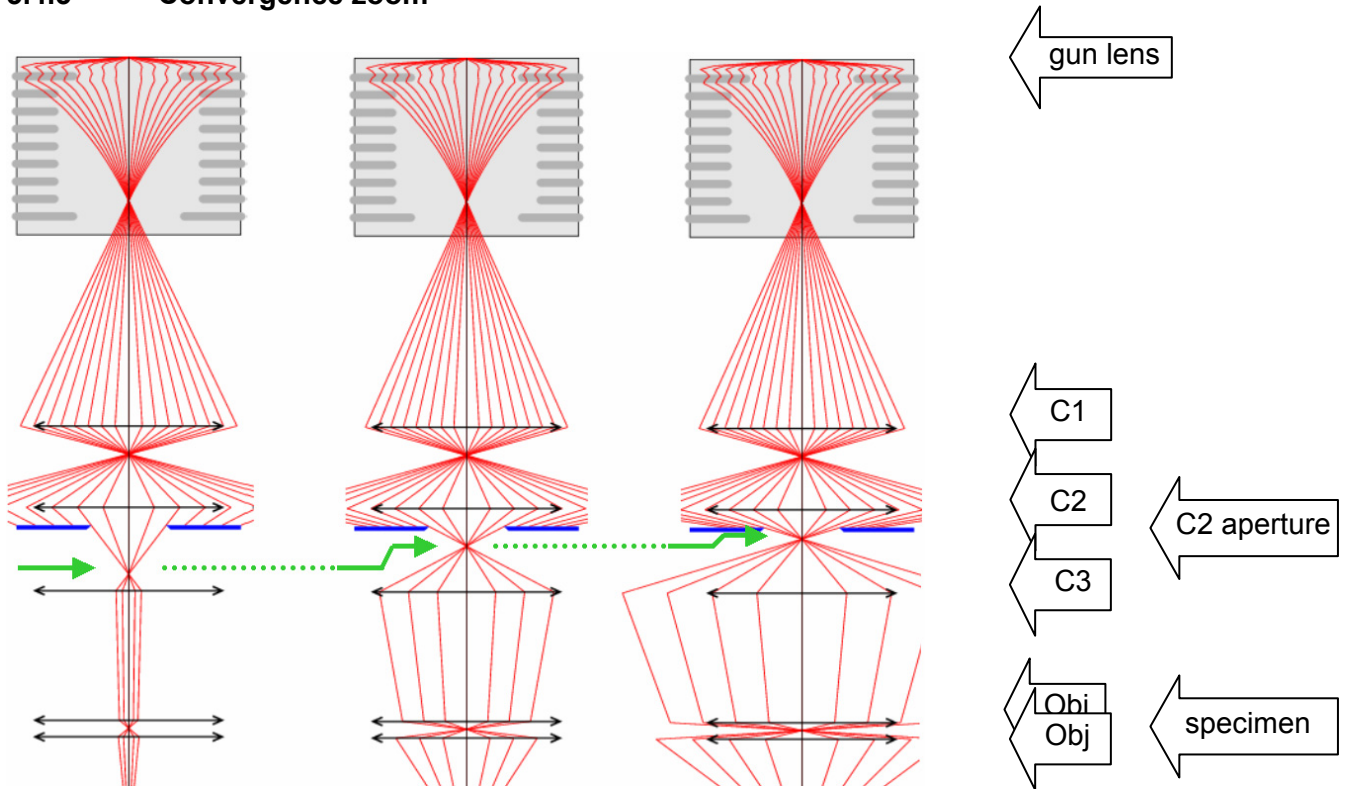*Changing the position of the intermediate image between C2 and C3 changes the illuminated area in TEM mode.*

When the user selects an area that is smaller than the smallest area that can be illuminated with a parallel beam, the system switches to condensing mode. In the condensing mode, the source is no longer focused in the front focal plane of the upper objective lens, but instead above, thus making the beam convergent towards the sample. When a zero-sized area is selected, the beam is simply focused as a probe on the sample. This is sketched in the figure below.

When the user selects an area which is larger than the largest area that can be illuminated with a parallel beam, the system switches to spreading mode. In the spreading mode, the source is no longer focused in the front focal plane of the upper objective lens, but instead below, thus making the beam divergent towards the sample. This is also sketched in the figure below.

Specimen illumination in TEM mode. The apparent C2 aperture is indicated by the blue edges. When C2-C3 is zoomed, the apparent C2 aperture changes size, and the size of the parallelly illuminated area is varied. When the user selects an area outside the range of parallel illumination, the beam switches to spreading mode or condensing mode.

3.4.3 Convergence zoom

Changing the position of the intermediate image between C2 and C3 changes the convergence angle in Probe mode.

Changing the position of the intermediate image between C2 and C3 changes the diameter of the beam at the C3 lens, and through this the convergence of the beam at the specimen in Probe mode (see figure on previous page). The user can vary the position continuously. The software takes care that C2 and C3 are simultaneously changed such that the probe remains focused.

The intermediate image between C2 and C3 does not necessarily have to be a real image. It is also possible to use C2 and C3 as a zoom system with a virtual intermediate image. Then the beam is zoomed between C2 and C3 from diverging to converging. The zoom range with a real intermediate image is much larger than the the zoom range with a virtual intermediate image. Therefore the first option is called 'large range' mode, and the latter option is called the 'normal range' mode.
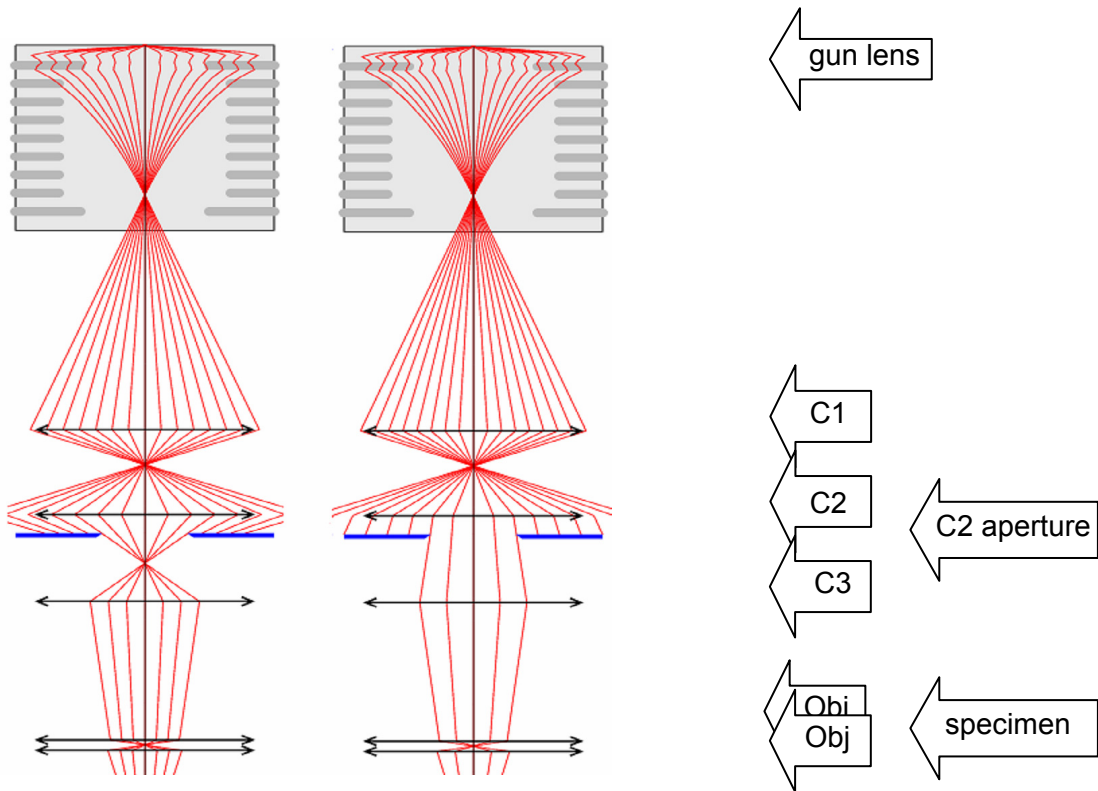
Left: in the 'large range', a real intermediate image exists between C2 and C3. Right: in the 'normal range', the image between C2 and C3 is only virtual.

The C2 lens contributes very little to the spherical aberration at the probe in the 'normal range' because the C2 lens is almost off: it contributes less than 0.02mm. In the 'large range', the contribution is considerably larger, especially at small angles where it can add up to 0.3mm to the total spherical aberration of the objective lens. Therefore, the 'normal range' is the preferred mode for normal applications like STEM and EDX. The 'large range' can be used for special applications like LACBED (large angle convergent beam electron diffraction).

3.5　　Fine tuning C3

In Probe mode, the beam is focused on the specimen by fine-tuning the C3 lens.

In TEM mode, the beam is focused on the front focal plane of the upper objective lens by fine-tuning the C3 lens. The sketch below illustrates how the position of the focus of the beam in front of the upper objective lens is related to the parallellity of the beam at the sample and to the position of the focus of the beam at the back focal plane of the lower objective lens.
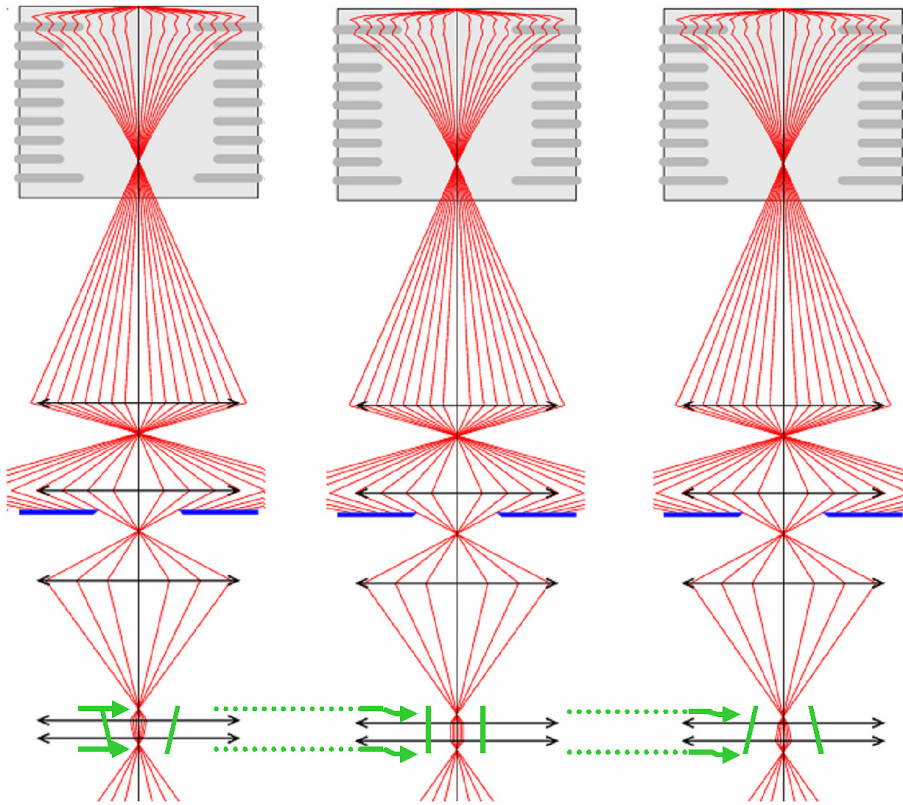

A converging or diverging beam at the sample can be tuned to a parallel beam by varying the height of the source image in front of the objective lenses. This height of the source image directly relates to the height of the diffraction pattern after the objective lenses.

3.6   Two-condenser lens mode

The user can switch off the C2 – C3 zoom system by selecting the 'C2 off' or 'C3 off' mode. This can be helpful when the C2 – C3 zoom is not aligned or misaligned. The condenser then behaves as a two-condenser system, similar to a Tecnai or a CM microscope. The beam is generally no longer parallel, as illustrated below.
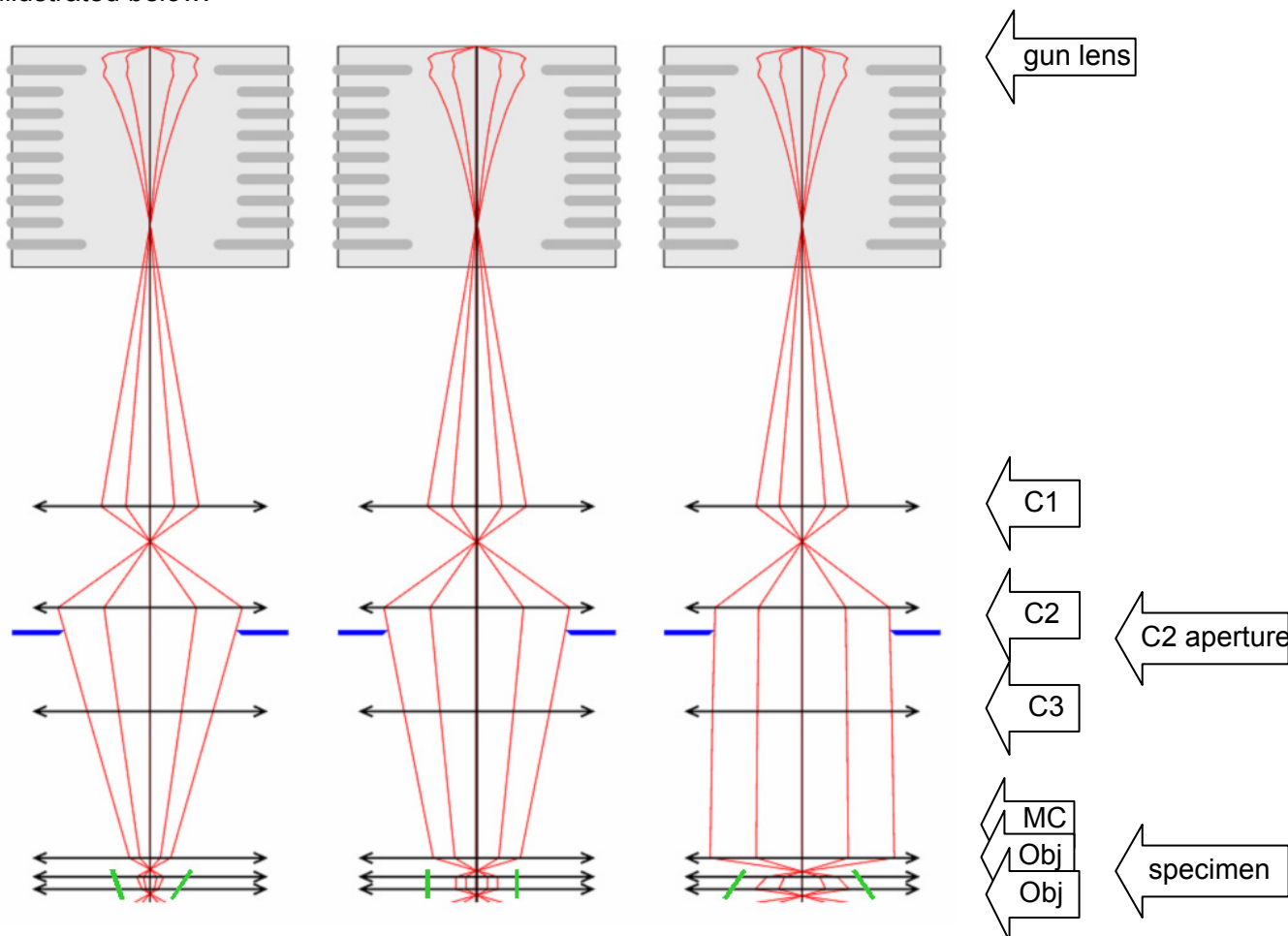
In the 'C3 off' mode, the condenser behaves as a two-condenser column. The beam changes from converging to parallel to diverging when the illuminated area is increased.

4 Fundamentals of parallel illumination

The next figure sketches a non-ideal TEM illumination:
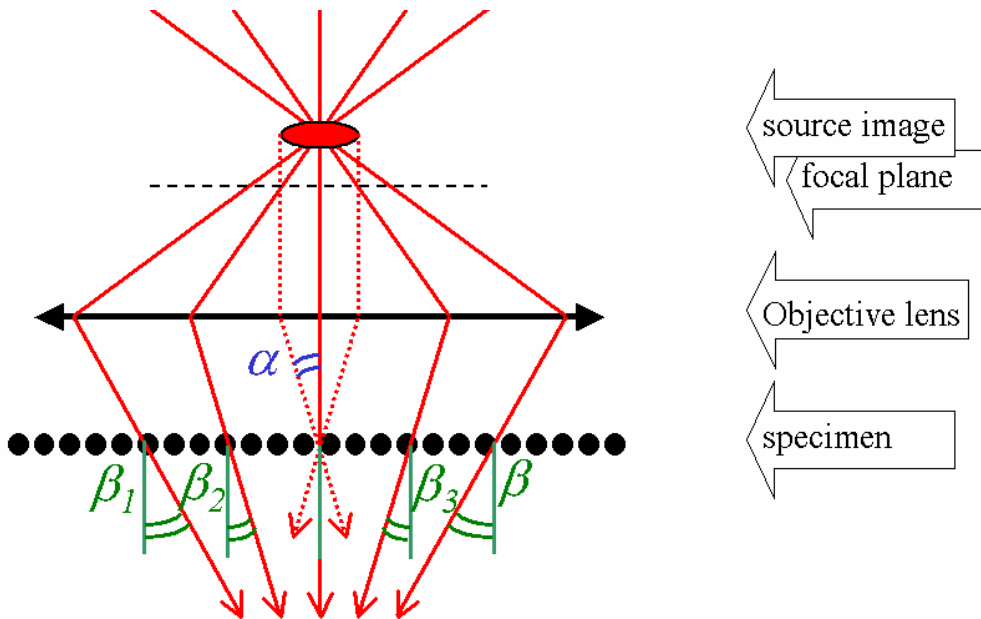
Non-ideal TEM illumination, with half-coherence angle α and non-isoplanatism β.

The illumination differs from ideal parallel illumination in two aspects:
- The half-coherence angle α is not zero. The finite size of the cross-over in the front-focal plane of the objective lens introduces a spread of beam tilts with which the beam hits a single point on the specimen.
- The non-isoplanatism β is not zero. Ideally, the source image should be in the front-focal plane of the objective lens so that the angle β with which the beam hits the specimen does not vary with the position on the specimen: this gives parallel illumination. However, in this example, the source image is not in the front focal plane of the objective lens and the angle β varies with the specimen position. This variation is called non-isoplanatism.
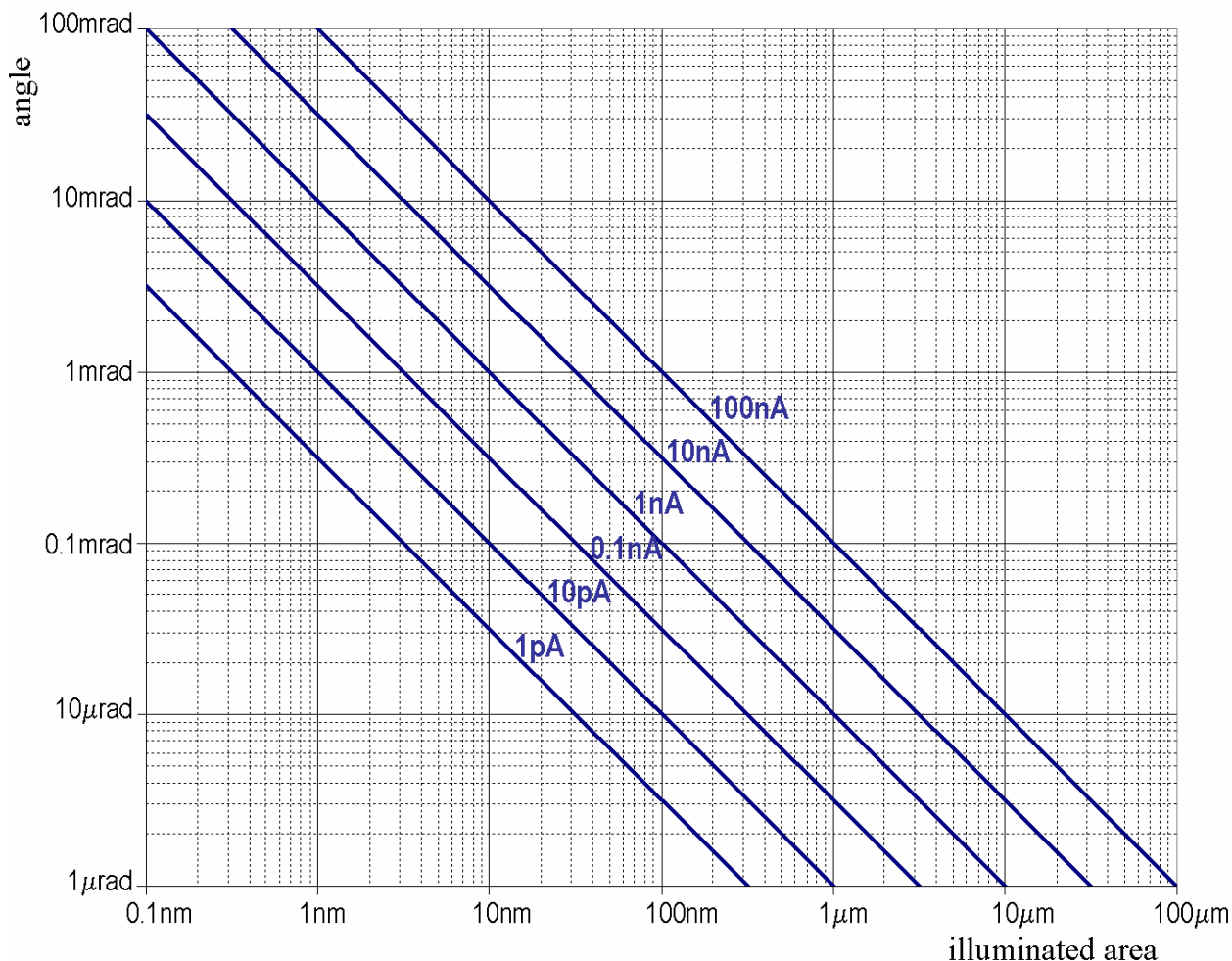
4.1 Coherence

The coherence angle can be tuned by changing the magnification from the source to the source image in the front focal plane of the upper objective lens. A higher gun lens or a higher spot number gives a smaller source image and a better coherence. However, it also gives less beam current. This balance between coherence and beam current is described by the law of conservation of brightness:

$$I = B \cdot \pi\alpha^2 \cdot (\pi/4)\, D^2 \cdot V_{rel}$$

where
  I = beam current on the specimen
  B = brightness of the FEG, typically between $5 \cdot 10^6$ and $2 \cdot 10^7$ A/m^2/sr/V
  α = half-coherence angle
  D = diameter of the illuminated area on the specimen
  $V_{rel} = V \cdot (1+V/V_0)$, the relativized high tension ($V_0 = 2m_{electron}c^2/e = 1022$kV)

The next graph shows how I depends on D and α for $B=10^7$ A/m^2/sr/V.

Beam current as a function of illuminated area and coherence angle for a FEG operated at brightness $B=10^7 A/m^2/sr/V$.

The beam current at the sample can not exceed 150 nA. The software forbids and disables modes which potentially can give a beam current larger than 150 nA.

4.2   Non-isoplanatism

Two important drawbacks of non-isoplanatism are the local variation of defocus in HR-TEM and the local variation of magnification when the specimen is tilted. This section discusses these effects, the limits that they pose on the non-isoplanatism, and typical values of non-isoplanatism in the Titan condenser system.

4.2.1   Focus variation in HRTEM

The next figure sketches a specimen illuminated by a diverging beam. Outer parts of the illuminated area on the specimen are imaged by outer parts of the objective lens. The spherical aberration of the objective lens causes that the focusing strength increases at the outer parts of the objective. Therefore, the outer parts of the illuminated area on the specimen are more strongly focused than the inner parts. This causes a defocus which varies over the field of view.
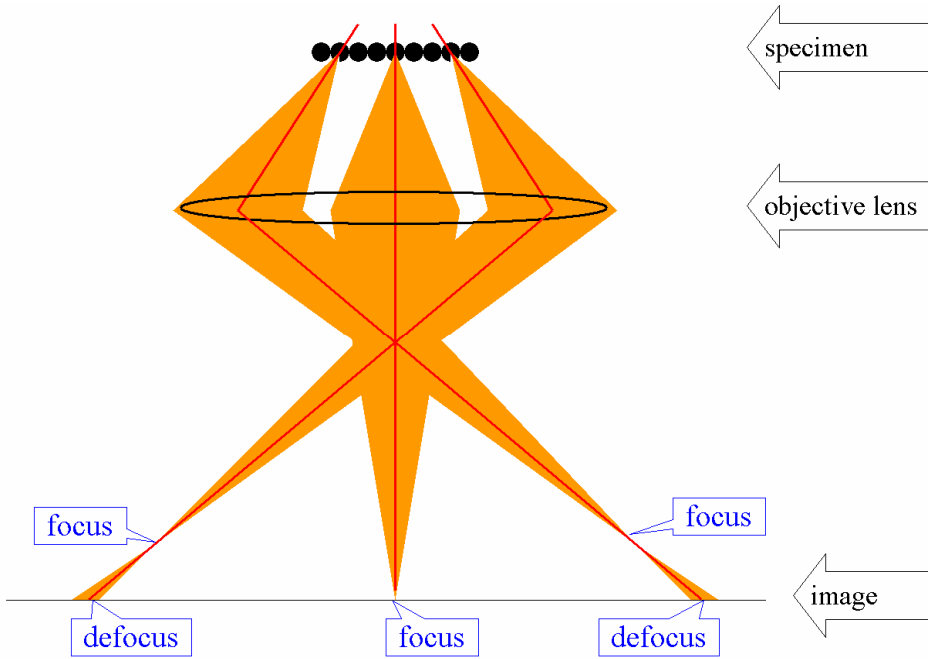
The image focus depends on the position on the specimen because the diverging illumination uses different parts of the aberrated objective lens.

This effect can be described with the wave aberration function

$$\chi(g) = (1/4)\ C_s\ \lambda^3\ g^4 + (1/2)\ \Delta f\ \lambda\ g^2 + \ldots$$

with g the spatial frequency, C_s the spherical aberration, λ the electron wave length, Δf the defocus, and the dots denote all other aberrations. A beam tilt β at the specimen corresponds to a shift of spatial frequency t = β/λ. This causes a phase shift

$$2\pi\ [\chi(g+t) - \chi(g)] \approx 2\pi\ t\ [\ C_s\ \lambda^3\ g^3 + \Delta f\ \lambda\ g\ ] + \ldots$$

which reduces to $2\pi\ t \cdot 2.9 \cdot (C_s\ \lambda^3)^{1/4}$ when we use Scherzer focus $\Delta f = -\ (C_s\ \lambda)^{1/2}$ and the point resolution limit g = 1/ [0.61 $(C_s\ \lambda^3)^{1/4}$]. We demand this phase shift to be less than $\pi/4$, which implies for a Titan 300 SuperTwin (C_s = 1.3mm, λ = 1.97pm) that β = t λ < 0.3 mrad[†].

A typical HRTEM image spans an area of 100 nm diameter. The beam tilt due to diverging or converging illumination is less than 0.3 mrad when the source image is at least 100 nm/0.3 mrad = 3 mm away from the specimen.

[†] At Scherzer focus, the limit on the beam tilt β will be stricter for higher spatial frequencies. However, frequencies (far) beyond the point resolution limit are usually imaged at a focus for which the contrast transfer function sin[$\chi(g)$] is more or less stationary around those frequencies. This happens to be the same condition for which the effect of a beam tilt $\chi(g+t) - \chi(g)$ is minimal, so also for higher frequencies it is reasonable to estimate β < 0.3mrad.

4.2.2   Magnification variation

Tomography requires a large series of images taken at different specimen tilt angles. For good 3D reconstruction, it is important that the magnification changes minimally between the images and minimally within an image. The figure below shows how a diverging beam in combination with a specimen tilt causes magnification change.
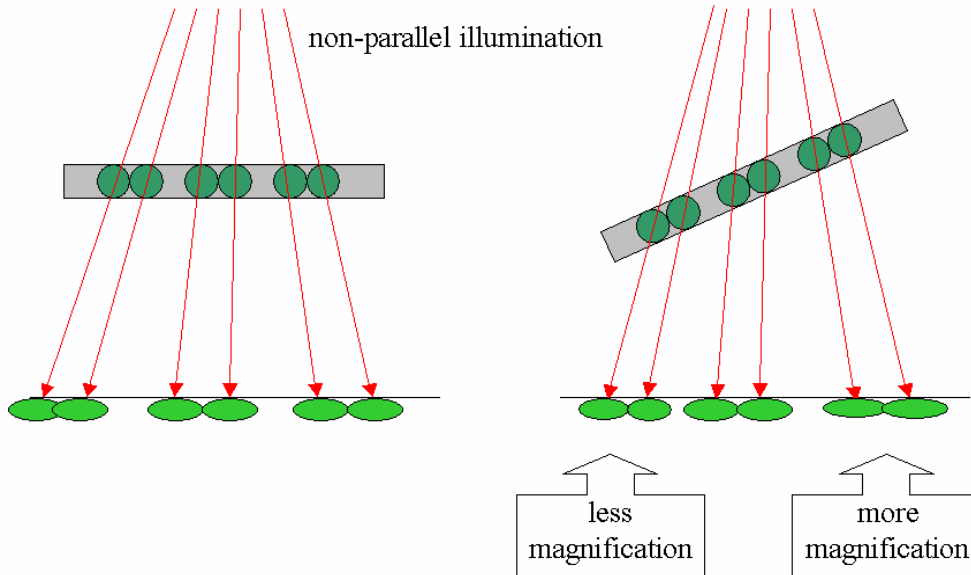
The combination of diverging illumination and changing specimen height causes a local variation of magnification.

We derive an upper limit on the divergence or convergence as follows:
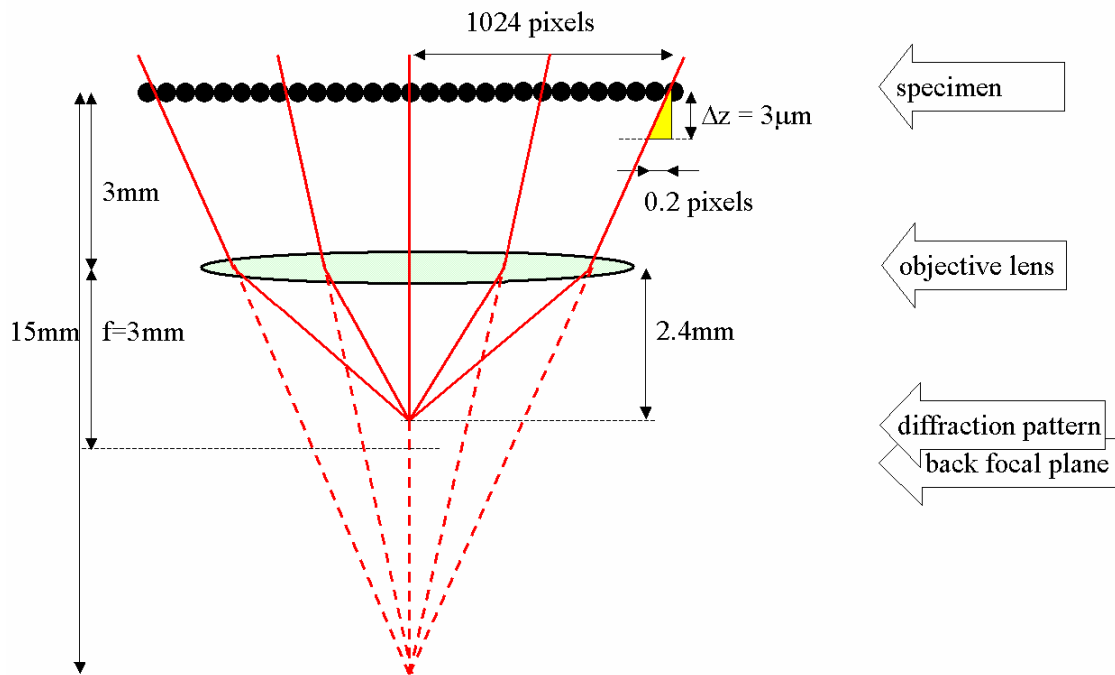
A converging illumination causes a change of magnification when the specimen is lowered.

Consider an experiment with a camera of 2048 by 2048 pixels, a tilt which lowers the specimen at most by Δz = 3 μm, and suppose the maximum acceptable image shift is 0.2 pixels. Thus the user maximally allows that after lowering by Δz = 3 μm, a feature on the edge of the camera shifts from 1024 pixels from the center to 1023.8 pixels from the center. Now we consider an extreme lowering Δz = 5120 · 3 μm = 15 mm. The feature on the edge of the camera will shift 5120 · 0.2 pixels = 1024 pixels, that is, to the center of the camera. All other features will also shift to the center of the camera. This simply means that, in this example, the source is imaged 15 mm below the original specimen position. It shows that in order to match the requirement of maximal 0.2pixels shift, the source must be imaged at least 15 mm away from the specimen. For an image of, say, 0.5 μm radius this corresponds to a non-isoplanatism of β = 0.5 μm/15 mm = 0.03 mrad.

4.2.3   Non-isoplanatism in parallel mode

Normally, the parallel mode is tuned such that the diffraction pattern is exactly in the plane of the objective aperture. However, the back focal plane of the objective lens is not exactly in the plane of the objective aperture. Due to changing magnetic saturation, it can vary with the high tension between 0.2 mm above and 0.5 mm below the objective aperture (the precise values depend on the type of objective lens).

This range of +0.2 mm to –0.5 mm goes well with the non-isoplanatism limits derived in Sections 4.2.1 and 4.2.2, which are a minimum distance between source image and specimen of 3 mm for HRTEM and 15 mm for tomography. As shown in the sketch in Section 4.2.2, 15mm distance means that the diffraction pattern must not be more than 0.6 mm above or below the back focal plane, for 3 mm focal distance. This is satisfied in all cases.

4.2.4   Non-isoplanatism in spreading and condensing mode

The range of parallel illumination in TEM is limited by the strengths of the condenser lenses.
When the user selects an area which is larger than the largest area that can be illuminated with a parallel beam, then the system switches to the spreading mode, in which the beam is diverging towards the specimen. When the user selects an area which is smaller than the smallest area that can be illuminated with a parallel beam, then the system switches to the condensing mode, in which the beam converges towards the specimen.
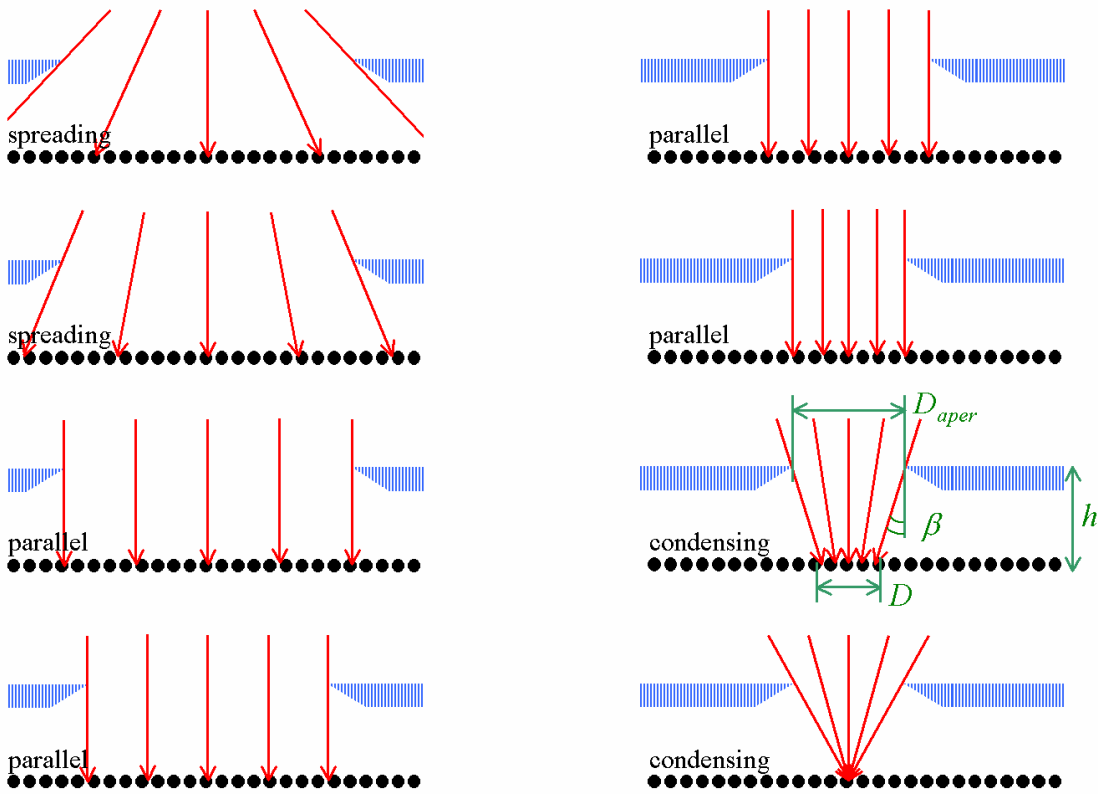
Specimen illumination in TEM mode. The apparent C2 aperture is indicated by the blue edges. When C2-C3 is zoomed, the size D_{aper} of the apparent C2 aperture changes, and the size D of the parallelly illuminated area is varied. When the user selects an area outside the range of parallel illumination, the beam switches to spreading mode or condensing mode, and the non-isoplanatism angle β becomes non-zero.

The sketch above shows that both in spreading and in condensing mode, the non-isoplanatism angle depends linearly on the size of illuminated area: $\beta = (D_{aper} – D)/(2h)$. The next graph shows the non-isoplanatism for four settings. When the 150 µm C2 aperture is replaced by the 50 µm C2 aperture, the non-isoplanatism and the diameter of illuminated area reduce by a factor of three. Of course, the current density does not change but the total current reduces by a factor of nine.
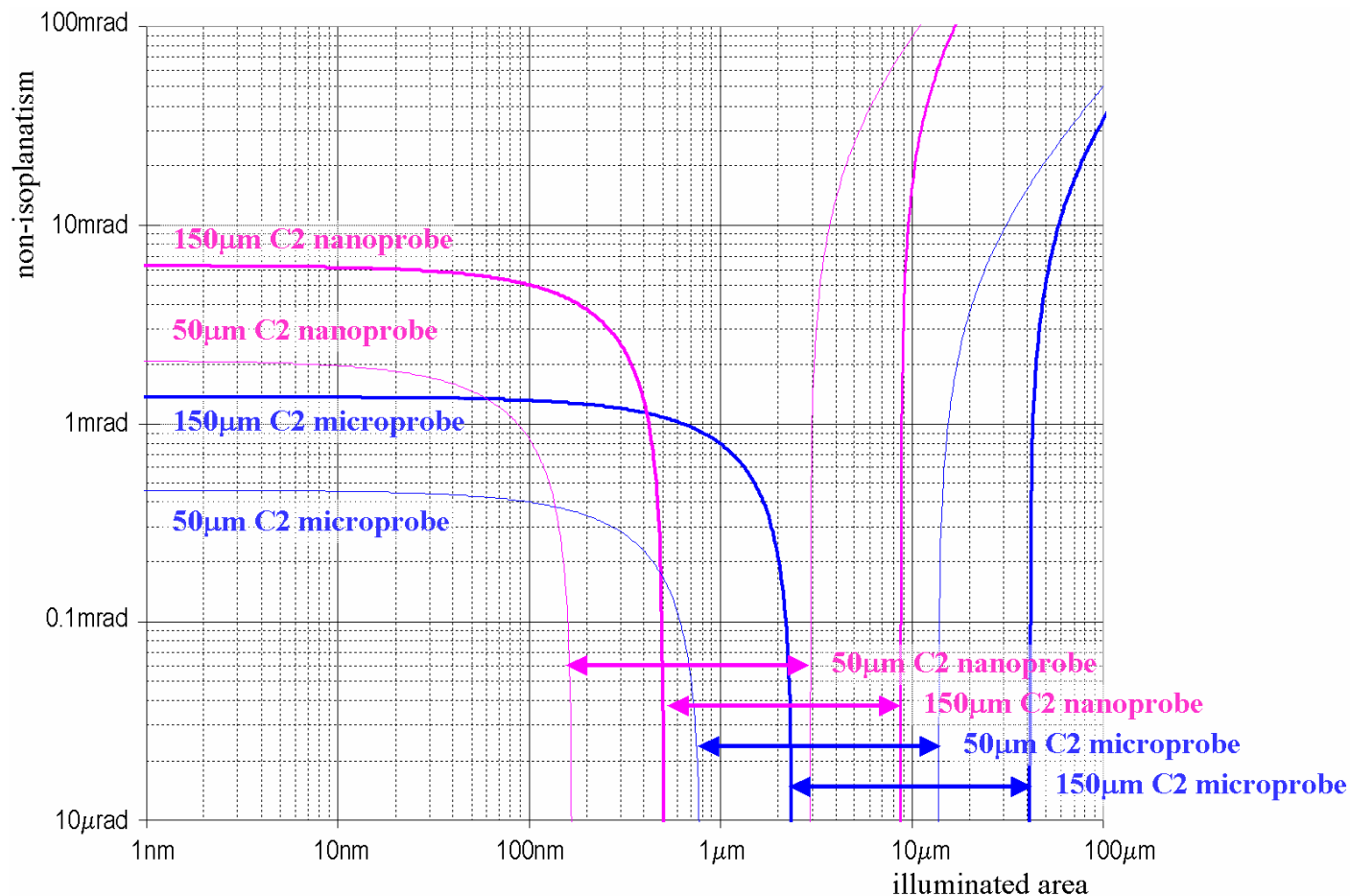
Non-isoplanatism β as a function of illuminated area, for microprobe (blue curves) and nanoprobe (pink curves) for a Titan 300 SuperTwin. The non-isoplanatism is the average tilt of the illumination at the edge of the illuminated area, relative to the average tilt of the illumination at the center of the illuminated area.

For each setting, parallel illumination is possible in the range indicated by the double arrows. The non-isoplanatism is zero in these ranges.

Microprobe is the preferred setting for (HR)TEM since it gives smaller non-isoplanatism in spreading and condensing mode (the reason for this is that in microprobe, the minicondenser lens partly compensates the upper objective lens, thus creating a considerably larger distance *h* between specimen and apparent C2 aperture). The non-isoplanatism is below 0.5 mrad with the 50 μm C2 aperture, which roughly agrees with the limit of 0.3 mrad derived in Section 4.2.1.

For tomography, the parallel mode is clearly to be preferred over the condensing or spreading mode. The graph shows that one can use microprobe for areas between 1 μm and 40 μm, and nanoprobe for areas between 0.2 μm and 8 μm. Since the default mode is microprobe in TEM, the tomography user should take care to switch to nanoprobe for areas between 0.2 μm and 1 μm.

Of course, in the converging mode, any sub-area can be illuminated with four times smaller non-isoplanatism by increasing the diameter of the total illuminated area four times, but this goes with a drop of current density by a factor of sixteen.

5   Hysteresis and normalization

The condenser system requires a high excitation (above 1T) of the C3 lens when a small area is parallelly illuminated in TEM. When the condenser switches afterwards to a setting with a lower C3 excitation, remanent magnetic fields of typically 1 μT can give a slight deflection in the C3 lens. The user can notice this as a hysteresis in the beam position of up to a few hunderd nanometers and a hysteresis in the beam tilt. They are highest for TEM illumination in combination with an area of which the size has been reduced in condensing mode past the probe focus to 'negative diameter'. Then C3 can be excited up to 100%.

The simplest way to handle this is to press 'Normalize condenser' to restore the beam to its normalized position. This position usually reproduces better than 10 nm. The user can choose to automize this condenser normalization. In the Normalization control panel, click on 'Illumination State', then select Condenser. The condenser will be automatically normalized when the illumination is untouched for 0.5 s after a change of the illumination.
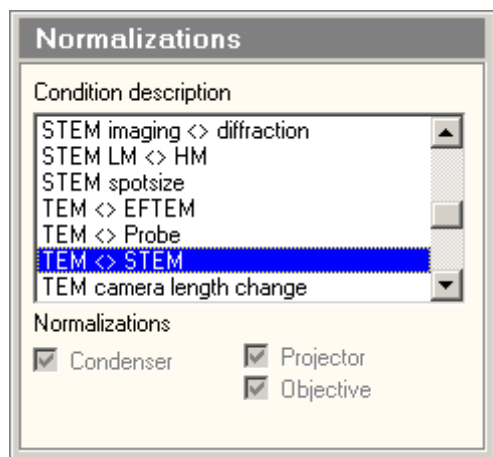
The Normalization Control Panel.

6   Some frequently asked questions

1. I have changed the FEG settings. What should be re-aligned?
Only the full gun alignment should be performed. Please note that it is not needed to re-align the condenser.

2. In TEM, a beam shift is observed when going parallel to condensing mode and vice versa. Should the condenser be re-aligned?
First it should be checked that the C2 aperture is well aligned in C3 off mode and that the gun shift is well aligned. When this does not help, the condenser alignment should be re-aligned.

3. I select TEM for parallel illumination but whatever I do with the Intensity knob, the illumination is always 'spreading'.
You are using spot 1. The Titan beam current is limited to 150 nA. At spot 1, it is potentially possible to get more than 150 nA at the specimen with parallel illumination. Therefore, the software forbids this mode. Try spot number 2 or 3.

4. I can illuminate 50 μm parallel with spot 4 but not with spot 3. What is happening?
The Titan beam current is limited to 150 nA. When you are using spot 2 and 50 μm parallelly illuminated area, it is potentially possible to get more than 150 nA at the specimen. Therefore, the software forbids this combination.

5. I want to illuminate 100 nm homogeneously, but the intensity is varying by 30% over the field of view.
Probably you are using the 100 μm or 150 μm C2 aperture and looking at the effect of the spherical aberration of the C1 lens. Try a smaller C2 aperture.

6. In Probe mode, the beam cannot be focused to a probe.
The specimen should be at eucentric height. Press 'Reset beam'. If this does not help, please do the Condenser alignment.

7. The Probe focus was okay, but I changed gun lens (or extraction voltage or high tension) and now the focus is off.
Probably the height of the image in front of the condenser has changed. Do the Gun alignment (Gun XO focus and stigmate).

8. In TEM mode, when I decrease the size of the illuminated area, the beam moves away. And the movement is even faster for small areas.
The condenser deflector is not well aligned. Please do the condenser zoom alignment (Alignments → Condenser → Condenser zoom).

9. I want to illuminate 20 nm with a beam as parallel as possible. Should I use TEM mode with condensing beam, or should I use Probe mode in the microprobe setting?
With the 50 μm C2 aperture, the convergence angle in condensing TEM mode is about 0.5 mrad. The convergence angle in Probe mode with microprobe setting is variable between 0.5 mrad and 8.8 mrad in the large angle range. At 0.5 mrad, those two settings are optically the same. The only difference is that TEM and Probe use separate sets of beam shift and beam tilt.

10. I can not find the beam. Can there be something wrong with the condenser alignment?
Press 'Reset Beam'. If the beam is still not visible, switch the illumination to 'Free Ctrl' and 'C3 off'. This switches off the C3 lens and makes the system much less sensitive to missing alignments or misalignments. If the beam is still not visible, the problem is probably not caused by the condenser.

11. The beam control panel can show the size of the illuminated area and can show the covergence angle. Why doesn't it show the probe size?
The probe size depends on too many parameters. It depends not only on the condenser setting, but also on how well the stigmators have been tuned, on the defocus of the probe, on the C2 aperture size and alignment, on the gun lens setting, on the extraction voltage, and on the high tension.