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Development of vertical compact ion implanter for gemstones applications

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ABSTRACT

Ion implantation technique was applied as an effective non-toxic treatment of the local Thai natural corundum including sapphires and rubies for the enhancement of essential qualities of the gemstones. Energetic oxygen and nitrogen ions in keV range of various fluences were implanted into the precious stones. It has been thoroughly proved that ion implantation can definitely modify the gems to desirable colors together with changing their color distribution, transparency and luster properties. These modifications lead to the improvement in quality of the natural corundum and thus its market value. Possible mechanisms of these modifications have been proposed. The main causes could be the changes in oxidation states of impurities of transition metals, induction of charge transfer from one metal cation to another and the production of color centers. For these purposes, an ion implanter of the kind that is traditionally used in semiconductor wafer fabrication had already been successfully applied for the ion beam bombardment of natural corundum. However, it is not practical for implanting the irregular shape and size of gem samples, and too costly to be economically accepted by the gem and jewelry industry. Accordingly, a specialized ion implanter has been requested by the gem traders. We have succeeded in developing a prototype high-current vertical compact ion implanter only 1.36 m long, from ion source to irradiation chamber, for these purposes. It has been proved to be very effective for corundum, for example, color improvement of blue sapphire, induction of violet sapphire from low value pink sapphire, and amelioration of lead-glass-filled rubies. Details of the implanter and recent implantation results are presented.

1. Introduction

In Thailand, the gem industry has been an important local industry for national revenue. A gemstone is the naturally occurring crystalline form of a mineral, which is desired for its beauty, valuable in its rarity and durable enough to be enjoyed for generations. Corundum is one type of gemstones where, in general, its popularity, value and hardness are second only to diamond. It is a crystalline form of aluminum oxide (Al_2O_3) which is naturally clear, but can have different colors that depend on chemical types of impurities within. The red variety of corundum is known as ruby, all the other colors of corundum are known as sapphires. Although new occurrences of natural gemstones are still found from time to time in many parts of the world, these localities combined with all historically important gem deposits have not always provided sufficient high quality material to meet the current demand. On the contrary, each mine owns plenty of low quality gemstones, e.g. those that have poorer clarity, color or size, thus having low market value. Accordingly, there is always an attempt to develop techniques for treating these low quality gems in private laboratories in order to enhance their appearance and thereby their marketability.

Heat treatment is the most popular technique commercially used for the improvement of gemstone quality [1]. The technique mainly modifies color, unifies inclusions, increases transmittance and improves luster [2,3]. However, heat treatment is time consuming and expensive and is not an efficient process to fulfill desirable

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changes in the properties of gemstones. For example, it involves a continuous annealing in a gas oven or electrical oven at 1000 °C or even above for a period ranging from few hours to few days depending on the type of gemstones. Different types of gemstones cannot be treated together. Alternative treatments are the exposure of gemstones to energetic particle beams or laser beams. A laser beam does not produce localized heating, whereas low mass particles such as electrons generate localized heating but yield poor coloration. Electron beam irradiation suits topaz more than corundum. Neutron irradiation makes gemstones radioactive. Last but not least, heavy ion beams seem superior to all the other candidates. The heavy ion beams have multiple potential in providing necessary tools for gem optical property improvement such as localized kinetic energy transfer or localized heat, defects, impurities and charges [4], as well as the capability to treat different gems individually. The limited availability and high cost of high-quality natural gemstones mean that their potential use for other applications, such as in high technology area, is also restricted.

In the past ion implantation on sapphires had been investigated from the point of view of improving their optical and mechanical properties [5–10] for the applications on optics, optoelectronics, photonics and tooling [11,12]. Several studies had dealt with understanding of basic and applied aspects of ion beam modification of sapphire but not many had focused on developing industry-ready technology. Our work aims at developing a heavy ion beam irradiation process for enhancing the quality of natural gemstones and thus increasing their market values. We have found recently that ion implantation is able to serve as a unique treatment for improving gemstone qualities [13]. However, the former ion implanter, originally designed for semiconductor applications, was inconvenient for gemstone treatment and too expensive to afford and too complicated to handle, from the customer's point of view. Therefore, a 100 kV vertical compact ion implanter becomes necessary and the program to develop such an ion implanter has been carried out. The design of the machine was aimed at providing our customers with simple operation, convenient in maintenance and low-cost machine for gem improvement, which would eventually contribute to the basic research and gem-industry developments. Details of the implanter along with some examples of particular challenges for the optical modification of gem materials are reported below.

2. Experimental details

2.1. Vertical compact ion implanter

In our efforts to develop ion beam technology for novel applications in gemology (one of the most important research programs of the country), a 100 kV vertical compact ion implanter was developed. The designing of the machine was aimed at providing our customers with a user friendly, convenient and low cost machine. The machine, as shown in Fig. 1, was designed in a vertical configuration so that the gem samples of irregular shapes and sizes could simply be placed in a horizontal tray at the target chamber without any need of glue.

The total length of the implanter is only 1.36 m. It consists of, from top to bottom, a duoplasmatron ion source, an einzel lens, a 100-kV(max) accelerating tube, a beam diagnostic chamber and a target chamber. In the first phase of development program, the $x-y$ scanner has not yet been included in front of the target chamber although the scanner and its power supply are available already. All power supplies were ready-made products purchased for us by the International Atomic Energy Agency (IAEA, Vienna). The beam line is evacuated by a powerful diffusion pump system. To prevent return-flow of the pumping fluid and enable the

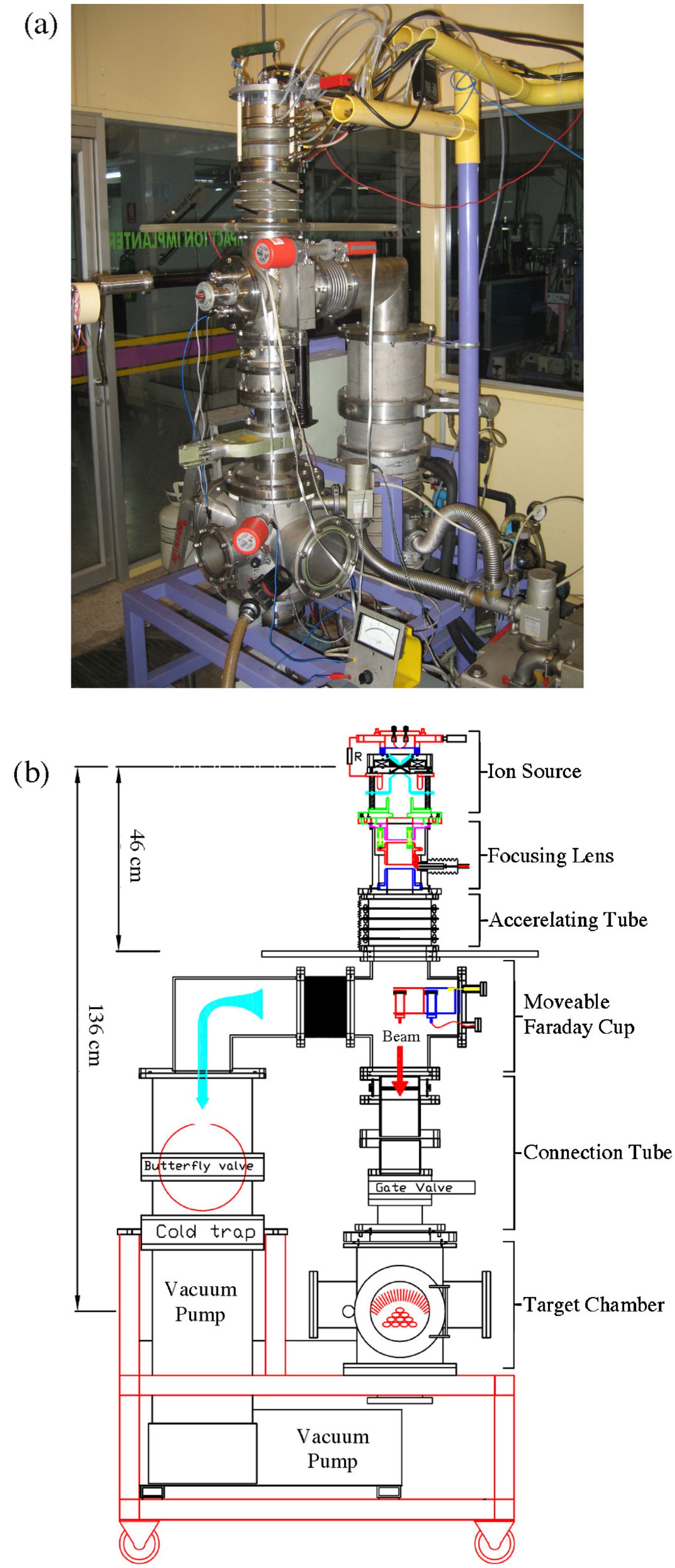

Fig. 1. (a) A photograph and (b) schematic diagram of the high-current vertical compact ion implanter.

diffusion pump to pump the system down to its ultimate possible, a cold trap was installed in front of the pump. The ion source was of a duoplasmatron type with certain modifications for high ion current performance. The ion source could be separated into two parts, a plasma generator and an extraction system. The first part included a