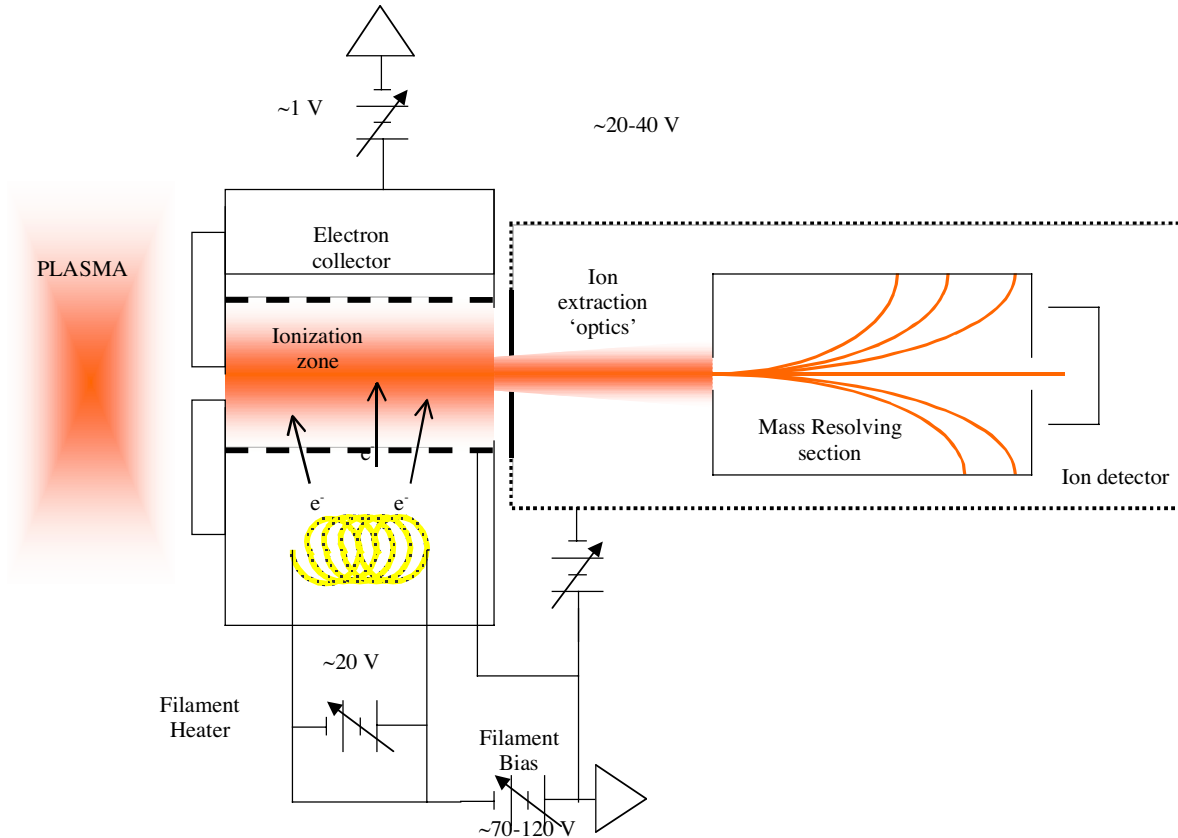


RGAs and Leak detectors

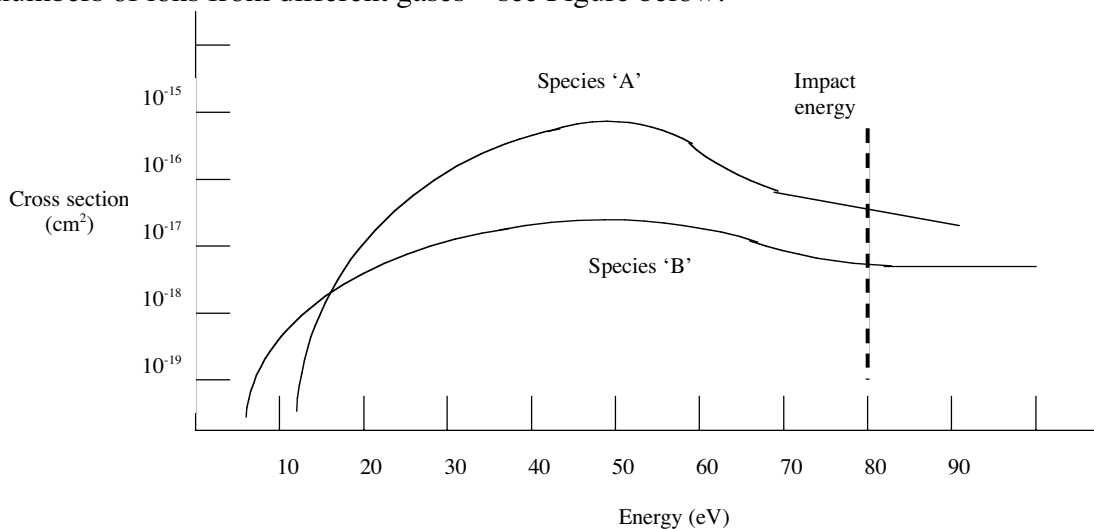
[Note that standard Ion Implanters are just overgrown RGAs!]

RGAs or Residual Gas Analyzers are also known as Mass Spectrum Analyzers. These can sometimes be upgraded to also include energy analysis – in which case they are known as Mass and Energy analyzers.) While the portion of the RGA that is used to perform the mass analysis differs from tool to tool there are many similarities between all RGAs. The basic system looks like:



We will go through the ionization part of the RGA first. The plasma produces a large variety of chemical species many of which are neutrals. To examine these neutrals we must be able to apply some well characterized forces to them. The simplest thing to do is to ionize the molecules and then use electromagnetic forces to push them around in the mass resolving section. [NOTE: if you turn off the ionization region than the only thing that you can look at is ions coming out of the plasma. This a useful variant to standard RGAs.] To ionize the neutrals we use fast electrons. These electrons are created by first heating a filament or wire that is known to give off large numbers of electrons at high temperatures. Common materials used for this is Tungsten, Thoriated-Tungsten (1-5% Thorium), or Lanthanum-hexa-Boride (LaB_6). Thoriated-Tungsten is perhaps the most common of these materials. This is because of its very high emission coefficient, higher than plain Tungsten, and it does not suffer the same material poisoning problems found with LaB_6 emitters. [Note that LaB_6 emitters are common in other applications.] To heat it, a current is drawn through the filament. Often the bias is on the order of 20 V and perhaps an amp of current but this depends on the size and type of the filament. The

typical temperature of the filament – at typical operating conditions – is 1600 to 1800 ° C. This is in color a very bright red to a white. When the filament reaches this temperature the electrons in the filament have sufficient energy to overcome the binding energies – and will leave the surface with a fraction of an eV of energy. (1 eV is energy gained by dropping an item charged to one electron charge through a voltage of of one volt.) Because we wish to ionize the gas in the ionization region, and this often takes 10s of eV in energy, we need to accelerate the emitted electrons. We do this with a bias voltage that is typically in the range of 70 to 120 V. By using a grounding cage around the ionization region, we assure that most of the electrons enter the region with energy near the bias voltage (times ‘e’). This bias voltage is chosen because the maximum in the ionization cross section for most gases is near 100 eV. It is very important to note that the maximum varies both in magnitude and peak location. Thus we will get different numbers of ions from different gases – see Figure below.



If we can determine the number of ions produced per neutral gas molecule we can determine the partial pressure of each of the species in the plasma. If our electrons suffer a number of collisions as they cross the ionization region than we will have a large range of energies at which the ionization collisions might take place. This would make it very difficult to determine the ratios of the densities of different species. Thus we need to make sure that the pressure in the ionization region is low enough that the mean-free path for ALL collisions is long compared to the total distance traveled by the electrons. Often at process conditions the background pressure is too high for this requirement – thus we often have a pin hole entrance aperture and use a high vacuum pump to drop the the RGA to pressures near 10 μ Torr. It is important to note that the HV pump is most often a Turbo-molecular pump because of those pumps pump most gases at the same rate and they do not add significant amounts of contaminants. [Ion implanters do not have this limitation. There we simply want to create as many ions of a specific species as possible. We are not trying to preserve density ratios.]

IN ADDITION TO IONIZING THE GAS, THIS SECTION ALSO BREAKS UP THE GAS INTO DAUGHTER SPECIES. THIS IS KNOWN AS ‘CRACKING’ AND WE WILL TALK ABOUT IT DURING THE NEXT CLASS PERIOD.

We have now created ions which exist at densities that small compared to the densities of the original gases. This ratio is of course set by the ionization cross section of the gas and the cracking pattern of the gas. (Some species that are stable as neutrals are not stable as ions and immediately fall apart.)

We now need to get the ions to our mass analysis region. To do this we accelerate the ion to approximately 20 eV using electrostatic ion 'optics'. [For implanters this is usually ~20 keV. This is because we can get more ions/area through the system at higher energies.] In its simplest form this amounts to a negatively biased plate with a hole in the center. Note that the rest of the RGA sits at this same potential... Thus when the ions enter the mass resolver and detector we do not disturb the orbit of the ions with this electrostatic field.

At this point we enter the mass resolution system. In reality this is a velocity resolution system – we use the fact that mass, energy and velocity are intertwined and we have set the energy using the ion optics. While there are numerous types of velocity analyzers, two are most commonly used. The first uses a static magnetic field or magnetic sector – we will go through the math on this one in a moment – while the second uses a quadrupole electric field containing both dc and rf parts. The later of these two systems is the most common in good RGAs. However, the analysis of how they operate is beyond the scope of the class. The Magnetic sector systems are not typically used in good RGAs BUT they are the mainstay of ion implantation mass resolution systems. We will go through the math on how these systems work here.

The equation of motion for a single particle of charge q and mass m is given by the Lorentz force law: $m \frac{d\mathbf{v}}{dt} = q(\mathbf{E} + \mathbf{v} \wedge \mathbf{B})$.

Cases 2: $\mathbf{E} = 0$; $\mathbf{B} = B_0 \mathbf{z}$

$$\begin{aligned} \frac{d\mathbf{v}}{dt} &= \frac{q}{m} (\mathbf{E} + \mathbf{v} \wedge \mathbf{B}) \\ &= \frac{q}{m} \mathbf{v} \wedge B_0 \mathbf{z} \end{aligned}$$

Thus we find

$$\begin{aligned} \frac{dv_x}{dt} &= \frac{q}{m} v_y B_0 \\ \frac{dv_y}{dt} &= -\frac{q}{m} v_x B_0 \\ \frac{dv_z}{dt} &= 0 \end{aligned}$$

To solve this set of equations, we must separate the components of the velocity. This is simple to do by differentiating the equations again and substituting to give.

$$\frac{d^2 v_x}{dt^2} = \frac{q}{m} \frac{dv_y}{dt} B_0 = -\left(\frac{q}{m} B_0\right)^2 v_x$$

$$\frac{d^2 v_y}{dt^2} = -\frac{q}{m} \frac{dv_x}{dt} B_0 = -\left(\frac{q}{m} B_0\right)^2 v_y$$

$$\frac{d^2 v_z}{dt^2} = 0$$

These second order equations are of course easily solved as

$$v_x = v_{x0} e^{\pm i\omega_c t}$$

$$v_y = v_{y0} e^{\pm i\omega_c t} \quad \text{where } \omega_c = \frac{q}{m} B_0$$

$$v_z = v_{z0}$$

Now taking into account the original coupled first order equations we find

$$v_x = v_{\perp 0} \cos(\omega_c t + \varphi)$$

$$v_y = -v_{\perp 0} \sin(\omega_c t + \varphi)$$

$$v_z = v_{z0}$$

Integrating a second time we find,

$$x = \frac{v_{\perp 0}}{\omega_c} \sin(\omega_c t + \varphi) + x_0 - \frac{v_{\perp 0}}{\omega_c} \sin(\varphi)$$

$$y = \frac{v_{\perp 0}}{\omega_c} \cos(\omega_c t + \varphi) + y_0 - \frac{v_{\perp 0}}{\omega_c} \cos(\varphi)$$

$$z = v_{z0} t + z_0$$

$$r_c = \frac{v_{\perp 0}}{\omega_c}$$

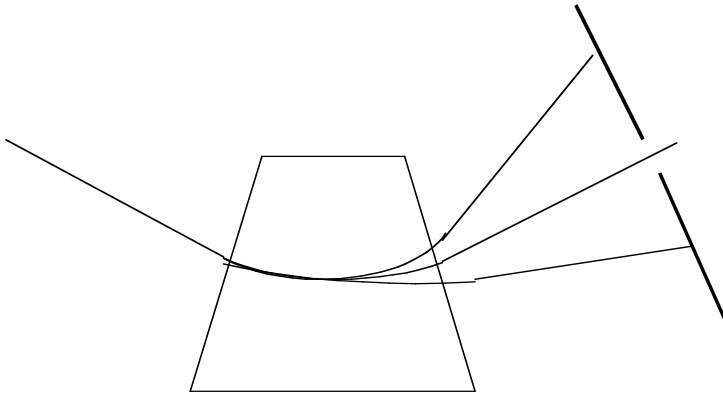
It is easy to see that $r_c = \frac{v_{\perp 0}}{\omega_c}$ is the radius of a circular orbit around the magnetic field

line; it is known as the Larmor radius or the cyclotron radius. Further we note that the positively charged particles orbit in a left-hand orbit while the negatively charged particles orbit in a right-hand orbit.

Now for our system the velocity is set by energy we have given the ion with the electrostatic accelerator. Thus we find that the particle travels in a circular orbit with a radius of

$$\begin{aligned}
 r_c &= \frac{v_{\perp 0}}{\omega_c} \\
 &= \frac{(2qV_a / m)^{1/2}}{qB / m} \\
 &= \frac{(2mV_a / q)^{1/2}}{B}
 \end{aligned}$$

Thus we can change the radius by either adjusting the magnetic field strength or by adjusting the accelerating voltage. Often some combination is used. By setting up our analyzer as thus:



We can eliminate all ions which do not match the required Larmour radius.

At this point we need to detect the ions that have made it all the way through the system. The simplest detection scheme is to use a Faraday cup. This amounts to a cup that simply collects all of the ions, and we measure the associated current.

The next thing that one might use is an electron multiplier – note that these are also used on photomultiplier tubes to measure photons. There are two main types the chain and the channeltron. Both make use of materials which produce significant quantities of secondary electrons when struck by either energetic ions or energetic electrons. These items greatly increase our currents – allowing use to measure single ion events. (Electron multipliers require high vacuum for a number of reasons...)

Add drawings of chain and Channeltron tubes.

We can change our detection system to include electrostatic retarding optics. By varying the potential on our retarding optics, we can stop some of the ions from entering the detection area. By measuring the current as a function of the retarding potential we can determine the energy distribution of the ions entering the detector – thereby allowing us to also measure the energy.

Cracking patterns