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A simple ion implanter for material modifications in agriculture and gemmology

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ABSTRACT

In our efforts in developing ion beam technology for novel applications in biology and gemmology, an economic simple compact ion implanter especially for the purpose was constructed. The designing of the machine was aimed at providing our users with a simple, economic, user friendly, convenient and easily operateable ion implanter for ion implantation of biological living materials and gemstones for biotechnological applications and modification of gemstones, which would eventually contribute to the national agriculture, biomedicine and gem-industry developments. The machine was in a vertical setup so that the samples could be placed horizontally and even without fixing; in a non-mass-analyzing ion implanter style using mixed molecular and atomic nitrogen (N) ions so that material modifications could be more effective; equipped with a focusing/defocusing lens and an X–Y beam scanner so that a broad beam could be possible; and also equipped with a relatively small target chamber so that living biological samples could survive from the vacuum period during ion implantation. To save equipment materials and costs, most of the components of the machine were taken from decommissioned ion beam facilities. The maximum accelerating voltage of the accelerator was 100 kV, ideally necessary for crop mutation induction and gem modification by ion beams from our experience. N-ion implantation of local rice seeds and cut gemstones was carried out. Various phenotype changes of grown rice from the ion-implanted seeds and improvements in gemmological quality of the ion-bombarded gemstones were observed. The success in development of such a low-cost and simple-structured ion implanter provides developing countries with a model of utilizing our limited resources to develop novel accelerator-based technologies and applications.

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1. Introduction

In developing countries such as Thailand, developing advanced technologies such as accelerator technology is possible but usually constrained by limited budgets and also usually targeting at those fields the nation urgently requires for economic growth and local people's needs such as agriculture and some national special industries. In Thailand rice is the most important food crop for feeding people as well as exporting. Constantly improving local rice quality is a continuous task for meeting international

competition and raising local people's health and income. Developing genetic mutation of rice is one of the effective choices. Among a number of mutational techniques, the recently developed low-energy ion beam biotechnology [1] in the country has been becoming a powerful tool for the purpose [2–4]. In ion beam biotechnology, ion implanters conventionally applied to ion implantation of solid materials have been used for ion beam bombardment of biological living samples. But, the operation is not convenient and beam line conditions are sometimes not satisfied for maintaining the living biological materials. Therefore a specialized ion implanter has been needed. In Thailand gemstone industry has been an important local industry for national revenue. Recently ion beams have been found to act as a unique treatment measure to improve gemstone quality and thus increase the commercial

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values [5]. In the same situation as that for ion beam biotechnology, previously conventional ion implanters were used for ion implantation of gemstones but operation was inconvenient. Both biological samples such as rice seeds and plant tissues and gemstone samples such as cut jewellerys have irregular sizes and shapes which make the sample fixing in vertical very difficult if the ion beam line is horizontal. Both types of samples should not be exposed to ion beam for too long time otherwise the biological samples would die and gemstones would receive additional heat treatment from the beam irradiation. Moreover, in service to our customers of agriculture and gem industry, if the users can join in the operation, the ion beam treatment may increase its efficiency and effectiveness. Therefore, a biotechnology- and gemmology-specialized, simply structured and user-friendly vertical compact ion implanter became necessary. The designing of the machine was aimed at providing our users with user friendly, convenient and easy operation of a simple and economic ion implanter for ion implantation of biological living materials and gemstones for crop mutation induction as well as for modification of gemstones, which would eventually contribute to the national agriculture, biomedicine and gem-industry developments.

2. The ion implanter

The completed ion implanter system is shown in Fig. 1. The implanter itself consists of a duoplasmatron ion source, a 100-kV accelerating tube, a small beam diagnosis chamber, an electrical x–y scanner and a target chamber. The beam line is evacuated by a powerful diffusion pump system and supplied by various power supplies. It should be particularly mentioned that all components of the machine came from our decommissioned accelerator machines and hence they were reused for greatly saving budget.

The ion source was of a duoplasmatron type with certain modifications (Fig. 2), originally used at our dismantled high-current non-mass-analyzing ion implanter for industrial applications. The ion source could be separated into two parts, a plasma generator and an extraction system. The first part included a filament cathode, an intermediate electrode and an anode. The second part consisted of two or three electrodes which were anode, extractor and ground. In order to find optimized operation conditions, both parts were intensively investigated. After testing the ionization process, the nitrogen plasma was stable about 60 min with an arc current of 2.0 A and an arc voltage about 80–85 V, which was in agreement with the theory on the general property of the arc

discharge [6], and the arc pressure was 6×10^{-1} Torr which was related to the sufficiency of the gas supply rate. The extraction voltage was normally fixed at 6 kV after optimization though its capacity was 15 kV. The accelerating tube was from a decommissioned 400-kV medium-energy ion beam analysis accelerator and modified with shortening. The beam emittance was measured based on the transformation matrix theory using a pepper pot plate at the beam diagnosis chamber (Fig. 3) to be $\varepsilon_x = 1.62$ -mm mrad. The electric x–y scanner (Fig. 4) was obtained from an uncompleted home-made secondary ion mass spectrometer. The 2-m-high ion implanter, without mass analysis, was able to accelerate ion beam of such as nitrogen and argon with the maximum voltage of 100 kV with a maximum current of about 1 mA, which was enough for ion beam modification of biological living materials and gemstones. The target chamber was deliberately made relatively small so that the pumping time could be short for maintaining biological samples alive. Inside the target chamber there were a sample holder stage and a beam current measurement plate which coordinated a Faraday cup in the beam diagnosis chamber to check the beam current. At the target the ion beam bombarding area could be as large as 100 cm² which made simultaneous ion implantation of a thousand rice seeds or tens of gemstone samples possible. A stack of power supplies and controllers managed the operation of the facility. To make the ion implanter user-friendly, the operation was computer-controlled. The whole system was housed in an appropriately-sized air-conditioned room to reduce the humidity from the tropical environment.

In most cases of ion implantation, nitrogen ion beam was applied. Since the system was a non-mass-analyzing ion implanter, it could offer a higher beam current of mixed atomic and molecular nitrogen ions in a normal ratio of 1:4. As a N₂⁺ ion would be broken into two atomic nitrogen ion/atoms as soon as it hit the target surface and then each atomic particle had energy half that the original ion had, the N-ion implantation could bring a broader ion depth profile in the target material due to two energies of ions. Both higher beam current and broad ion distribution were just needed by applications of ion beam biotechnology and gemmology as in these cases the factor of ion species was not critical.

3. Application in materials modification

The ion implanter has been put into applications of ion implantation of local rice seeds to induce mutation and local corundum

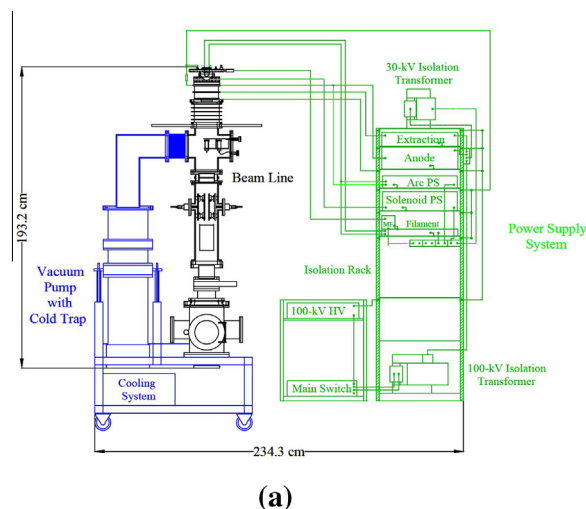


Fig. 1. The completed simple and economic compact ion implanter system at Chiang Mai University. (a) Schematic diagram. (b) Photograph (front view). At the left side is the vertical ion implanter and at the right side is the power supply stack.

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