Surface Preparation:
"Glow Bars" for Plasma Cleaning

A "glow bar" is a high-voltage cathode used for generating a plasma for plasma cleaning at a gas pressure of a few microns up to several Torr. A glow bar often can be found in deposition systems, such as in optical coating facilities using thermal evaporation, where the deposition takes place in a good vacuum.

In a simple DC diode (non-magnetically confined) discharge, electrons are accelerated away from the cathode. These establish the plasma, but also many of the electrons reach high energies and bombard any surface on which they impinge. Thus, the glow bar provides two possible cleaning mechanisms: 1) plasma cleaning, which occurs on all surfaces in contact with the plasma, and 2), electron bombardment of surfaces facing the cathode. Both mechanisms have been shown to be effective in cleaning glass.

A plasma in contact with a surface generates a negative potential on the surface with respect to the plasma (sheath potential) due to the higher mobility of the electrons in the plasma compared to the ions. This potential will depend on the local plasma density and temperature. The potential will be increased if the surface is also being bombarded by high-energy electrons from the cathode. Figure 1 shows the effects involved with plasma cleaning.

Glow bars can have many shapes. The most common design is a rod or tube attached to a high-voltage feedthrough. As shown in Figure 2a, the high-voltage insulator must be protected from depositing metals by a baffle-type shielding. The rod or tube is usually made of aluminum and can be bent into any shape. The tube can be water cooled using two high-voltage/fluid feedthroughs and an insulating break in the water-cooling line. Deionized water should be used for cooling. Other shapes, such as plates or moveable shutters, can be used to create a more uniform plasma over the surface to be cleaned, or the surfaces may be passed in front of the glow bar.

Aluminum is the most common glow bar material because it forms a thin coherent oxide, and the oxide has a low sputtering rate. Unless you are depositing aluminum, it may be important to shield the glow bar from deposition because the surface material on the glow bar will tend to be sputtered when the glow discharge power is on.

Ground shields can be used to control the area on the cathode that produces the plasma. If a ground shield is placed closer than the distance dictated by the width of the cathode dark space, a discharge will not be sustained between the ground and the high-voltage electrode. By making the spacing very small, pressures higher than those used for sputtering can be used, allowing a high-density plasma to be formed at low voltages and at higher pressures.

The advantage of using empty space as an insulator is that you don’t have to worry about metal deposits shorting out the insulator. However, in regions where deposition is unlikely, an insulating material such as Teflon™ can be used in the space. Teflon™ has a voltage standoff of greater than 1000 volts per mil.

Increasing the target voltage (at a constant pressure) causes the dark space to decrease in thickness. Decreasing the gas density (at constant voltage) makes the dark space thicker. The product of the pressure and the dark space thickness is fairly constant. For example, in argon at 10 mTorr and 1000 VDC, the cathode dark space is about 0.5 cm. A grounded conductor placed closer than this will not allow a glow discharge to be self-sustaining.

Figure 1: The effects involved with plasma cleaning.
By shaping the active area of the glow bar, the ejected electrons can be focused on the surface to be cleaned. Figure 2b shows a shaped electrode with a closely spaced ground shield to make the concave portion of the cathode the active surface. The high-energy electrons accelerated away from the cathode produce a high surface potential on a dielectric surface (or electrically isolated surface). This increases the sheath potential between the substrate and the plasma.

When using a continuous DC high-voltage potential, particularly when using air as the working gas, there may be occasional arcs on the active cathode surface. These arcs can produce molten droplets and particulates that can contaminate surfaces. It is important that the DC power supply has an arc-quenching circuit, or better yet, use pulsed DC or mid-frequency bipolar power on the glow bar to prevent arcing.

For the greatest flexibility in voltage and pressure, the spacing between the ground and the high-voltage electrode should be small to prevent establishing of a glow discharge in the pressure range of 10-20 mTorr. Stray magnetic fields should be eliminated in that they may allow a glow discharge to be established in the space. Generally, it is better to use lower voltages and higher currents than to use higher voltages and lower currents to obtain a specific cleaning power. Power supplied to the cathode may be DC (with arc suppression), pulsed DC, or AC (symmetric or asymmetric bi-polar). Usually the power (W/A) to the cathode is voltage controlled. For a specific gas and gas pressure, the voltage and current should be reproducible for a specific power. For pulsed power systems, the power is averaged over the whole cycle. For example, at a 50% duty cycle, the actual instantaneous power to the cathode during half the cycle will be twice the indicated power. If the duty cycled is decreased, the instantaneous power will be increased to give the same average power.

In 1889 F. Paschen studied the effect of gas pressure (actually gas density) on voltage breakdown between two electrodes. This led to “Paschen’s Law,” which essentially states that above a certain minimum pressure, a gap will have a breakdown voltage (V) that is a function of the gas pressure (p) times the gap separation (d) (i.e., V = f(p·d) below this value of (p·d), the breakdown voltage rises rapidly with decreasing pressure. The minimum (p·d) for air and copper electrodes is about 0.6 Torr-cm (20°C), where the breakdown voltage is 350V. Generally, the high voltage for glow discharge cleaning should not be turned on until the high vacuum pump is opened, or a destructive arc may occur.

SAFETY: For reactive cleaning by oxidation, pure air (medical air) is generally used, although oxygen-gas mixtures such as O₂-Ar may be used. Be very careful if pure oxygen is used because compression of the oxygen in contact with hydrocarbon oil can cause an explosion (diesel effect).

SAFETY: When using an electrically isolated metal chamber, be sure to turn off the plasma power supply before venting the chamber. If you do not, the chamber may lose its ground as the chamber is vented, allowing the insulating O-ring to expand. The plasma will attempt to take the now electrically floating surface to the cathode potential, giving a high voltage on the metal chamber. To prevent this, the chamber can be grounded at all times or the plasma supply turned off before the chamber is vented.

![Figure 2](image1.png)

**Figure 2**: Figure 2a shows a shielded high-voltage feedthrough. The gaps between the shields should be less than the cathode dark space distance. Figure 2b shows a water-cooled shaped cathode where the active surface is defined by the conformal ground shield. The focused and accelerated electrons from the cathode increase the sheath potential at the substrate surface.

![Figure 3](image2.png)

**Figure 3**: Breakdown voltage (V) between two parallel electrodes with a separation of d = 1 cm in a homogeneous electric field as a function of gas pressure (gas density).

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