Electron impact gas ion source development; evaluation of different electron injection sources

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An electron impact gas ion source is being developed to improve the brightness for MeV proton beam writing applications. Radio frequency (RF) ion sources are commonly used to provide proton and helium ion beams for lithography and nuclear microscopy applications in MeV accelerators. Proton beam writing has the advantage of proximity free fabrication of high aspect-ratio nanostructures in photo-resist. Recently a proton beam size of 13 × 30 nm^2, has been achieved at a current of about 4 fA. The reduced brightness was measured to be about 10 A/m^2SrV [1]. For proton beam writing, the exposure dosage for photo-resist is typically 10-100 nC/mm^2. The beam resolution and writing time are limited by the low brightness RF ion source.

The electron impact gas ion source designed in Delft is expected to give much higher reduced brightness, about 10^7 A/m^2SrV. Prototypes of the new ion source have been fabricated and tested using a Schottky electron source as injector. The idea is to introduce an electron beam to a gas chamber with small spacing (100-1000 nm), where gas particles are ionized (**Fig 1**). With a 1 keV electron beam, the extracted ion currents for different gases are shown in **Fig 2** as functions of gas inlet pressure [2].

The ion beam current is a function of the electron current, ionization path length and electron ionization cross-section, and the gas particle density (or pressure). The ion beam reduced brightness therefore depends on the gas ionization chamber geometry, the gas type and pressure, electron beam energy and brightness. The main focus of this paper will be the theoretical evaluation of conventional electron emitters as injector for this electron impact gas ion source and the gas ionization chamber geometry. We will compare tungsten hair-pin, LaB6 and Schottky electron sources with hydrogen gas for 10 nm to 10 μm aperture sizes and 100 nm to 1 μm ionization path length (ie membrane spacing). Increasing the path length will yield higher ion current densities at the expense of ion energy spread. The electron beam is optimized for maximum current density in the chamber by considering the electron source brightness and system optical aberrations, without including coulomb interactions [3]. **Fig 3** shows the calculated ion beam reduced brightness as a function of aperture size.

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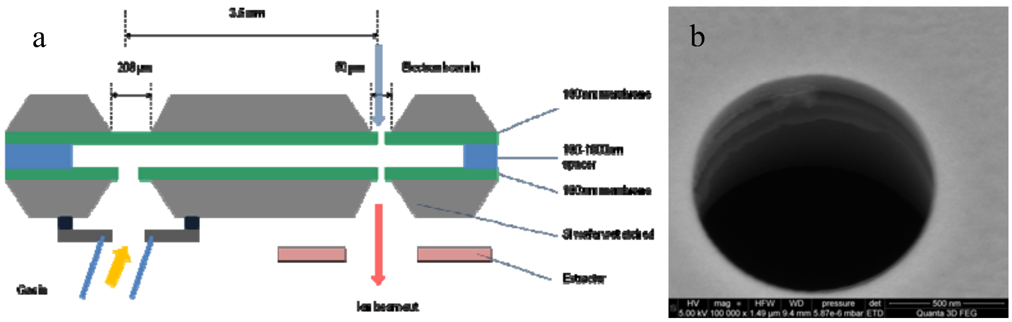

Figure 1: Electron impact gas ion source. a) A narrow channel path for gas is created by depositing thin membranes on Si. Two openings of 50 µm and 200 µm on Si wafer for beam transport and gas inlet are created respectively. b) High magnification of 900 nm apertures surrounding the gas ionization chamber.

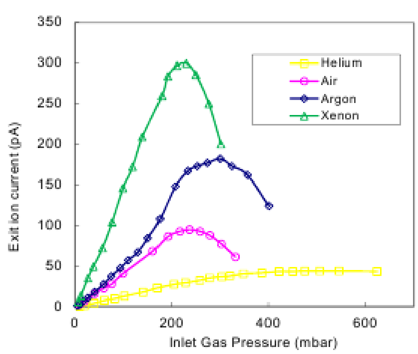

Figure 2: The ion beam current outputs from the source with different gases. At an electron current of 14 nA the ion current varies as a function of pressure and ion type. The current drops with higher gas pressure due to the reduced mean free path.

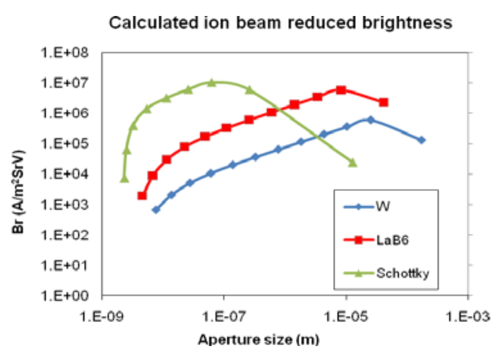

Figure 3: Ion reduced brightness of hydrogen gas with tungsten hair-pin, LaB6 and Schottky electron sources as a function of aperture size. The ionization path length is 100 nm and the electron beam energy is 1 keV.

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