CHAPTER 1

INTRODUCTION

1.1 Introduction

It has been well known that high energy (>MeV) ion beam irradiation of biological causes or introduces living materials has effects such as killing cells or inducing mutation (Thopan et al., 2012). In recent few decades, low-medium energy (10-100 keV) ion beams have been applied to induce crop mutation and gene transfer (Yu Zengliang, 2006). Significant achievements have been made in applications, fundamental understanding of mechanisms involved has been little. Ion energy deposition in the ion-bombarded materials dominantly occurs in the low-energy range. Ions lose their kinetic energy during travelling in the material to be in low energy when they interact with DNA inside the cell nucleus. A majority of ion energy is deposited in the target material around the Bragg peak which is immediately before the ion comes to rest (Yu Zengliang, 2006). Primarily implanted ions also knock out many recoiled atoms from the target material and these low-energy recoils may further interact with target atoms. Therefore, study of low-energy ion interaction with DNA is important in understanding and revealing of ion beam effect on biological materials. Two types of interactions are involved, namely direct and indirect interactions. The former refers to implanted ions directly interacting with DNA to cause displacements of the atom in DNA and bond breakage. The latter involves secondary effects induced by ion implantation, such as X-ray, secondary electrons, free radicals, and heat, which can further interact with DNA (Yu Zengliang, 2006). My study has been focused on the former.

There have been a number of studies on low-energy ion bombardment effect on extracellular DNA. Ions of keV can cause single and double strand breaks of DNA to certain degree of damage. The damaged DNA has potential in inducing mutation of cells. Most of the previous work used ion energy around keV, but very few used ion energy lower than 1 keV. Ions are extracted from an ion source requires a high voltage of at least kV to form an ion beam. On the other hands, if without extraction, the ion energy in the ion source plasma is very diverse, although low. To obtain ions with uniformly low energy, deceleration of the extracted/accelerated ion beam is necessary. The deceleration of ion beam is actually using an electric field with its direction opposite to the ion beam traveling direction. Several studies have been carried out on ion beam deceleration methods and designs, including a model of deceleration lens (O'Connor et al., 1991), properties of ion beam optics (Freeman et al., 1978), ion beam focusing using Einzel lens (O'Connor et al., 1991) (O'Connor et al., 1991) (Abdelrahman, 2008), and measurement of ion beam current (Matsumoto et al., 2004)(Rajput et al., 2010), including techniques using SIMION program version 8.0 (Manura and Dahl, 2008) for showing data. Learning from the previous knowledge and experience, the deceleration lens was designed, constructed, and installed for the 30-kV bioengineering vertical beam line (CMU3) at our laboratory.

1.2 Literature review

1.2.1 Deceleration lens

P.J. O’Connor et al. (1991) developed a deceleration lens, including the deceleration lens designing, construction, characterization, and measurement of ion beam energy after pass through deceleration lens system. The goals this research were that the deceleration system must satisfy some specific criteria, as follows: (1) decelerate a 1000-, 2000-, or 3000-eV ion beam to <2-200 eV; (2) provide good focusing (final beam diameter <4.25 mm); (3) convert the beam symmetry from planar to cylindrical; (4) produce a highly collimated beam (divergence haft-angle <5°); (5) maintain high ion transmission; (6) produce minimal kinetic energy perturbation (energy spread <0.5 eV) and (7) possess mechanical simplicity for precise alignment (minimizing aberrations). The deceleration lens system was designed by using the program SIMION PC/PS2. The deceleration lens system had two models; the first model was exponential deceleration lens which consisted of 40-cylindical electrodes. The electric potentials of each electrode were the exponential function of its axial distance. A very important parameter of this model was the ratio of the initial beam diameter to the lens aperture diameter to be 1:15. The second model consisted of 6-cylindrical electrodes including a focusing part called einzel lens and a decelerated ion beam energy part. It could be seen that the second model had advantages over the first model in alignment and construction system which could reduce the ellipsoidal aberrations arise from imperfections in the electrodes and the alignment of the ion beam axis of the lens assembly.

J.H. Freeman et al. (1978) studied an electrostatic lens for the acceleration and deceleration of high intensity ion beams. The lens system consisted of two rectangular plates which were considered in two cases of acceleration and deceleration of ion beams. The trajectories of ion beams without space charge effect were simulated by digital computer simulation. The simulation took into account for the ratio of the post-acceleration voltage to the ion source voltage for the acceleration case meanwhile for the deceleration case the ratio of the post-deceleration voltage to the final voltage. The acceleration and deceleration modes were noted that the beam remained almost parallel for a small value of the ratio, however when the ratio increased the focal point moved from the target towards the lens.

M.M. Abdelrahman (2008) designed and simulated a three diaphragm lens system (einzel lens) using the SIMION computer program, where deferent parameters for this lens system had been studied and investigated without and with space charge current. The objectives were to adjust the parameters in order to minimize the beam emittance and the beam diameter.

J. Rajput et al. (2010) designed and simulated a deceleration lens system using the SIMION program. The deceleration lens was based on a retarding electrostatic field where the electric potentials of electrodes from the first to final electrode increased. The lens consisted of a set of five cylindrical electrodes followed by a cone shaped electrode, all arranged along a common axis, and the six electrodes were made from stainless steel (SS 304) and connected to each other using ceramic spacers. The first electrode was at the ground potential and the last electrode was connected to the experimental chamber. The deceleration lens was tested with Ar^{8+}, extracted from an electron cyclotron resonance ion source, having an initial energy of 30 keV and the final energy as low as 70 eV was achieved. The final energy of the beam was measured using a repelling analyzer (RPA). The RPA consisted of four metal electrodes, tree rings and one plate. The RPA was based the retarding voltage approaching the final energy of ions. The ion beam current dropped steadily and finally vanished when the retarding voltage exceeded the energy of ion beam.

1.2.2 Low-energy bombardment of DNA

C.A. Hunniford et al. (2009) studied conformational change to plasmid DNA induced by low energy carbon ions. Changes in the form of the plasmid DNA depended on the number of ions incident and kinetic energy of these ions and their charge state.

C. Ngaojampa et al. (2010) simulated ultra-low-energy ion bombardment of A-DNA in vacuum. The Monte Carlo (MC) and molecular dynamics (MD) simulations were applied in this research. The study had two parts: (1) MC simulation of N^+ bombardment of a DNA strand, and (2) MD simulation of the effect of N^+ implantation on a DNA strand. Vacuum of the system was at a pressure of 10^{-4} Pa and ion beam energies were 0.1, 1, 10, and 100 eV. The result showed that when the ion fluence increased, the amount of DNA in the supercoiled form decreased and the amount in the linear form increased for N-ion bombardment.

L.D. Yu et al. (2009) found that low-energy and low-fluence ion bombardment of naked plasmid DNA in vacuum could indeed cause DNA damage in the forms of single strand, double strand, and multiple double strand breakage. Naked plasmid DNA was bombarded by nitrogen ions at 2.5 keV and argon ions at 5 keV (both having almost the same ranges in most materials) to fluences of 3, 6, and 9 × 10^{13} ions/cm^2, using the 30-kV vertical bioengineering beam line (CMU3) and the plasma immersion ion implantation (PIII) facility at Chiang Mai University. The result showed that irradiation of naked DNA with low-fluence ions at energy lower than a few keV could induce damage in DNA structure.

1.3 Research objectives

1.3.1 To study the ion beam optics and relevant limitations in the construction of a deceleration lens and its associated components in order to fit well with the 30 kV vertical bioengineering ion implanter (CMU3).

1.3.2 To decrease the ion beam energy from a few tens keV to about 10-100 eV.

1.3.3 To study the effect of the ultra-low-energy ion beam bombardment induced effect on naked DNA.

1.4 Usefulness of the research

This study will

1.4.1 Provide knowledge on basic beam optics and experience in constructing a deceleration lens to fill a gap of lacking ion beam deceleration in the laboratory.

1.4.2 Promote the utility of the 30-kV vertical bioengineering ion implanter (CMU3) at Chiang Mai University for biological research.

1.4.3 Provide understanding of the fundamentals of physical properties of naked DNA after bombardment with ultra-low energy ion beam to pave a road to revealing mechanisms involved in ion-beam-induced mutation of biological cells.

1.5 Methodology and scope

1.5.1 Designing, construction, and installation of a deceleration lens system by computer program simulation and workshop work.

1.5.2 Measurement of the decelerated ion beam energy by inventing a novel method.

1.5.3 Bombardment of naked DNA using the decelerated ultra-low energy ion beam and analysis of the ion-bombarded DNA forms using gel electrophoresis.