A VERTICAL COMPACT ION IMPLANTER FOR NOVEL APPLICATIONS IN BIOTECHNOLOGY AND GEMMOLOGY

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Abstract

In our efforts in developing ion beam technology for novel applications in biology and gemology, one of the most emphasized research programs in the country, a compact ion accelerator/implanter especially for the purpose was constructed with the support of IAEA under project THA5049-90-02, Establishing an Ion Beam Biotechnology Center to Develop Improved Crops for Agriculture and Horticulture. The designing of the machine was aimed at providing our users with user friendly, convenient and easy operation of a simple accelerator for ion implantation of biological living materials and gemstones for crop mutation and gene transformation inductions as well as for modification of gemstones, which would eventually contribute to the national agriculture, biomedicine and gem-industry developments. For convenient holding irregularly sized and shaped biological and gemological samples which were hard to hold vertically, the machine was in a vertical setup so that the samples could be placed horizontally and even without fixing. For a high beam current and intensity and a simple structure, the machine was a non-mass-analyzing ion implanter using mixed molecular and atomic nitrogen (N) ions so that material modifications could be more effective. For a homogeneous ion implantation, the machine was equipped with a focusing/defocusing lens and an X-Y beam scanner. For fast evacuation and short vacuum exposure to better maintain biological living samples surviving, the target chamber was made relatively small while supported by a powerful pump. To save equipment materials and costs, most of the components of the machine were taken from abandoned ion beam facilities, while the IAEA supported two main power supplies. The total maximum accelerating voltage of the accelerator could be up to 100 kV, which was ideally necessary for crop mutation induction and gem modification by ion beams from our experience. The entire facility consisted of, from the top to the bottom, a modified duoplasmatron ion source, an Einzel lens, a home-made accelerating tube, a small beam diagnosis chamber, an X-Y electrical scanner, and a target chamber. 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. A stack of power supplies and controllers managed the operation of the facility. The whole system was housed in an appropriately-sized air-conditioned room to reduce the humidity from the tropical environment. The total height of the machine was about 2 meters. The N-ion beam current could be hundreds of μA and the maximum beam spot at the target was 8 cm in diameter. 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 gemological quality of the ion-bombarded gemstones were observed, demonstrating the IAEA-supported ion accelerator/implanter successfully completed and working satisfactorily. The success in development of such a low-cost and simple-structured ion accelerator/implanter provides developing countries with a model of utilizing our limited resources to develop novel accelerator-based technologies and applications.

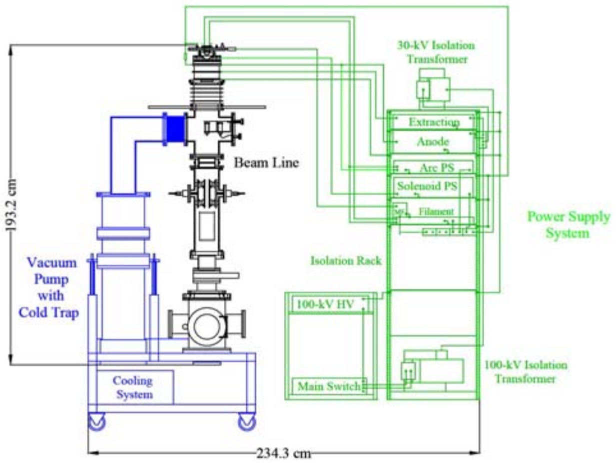
INTRODUCTION

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 [2,3,4]. 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 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 jewelleries 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, simple structured and user-friendly vertical compact ion implanter became necessary. The program of developing such an accelerator-based ion implanter then fortunately received support from the International Atomic Energy Agency (IAEA) under project THA5049-90-02, Establishing an Ion Beam Biotechnology Center to Develop Improved Crops for Agriculture and Horticulture. The designing of the machine was aimed at providing our users with user friendly, convenient and easy operation of a simple accelerator for ion implantation of biological living materials and gemstones for crop mutation and gene transformation inductions as well as for modification of gemstones, which would eventually contribute to the national agriculture, biomedicine and gem-industry developments.

THE ION IMPLANTER

The completed compact ion implanter system is shown in Figure 1. The implanter itself consists of, from the top to the bottom, a duoplasmatron ion source (Figure 2), a 100-kV accelerating tube, a small beam diagnosis chamber, an electrical x-y scanner (Figure 3), and a target chamber. The beam line is evacuated by a powerful diffusion pump system and supplied by various power supplies, some of which were supported by IAEA. It should be particularly mentioned that all components of the machine have come from our abandoned accelerator machines and hence they are reused for greatly saving budget.



(a)

(b)

Figure 1. The completed compact ion implanter system at Chiang Mai University. (a) Schematic diagram. (b) Photograph (front view). At the right side is the power supply stack, where some power supplies were supported by IAEA.

The ion source was of a duoplasmatron type with certain modifications (Figure 2), originally used at our high-current non-mass-analyzing ion implanter for industrial applications but later dismantled. 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 minutes with an arc current of 2.0 A and an arc voltage about 80-85 V, which was in agreement with the IA, max theory, 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 an abandoned 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 (Figure 3) to be $\varepsilon_x = 1.62$ mm mrad. The electric x-y scanner (Figure 4) was obtained from an uncompleted house-made secondary ion mass spectrometer. The IAEA supported its power supply. The ion implanter, totally about 2 m in height, without mass analysis, was able to accelerate ion beam such as nitrogen and argon with the maximum voltage of 100 kV with a maximum current of about 2 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. 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 cm^2 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, molecular nitrogen ion (N_2^+) 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 N_2^+ 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.

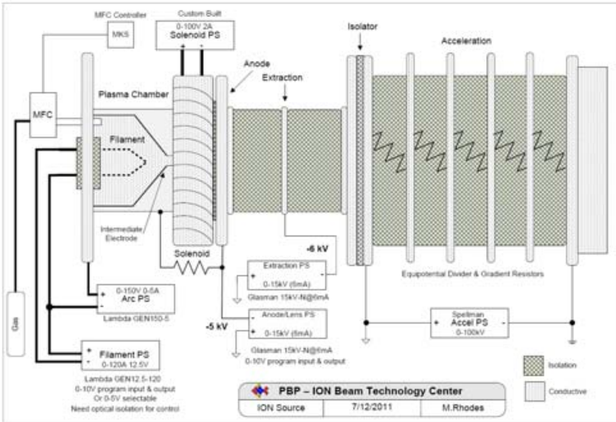


Figure 2. Schematic diagram of high-voltage terminal system including the duoplasmatron ion source and the house-modified accelerating tube with their power supplies.

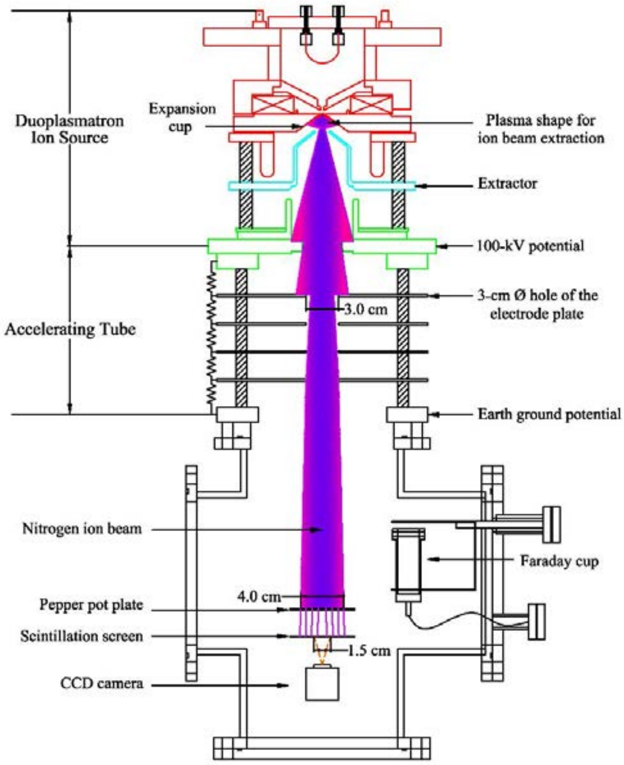


Figure 3. Schematic of the beam emittance measurement and the beam profile in the ion source and the accelerating tube and afterward.

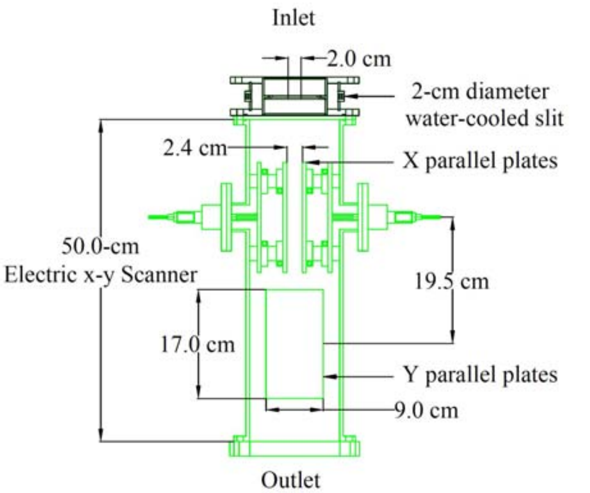


Figure 4. Schematic diagram of the electrical x-y scanner.

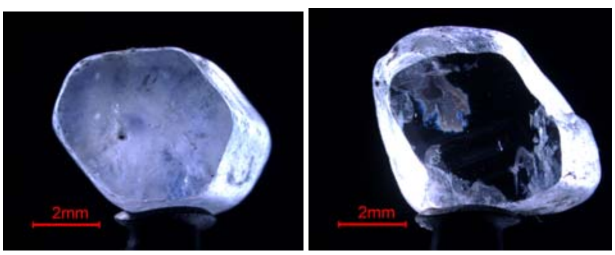
(a)

(b)

Figure 5. Ion beam biotechnology application in inducing mutation of local Thai rice. (a) Photograph of the specially designed rice seed sample holder. Some rice seeds are being held in the holes of the holder. (b) A comparison in a phenotypic change in the rice grain color between the original purple rice (right) and the mutant (left).

APPLICATIONS

The vertical compact ion implanter has been put into applications of ion implantation of local rice seeds to induce mutation and local corundum samples to improve their optical quality. A special rice seed holder which was made from copper for better dissipating ion-beam heating with hundreds of holes, as shown in Figure 5a, was used to hold hundreds of seeds in the holes. The seed embryo tips were first exposed by peeling the coat and erected in the holes to face the ion beam coming direction. For inducing mutation, N-ion beam was normally applied with ion energy around 30-60 keV and fluences in an order of at least 10^{16} ions/cm^2. After ion beam bombardment, the rice seeds were planted, survival rate was measured and mutation was screened during the whole growing period till harvest. Normally at a survival rate of about 50%, a mutation frequency could be about 1/1000 (Figure 5b). Local corundum from a variety of customers was also ion-beam treated at the compact ion implanter. The corundum was hard to be improved by electron beam irradiation as used for treating other gemstones but could be modified by ion beams. In contrast to previous inconveniency in fixing the gem samples in vertical due to the horizontal beam line, now a number of the gem samples could be easily just placed in a tray together and be irradiated by ion beams. In this case the ion energy was normally around 40 keV and beam fluences around 10^{17} ions/cm^2 or higher. After ion beam treatment, the corundum became more transparent, shining and clear, the color was more homogeneous and originally existing flaws disappeared (Figures 6 and 7). The gemological professionals judged the gem value and confirmed the values increased.



(a) **(b)**

Figure 6. White sapphire (a) before and (b) after N-ion implantation. The front side of the sapphire is a cut surface which is the ion implanted side.

Figure 7. Original low-quality sapphire, as shown at the central ones, after N-ion implantation and cut became high-quality jewellery as shown at the two sides.

CONCLUSION

The vertical compact ion implanter has been constructed and installed at Chiang Mai University under IAEA support. The machine was featured with simple structure, low cost, and user-friendly operation particularly for applications in biotechnology and gemology. The ion implanter has been applied to successfully induce local rice mutation and improve local corundum quality. The success in development of such a low-cost and simple-structured ion accelerator/implanter provides developing countries with a model of utilizing our limited resources to develop novel accelerator-based technologies and applications.

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