Beyond helium: The future of helium ion microscopy

Mohan Ananth, Lewis Stern, John Notte, Larry Scipioni, Chuong Huynh, David Ferranti

Carl Zeiss NTS LLC, 1 Corporation Way, Peabody MA 01960

email. m.ananth@nts.zeiss.com
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The Helium Ion Microscope has been described as an impact technology offering new insights into the structure and function of nanomaterials [1]. Combining a high brightness Gas Field Ion Source (GFIS) with unique sample interaction dynamics, the helium ion microscope provides images offering unique contrast and complementary information to existing charged particle imaging instruments such as the SEM and TEM [2]. Formed by a single atom at the emitter tip, the helium probe can be focused to below 0.25nm offering the highest recorded resolution for secondary electron images. The small interaction volume between the helium beam and the sample also results in images with stunning surface detail.

Besides imaging, the helium ion beam can be used for fabricating nanostructures at the sub-10nm length scale. Researchers have used the helium ion beam for exposing resist and features as small as 4nm have been reported [3]. The main advantage of helium ion lithography over electron beam lithography is the minimal proximity effect. The helium ion beam has also been used for deposition and etching in conjunction with appropriate chemistries [4]. Helium induced deposition results in higher quality deposits than with Ga-FIB or EBID (Electron Beam Induced Deposition). Finally, the helium ion beam can be used for direct sputtering of different materials. Patterning of graphene has resulted in 5nm wide nanoribbons and 3.5nm holes in silicon nitride membranes have been demonstrated. However, due to its lower mass, the helium sputter rate is significantly lower than with gallium. Further, helium tends to implant rather than sputter silicon which is an issue for FIB applications in semiconductors. To overcome these issues, we have developed the GFIS to operate with Ne.

The Gas Field Ion Source has been modified and the gun redesigned to allow the use of both He and Ne source gases. Although Best Imaging Voltage (BIV), defined as the optimal voltage to get the highest source brightness, is lower for Ne, the system is optimized to operate under the same column conditions for both gases. The neon probe size is greater than helium and is measured between 1-2nm although additional improvements are expected. However this is not a limitation from a nanofabrication standpoint. The sputter yield of Ne is about 30X higher than He, and the Ne beam has a shallower penetration depth resulting in lower sub-surface damage. Figure 1 shows a simulation comparing the sputtering of Si with Ga, He, and Ne. The performance of Ne is significantly better than He and generally within a factor 2X of Ga.

Neon ion beam has been used for Lithography and is shown to be 1000X more efficient than 30keV electron beam with the ability to print 7nm lines [5]. Ne has also been shown to unambiguously sputter Si and other materials. Figure 2 shows a comparison between He and Ne induced sputtering of Si. Ne induced deposits have better conductivity (lower resistivity) than helium although there are specific chemical precursors that offer improved conductivity with helium as well. This work has culminated in the development of an ion microscope with a gas field ion source that can operate with both He and Ne and we will announce this instrument and present early results for the very first time at this conference.

References

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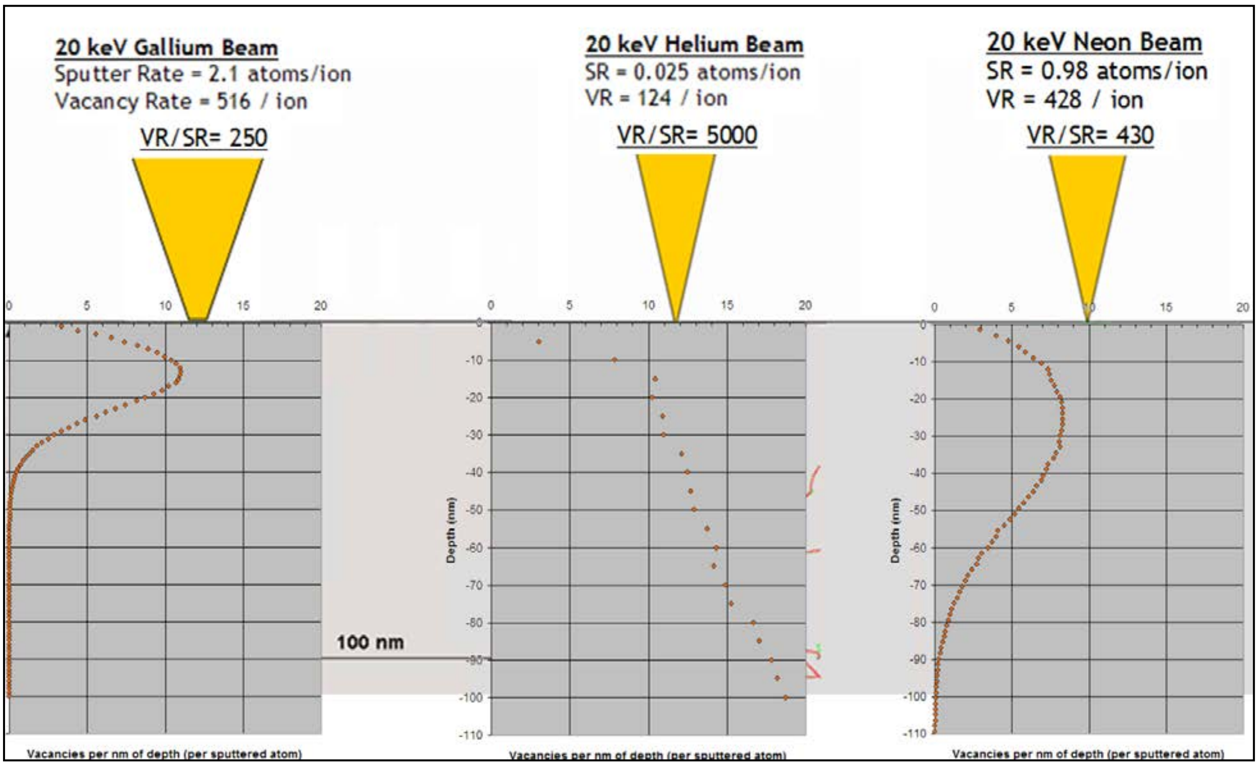

Figure 1. *Simulation of normally incident Ga, He, and Ne beams in Si*

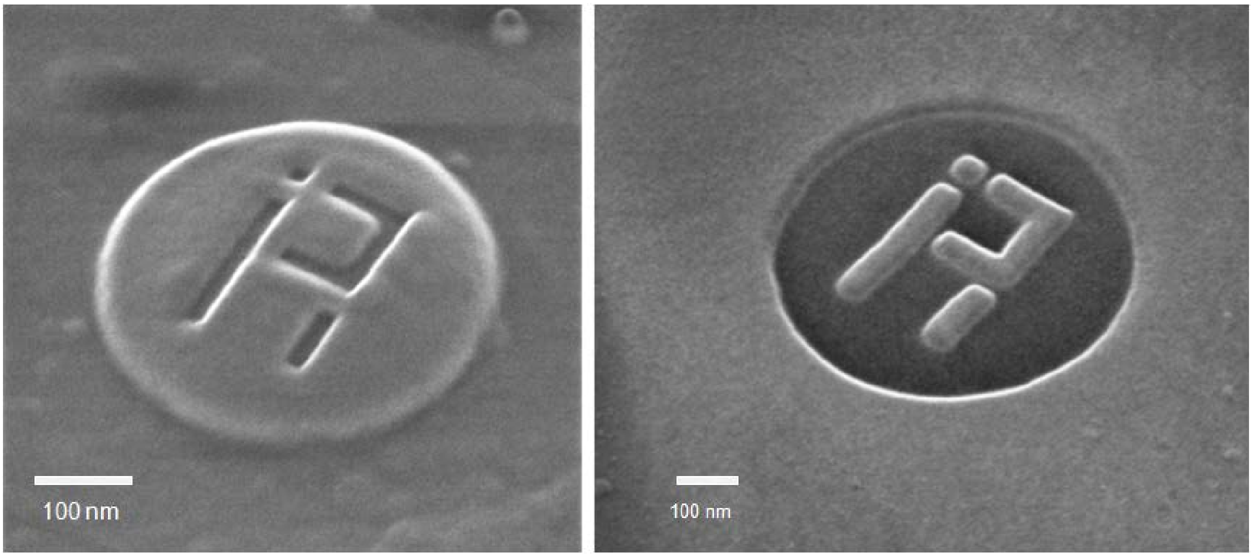

Figure 2. *Patterning of Si with He (left) and Ne (right). Excessive He dosing of Si can produce swelling whereas Ne unambiguously sputters.*