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## Imaging on a PHI 600 or 660 System

One of the more common questions that we get from 600 and 660 system operators is, “How can I get better images?” The answer is simple once you understand how the 25-120A analyzer optics function. This article will take you step by step through an explanation of the electron optics and their operation. We will begin with a basic theory of operation for the electron column, which is followed by procedures for optimization of the electron beam and acquisition of high resolution, high quality images.

### ***Theory of Operation***

The electron beam starts at the top of the column in the LaB6 filament assembly. (See Figure 1.) Current is applied through the filament and electrons emit from the tip. With a new filament the nominal current is about 1.4 A. You do not want to run the filament any higher than necessary to obtain sufficient emission and beam current, or you will shorten the filament lifetime unnecessarily. The emission voltage is applied to the Wehnult cap which suppresses electrons from emitting from the tip of the LaB6 filament. As the emission voltage is reduced, more electrons emit from the filament tip. Thus, there is an inverse relationship between the emission voltage and the emission current. (The emission current should never be operated higher than 100  $\mu$ A.)

One also needs to understand the difference between the emission current, beam current and target current. The emission current is the electrons which leave the filament tip and are absorbed by the Wehnult cap. The beam current is the electrons that leave the assembly through the aperture at the bottom of the Wehnult cap. The target current is the portion of the beam current that passes through the electron column and impacts the target. Under some operating conditions, the beam current and the target current are almost identical.

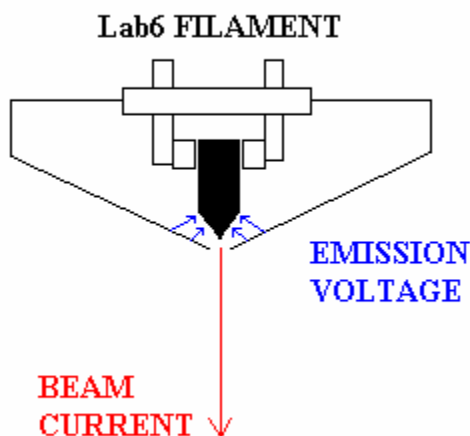


Figure 1. Wehnult cap and filament assembly

Finally, the filament and emission voltages are floated on the beam voltage. At higher beam voltages, the electrons are accelerated towards the target faster and beam coherency increases. Typically, better imaging is available at higher beam energies. Operation of the beam voltage above 20 kV is not recommended due to the possibility of arcing and system damage. Typically 15 kV is adequate for high resolution imaging, and 10 kV is often chosen because there are AES sensitivity factors for 3, 5 and 10 kV.

As the electron beam leaves the Whenult cap, it passes by the beam blank plates. (See Figure 2.) One of the beam blank plates is grounded and the other is connected to the beam blank BNC outside of the analyzer. During normal operation of the electron gun (for maximum target current), there is no voltage applied to the beam blank connection. When voltage is applied (-100 V), however, the beam is deflected and does not pass through the remainder of the electron column. (An alternate method used to blank the beam is increasing the emission voltage to 100% which totally suppresses all electron emission from the filament.) It should also be noted that the beam blank BNC can be useful for positioning a new filament after installation if you are unable to obtain any target current. You can simply connect a biased ammeter to the beam blank BNC and adjust the filament position knobs for maximum current.

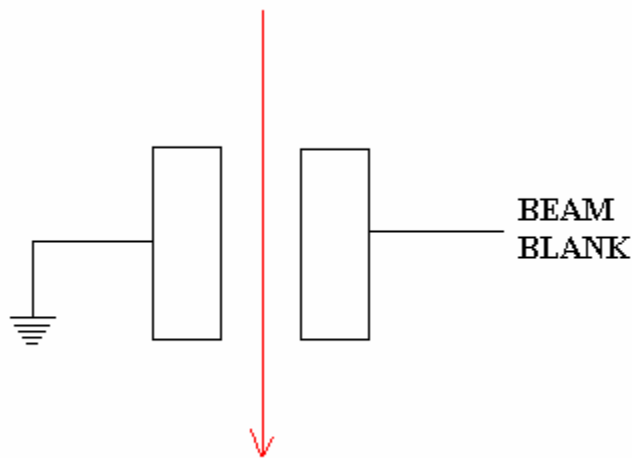


Figure 2. Beam Blank Plates

Next, the beam passes by the condenser lens and condenser steering plates. (See Figure 3.) As more current is applied to the condenser lens, less beam current passes through the lens. The condenser steering plates, on the other hand, have DC voltages applied to them. Their function is to steer the beam in the column for optimum performance and minimal beam distortion.

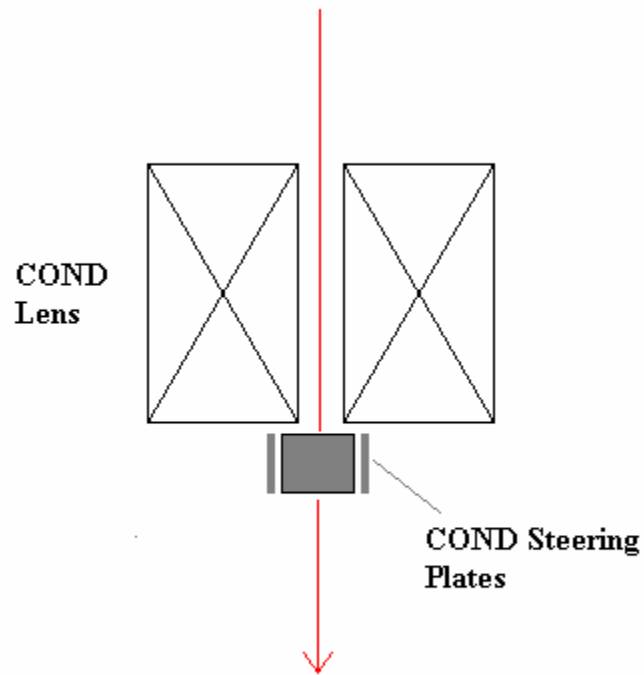


Figure 3. Condenser Lens and Steering Plates

Looking at the sample data in Figure 4, it is clear that the relationship between the beam current and the condenser current is nonlinear. There are two places where the condenser lens percent in AugerMap produces the highest current. One point is typically between 15% and 20%, and the second point, which produces slight less current, is typically between 34% and 38%. Since you rarely need the absolute maximum current produced by the lower maximum, it simplifies the operation of the electron gun to locate the higher local maximum and use that for high beam current applications. For lower beam current applications it is best to use a higher condenser percentage above this point since the beam current decreases monotonically up to a setting of 100%.

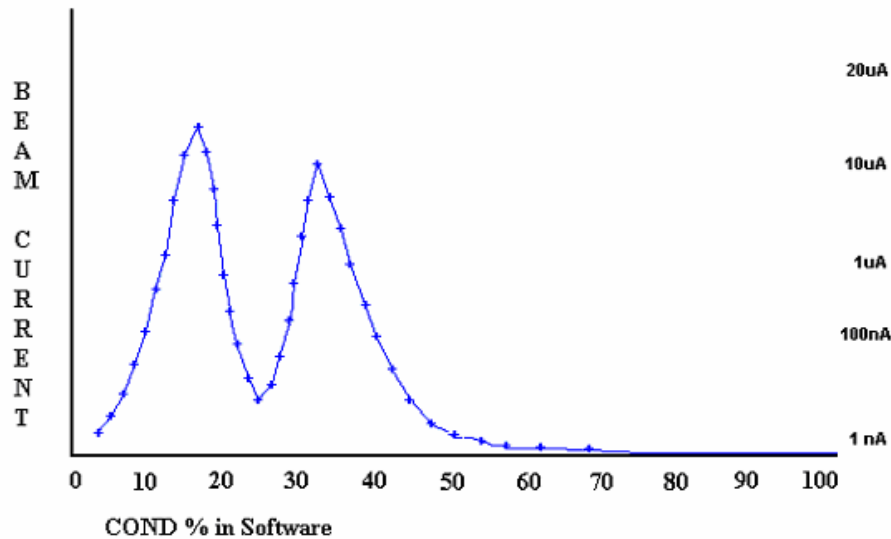


Figure 4. Beam Current vs. Condenser Lens Setting

There are 3 other points that yield convenient beam currents and beam sizes: 40%, 50% and 60%. 40% gives enough beam current to obtain reasonable AES data and also image up to ~5,000x magnification. At 50% there will be about 1nA of beam current. Data can be acquired, but the signal to noise is rather poor, so you will need to use many sweeps or a larger time/step. The images, however, are noticeably better at 50%, and you can image up to ~20,000x. Finally, 60% yields only 0.1 nA of beam current. This setting gives you the minimum beam diameter size and therefore the highest possible magnification. At 60%, the beam current is too low to acquire data, so this setting is only useful for SEM imaging.

After the beam passes through the condenser lens and steering, it passes through the objective aperture. The objective aperture helps to shape the beam before it enters the objective coil. There are five different apertures that are selected by turning the objective aperture knob on the analyzer. (See Table 1 and Figure 5.) The control knob increases the aperture size as it is turned clockwise. You can feel an indent at every 180° of rotation, each of which indicates a different aperture setting. (In one location there is no indent where the aperture selection starts over.) You can also look at the target current with a biased picoammeter to see which aperture you are on by the relative amount of target current at each aperture setting.

Table 1. Aperture settings

Aperture Number	Aperture Size	Typical Beam size
1	.004"	250Å to 1100Å
2	.004"	250Å to 1100Å
3	.008"	1100 Å to 1uM
4	.016"	1uM to 2uM
5	.093"	High beam current mode

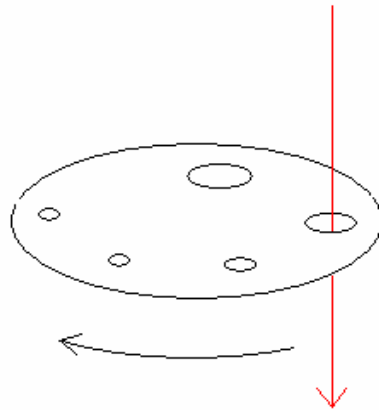


Figure 5. Aperture wheel

At this point, the beam passes through the objective steering plates and into the objective lens. (See Figure 6.) The objective steering plates guide the electron beam into the center of the objective lens and the objective lens focuses the beam on the target.

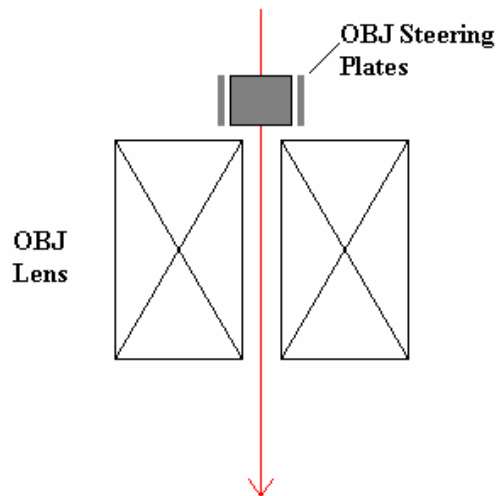


Figure 6. Objective lens and steering plates

Finally, the beam passes the octupole deflection plates and leaves the analyzer to impact the target. (See Figure 7.) The deflection plates are used to raster the beam for TV images and area-mode scans. They also position the beam for point and line scans. With the octupole design, the eight plates are arranged in a circle and stigmator

voltages are added to the deflection plates to shape the beam. (Each plate has a portion of the deflection and stigmator voltages applied to it.)

Now that the operation of the electron column has been addressed, we will now cover how to optimize the performance of the electron beam as well as obtain high-resolution images with the instrument.

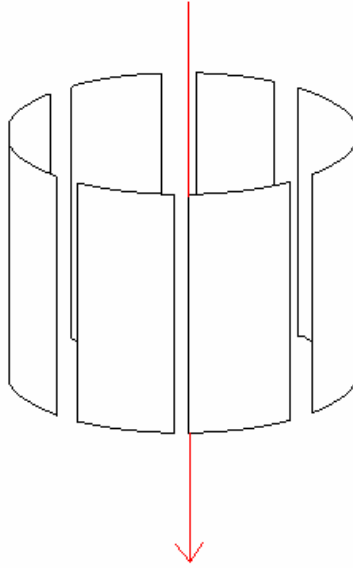


Figure 7. Octupole Assembly

## **Beam Optimization Procedure**

First we need to maximize the target current by adjusting the filament housing adjustment micrometers. *You do not need to do this every time that you want to image with higher resolution, but it is essential to do this periodically to ensure that the column is properly aligned.* This procedure requires that you have a conducting sample in the stage – an empty sample mount will work fine.

1. Select the largest objective aperture.
2. If the SED multiplier voltage is on, turn it off to prevent saturation of the SED multiplier.
3. Set the beam voltage to 3 kV.
4. Turn the filament current on the 20-610 to 1.3 A (or the normal current).
5. Adjust the emission voltage until you have 50 to 65  $\mu\text{A}$  of emission current. *The emission current should never be operated above 100  $\mu\text{A}$ .*
6. Make sure that the beam offsets (image shift) are set to zero in AugerMap.
7. Now set the beam voltage to 10 kV.
8. Re-adjust the emission voltage, if necessary, for 50 to 65  $\mu\text{A}$  of emission current.
9. Measure the target current through the bias box and an electrometer (bias box set to target, ammeter at +90 V) or using AugerMap. (An ammeter is more accurate, especially if the beam current in AugerMap is not calibrated!)
10. Set the condenser lens to about 34% and adjust slightly up and down for maximum target current.
11. Next, adjust the filament housing micrometers to maximize the target current. Sometimes the housing sticks a little bit. If so, contact RBD Enterprises for a procedure on how to repair the filament alignment housing.

The filament housing is now adjusted for maximum target current and is also centered down the column. Next we need to optimize the filament current and emission current settings. Each filament is different, but most new filaments will operate with about 1.3 to 1.4 A of filament current. In addition, there is usually a sweet spot of emission current where you will get the most target current. (If there is no peak, then operate the emission at 100 uA of emission current.) As the filament wears down with use, it will require more filament current to maintain maximum performance. When the filament requires 1.6 to 1.8 A of current it is reaching the end of its lifetime.

To characterize the filament, follow the following procedure:

1. Set the filament current to 1.2 A.
2. Measure the target current.
3. Change the emission current from 0 to 100 uA as you monitor the target current.
4. Note the maximum current spot. Sometimes this is around 20 uA, sometimes around 60 uA, sometimes 100 uA. *Never exceed 100 uA of emission current.*
5. Increase the filament current to 1.3 A and repeat the procedure.
6. Repeat the procedure up to 1.5 A of filament current.

By characterizing the filament in this manner you can determine the correct filament and emission settings that obtain the maximum target current with the least amount of filament current. Running the filament with the lowest current that yields a reasonable current will extend the life of the filament.

Figure 8 gives an example of target current vs. emission current at different filament currents. The best filament current to use is 1.3 A (in blue) because there is no increase in target current at the higher filament current setting.

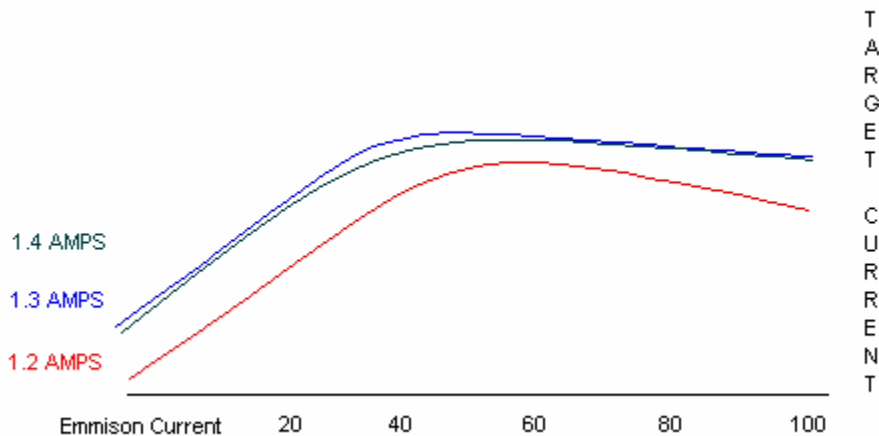


Figure 8. Relationship between beam current, filament current, and emission current

During the course of these measurements, you should find that the maximum target current on the largest aperture should be greater than 10 uA with a beam voltage of 10 kV. Most new filaments will be able to produce 20 uA or more. Once a filament can only produce 3uA or less, it is time to replace the filament. RBD provides replacement LaB6 and CeB6 filaments for most PHI scanning Auger systems, including the 600 and 660.

Now that we know the optimal filament current and emission current parameters, we are ready to image at high magnification.

## High Resolution Imaging Procedure

There are three condenser lens settings that provide consistent results when imaging and are also very easy to remember: 40%, 50% and 60%. Using objective aperture 2, the approximate target current and beam size for these settings can be found in Table 2.

Table 2. Condenser settings

Condenser Setting	40%	50%	60%
Target current	10 to 40 nA	1 nA	0.1 nA
Beam Diameter	0.5 to 0.1 $\mu\text{m}$	750 $\text{\AA}$ to 1,000 $\text{\AA}$	250 $\text{\AA}$ to 350 $\text{\AA}$
Auger data	Reasonable	Very Noisy	None – too noisy
Image Quality	Average	Good	Excellent

**Note:** For better signal to noise with Auger data, use a higher beam current.

The procedure for obtaining high resolution images is as follows. A sample with micro-scale detail will be useful, as it will allow for focusing on a small feature of interest. Use a low beam current for any semiconductor materials so as to avoid charging.

1. Position the sample at the focal point of the analyzer using the elastic peak alignment.
2. Select objective aperture 2.
3. Set the condenser to 40%.
4. Set the beam voltage to 10 kV.
5. Set the magnification to 1000x.
6. Select SED video mode and adjust the SED voltage until you have an image.
7. Focus the image using the objective setting in the software and the electron fine-focus knob, if available on your system.
8. Adjust the stigmators for the sharpest image.
9. Set the magnification to 2,000x.
10. Refocus the image.
11. Adjust the condenser X and Y steering for minimum image movement. You can adjust the rocking distance and speed parameters so that the image does not move too quickly or too far. 2% is typically about right on the distance.
12. Adjust the objective X and Y steering for minimal movement. The objective steering is more sensitive than the condenser steering. About 0.5 % to 1% is usually enough distance.
13. Readjust the focus and stigmators for the sharpest image.

At this point, all magnifications up to 2,000x should be clear and in focus. These parameters will also allow for the acquisition of Auger data with a reasonable signal to noise. For better images at magnifications up to 20,000x, repeat the procedure using a condenser of 50%. (It may be useful to first focus the image at 10,000x before attempting 20,000x.) With these parameters you will have noticeably better images and still be able to acquire Auger data, however, the data will be noisy and will require additional sweeps (or a larger time/step) to improve the signal to noise.

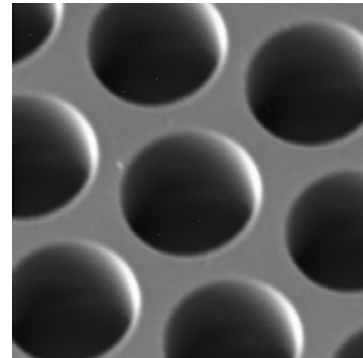
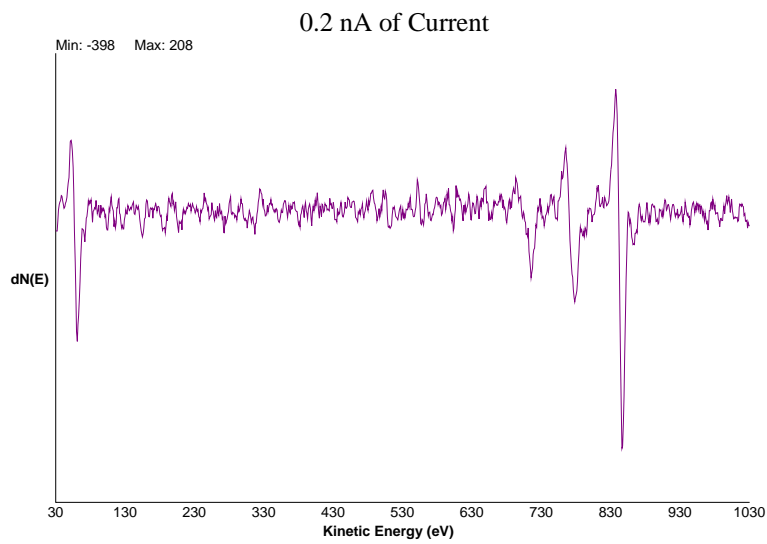
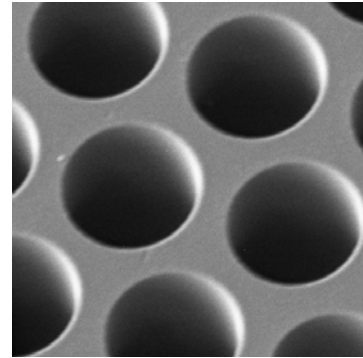
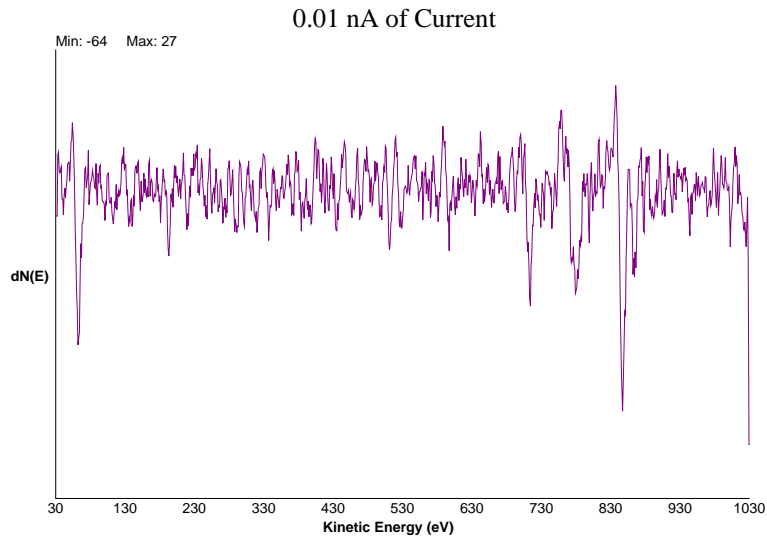
For the best possible image resolution, repeat the procedure using a condenser of 60%. This setting will yield the smallest beam diameter and therefore the clearest images at high magnification. You will be able to image up to 100,000x, although above 40,000x the images will not be as clear. This condenser setting will not yield Auger data in a timely fashion.

Finally, you can save all of these different electron gun settings in the Scanning Dialog box of AugerMap. When you need a certain configuration, you can just open the appropriate settings file. The last section of this TechTip contains an example demonstrating the effect of different condenser settings.

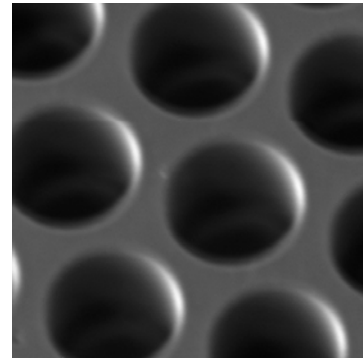
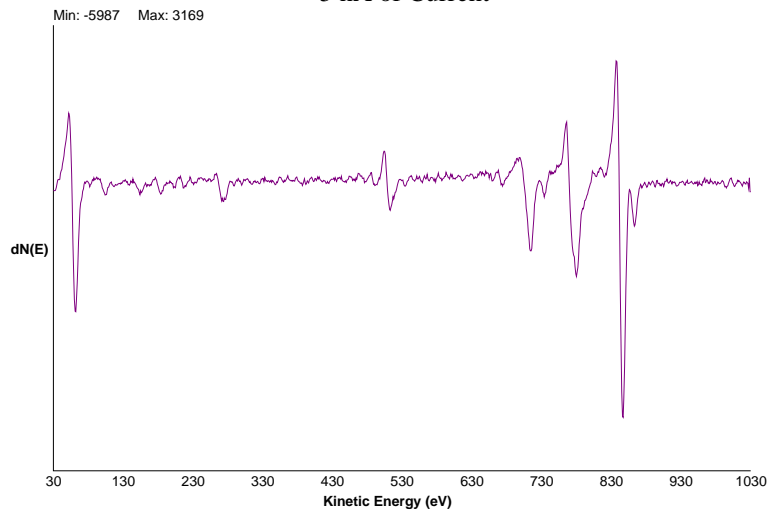


### Example: Increasing Beam Current

The following table contains examples of differentiated Auger data and SED images taken at 5000x with increasing beam current. The resolution of the SED images is highest at low beam currents. Conversely, the signal to noise in the Auger data is best at high beam currents.



5 nA of Current



85nA of Current

