High throughput scanning electron microscopes with MEMS-based multi-beam optics

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A combination of fast data processing, large memory sizes and high speed CMOS cameras is enabling ever faster imaging and microscopy. However, this is not leading to faster scanning electron microscopy because in SEM the speed is limited by the primary beam current, similar to the throughput limitation in electron beam lithography. Yet, there would be important applications of high throughput SEM, both in the semiconductor industry and in biological imaging. We will present two approaches to faster SEM with first experimental results.

The basic limitation to the beam current is in the brightness B of the electron source: An electron probe of diameter d at acceleration voltage V, irradiated through an opening angle α can only contain a current $I = \pi^2/4\, B d^2 \alpha^2 V$. The diameter d is limited by the required resolution and α is limited by the lens aberrations. The only option is to use multiple beams. We can do this in two ways: separate beams that each scan part of the sample surface, or multiple beams that all point from different directions at the same sample position. The first solution effectively increases d without loss of resolution, the second effectively increases α.

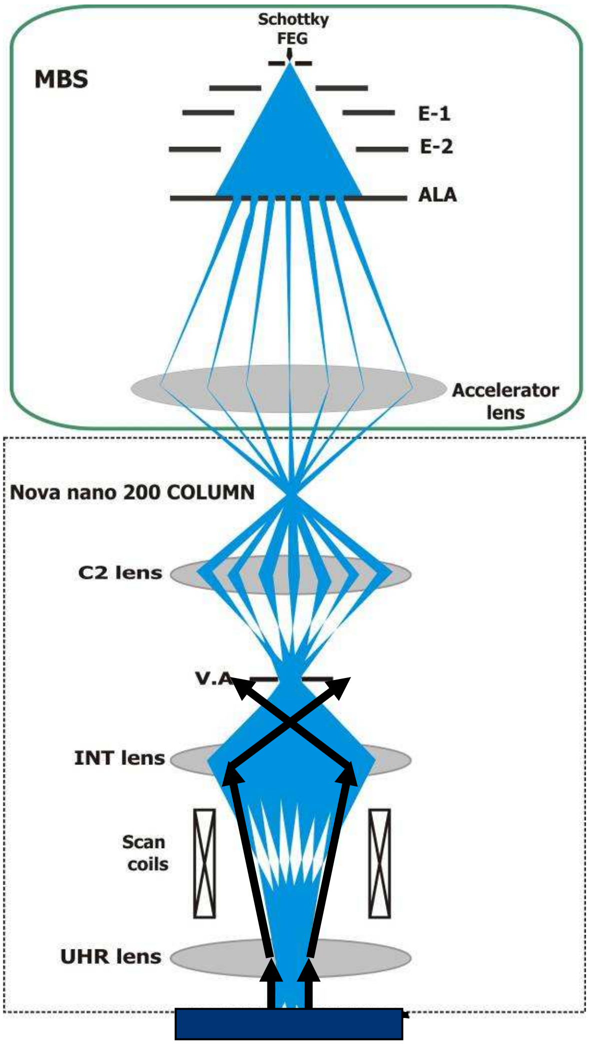
Earlier, we developed a multi beam probe instrument based on a regular FEI Nova-Nano 200 SEM. It contains a MEMS based multi-electron beam source module [1,2] that delivers a 14x14 array of focused beams, which are all de-magnified by the optical column of the SEM with a resolution and current per beam comparable to a state of the art single beam SEM. However, in order to use this system as an imaging system, either parallel detection of the secondary electrons generated by the 196 beams is required, or all beams have to be brought back to a single focus.

For the multi beam detector, we designed a system that guides the 196 SE (secondary electron) beams to a position sensitive detector in the variable aperture (VA) plane (see figure 1). In this plane an image of the sample is formed, using the secondary electrons. It is important to focus the SE beams in the detection plane with sufficient magnification because to get separated images of different SE beams, the pitch of neighboring SE beams should be larger than the spot size of each beam in the detection plane. The first images of the detection plane with separated SE beams will be presented.

For bringing the 196 beams into a single focus, we designed a novel, MEMS based multi beam objective lens array (see figure 2). Although each individual micro-lens will be of lower quality than a single macro objective lens, we still expect to obtain a system with larger beam current than the conventional SEM. Our goal is to focus a total current of 200 nA within 50nm at a landing energy of 500eV.

When we compare the two solutions, the first one retains the original SEM resolution and can in principle increase the throughput by a factor equal to the number of beams. However, the detection system is much more complicated and it is not sure yet if a sufficiently efficient and fast position sensitive detector can be found. The second solution has a much simpler detection system, but it will be impossible to reach the original SEM resolution so it has to compete with a SEM mode in which the single beam already has a high current.

[1] A. Mohammadi-Gheidari and P. Kruit, Nucl. Instr. and Meth. A645, 2011, 60–67.
[2] Y. Zhang, and P.Kruit, JVST B 25(6), 2007, 2239-2244.



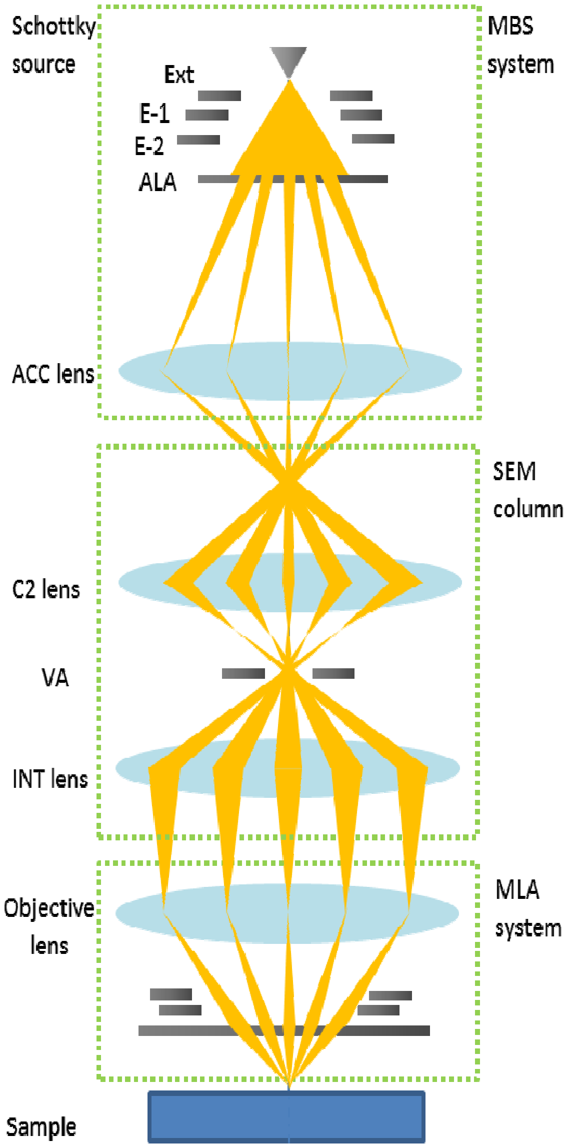


Figure 1. Schematic overview of the electron optical system for the multi-beam SEM with multi-beam detector.

Figure 2. Schematic overview of the electron optical system with multi-beam, single probe objective lens.