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Fundamentals of the KDC-10 Kaufman Ion Source for the IBS/e and Operational Notes

Ion Source Structure

A schematic diagram of a Kaufman ion source is shown in Figure 1. The plasma is ignited in the ionization chamber by using a hot filament that emits electrons that are accelerated to that anode. A permanent magnet in the Kaufman ion source increases the path length of the electrons by causing them to spiral to the anode, which increases the ionization efficiency of the gas, usually an inert gas such as Ar. The screen grid is floating and contains the plasma. Its potential depends on the plasma potential, which, in turn, is determined by the discharge parameters. The ion current available from the ion source are determined by the ion source parameters, such as gas pressure, cathode power, anode potential, geometry, etc. The accelerator grid serves two purposes: 1) to extract the ions from the discharge chamber, and 2) to determine the ions trajectories, i.e. focusing. The anode is biased to the beam voltage which determines the ion energy that goes to the sample. A neutralizer can be added to the system. The neutralizer is a hot filament which supplies electrons that are available to neutralize the ions on their way to the sample. If the neutralizer current is made to be the same as the ion current, the beam can be completely neutralized. Neutralizing the beam does not affect the trajectories of the ions/neutrals.

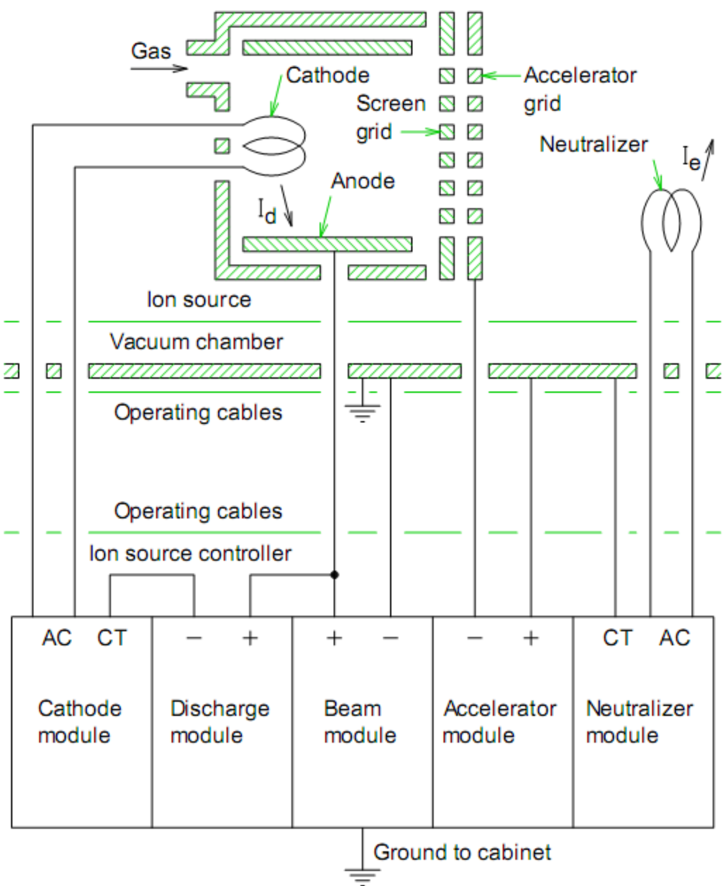

Figure 1 Electrical schematic of a Kaufman ion source.

Multi-Aperture Grids and Ion Current Limitation

The beam voltage and beam current of a Kaufman ion source can be adjusted independently, but with some limitations. In normal operation, the measured accelerator current results from the collection of low energy charge-exchange ions. Figure 2a and Figure 2b show schematic diagrams of a collimated set of grids under different low ion current and normal ion conditions, respectively. In both conditions, the ions are not directly striking the accelerator grid aperture. The maximum ion beam current is the maximum value that can be obtained without the direct impingement of energetic ions on the accelerator grid as shown in Figure 2c. An ion current that is higher than this, shown in Figure 2d, would cause both heating and extensive erosive wear of the grid. The maximum beam current is a function of beam and accelerator voltages.

[1] Note: The ion source images, notes, and some text have been reproduced from the KRI ion source manual and the book, Operation of Broad-Beam Sources, H.R. Kaufman and R.S. Robinson, Commonwealth Scientific Corp., Alexandria, by permission from KRI, Inc.

Accelerator Current and Lifetime of Grids

The charge-exchange will occur between the ions in the ion beam and background gas in the vacuum chamber. The new low energy ion will be attracted to the accelerator grid. Over time, these ions will sputter etch pits on the accelerator grid between holes. When these etch holes perforate the grid, it is time to replace the accelerator grids and for optimum performance, both grids should be replaced. The grids are precision machined and are made from special, thermally stable graphite. The rated lifetime should be greater than 2000 hours for typical usage. At lower ion currents and low operating pressures, the grids will last much longer.

Maximum Power, Ion Currents, and Recommended Accelerator Voltages

Table 1 gives the maximum argon ion beam currents for the graphite ion optics over a range of ion beam voltages. The recommended accelerator voltages (negative) are 15 percent of the beam voltages (see Section 4.5), except for the 100 V beam. As was shown in Figure 2a, some spreading of the beam will occur when a lower ion current is used. Typically, for the IBS/e, this is usually not a problem. The best focusing will usually be found between about 60-80 percent of the maximum ion beam current. The constant operation of the ion source is limited to 50 watts. This limit is imposed in order to prevent overheating of the permanent magnet in the ion source. The cathode power is about 35 watts, so this limits the ion source discharge to 15 watts. At an anode voltage of 40 V, this limits the discharge current to 0.38A. For short term operation, these limits can be exceeded, but (time) x (power) should not exceed 1400 Watt-m. (See KRI Manual for a full discussion.)

Table 1 Maximum argon ion beam current

Beam Voltage (V)	Accelerator Voltage (V)	Max. Beam Current (mA)
100	60	1
200	30	2
300	45	4
400	60	7
500	75	11
600	90	14*
700	105	20*
800	120	26*
900	135	32*
1000	150	38*
*Max currents for time limited operation. For continuous operation, use 10 mA. See manual for discussion.		

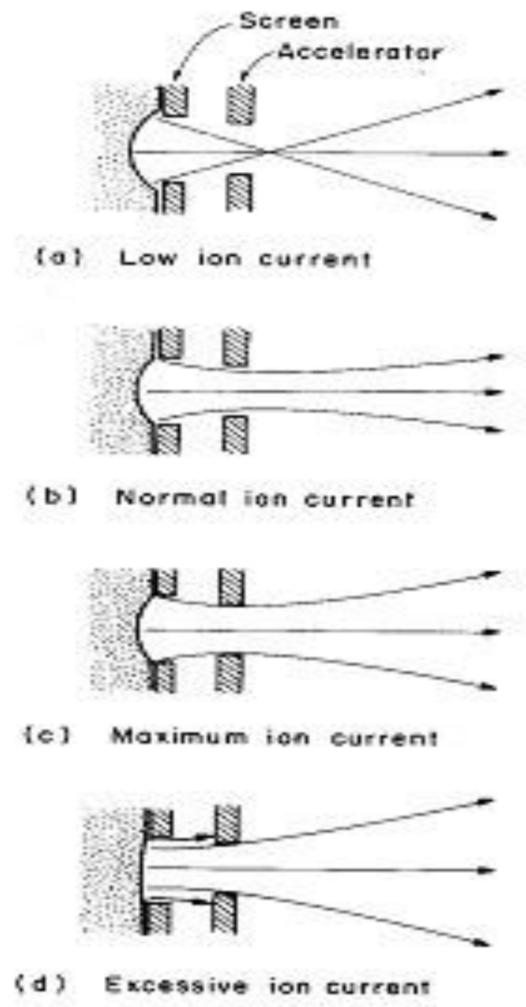

Figure 2 Multi-aperture grids with different current conditions.

Another issue to consider when determining what ion beam current to select is beam heating. If the full beam is incident on the sample, then the power deposited on the sample can be estimated by simply multiplying the Beam Voltage and Beam Current (A) together. For example, if 600 V is used with 10 mA, then a power of 6 watts is being put onto the sample. For a sample in a vacuum system, this can lead to considerable heating. At 600V, 5mA, the power is 3 watts. When selecting the beam voltage and beam current values, a maximum in the sputtering efficiency is found at about 250 V. The sputtering efficiency would be the number of ions sputtered per watt. This should not be confused with sputtering rate, which is dependent on the energy and will increase with increasing beam voltage.

The maximum ion beam current can be increased at a given beam voltage by increasing the negative accelerator voltage. But the user should be aware that the beam will diverge more as the negative voltage is increased. If the increase in negative voltage is moderate, the maximum ion beam current can be calculated from the total voltage - the sum of the beam voltage and the absolute value of the accelerator voltage. For example, the maximum beam current in Table 1 is 11 mA for a 500 V beam. The total voltage for this 500 V beam is 500 + 75

= 575 V. As a first approximation, the same maximum beam current of 11 mA can be obtained with a 300 V beam by increasing the accelerating voltage to 575 - 300 = 275 V. With this large accelerator voltage, however, the 300 V ion beam will be much broader than the 500 V beam. The broad ion beam may be acceptable if a larger area is being processed or unacceptable if a tightly focused ion beam is desired. Also, the grid lifetime can be expected to be reduced. In this example, the power is decreased by 40%. In practice, it is best to reduce the increased current by a little if this method is used to increase the desired beam current.

Focusing and Defocusing Optics

If the grid holes are misaligned, the ion trajectories will be deflected. If the holes in the grid of the accelerating grid are precisely and purposely misaligned in a radial direction relative to the screen grid holes, then the cumulative effective of all of the holes will be that the total beam can be focused or defocused (spread). Figure 3a shows the cumulative effect of ion trajectories that give a focused beam and Figure 3b shows the defocused beam. Experimentally, the etch rate of a focused beam is approximately twice that of the collimated beam. For the KDC-10, the option is available to switch the optics assembly with a collimated, focused, or defocused set, dependent on the user’s needs. At normal incidence, 600 V beam voltage and 5 mA, the focused ion optics in the KDC-10 in the etch position of the IBS/e gives an ion processed area of about 0.7 inches in diameter, the collimated ion optics give a diameter of about 1.25 inches, and the defocused ion optics give a diameter of about 1.75 inches. Figure 4 shows the sputter etch patterns for the different optics that can be used with the KDC-10 in the IBS/e of a gold film that was deposited on the two inch sample holder with a penny on it at normal incidence, 0°.

Ion Optic Options for the KDC-10 on the IBS/e

There are two practical options for routinely switching between the different optics for the KDC-10 on the IBS/e. You can have one ion source and switch the individual ion optics or you can have a different ion source available with the ion optics already installed and switch that. Figure 5 shows the KDC-10 ion source and socket assembly in different states of assembly. The socket assembly is on a feedthru vacuum flange on the IBS/e. Figure 5a shows the ion source as it is in the socket. Figure 5b shows the ion source removed from the socket. The easiest exchange for the ion optics would be to have a second ion source and exchange it at this point. An important point here is that the ion source will be hot after use and must be cooled to room temperature before removing from the IBS/e system. Figure 5c shows the ion source in its stand. The ion optics are pre-aligned with the ion source body. The maintenance stand and ion source components have a notches that helps maintain that the de-assembly and re-assembly of the ion source is

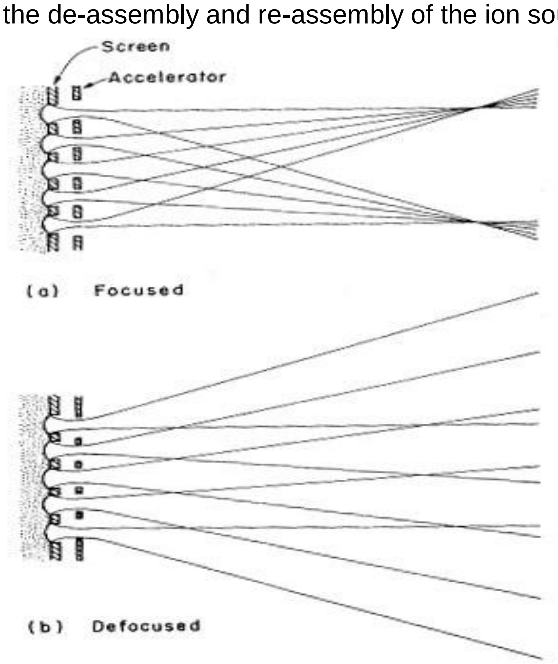

Figure 3 Ion grid optics for (a) Focused and (b) Defocused conditions.

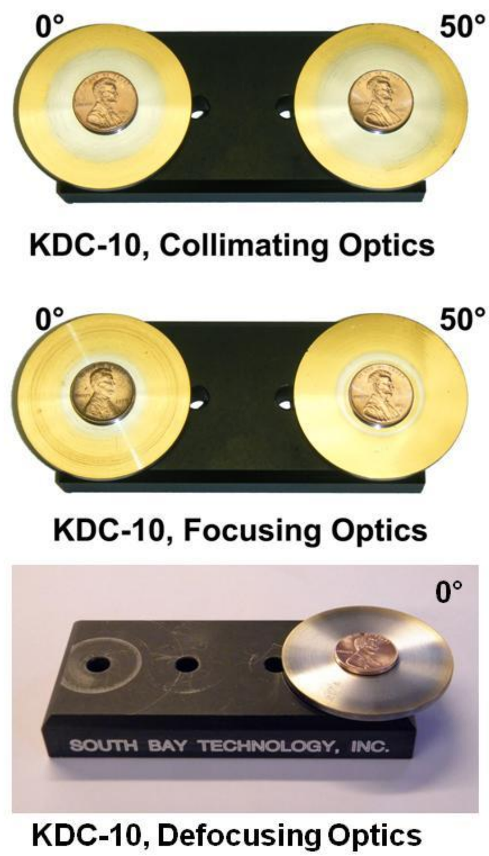

Figure 4 Etch patterns for the KDC-10 in the IBS/e.

carried out correctly. Figure 5d shows the ion optics removed from the ion source. If only one ion source is owned, a second ion optics type could be exchanged at that point.

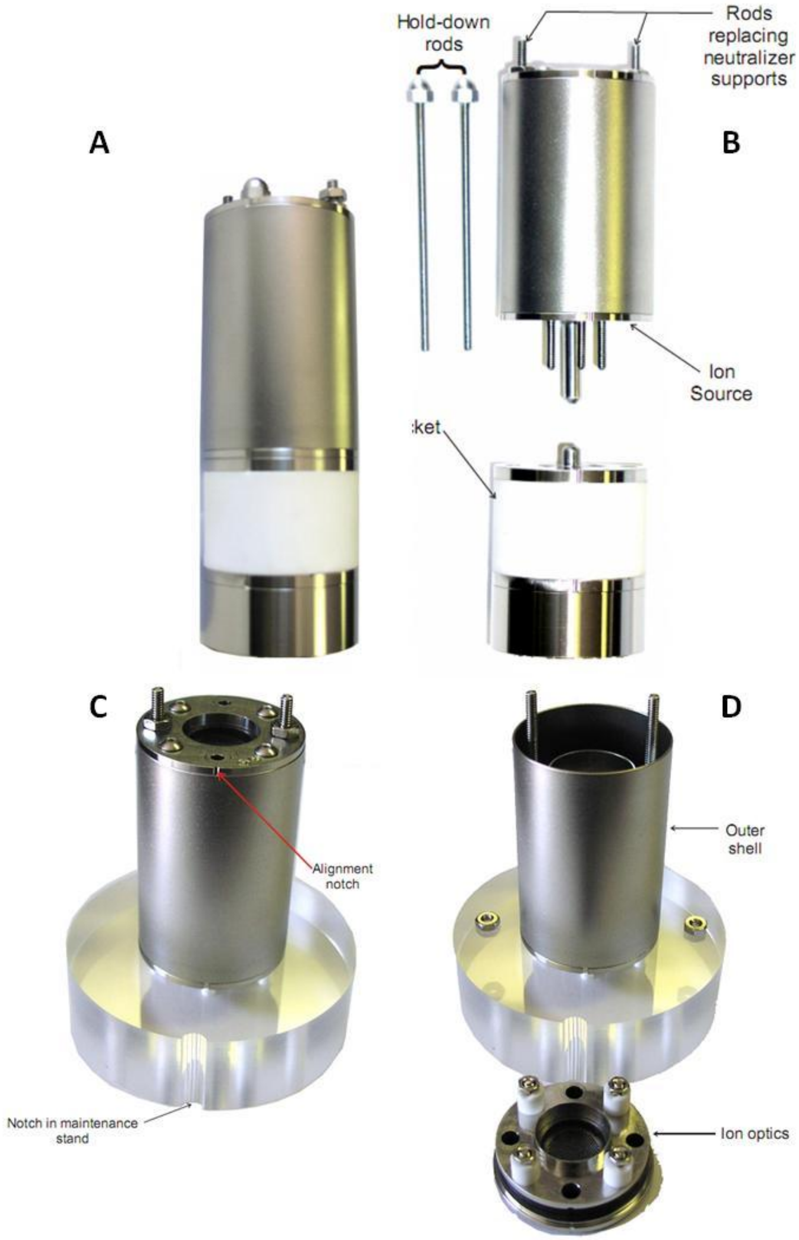

Figure 5 Ion Optics change for the KDC-10 Ion source.