Nuclear Instruments and Methods in Physics Research B 362 (2015) 72–79

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research B

journal homepage: www.elsevier.com/locate/nimb

Comparison of experimental and Monte-Carlo simulation of MeV particle transport through tapered/straight glass capillaries and circular collimators

F. Hespeels [a,*,1], R. Tonneau [a,1], T. Ikeda [b], S. Lucas [a]

[a] University of Namur, PMR, 61 rue de Bruxelles, 5000 Namur, Belgium
[b] RIKEN Nishina Center, 2-1 Hirosawa, Wako, Saitama 351-0198, Japan

ARTICLE INFO

Article history:
Received 24 April 2015
Received in revised form 9 September 2015
Accepted 10 September 2015
Available online 21 September 2015

Keywords:
Micro beam
Collimators
Glass capillary
Focusing effect
Ion beam analysis

ABSTRACT

This study compares the capabilities of three different passive collimation devices to produce micrometer-sized beams for proton and alpha particle beams (1.7 MeV and 5.3 MeV respectively): classical platinum TEM-like collimators, straight glass capillaries and tapered glass capillaries. In addition, we developed a Monte-Carlo code, based on the Rutherford scattering theory, which simulates particle transportation through collimating devices. The simulation results match the experimental observations of beam transportation through collimators both in air and vacuum. This research shows the focusing effects of tapered capillaries which clearly enable higher transmission flux. Nevertheless, the capillaries alignment with an incident beam is a prerequisite but is tedious, which makes the TEM collimator the easiest way to produce a 50 μm microbeam.

1. Introduction

Among the field of potential interest for high energetic particle microbeams, ion beam analysis (IBA) and radiobiological irradiation [1] can be mentioned. First, the interaction between the beam and a non-biological target is used to acquire information about the target profile and chemical depth composition. For techniques such as Nuclear Reaction Analysis (NRA), Particle Induced X-rays Emission (PIXE) or Rutherford Back Scattering (RBS), using a microbeam allows more specific and precise area analyses [2–4]. Secondly, MeV protons and alpha particles are used to study the effects of radiation on living cells [5]. To observe cell response, the development of micrometer-sized ion beams is advantageous to deposit energy in a microscopic volume of a cell region [6,7]. Microbeams can be obtained by active focusing (microprobe) or passive collimation. In the first case, it is possible to focus ion beams to diameters of a few hundred nanometers and enable localized irradiation or scanning to map with a high flux beam. However, these active devices development is quite complex and expensive. Passive collimation devices are multi-ion compatible, cheap and easy to use but suffer low transmission due to a lack of focusing. However, tapered capillaries with a conical geometry offer a beam transmission enhancement [8–10]. This work aims at (1) developing a Monte Carlo code, based on the Rutherford scattering theory, dedicated to beam transportation through cylindrical or conical-shaped collimation devices with micrometer-sized diameters, and (2) finding optimum collimation devices by comparing setups designed to produce proton or alpha particle microbeams. To achieve this goal, three methods of passive collimation were tested: (1) collimators used in electron microscopy (TEM), (2) straight glass capillaries and (3) tapered glass capillaries. Beam energy was set on 1.7 MeV for protons and 5.3 MeV for alpha particles. The following section describes the experimental setup, from the beam production to its detection, followed by a section about the details of our Monte Carlo simulation. The last section compares the simulations with experimental results.

2. Experimental methods

A schematic representation of the experimental setup is given in Fig 1.

2.1. Beam generation

An incident broad and parallel beam (≈3 cm^2) is generated with the ALTAIS accelerator, a 2 MV Tandem accelerator (High Voltage Engineering, NL). It produces protons, using a negative sputtering ion source, and alpha particles, from a Duoplasmotron ion source. The beam energy is modulated by the accelerator terminal voltage.

* Corresponding author.
E-mail address: felicien.hespeels@unamur.be (F. Hespeels).
[1] These authors contributed equally to this work.

http://dx.doi.org/10.1016/j.nimb.2015.09.030
0168-583X/

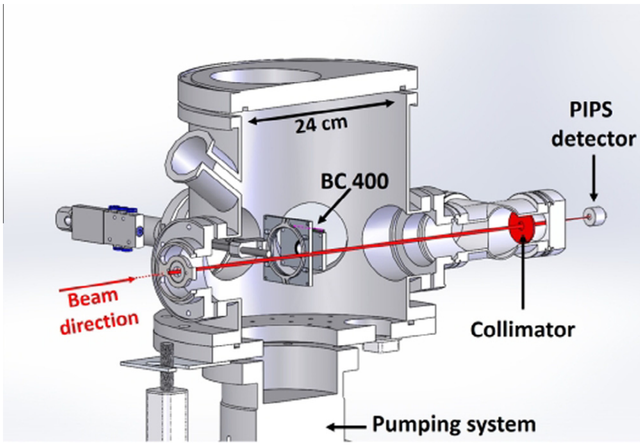

Fig. 1. Experimental setup.

Once the particles are accelerated, they enter the selected beam line and then, they are collimated at the beam port connected to a vacuum chamber as show in Fig 1 (base pressure: 9×10^{-6} mbar). The beam homogeneity is monitored by a BC400 plastic scintillator and tuned by electrostatic lens placed along the beam axis. At the end of the line, a Si_3N_4 film (1 μm thick) allows the beam to pass from vacuum to air. For this type of accelerator, the divergence of the beam is negligible and the beam can be considered parallel to the axis of the beam line.

2.2. Collimation systems

Three different collimating systems were used as shown in Fig 2: classical TEM like collimators, straight capillaries or tapered glass capillaries.

The platinum TEM collimators has a diameter of 20 or 50 μm (Bio-Rad Laboratories) and a thickness of 20 μm. The straight borosilicate capillaries were purchased from PostnovaAnalytics, Germany [11], and their inlet and outlet diameter is 20 or 50 μm. The tapered capillaries were fabricated at RIKEN institute in Japan [12] and made of borosilicate. Their inlet diameter is 0.8 mm and the outlet diameter 20 or 50 μm. Tapered and straight capillaries both measure 40 mm long. Various articles highlight the "focusing" effect and high transmission efficiency of tapered capillaries, due to their shape, which allows redirecting the particles [13–16]. TEM collimators, mounted either in vacuum or in air downstream of the Si_3N_4 film, are represented in Fig 3. The straight and tapered capillaries, only placed in vacuum, were mounted with an alignment system in order to line up with the incoming beam axis.

2.3. Detection systems

Two detection devices were used: a Passivated Implanted Planar Silicon (PIPS) detector and a solid state nuclear track detector (CR-39). The PIPS detector (PD 25-10-500 AM, CANBERRA Industries) allowed us to obtain the flux through each collimator and the beam energy distribution. The PIPS detector was always mounted in air and placed 1 mm after the Si_3N_4 window. When we used TEM collimators in air (Fig 3(b)), the PIPS detector was placed 1 mm after the collimator. CR-39 pieces were used for beam spatial distribution measurements [17,18]. For vacuum irradiation, the distance between the collimator and the CR-39 piece was set to 11.5 mm for the TEM collimator or 2 mm for both capillaries, as shown in Fig 3(a). For in air use, the distance d varied as shown in Fig 3(b). After irradiation, each CR-39 piece was etched with a 6 M NaOH solution at 80 °C for 1 h. Then, the pits induced by protons or alpha particles were observed with an optical microscope.

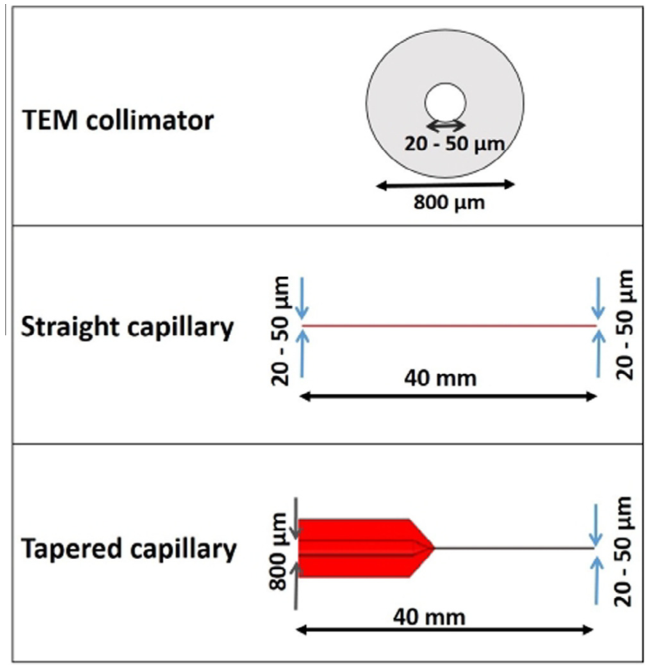

Fig. 2. Collimator devices used to produce micrometer-sized ion beams.

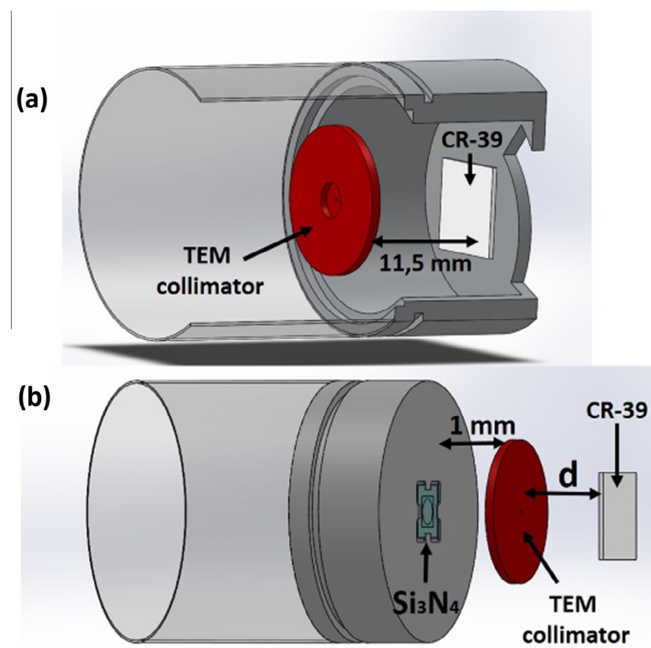

Fig. 3. Collimation geometries (a) in vacuum and (b) in air. The distance, d, between the collimator and the CR-39 was variable for in air irradiation.

3. Monte Carlo simulation

To investigate the beam transmission in each collimation system, we developed a Monte-Carlo code based on the small angle scattering. Users can choose multiple incident beam characteristics (energy, particle type, number and their angular distribution) and define the collimating device geometry (length, inlet and outlet diameter and optionally, the taper angle). Collimators experimental geometries were used in this simulation. The stochastic interaction process between incident particles and the walls, as implemented in the code, is based on a Rutherford differential scattering cross section as described by Hasegawa et al. [19]. Only the elastic