# EFFECTS OF SURFACE AND VOLUME PRODUCTION ON EMITTANCE IN A VOLUME- TYPE NEGATIVE ION SOURCE

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***Abstract***

A volume- type negative ion source has been modeled using a version of the Negative Ion Injector Design Analysis Program (NIIDeAP). The purpose of the study was to investigate the relative effects of surface-produced ions and volume-produced ions on the emittance of the total extracted beam. The differences between the two types of ion production can be expected to influence energy and emittance distributions for several reasons. Even though the fundamental physics of ion production in the source imply a low temperature, the effects of magnetic field, internal surface geometry, plasma potential, and superposition of two different populations can result in a significant increase of the apparent temperature. A high precision ion trajectory integrator was used.

## 1.0 The Code

Although the NIIDeAP code[1] can find the self-consistent Poisson-Boltzmann-Vlasov solution for extraction of multiple species from a plasma, a perfectly flat sheath and uniform acceleration field were artificially used in the simulations, and the results are current-independent. Sheath curvature, nonuniform charge distributions, and acceleration fields can cause aberrations, but probably no stochastic emittance growth. The code can also simulate destruction of negative ions by collisions but this has also been turned off. As a test of the accuracy of the orbit integrator, a distribution with 0 eV temperature was accelerated to 10 kV. The resulting spread of 0.001 eV provides an estimate of the cumulative errors associated with the ion trajectory integration algorithm.

## 2.0 Discussion

The geometry simulated is shown in figure 1 along with the rays from both surface and volume production. It is similar the LBL 20 cm diameter negative ion source with 1 cm diameter aperture and a collar[2]. A similar magnetic field configuration was also used.

There are several possible differences between surface and volume produced distributions that are interesting to explore:

• Negative ions produced on the conductor wall may be at a lower potential energy, compared with volume produced ions. This is because the plasma potential, minus the work function, is what surface produced ions fall through to reach the plasma. This will give a drift on the order of a few eV to the thermal distribution. In contrast, volume produced ions are already in the plasma when they are produced, and their distribution will be Maxwellian with no drift energy added.

• Some surface produced ions may have large transverse energy when they are extracted from the plasma, simply because of the angle they make in order to get to the extraction region from the production regions (i.e. the collar and/or washer area).

• There may be an emittance filtering effect of the collar, so volume produced ions come into the extraction region at a lower transverse energy than surface produced ions.

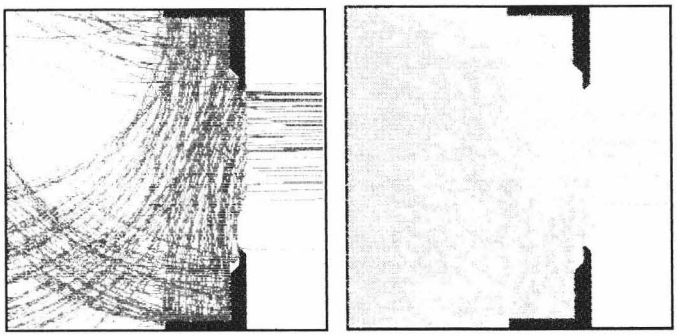
• The combined effects of internal surface geometry of the extraction aperture and collar, coupled with the magnetic field of the electron suppressor field may have a energy analyzer effect on the fraction of the ionic population that is successfully extracted. This could be different for surface produced ions vis-a-vis volume produced ions, some of which may come from deep inside the plasma, with longer travel distances through higher fields.

• Both surface and volume production are known to occur in so-called "volume" sources. The superimposition of two populations both with low temperatures and emittances, can result in a composite distribution with a larger effective emittance temperature.

### 2.1 Volume Production

Volume production of negative ions is usually assumed to result from rotational or vibrational excitation of hydrogen molecules interacting with fast electrons, followed by dissociative attachment with cool electrons[3]. For this study it was assumed that the ions are produced with a Maxwellian distribution of 0.2 eV temperature. In contrast, surface ions are given the same temperature, but then acquire a drift of 2 eV as they fall through the plasma potential minus work function. Figure 2.0 shows the emittance (a) and energy (b) distributions of the volume ions. A completely uniform extraction field was artificially used in order to minimize contributions from geometric aberrations. All of the emittance temperature "measured" in this simulation is stochastic in nature. The actual formula for the measured emittance temperature, appropriate for 2D Cartesian geometry of the simulation code, using a slot width $s$, was [5],

$$kT_\varepsilon = (\varepsilon_{n,4rms}/0.0377s)^2$$



(a) (b)

**Figure 1.** *Ion source geometry used in simulation showing* (a) *surface produced ions, and* (b) *volume produced ions. Surface ions are created on the inner surfaces of the collar and extraction aperture. Volume ions are created in the plasma, to the left of the extraction aperture.*

### 2.2 Surface Production

The emittance, energy, and y- Distributions for the surface produced ions are shown in figure 3(a), (b), and (c) respectively, below. A popular explanation of the production process is that neutral $H^\circ$, along with more numerous and energetic $H^+$, $H_2^+$, $H_3^+$, etc... ions impinge on the surface, causing hydrogen sputtering from a chemisorbed layer, resulting in a hydrogen atom leaving the surface of the conductor, picking up an electron, falling through the plasma potential (minus work function), and acquiring kinetic energy in the process[4].

### 2.3 Surface and Volume Production

The emittance and energy distributions for the combined surface and volume produced ions are shown in figure 4. Approximately equal numbers of surface and volume ions were used, when in fact surface production can dominate by as much as 4 to 1 in cesiated sources, which would probably give a higher emittance temperature.

### 2.4 Simulations with B=0

The NIIDeAP orbit integrator gives an impulse at each cell interface that is consistent with the change of potential from cell to cell. The magnetic field then rotates the velocity vector by an angle proportional to the time spent in the cell, leaving the magnitude unchanged.

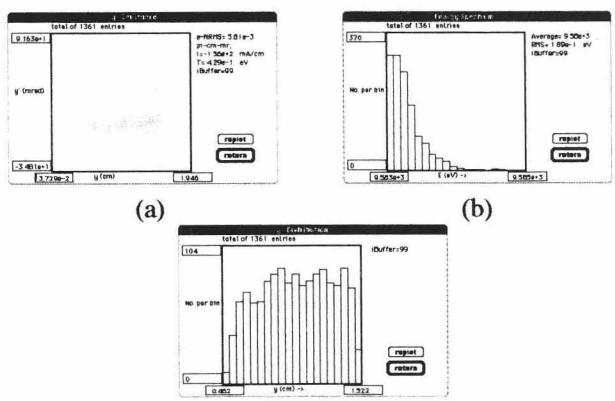
The emittance diagrams of the two population types with magnetic field turned off is shown in figure 5. The "measured" emittance temperature is about 0.191 eV for volume species, close to the RMS energy, verifying the code and the equation for emittance temperature in section 2.1. The magnetic field apparently makes the emittance worse for volume production, perhaps by bending lower energy ions more, thus broadening the phase space distribution in the vertical axis (angle) direction. The effect is quite the opposite on the surface population. The "measured" emittance temperature with the B field off is 4.7 eV, much bigger than the 0.2 eV temperature of production. This may be because the few ions that intersect the sheath and are extracted (without the help of the field to bend them in) arrive with the 2 volts of kinetic energy in opposite directions (from the top and bottom inner surfaces of the collar in figure 1a).

### 3.0 Conclusions

Overall it can be seen that some of the hypotheses suggested in section 2.0 are validated. Even though the fundamental physics of ion production in an ion source dictate a low temperature (here set to be 0.2 eV), the effects of magnetic field, geometry, and superposition of two different populations can result in an increase of the apparent temperature to about 1.8 eV.

The assumption of a 2 eV drift and 0.2 eV spread for the surface produced negative ions may be somewhat conservative when the incident kinetic energy of the positively charged ions that impinge on the production surface is taken in to account.

Numerical experiments with the magnetic field off show distinctly opposite effects on the two types of ions. With B=0 the volume ions have a lower emittance temperature that is close to their RMS energy spread, (which also verifies the code and the formula for emittance temperature). The surface ions have a significantly higher emittance temperature with B=0, presumably because the energy is mostly transverse and in opposite directions.

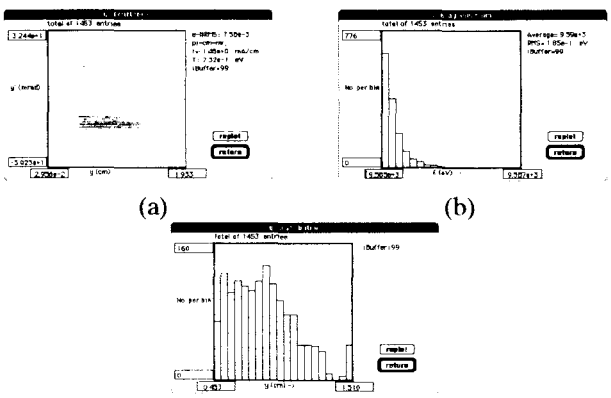


(a) (b)

(c)

**Figure 2.** (a) *Emittance of volume produced ions. No extraction aberrations are present, the tail on the right is due to the geometric and magnetic selection effects inside the source aperture. The emittance temperature is 0.429 eV, slightly larger than the actual temperature of production, which is set at 0.2 eV inside the volume.* (b) *Energy of volume produced ions. No aberrations are present. The*

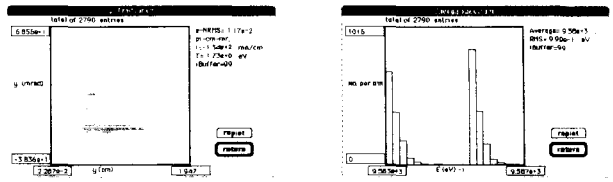
*"measured" RMS energy variation is 0.189 eV, slightly less than the actual temperature of production assumed to be 0.2 eV. Note the accuracy of the ray orbit integrator: the horizontal plot limits are less than a couple of volts out of an average of 9.583 kV. The plot buffer is at the far right of the simulation region shown in figure 1. Simulations with populations of ions produced with no energy spread yield a RMS energy of less than 0.001 eV at 9.583 kV, showing that the integration algorithm is very nearly floating point arithmetic- limited in accuracy.* (c) *Spatial (y) distribution of rays.*



(a) (b)

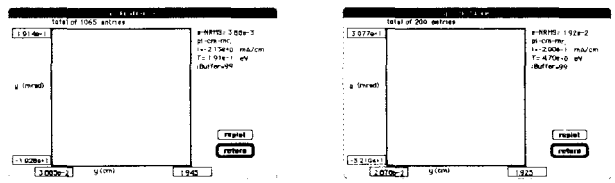
(c)

**Figure 3.** (a) *Emittance of surface produced ions. No aberrations are present. The emittance temperature is 0.732 eV, slightly larger than the actual temperature of production at the surface which was set to 0.2 eV. The peculiar hollow shape of the distribution in phase space is characteristic of surface production around the periphery of an aperture. A true 3D treatment might smear this out somewhat. The points in the upper part of the diagram come from the small amount of rays produced on the top part of the collar in figure 1.0 that the magnetic field allows to find their way to the extraction aperture The relatively more numerous bottom particles are actually helped by the field as they are bent into the extraction aperture. The angular difference between upper and lower production sites results in the approximate quantization of angle (y' on the vertical axis).* (b) *Energy of surface produced ions. The "measured" RMS energy variation is 0.185 eV, slightly less than the actual temperature of production, 0.2 eV.* (c) *y-Distribution of surface produced ions. Note the asymmetry caused by the magnetic field and internal geometry shown in figure 1.0. In contrast, the y-distribution of the volume produced ions (Figure 2c) is more symmetric and uniform. Although this density nonuniformity will cause aberrations when space charge and sheath curvature are self-consistently taken into account, it is not expected to have any influence on the stochastic emittance.*



(a) (b)

**Figure 4.** *Simulation results for volume- type ion source.* (a) *Emittance diagram of the combined populations. Note that the "measured" emittance temperature is about 1.73 eV even though each is a Maxwellian produced with 0.2 eV. The LBL measurements observe a lower limit temperature of about 1.8 eV after aberrations have been minimized.* (b) *Energy of the combined populations. Note the individual Maxwellian peaks separated by the 2 eV drift of the surface produced ions. The "measured" RMS energy variation is 1 eV, significantly more than the actual production temperature of 0.2 eV for each type of ion.*



(a) (b)

**Figure 5.** *Emittance with magnetic field turned off, (B=0).* (a) *Emittance diagram of the volume population. The "measured" emittance temperature is about 0.191 eV, similar to the RMS energy, verifying the code and the equation for emittance temperature. A nonzero field evidently bends the low energy ions more, causing a spread in y'.* (b) *Emittance diagram of the surface population. The "measured" emittance temperature is 4.7 eV, much bigger than the 0.2 eV temperature of production. The skew is from the drift/acceleration. The few ions produced on the collar that enter the extraction aperture have a large transverse energy. Obviously the magnetic field has very different effects on the two types of ions [figures 2(a) and 3(a)].*

## References


[1] J. L. Orthel, Bull. Am. Phys. Soc., **3 5**, 1797 (1990).

[2] J. W. Kwan et al, Rev. Sci. Instrum. **6 1**, 369 (1990).

[3] J. R. Hiskes, Comments At. Mol. Phys. **1 9**, 59 (1987).

[4] See for example: A. W. Kleyn, *Surface Production of Negative Hydrogen Ions*, in Fifth International Symposium on Production and Neutralization of Negative Ions and Beams, Brookhaven, NY, AIP Conference Proceedings No. **2 1 0**, p. 3, 1990.

[5] The Physics and Technology of Ion Sources , edited by Ian G. Brown, John Wiley and Sons, p. 38, 1989.