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The Neon Focused Ion Beam – Stabilizing the Emission Process

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The gas field ion source (GFIS) provides a high brightness beam of ions that has been commercially incorporated into the ORION family of products since 2007 [1]. The high brightness is the result of a process in which the imaging gas atoms (conventionally helium) are ionized in the high electric field adjacent to the most protruding atoms at the apex of a sharpened emitter [2]. The stability of the resulting ion beam therefore depends upon the atomic stability of the emitter over long periods of time (e.g. weeks). When operated with helium, the resulting beam can be focused to a 0.5 nm probe size due to the high brightness, low diffraction, and low energy spread of the ion beam. Such a helium beam is well suited for imaging applications because of its low sputter yield, high secondary electron yield, low backscatter yield, and a favorable charging mechanism. Other applications have exploited this same beam for lithography[3], patterning dislocations[4], beam induced chemistry[5]. However for sputtering applications, the helium beam is suitable for extremely small scale features such as nanopores[6] and thin films[7]. Therefore, the same GFIS technology has been extended to the next noble gas species, neon.

The direct adoption of the neon imaging gas into the existing GFIS technology however is not immediately successful. For optimal ionization, neon requires an appreciably lower electric field compared to helium (3.3 V/Å compared to 4.4 V/Å). This lower field significantly changes the surface dynamics, allowing various adatoms to arrive at, or near, the ionizing atom of the emitter. Such an adatom arriving at the emission site generally causes a dramatic increase in the emission, which persists until the adatom is desorbed or moves to an adjacent site. Whereas if the adatom arrives at an atomic site adjacent the emission site, the desired emission current is reduced until the adatom departs. The timescale for these events is commonly 0.1 to 10 seconds. In some cases, the adatoms can effectively pull off the atom from the bulk of the emitter causing a complete loss in current. The activity of more distant adatoms accumulating over longer times (hours) can produce overall shape changes to the emitter and gradual loss of emission current. Additional damaging effects can arise from the continuous impact of high energy neon atoms on the emitter, and the effect of negative secondary ions.

Several improvements have been undertaken to improve the overall stability of the neon GFIS over both short and longer timescales. The analysis suggests that there can be several root causes and their relative impact varies from system to system. To reduce the number of available adatoms, the vacuum preparation of the GFIS gun has improved to achieve a base vacuum to a level of < 2E-10 Torr. This includes better vacuum baking and preparation of some in-vacuum components. A regular routine is automatically regularly refresh the cryogenic surfaces to keep the cryo-pumping effective. Adatoms can also be delivered by way of the bottled neon gas, so improvements have been made to the storage cylinder, and the various components of the gas delivery manifold. Finally some significant changes are implemented in the mode of operation, so that neon is utilized under the best possible emission circumstances. With these combined changes it is routine to see the neon emission trimer persist for 10 or more hours, and the emission current be more steady over longer periods of time. A stable neon beam permits applications that demand a higher sputter yield (about 40X more than helium, and about 50% of gallium), such as nanofabrication, cross sectioning, and polishing.

[1] http://www.zeiss.com/microscopy/en_us/products/multiple-ion-beam.html
[2] Hill, et al. in "Advances in Imaging and Electron Physics, Vol 170.), ed. Peter Hawkes, (Elsevier, Boston) p.65.
[3] D. Winston, et al., J. Vac. Sci. Technol. B **27(6)** (2009).
[4] Cybart, et al., Nature Nanotechnology Letters **10** (2015), p. 598.
[5] Wu, et al., J. Mater Sci. Mater Electron **25** (2014), p 587.
[6] Ananth, et al., SPIE Scanning Microscopies **8036** (2011).
[7] Kalhor et al., Microelectronic Engineering **114** (2014), p. 70.

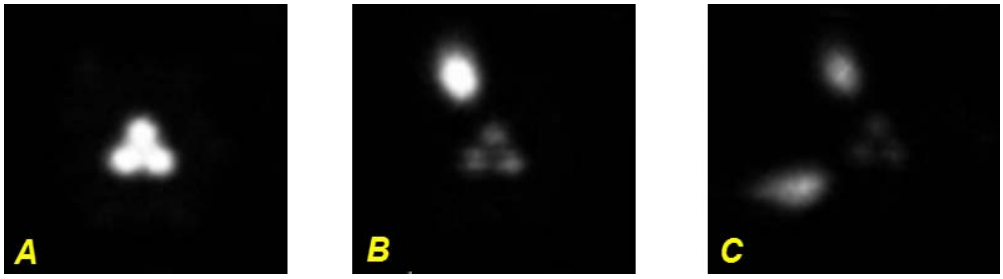

Figure 1. Before Improvement. Image A shows the initial arrangement of the atomic emission sites in the conventional "trimer" arrangement. Only the central portion of one of these atoms is selected by aperture and utilized for focused neon probe formation, corresponding to just a few pA. After some time (B), the arrival of a nearby adatom causes the useful current to be abruptly diminished by about 5X. After further time (C) the original adatom is joined by another adatom causing another abrupt 2X current loss. The time elapsed from A to C might be just a few hours.

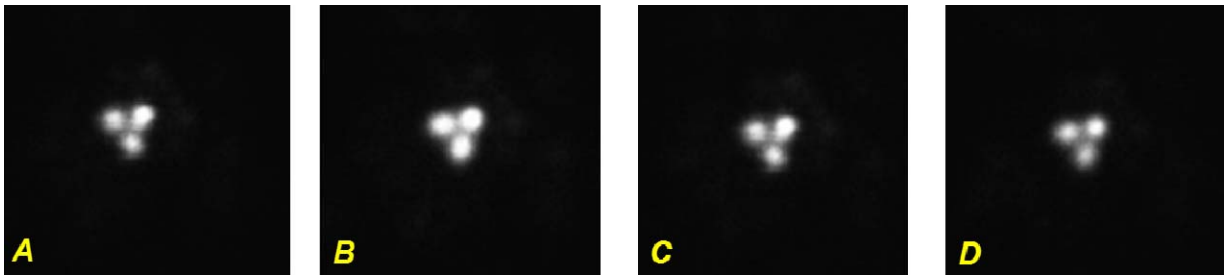

Figure 2: With the described improvements in place. Image A shows the initial neon emission pattern. Images B, C, and D represent the emission pattern in successive 2 hour intervals.

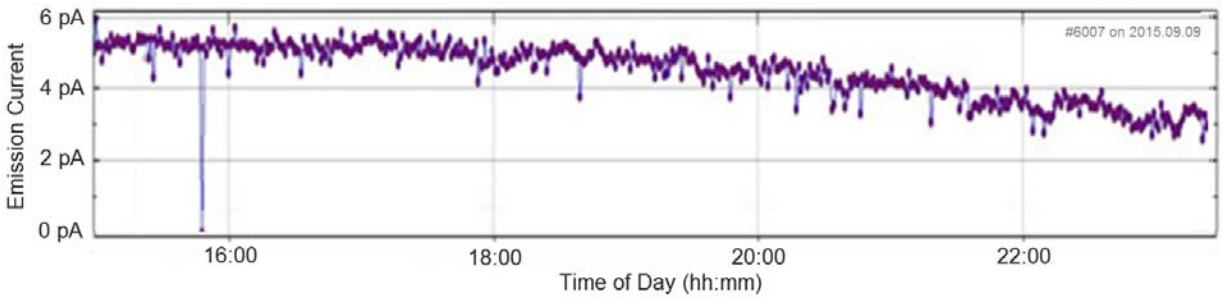

Figure 3: With several improvements in the vacuum, gas system, and operational methods, the emission current can be considerably improved. The figure shows the emission current remaining stable over a time period of 8 hours with only minor loss of emission current.

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