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Performance test of high brightness nano-aperture ion source

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ABSTRACT

The nano-aperture ion source (NAIS) is a candidate to be part of a compact proton beam writing system, which has the potential of high throughput with sub 10 nm spot sizes. To evaluate the performance of this ion source, different NAIS chip configurations were examined through simulation. This study suggests that a proton reduced brightness of more than 10^6 A/(m^2srV) can be achieved, with an ion energy spread of less than 1 eV. Meanwhile, a prototype NAIS has been fabricated and tested to deliver 800 A/(m^2srV) of reduced brightness for Ar^+ beam. Current limitations and further improvements of this prototype NAIS are discussed.

1. Introduction

Proton beam writing (PBW) is a promising candidate as a next-generation lithographic technique with the capability to fabricate high aspect ratio nano-structures [1–10]. Compared with electron beam lithography (EBL), focused MeV protons deliver a straighter and deeper energy deposition in materials. A minimal proximity effect is observed in structures because of limited energy transfer from incoming protons to substrate's secondary electrons, due to their mass mismatch [11,12]. Based on these prime features, PBW has been employed in many research areas like photonics, microfluidic devices, nano-imprinting, and material modification [2,13]. Currently, the smallest structures written by PBW are 19 nm lines in 100 nm thick hydrogen silsesquioxane [14]. A 9.3×32 nm^2 proton beam spot size has been achieved at Centre for Ion Beam Applications (CIBA), National University of Singapore [15]. But currently, the low brightness radio frequency (RF) ion source (20–30 A/(m^2srV)) [16,17] restricts the beam resolution and throughput in PBW. People are developing alternative high brightness ion sources following different strategies [18–20]. According to our knowledge high brightness proton sources (>10^4 A/(m^2srV)) have not been reported. To further improve the performance of PBW, a high brightness nano-aperture ion source (NAIS) [21–24] is under development in CIBA. The aim of this ion source is to improve the beam brightness through source size reduction down to 100 nm with a sub-micron ionization chamber, as shown in Fig. 1.

2. Simulation of NAIS configurations

The concept of NAIS is to ionize gas that is present in the sub-micron ionization chamber through high energy electrons, as shown in Fig. 1. The beam parameters for an ideal NAIS performance have been simulated and evaluated as explained in the following steps. First, the gas distribution (in the sub-micron ionization chamber) is analyzed using COMSOL Multiphysics® [25], a finite element analysis software (see Fig. 2). The gas distribution and injected electron distribution determine the ion beam emission profile. Second, Poisson Superfish [26] is applied to calculate the electric field generated in z-axial symmetric cylindrical coordinates. Results from these simulations are fed into General Particle Tracer (GPT) package [27], to simulate beam trajectories and beam emittance from the NAIS. The injected electron energy is fixed at 1 keV as a trade-off between the ionization cross section and practical performances of available electron guns [21]. The extractor plate is biased to – 1 kV and is placed 1 mm away from NAIS, so as to extract the ion beam and at the same time prevent the injected electrons from entering the downstream of the setup.

2.1. Simulation of gas distribution in the NAIS

Inside the NAIS ionization chamber, ions are not generated from a single point or plane but originate from a sub-micrometer volume. Since the ionization probability is directly dependent on the availability of gas molecules, it is important to identify the gas distribution inside the ionization region. Knowing the spatial distribution, where individual ions are generated, will provide information about initial energy spread of the proton beam originating from the

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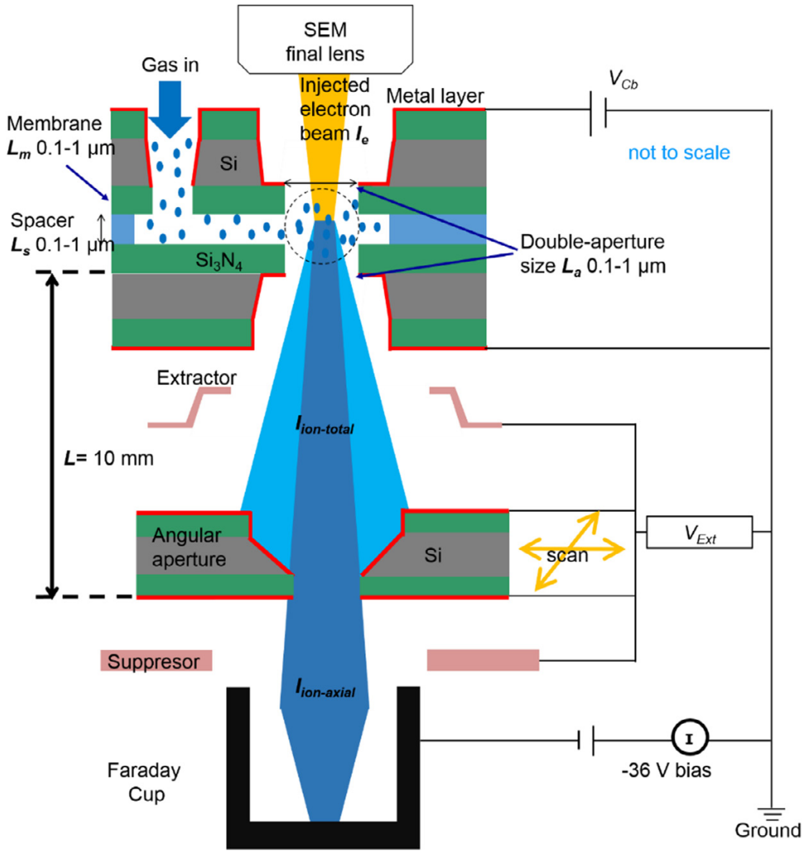

Fig. 1. Schematic setup of NAIS and the brightness measurement.

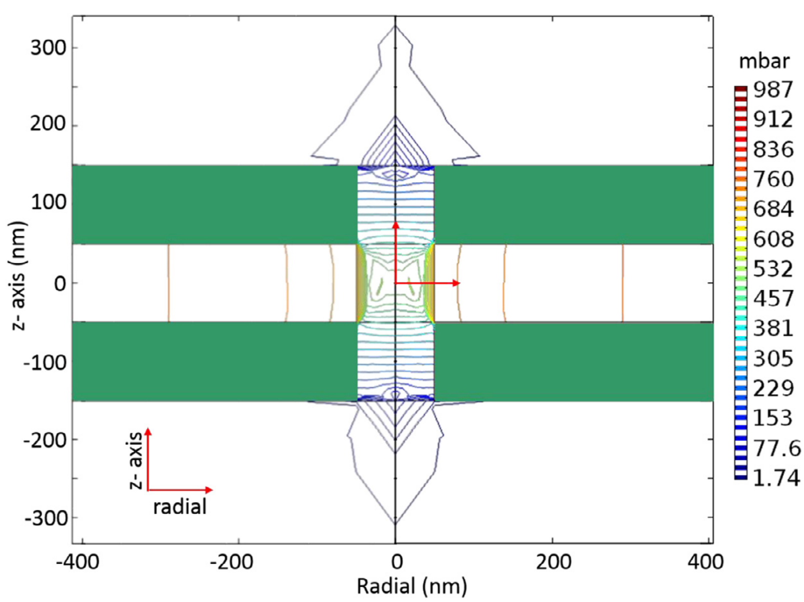

Fig. 2. Hydrogen gas pressure contour (simulated by COMSOL) for 100 nm spacer, 100 nm membranes, and 100 nm double-aperture configuration at 1000 mbar inlet gas pressure.

NAIS. To simplify the simulation, the gas distribution is considered to be cylindrically symmetric along the z-axis. The electric field inside the ionization chamber is fixed at 10^7 V/m. The choice of this value is a trade-off between reduced Coulomb effect and minimal energy spread. The input pressure of hydrogen gas is assumed to be 1000 mbar at room temperature (~300 K) and is in the laminar flow regime. In the spacer, the gas density reduces from the gas inlet to the centre of the chip (see Fig. 2). While the injected electron current density is taken to be a Gaussian distribution [28], we calculated that the generated proton beam is quasi-uniformly distributed in the radial plane of NAIS. Considering that the electron beam along the z-axis is continuous and uniform, the generated