A new Liquid Metal Ion Source configuration for improving Focused Ion Beams machines.

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Nowadays Focused Ion Beams (FIBs) machines have become very important tools capable of fulfilling many challenges ranging from micro- to nanofabrication. These tools are widely used both for industrial[1] and emerging nanosciences applications[2]. Traditionally FIB technology has been mainly based on gallium Liquid Metal Ions Source. The very high brightness, long lifespan, small source size of the LMIS, and its easy handling, remain its chief and most decisive advantages, but some weaknesses are also well known that inhibit improvements in the resolution of LMIS-based FIB. Therefore progress on ion sources operational characteristics remains very desirable.

In particular a LMIS has a minimum stable emission current, typically around 2-3µA, where the FIB performances are optimum. It has been shown that in a FIB machine operated under a given fixed optical configuration, the resolution or spot diameter is the smallest for an emission current about 2 µA. For higher emission currents the beam energy spread increases, and the beam diameter d at target increases, principally due to the contribution from chromatic aberration. But at lower emission currents ($I_e < 1.5$ µA) the probe size is generally found to grow again (*Figure 1*) and very often emission pulses are observed that can lead ultimately to the destruction of the LMIS tip apex[3].

In this presentation we will summarize our recent efforts aiming at optimizing a Ga-LMIS "needle type" configuration within a dedicated environment for stable operation below the 1µA regime. The setup, we will detail, that has been integrated in our FIB nanowriter now allows important performance gains. This setup concept aims at protecting the LMIS from the deleterious effects of secondary electron impact and sputtered contaminants[4]. In parallel a dedicated electronics for source emission control limits the hydrodynamic instabilities threshold. Both FIB imaging and patterning resolution were found to continuously improve when reducing the emission current, thus paving the way to new insights for better ion beam selectivity and low dose ion irradiation control for Ga-FIB technology (*Figure 2*). The improvements will be presented through application results from selected nanofabrication challenges.

[1] J. Orloff, Scientific American Oct. 1994, pp.74-79
[2] J. Gierak Nanofabrication 2014; Volume 1: pp. 35–52
[3] Van Es, J.J., Gierak, J., Forbes, et al. (2004) Microelectronic Engineering, 73-74, pp. 132-138
[4] J. Gierak and R. Jede, Patent US8546768 B2, WO2010029270A1; Sept 2008

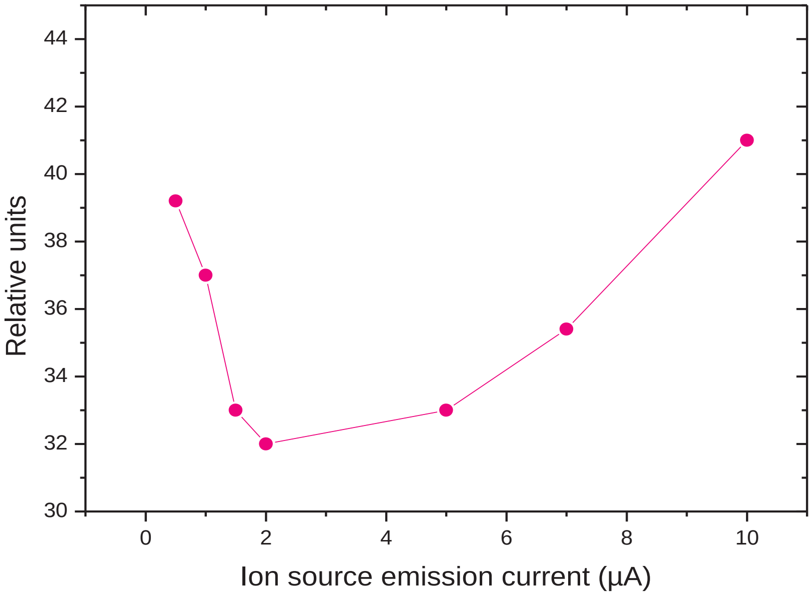

Figure 1: Typical evolution of the spot size FWHM for a conventional gallium FIB machine. Optimum resolution is observed for a emission current in the 2 - 3 µA range. The spot diameter increase below 1.5µA is commonly explained by hydrodynamic instabilities at source apex.

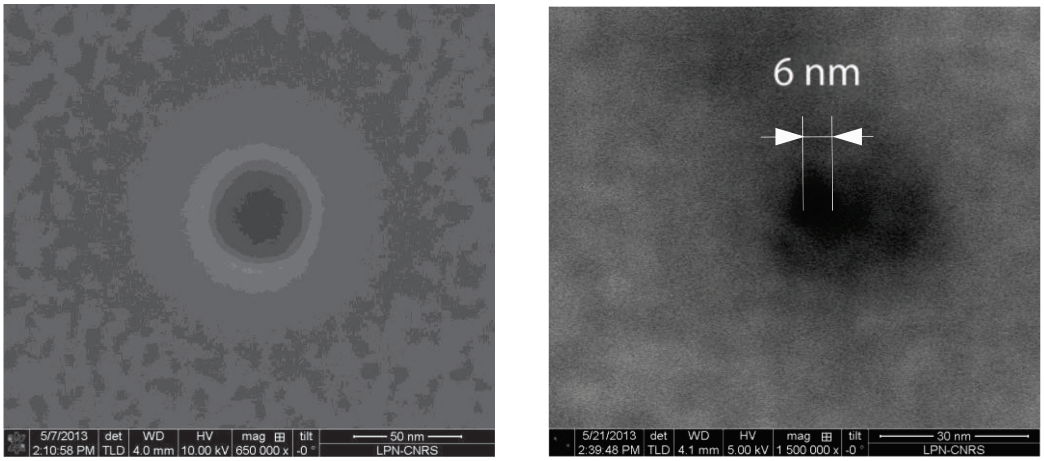

Figure 2: SEM images of a nono-sized holes drilled using our new LMIS configuration on respectively: (**Left**) a SiC membrane (100nm) covered with a 50 nm thick Au film and (**Right**) in a suspended CVD-grown graphene film (1 monolayer). Note the selectivity of the engraving processes on these otherwise challenging materials.