The High Brightness Neon Beam - From Source to Sample

J. Notte, J. Huang, H. Wu, D. Ferranti

Carl Zeiss Microscopy, Ion Microscopy Innovation Center, Peabody, MA 01960

The neon Gas Field Ion Source (GFIS) has become commercially available via the ORION NanoFab after many years of steady advancement by a variety of developers[1, 2, 3]. The critical characteristics of the neon beam are the low energy spread (~ 1 eV or less) and the high brightness (2×10^9 A cm^{-2} sr^{-1} at 25 kV). Together, these characteristics allow it to be focused to a relatively small probe size (< 1.9 nm) to serve several important roles in nanofabrication. This paper will focus on the specific characteristics of this ion beam that distinguish it from the better established helium GFIS beam.

The operation of the neon GFIS is considerably more difficult than the operation with helium for several reasons. First, the neon gas must be ionized with a lower electric field strength, and this reduced field invites vacuum contaminants (e.g. N_2, H_2, CO) to arrive at the emitter where they cause beam emission fluctuations or gradual corrosion of the emitter. Additionally, the neon beam produces appreciable sputtering (e.g. 20x more than helium) and some fraction of these sputtered atoms can be negatively charged and be back accelerated to the emitter where they cause damage. Within the column, the neon beam is more prone to scattering and even charge exchange from the presence of gas molecules along the beam path in the column.

Finally, as the beam interacts with the sample, neon distinguishes itself most significantly by its high sputter rate, and shallower penetration depth. Compared to helium, there is less transparency and bright edge effects when imaging with neon. The combination of a higher sputter rate and a shallower penetration depth means that sub-surface swelling, in silicon in particular, is greatly reduced with the neon beam. Neon imaging tends to provide excellent channeling contrast (Fig. 1) because of its inherent ability to provide mild surface sputtering to remove surface hydrocarbons and oxides. Aside from imaging, the neon beam also offers some advantages for lithography, precision milling, and beam-induced etch and deposition (Fig 2).

[1] Nishikawa O, Mueller EW. 1964. Operation of the field ion microscope with neon. *J Appl Phys* 35:2806–2812.

[2] Janssen AP, Jones JP. 1972. The effect of neon in the helium ion imaging in the field ion microscope. *Surf Sci* 33:553–564.

[3] Kuo HS, Hwang IS, Fu TY, Lin YC, Chang CC, Tsong TT. 2006. Noble metal/W(111) single-atom tips and their field electron and ion emission characteristics. *Jpn J Appl Phys* 45:8972–8983.

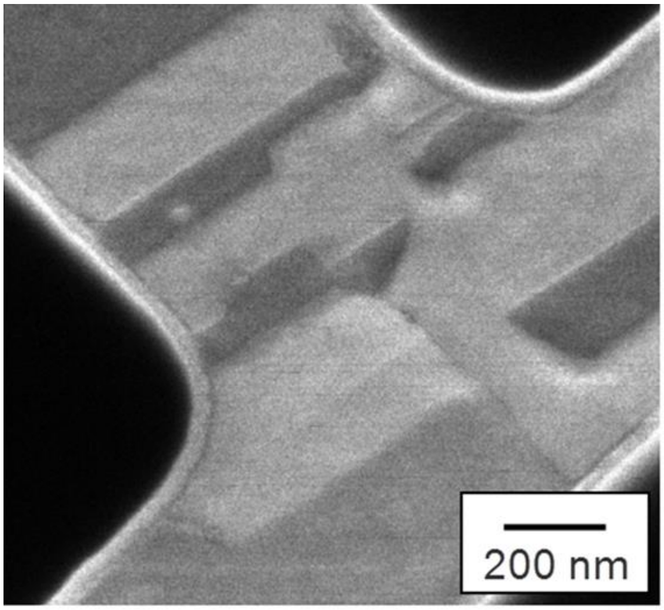

Figure 1: Copper structure imaged with the neon beam. The individual grains are readily recognizable through channeling contrast.

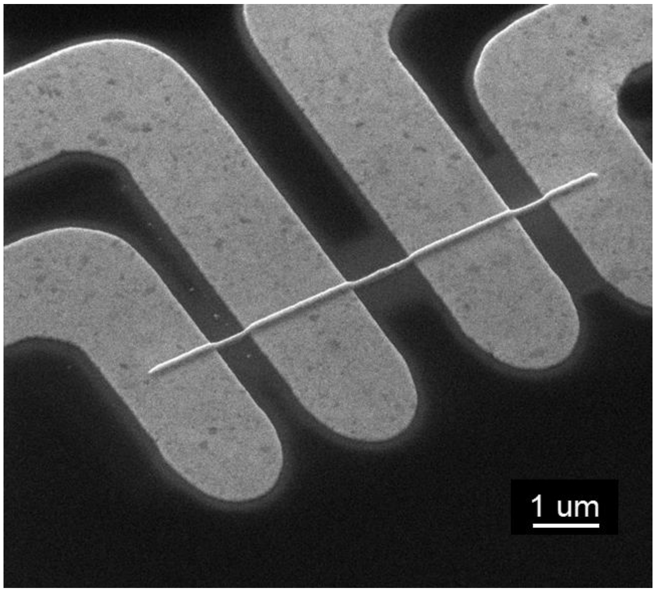

Figure 2: A deposited tungsten line across the four electrical pads. The tungsten line width is 100 nm, and was deposited with a 32 kV, 1.5 pA neon beam using $W(CO)_6$ *as the precursor gas. The resistivity has been measured to be as low as 160 micro-ohm-cm.*