The Cameca NanoSims 50
Users guide
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1 Introduction

The primary ion optic is composed of four different sections: the source chamber called also Cs/duo switch, the intermediate section, the central column and the coaxial column. The two first sections are exclusively used by the primary ion beam while the two last are common to secondary and primary ion beams. Cs⁺, O₂⁺, O⁻ and O₂⁻ can be used as primary ions depending of the source and of the polarity of the instrument.

2 The Cs/Duo switch

2.1 Overview

The Cs/Duo switch receives two ion sources: the Cameca Cs microbeam ion source and the Duoplasmatron gas source. In addition while using the duoplasmatron a Wien Filter is available. This sources chamber is insulated from the primary ion column by a gate valve, and is equipped with one turbo pump. This allows the maintenance of the sources without venting the primary column. The source interchange mechanism allows switching between ion sources without venting. A trolley supporting the Cesium source and the lens Lduo can be moved under vacuum between two different positions; position 1 the Cesium source is set on the axis of the primary column; position 2 the lens Lduo is set on the axis of the primary column.

Total time for switching the source:

- From cesium to duoplasmatron: 45 minutes which is the time needed to cool down the Cs source before increasing the oxygen pressure.
- From duoplasmatron to Cesium: 10 minutes time needed to reach the base pressure in the source chamber.
2.2 Description

List of elements:

<table>
<thead>
<tr>
<th>Device</th>
<th>Label</th>
<th>Description and functionality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cs Source</td>
<td>Cs HV IONIZER</td>
<td>Cs HV is the source High Voltage with respect to the ground. IONIZER is the electron current flowing between the ionizer filament and the ionizer.</td>
</tr>
<tr>
<td></td>
<td>RESERVOIR</td>
<td>RESERVOIR is the electron current flowing between the reservoir filament and the reservoir.</td>
</tr>
<tr>
<td>Duo Source</td>
<td>Duo HV ARC</td>
<td>Duo HV is the source High Voltage with respect to the ground. ARC is the plasma arc current. COIL is the duoplasmatron coil current.</td>
</tr>
<tr>
<td></td>
<td>COIL</td>
<td></td>
</tr>
<tr>
<td>Corrector Cduo</td>
<td>CDuo</td>
<td>A 4 plate deflector used to center the Duoplasmatron ion beam before entering the Wien filter.</td>
</tr>
<tr>
<td>Wien Filter</td>
<td>CWF WFcoil</td>
<td>A Mass Filter consisting of 2 deflection plates (CWF) and a coil (WF Coil).</td>
</tr>
<tr>
<td>Lens Lduo</td>
<td>LDuo</td>
<td>Lens used to focus the Duoplasmatron ion beam on D0 at the exit of the Wien filter.</td>
</tr>
<tr>
<td>Corrector C0</td>
<td>C0</td>
<td>A 4 plate deflector used to center the primary ion beam at the exit of the Cs/duo switch.</td>
</tr>
<tr>
<td>Diaphragm D0</td>
<td>D0</td>
<td>Aperture stop which limits the angular aperture of the Cs ion beam or acts as a mass selection diaphragm for the Wien filter. 4 different diameters are available.</td>
</tr>
</tbody>
</table>
2.3 Using the Cs source

2.3.1 Overview

In the vapor state, cesium ionizes into positive ions Cs$^+$ when it comes into contact with the surface of a tungsten plate at high temperature. If an electric field is applied to the surface of this tungsten plate Cs$^+$ ions are extracted and can be used as primary ions. The CAMECA Microbeam Cesium Source has been designed on this principle (See the figure 1 below).

The cesium vapor is generated from a cesium chromate (Cs$_2$CrO$_4$) or a cesium carbonate (Cs$_2$CO$_3$) pellet contained in a reservoir raised to a temperature of 400°C. This temperature is required to release the cesium vapor.

The cesium vapor comes into contact with a tungsten plate enclosed in the ionizer head heated to 1100°C. The hot tungsten plate ionizes the vapor into Cs$^+$. The reservoir and ionizer are set to a voltage adjustable between 6 and 10 kV and heated independently by electric bombardment by means of two annular filaments (set at 0 Volt).

The extraction electrode, placed in front of the ionizer, at ground potential, generates an electric field to extract and accelerate the Cs$^+$ ions. Figure 1 shows the layout of the various parts of the source.

The Cs Microbeam source

Figure 1
A constant emission of cesium ions is obtained by regulating the electron current flowing between the ionizer and its associated filament ($I_{\text{ION}}$) and between the reservoir and its associated filament ($I_{\text{res}}$). The total current delivered by the high voltage power supply ($I_{\text{TOTAL}}$) is the sum of the ionizer and reservoir electron currents and a leak current mainly due to secondary electrons produced by low density plasma surrounding the source.

$$I_{\text{TOTAL}} = I_{\text{RES.}} + I_{\text{ION}.} + I_{\text{Leakage}}$$

*Note:* $I_{\text{Leakage}}$ negligible during normal operating conditions, may be important during a runaway (first usage of a source); however, a security is designed to limit the overheating of the source.

### 2.3.2 Tuning and aging issue

2 types of Cs sources are available:
- The chromate source (Cs$_2$CrO$_4$)
- The carbonate source (conic Cs$_2$CO$_3$)

These two different types of Cs source correspond to different typical ionizer and reservoir currents.

<table>
<thead>
<tr>
<th>Type</th>
<th>Ionizer at 8kV</th>
<th>Reservoir at 8kV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chromate(Cs$_2$CrO$_4$)</td>
<td>1.6 mA</td>
<td>1.80 mA</td>
</tr>
<tr>
<td>Carbonate (Cs$_2$CO$_3$)</td>
<td>1.6 mA</td>
<td>0.35 mA</td>
</tr>
</tbody>
</table>

Table 1

The Cs$^+$ current varies dramatically with the reservoir current, and slightly with the ionizer current.

The following data (Figure 2) have been recorded with a Cs carbonate source:

![Figure 2](image-url)
**Cs Source aging, reservoir current**

Over long term, for a given spot size it is observed a trend to a current density decrease. This decrease must be compensated by increasing the reservoir current. For example, for a Cs$_2$CO$_3$ reservoir, at an acceleration voltage of 10 kV, and an ionizer current of 1.7 mA, typical reservoir heating values are:

- Just after degazing the source, the reservoir current must be set to 0.2 mA.
- In the following days, it must be risen up to 0.3 mA.
- In the following weeks it gets more stable around 0.35 mA and can reach 0.6 mA at its life end.

It may occur that this aging is not uniformly going on and that the reservoir current must be set to higher value for a while and has to be reduced further.

**Remark:**

It may be required to decrease the acceleration voltage in the case of very low impact energy. When modifying the source acceleration voltage, in a first approach, both the reservoir and the ionizer currents must be modified so that both heating powers ($I_{res} \times \text{Accel}$) and ($I_{ion} \times \text{Accel}$) remain constant.

### 2.3.3 Centering the Cs source

Each time you switch from Duoplasmatron to the cesium source you must re-center it by acting on the rotating knob:

1. Select the FCp mode (the primary ion beam is then directed towards the Faraday cup set at the end of the primary ion column) in the "Tuning" window or on the Keyboard.
2. Set all correctors (C0x, C0y, C1x, C1y) to "0" Volts.
3. Maximize the current with the knob. Check with C0x and C0y that the FCp current is really maximized.

For a more precise setting of the source and C0 plates, FCo can be used.

### 2.4 Using the Duoplasmatron source

#### 2.4.1 Physical principles

A gas is introduced at low pressure to the interior of the hollow cathode through an adjustable leak. Plasma is produced by an arc maintained between the hollow cathode and anode which is kept at several hundred volts relative to the cathode. The discharge is maintained close to the axis by a conical intermediate electrode at a floating potential.

A magnetic field produced between the intermediate electrode and anode by a coil concentrates the plasma close to the axis. A part of the plasma passes through the opening in the intermediate electrode and expands in a second chamber. Ions are extracted in this chamber through a hole (diameter is 400 µm) in the anode.
The duoplasmatron can produce positive or negative ions (O$_2^+$, O$^-$ and O$_2^-$) according to the polarity of the extraction potential. To obtain negative ions, the axis of discharge should be displaced relative to the axis of the extraction hole (roughly centered). This decentralization permits extraction of negative ions, which are concentrated in the periphery of the plasma and to avoid a strong electron flow which would be produced if the plasma remained centered. In practice, this is done by moving the intermediate electrode relative to the anode by approximately 0.8mm. Practically, turn the button up to the mechanical limit (clockwise or reverse) and turn back by roughly 270°.

The gas species generally used are Argon and Oxygen. Argon produces Ar$^+$. Oxygen produces positive or negative ions. For positive ions, the beam is composed of O$_2^+$ and O$^+$. The abundance ratio O$_2^+$/O$^+$ is approximately 10. For negative ions, the beam is composed of O$^-$ and O$_2^-$. In this case, the abundance ratio is reversed, i.e., O$_2^-$/O$^-$ = 1/4.

### 2.4.2 Practical settings

On the N50 the duoplasmatron is only used to produce O$^-$ beam. The central electrode must be shifted on the side in order to maximize the extracted current. Table 2 gives typical values for the Oxygen pressure, the arc and the coil current.

<table>
<thead>
<tr>
<th></th>
<th>Oxygen pressure</th>
<th>Arc current</th>
<th>Coil current</th>
</tr>
</thead>
<tbody>
<tr>
<td>O$^-$</td>
<td>10$^{-5}$ Torr</td>
<td>80 mA</td>
<td>1.6 A (3000 digits)</td>
</tr>
</tbody>
</table>

Table 2
2.4.3 The Wien Filter

*Physical principle*

A *Wien Filter* is basically formed by superimposing an homogeneous electrostatic field and a magnetic field. In the above figure, the magnetic field \( \mathbf{B} \) is parallel to Oy axis while the electric field \( E \) is parallel to Ox axis so that a charged particle moving along Oz axis is submitted to two forces parallel to the Ox axis.

The charged particle is not deflected if the electrostatic force and the Lorentz force balance along the z axis.

\[
\frac{e \frac{V_0}{M_0}}{ \text{[eV/amu]}} = 4.9 \times 10^{-3} \left( \frac{E_0}{B_0} \right)^2
\]

Where \( E_0 \) and \( B_0 \) are respectively expressed in V/cm and gauss. \( M_0, eV_0 \) and \( e \) are respectively the mass, the energy and the electric charge of the particle. \( M_0 \) is expressed in amu.

As \( eV_0/M_0 \) is proportional to the particle velocity, it can be said that the Wien filter is a velocity filter. As it can be assumed that the particle energy \( eV_0 \) is constant, a Wien filter is in fact a mass filter. The main advantage of the Wien filter is to be straight-line.

For achieving a mass filter, a stop must be included in the system, downward the combined electric and magnetic fields, so that the selected \( M_0 \) trajectories can pass through the stop while the deflected mass trajectories are stopped.

When using a Wien filter in an ion optical system where the charged ions are accelerated at \( V_0 \), the ratio \( E_0/B_0 \) is determined by the mass \( M_0 \) which must be kept on axis, while both \( E_0 \) and \( B_0 \) intensities are determined by the closest mass \( M_1 \) minimum deflection \( \alpha_1 \) required to be rejected by the stop.
\[ \alpha_1 = \frac{B_0 \text{ (gauss) } L \text{ (cm) } e^{1/2}}{204 V_{0}^{1/2}} \left( \frac{1}{M_1^{1/2}} - \frac{1}{M_0^{1/2}} \right) \]

\( L \) is the combined field length.

The electric field \( \vec{E} \) is controlled by the voltage \( V \) applied onto the electric plates, and the magnetic field \( \vec{B} \) is controlled by a current \( I \) supplying the coils of a magnetic circuit.

The N50 Wien filter consists of a pair of 76 mm height plates, biased by a voltage supply ranging within \( \pm 250 \) Volts and a magnetic circuit. This circuit both inside and outside the vacuum chamber is excited by a coil supplied by a 7A source. Both the plate voltage and the coil current are controlled from the tuning user interface.

The Wien filter is used as a mass filter to eliminate spurious elements which can be generated in the Duoplasmatron. These species must be eliminated if they are considered as contaminants for the analyzed sample. When using the duoplasmatron with oxygen in the positive polarity the major specie extracted from the source is the polyatomic ion \( ^{16}\text{O}_2^+ \), but for instance \( \text{NO}^+ \) and \( ^{16}\text{O}^+ \) also exist, with an abundance of 1 or 2 decades below \( ^{16}\text{O}_2^+ \). It is necessary to eliminate \( \text{NO}^+ \) and \( ^{16}\text{O}^+ \) if a fine spot is required since all species spots are not focused exactly at the same location because of earth or spurious magnetic fields.

In the negative polarity there are three major peaks as shown on figure 3: \( ^{16}\text{O}^- \), \( ^{16}\text{O}_2^- \), \( ^{16}\text{O}_3^- \).

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NanoSIMS 50 User’s Guide: Primary column
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Figure 3: Wien filter mass spectrum

Figure 4 displays the experimental relationship between CWF and WF coil for \(^{16}\text{O}^+\) ions. It can be checked than the plate voltage is proportional to the magnetic field. When increasing both the magnetic field and the plate voltage, it can be useful to re-adjust D0.

Practical settings for the Wien filter when the column is used at 8kV:
- Wien coil: 2A
- CWF plates: 311 digits (30 volts)

Figure 4: Experimental relationship between Cwf and the coil current
2.4.4 Tuning LDuo

Each time you clean the duoplasmatron source you must re-center Lduo by acting on the rotating knob:

0 Select the FCp mode - the primary ion beam is then directed towards the Faraday cup located at the end of the primary ion column - in the "Tuning" window or on the Keyboard.
0 Set all correctors (Cduox, Cduoy, C0x, C0y, C1x, C1y) to "0" Volts.
0 Tune Lduo voltage to the standard value (1610 digits at 8kV).
0 Maximize the current with the knob, with Cduo and finally with C0.
0 Select D0-2 (2nd position of diaphragm D0) and maximize the current by acting on Lduo. Lduo value must be 1610 +/- 25 digits at 8 kV.
0 Set the Wien filter to 2A and maximize again the beam current in FCp by changing CWF without changing C0 or Cduo. D0y can be slightly adjusted if necessary.

For a more precise setting of the Wien filter, FCo can be used.
3 Intermediate section

3.1 Overview

This section of the N50 is either used to increase the primary ion beam current or to demagnify the cross-over of the source. In addition a Faraday cup allows to measure the beam current entering in the central column.

3.2 Description

<table>
<thead>
<tr>
<th>Device</th>
<th>Label</th>
<th>Description and functionality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lens L0</td>
<td>L0</td>
<td>Lens used to vary the demagnification of the source image.</td>
</tr>
<tr>
<td>Lens L1</td>
<td>L1</td>
<td>Lens used to vary the demagnification of the source image.</td>
</tr>
<tr>
<td>Corrector C1</td>
<td>C1x</td>
<td>A 4 plates deflector used to center the primary ion beam.</td>
</tr>
<tr>
<td>Corrector Cx</td>
<td>Cx</td>
<td>A 2 plates deflector used to direct the primary ion beam in FCp</td>
</tr>
<tr>
<td>Secondary electrons Suppressor</td>
<td>SE FC</td>
<td>Tube at –30 volts used to prevent secondary electrons to escape from the primary Faraday Cup FCp</td>
</tr>
<tr>
<td>Faraday Cup</td>
<td>FCp</td>
<td>Faraday Cup used to measure the primary ion beam current at the exit of the intermediate section.</td>
</tr>
</tbody>
</table>
3.3 Tuning L0 and L1

L1 can be used to modify the demagnification of the source image. L1 produces a real reduced image which will be seen by the following part of the primary column as a real object. This reduced image is located in between L1 and SS30. For the Cs source at 8kV Figure 5 shows the variation of the Gaussian probe size versus L1. This theoretical graph has been computed with a 40 microns source size at the exit of the Cs source. While reducing the probe size, the probe current will decrease. Figure 6 shows the theoretical and experimental variations of the probe current versus L1 for the same D1 diameter.

![Gaussian demagnification vs L1](image1)

**Figure 5**

![Relative probe current vs L1](image2)

**Figure 6**
L0 or L0 and L1 are also currently used to increase the probe current. Of course while increasing the probe current, the probe size increases. Probe current limitations are no more only due to D1 but also to the small differential pumping tube located between the source chamber and the central column. Figure 7 shows the variation of the probe current vs L0. L1 is kept at 0 volt and the source specie is Cs⁺.

A comparison has been made between theoretical and experimental values showing the effect of the pumping tube which limits the current at high L0 values.

One can find different couple of values giving a maximum for the probe current as shown on Figure 8 and 9 while using L0 and L1 for Cs⁺.

29 nA of Cs⁺ has been measured for the following settings: FCp = 50 nA, D1-1 = 750 microns, L0 = 4250 V, L1 = 3100 V.

In these extreme conditions the probe size is huge and aberrations dominate the probe shape, leading to very long tails.
Figure 8

Figure 9

<table>
<thead>
<tr>
<th>Experimental Conditions</th>
<th>Simulation made without beam stops</th>
</tr>
</thead>
<tbody>
<tr>
<td>FCp = 33.45nA</td>
<td>Maximum beam current : 29 nA</td>
</tr>
<tr>
<td>D1-1 (300µm)</td>
<td>FCp = 50 nA</td>
</tr>
<tr>
<td></td>
<td>D1-1 (750µm)</td>
</tr>
</tbody>
</table>

While using the Duoplasmatron, the optical column description is relatively similar. As the primary ion beam is focused in D0 after the Wien filter, D0 acts like a source for the primary ion column. L0 is mainly used to focus the beam in the differential pumping tube located between the source chamber and the central column. As D0 is very close to L0, L0 must be set at a higher voltage.
Figure 10 shows the variation of the probe current vs L1, L0 kept at 2250 bits for 0-31. Typical C1X and C1Y variations are also shown. Experimental conditions were the followings:

- FCp = 530 nA with D0-1 (200 microns),
- Wien Filter : Icoil = 2.0 A, CWF = 29.9 V,
- Lduo = 1608 bits.

3.4 Monitoring the primary current with FCp

Choose FCp mode in the Tuning window or press FCp on the keyboard. L1 and Cx will be set at preset values. The primary ion beam is focused by L1 at the entrance of the FCp and centered in FCp by Cx.

The beam current will be displayed in the “FC part” of the Tuning Window.
4 **Central column**

4.1 **Overview**

This section of the primary column is used to send the primary ion beam on the axis of the coaxial column and to raster the beam on the sample surface. An octopole is available to correct the astigmatism.

4.2 **Description**

<table>
<thead>
<tr>
<th>Device</th>
<th>Label</th>
<th>Description and functionality</th>
</tr>
</thead>
<tbody>
<tr>
<td>SS30 78° ESA</td>
<td>SS30</td>
<td>30 mm radius spherical electrostatic sector used to rotate the primary ion beam by 78°.</td>
</tr>
<tr>
<td>L3</td>
<td>L3</td>
<td>Lens used to couple SS30, P1 and P4 in order to provide an achromatic deviation of the primary ion beam.</td>
</tr>
<tr>
<td>B1</td>
<td>B1</td>
<td>A 4 plates deflector used to scan the primary ion beam on the sample surface.</td>
</tr>
<tr>
<td>B2x B2y</td>
<td></td>
<td>A 4 plates deflector used to scan the primary ion beam on the sample surface.</td>
</tr>
<tr>
<td>Oct-90 Oct-45</td>
<td></td>
<td>Octopole used as a stigmator which acts like two quadrupole at 45°.</td>
</tr>
<tr>
<td>Plates P4</td>
<td>P4h</td>
<td>Deviating plates used to rotate the primary ion beam by 6°.</td>
</tr>
<tr>
<td>Plates P1</td>
<td>P1h</td>
<td>Deviating plates used to rotate the primary ion beam by 6° and to rotate the secondary ion beam by -6°.</td>
</tr>
<tr>
<td>Scanning plates</td>
<td>B3</td>
<td>A 4 plates deflector used to scan the primary ion beam on the sample surface and which also act as a dynamic transfer system for the secondary ion beam.</td>
</tr>
</tbody>
</table>
4.3 Rastering the primary ion beam

The primary ion beam is scanned over the sample surface by the action of a set of three pairs of parallel plates B1, B2 and B3. The plates B3 are powered in synchronism with the two others scanning plates, so as to cancel the motion of the secondary ion beam (dynamic transfer) at the entrance slit. Maximum practical field of view is 200*200 square microns, with a number of pixels ranging from 64x64 to 1024x1024. Increasing the field of view above 50 microns leads to defocusing effects on the primary ion probe. As the sample surface image is located near D1, D1 acts also as a field aperture diaphragm and thus limits the maximum field of view.

Practical rules: Field of view = 0.6 * diameter of D1

Tuning of B1, B2 and B3 is mainly linked to the dynamic transfer. B3 and B1 are set at their theoretical values respectively: 4096 and 3700 bits. B2 is the free parameter and can be tuned independently in X and Y. Theoretical values for B2: B2X = 3170, B2Y = 3480.

Electronic board uses two different types of amplifiers in the final amplification stage: up to 20 volts (2000 bits) ultra low noise amplifiers, above 20 volts low noise amplifiers. The practical field of view must be measured for both amplifiers:

0 Introduce the Silicon grooved sample and measure the real field of view around 40 microns SField_m.
0 Enter in the Setup/Keyboard/Raster section the new value for the field of view SField_m in microns and SField_b for the field in bits (Dac).
0 Increase the field of view to 80 microns and measure the real field of view LField_m and LField_b
0 Enter in the Setup/Keyboard/Raster section the new value for Field correction factor:
   \((LField_m/ SField_m) \times (SField_b/LField_b)\)

Standard values are respectively 50 microns à 1900 bits and 10.

4.4 Dynamic Transfer

The plates B3 are powered in synchronism with the two others scanning plates B1 and B2, so as to cancel the motion of the secondary ion beam (dynamic transfer) at the entrance slit.
**Procedure:**

1. Implant a large area 70 microns without D1,
2. Reduce the scanning field to 10 microns and set up D1-2 and ES5,
3. Tune E0S and the slit position to maximize the secondary ion beam current,
4. Increase the scanning field to 60 microns and tune B2X and B2Y independently to get a homogeneous image.
5. Introduce these new values in the setup
6. Check again the raster relationship and the large field coefficient. Standard values are respectively 50 microns à 1900 bits and 10.

Theoretical standard values for B2: B2X = 3170, B2Y = 3480

5 Coaxial column

5.1 Overview

The same optical system is used to focus the primary ion beam and to collect secondary ions. The objective column is the common path for primary ions, secondary ions, primary and secondary electrons.

Compared to other SIMS instruments where the primary ion beam is introduced obliquely, this arrangement has the great advantage of considerably shortening the distance between the sample and the probe forming lens. Thus, focal length and aberrations of the objective lens are minimized, which leads to a smaller probe diameter for a given ion current.

A second advantage of this experimental setup is that secondary ions experience a strong electric field as they leave the sample leading to a higher useful yield, and to a dramatically reduction of the broadening of the secondary ion beam at the exit of the probe forming system, due to the initial angular and energy distribution. In addition, the normal incidence as opposed to oblique incidence of the primary ions minimizes shadowing effects on rough samples.

The diaphragm D1 controls angular aperture of the primary ion beam and acts as a field diaphragm for secondary ions.
5.2 Description

<table>
<thead>
<tr>
<th>Device</th>
<th>Label</th>
<th>Description and functionality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lens L4</td>
<td>L4</td>
<td>Fourth electrode of the immersion lens, acts mainly on the secondary ion beam.</td>
</tr>
<tr>
<td>Diaphragm D1</td>
<td>D1</td>
<td>Aperture stop which limits the angular aperture of the primary ion beam and limits the field of view.</td>
</tr>
<tr>
<td>Electrode E0S</td>
<td>E0S</td>
<td>Third electrode of the immersion lens E0 which acts mainly on the secondary ion beam.</td>
</tr>
<tr>
<td>Lens E0P</td>
<td>E0P</td>
<td>Second electrode of the immersion lens E0 which focus the primary ion beam on the sample.</td>
</tr>
<tr>
<td>Electrode E0W</td>
<td>E0W</td>
<td>First electrode of the immersion lens E0 which acts mainly on the secondary ion beam.</td>
</tr>
<tr>
<td>Faraday Cup</td>
<td>FCo</td>
<td>Faraday Cup used to measure the probe current.</td>
</tr>
</tbody>
</table>

5.3 Monitoring the probe current with FCo

Click on FCo button in the Holder window, FCo mode will be automatically selected in the Tuning window. The sample stage will move to a preset position where the primary ion beam can travel through it and reach the Faraday cup located on the main flange. The immersion lens E0 will be set at preset values to focus the primary ion beam in FCo.

The beam current will be displayed in the “FC part” of the Tuning Window.

To come back to the analysis position, click on the “SIMS” button in the holder window.
Remark: For a given D1 diameter FCo beam current is proportional to FCp beam current. For D1 = 300 microns FCo = 10^4 FCp. The probe current is also proportional to the power 2 of the D1

5.4 Probe diameter

Probe size can be theoretically determined by means of the following relationship:

\[(\text{Probe size})^2 = (\text{Gaussian size})^2 + \Sigma (\text{aberrations})^2\]

Main aberrations for this kind of optical system are:

- Aperture aberration: \(\frac{1}{2} \text{Cs} \alpha^3\)
- Chromatic aberration: \(\text{Cc} \alpha \Delta E/E\)

\(\alpha\) being the half aperture at the sample and \(E\) and \(\Delta E\) are respectively the nominal energy and the energy spread of the primary ion beam. Cs and Cc are respectively aperture and chromatic aberration coefficients.

Cs and Cc are linked to the optical properties of the immersion lens. Electrodes shapes have been designed to minimize these two coefficients; practical values for the N50 are Cs = 66 mm and Cc = 16 mm.

For a given probe size (d) one can theoretically determine an optimum value for D1 (or \(\alpha\)) which maximizes the probe current. In a first approximation by neglecting chromatic aberrations one can determine this optimum:

\[\alpha_{\text{opt}} = \frac{1}{2} (d/Cs)^{1/3}\]

And

\[I_{\text{opt}} = \left(\frac{3\pi^2}{16}\right)B (1/Cs)^{2/3} d^{8/3}\]

A complete simulation with chromatic aberrations gives for a probe size of 100 nm, \(D1 = 240\) microns and \(I_{\text{opt}} = 2-3\) pA.

Above simulations have been made with the following hypothesis at 8keV with Cs+ primary ions and the followings hypothesis: Source size 40 microns, \(\Delta E = 1\) eV (at least 15 eV for the duoplasmatron source), Cs = 66 mm, Cc = 16 mm.

As D1 is not continuously adjustable one has to do a compromise for each probe size, table 4 is a summary of practical D1 vs probe size for Cs+.

<table>
<thead>
<tr>
<th>Probe size</th>
<th>D1</th>
<th>L1</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 – 120 nm</td>
<td>D1-2 or D1-3</td>
<td>0</td>
</tr>
<tr>
<td>70 – 100 nm</td>
<td>D1-3 or D1-4</td>
<td>6000 &lt; L1 &lt; 7000</td>
</tr>
<tr>
<td>&lt; 70 nm</td>
<td>D1-4 or D1-5</td>
<td>&gt; 7000</td>
</tr>
</tbody>
</table>

Table 4: Practical rules for small probe diameters with Cs+

<table>
<thead>
<tr>
<th>D1 #</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>750</td>
<td>300</td>
<td>250</td>
<td>200</td>
<td>150</td>
</tr>
</tbody>
</table>
Table 5: D1 Standard aperture diameter
While using O- beam the rules are more complex as in addition to D1, D0 has to be chosen. Table 6 is a summary of practical D1 and D0 vs probe size for O-.

<table>
<thead>
<tr>
<th>Probe size</th>
<th>D0</th>
<th>D1</th>
<th>L1</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 2 microns</td>
<td>D0-1</td>
<td>D1-1</td>
<td>0</td>
</tr>
<tr>
<td>600 – 1000 nm</td>
<td>D0-1</td>
<td>D1-2 or D1-3</td>
<td>0</td>
</tr>
<tr>
<td>400 – 600 nm</td>
<td>D0-2</td>
<td>D1-3 or D1-4</td>
<td>0</td>
</tr>
<tr>
<td>300 – 400 nm</td>
<td>D0-3</td>
<td>D1-3 or D1-4</td>
<td>0</td>
</tr>
<tr>
<td>&lt; 200 nm</td>
<td>D0-4</td>
<td>D1-4 or D1-5</td>
<td>0</td>
</tr>
<tr>
<td>&lt; 200 nm</td>
<td>D0-4</td>
<td>D1-4 or D1-5</td>
<td>6000 &lt; L1 &lt; 7000</td>
</tr>
</tbody>
</table>

Table 5: Practical rules for small probe diameters with O-

5.5 Probe size vs E0P
In much analysis the primary ion beam cannot be used focused as the beam will drill a very deep and narrow hole. Decreasing E0P will increase the probe size as shown on Figure 11.

Experimental conditions were as following: Cs+ at 8 kV, D1 = 150 microns. In this measurement Delta E0P was in fact negative. Practical value is 52V per micron for D1 = 150 microns.

![Figure 11](image.png)

5.6 Influence of Z
The N50 has been designed to work with a distance between the immersion lens E0 and the sample set to 400 microns. Any change of this value will affect the focusing value of E0P and thus the focal length.
Practical rules for E0P: 60 Volts = 100 microns in Z
Question: will any change of Z affect the lateral resolution?

Figure 12 and 13 show the typical relationship between aberration coefficients Cs and Cc and the focal length.

As shown on above Figure 13, Cc is proportional to \( f^{0.83} \) and Cs is proportional to \( f^{2.93} \). f is the E0 focal length (roughly 6 mm). Changing Z is equivalent to changing the focal length of E0 leading to \( \frac{dz}{z} = \frac{df}{f} \). In addition relative variation of alpha will be also equal to relative variation of f: \( \frac{da}{a} = -\frac{df}{f} \).

Lest assume that aberrations are expressed by:

\[
Ab = \frac{1}{2} Cs \alpha^3
\]

Thus:

\[
dAb/Ab = dCs/Cs + 3 \frac{d\alpha}{\alpha}
\]

\[
dAb/Ab = 2.93 \frac{df}{f} - 3 \frac{df}{f}
\]
\[ \frac{dA_b}{A_b} = -0.07 \frac{df}{f} \]

As \( f = 6 \text{mm} \) and Delta \( z = 100 \text{ microns} \): \( \frac{df}{f} = 0.015 \) leading to \( \frac{dA_b}{A_b} = 0.001 \). This result shows obviously that even a \( z \) variation of 100 microns will have no real effect on the aberration.

As the Gaussian reduction factor is directly proportional to the focal length, it will also be negligible.

In conclusion any \( z \) variation will not have any effect on the lateral resolution.