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Current Status of Ultra-low Fluence Ion Implanter at KOMAC

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1. Introduction

Diamond color centers are attracting attention as candidates for room temperature qubits.[1-6] Ion implantation is an essential method to create color centers in diamond. To implement room-temperature qubits, single color centers must be created and optically detected. Single color centers can be created using ultra-low fluence ion implantation method. We have developed and verified the ultra-low fluence ion implanter. Ultra-low fluence ion beams have been available to quantum information scientists since 2023. In this study, the status of ultra-low fluence ion implanter at KOMAC will be discussed.

2. Methods and Results

2.1 Development of ultra-low fluence ion implanter

Figure 1 shows Ultra-low fluence ion implanter at KOMAC. The implanter consists of ion source, einzel lens, Faraday cup, dipole magnet, raster scanner and target chamber. CHORDIS (Cold and HOt Reflex Discharge Ion Source) can extract various ion species using gas mode and sputtering mode. Table 1 represents operation conditions of ultra-low fluence ion implanter. We can provide 9 ion species with energy ranges from 3 to 30 keV and with fluence ranges from 10^8 to 10^{16} ions/cm^2. Beam currents were controlled using a home-built beam current control device. The device was installed between ion source and mass separation electromagnet and has 8 different diameters of apertures. First, the high current ion beam was transported to the target chamber. The beam uniformity was confirmed by beam irradiation and scanning of polymer film. And then, the beam current was lowered by changing the apertures. Beam current was monitored using Faraday cup and the home-built ultra-low current integrator (UCI). Since UCI has capacitors with a minimum capacitance of 10^{-15} F, it can detect ultra-low current such as 10^{-14} A.

Table 1. the specification of ultra-low fluence ion implanter

	2023	2024	2025.08
Ion species	H^+, He^+, $^{14}N^+$, $^{15}N^+$, C^+, Si^+, Sn^+,	Ge^+, Cu^+,	+ α
Energy	3 ~ 30 kev		
Fluence	10^8 ~ 10^{16} ions/cm^2		

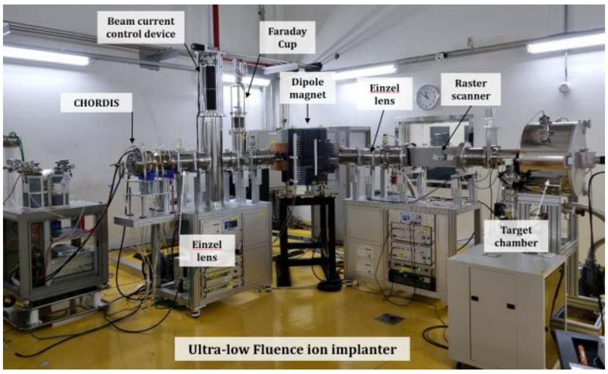

Figure 1. Ultra-low fluence ion implanter at KOMAC

2.2 Verification of Ion Species and Fluence

The verification of ion species was carried out using RBS (Rutherford Backscattering Spectrometry) measurements as shown in Fig. 2. 30 keV Ar^+ ions were implanted into a silicon wafer. The ion species, which was injected into silicon wafer, was controlled by the dipole magnet. According to RBS data, the implanted ion species was consistent with the controlled ion species. The fluence monitored using UCI showed 5 % difference from the measured value as shown in Fig. 2. The verification of the ultra-low fluence was carried out by fabricating single NV centers in diamonds.

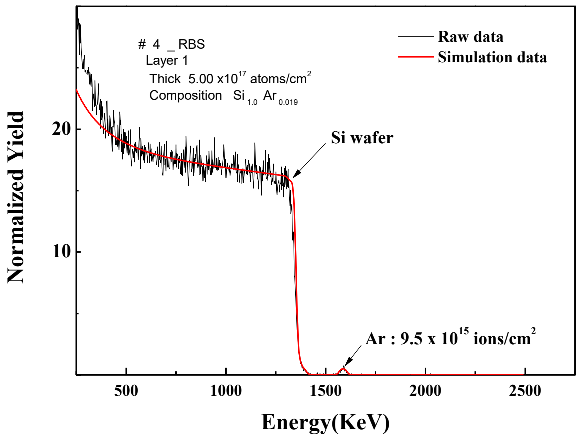

Figure 2. RBS data: 30 keV Ar^+ implanted Si wafer (1.0 X 10^{16} ions/cm^2)

2.3 Fabrication of single color center

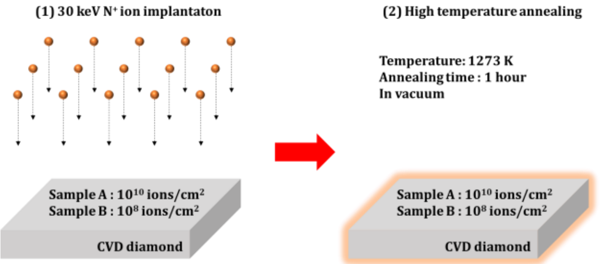

Figure 3. schematics of fabrication of NV centers.

The NV centers were fabricated using ultra-low fluence ion implantation and subsequent annealing process as shown in Fig. 3.[7] 30 keV N^+ ions were implanted into electronic grade CVD diamonds (Element Six. Corp.) with fluences of 10^8 and 10^{10} ions/cm^2, respectively. And then, the samples were annealed at 1000 degrees for 1 hour in vacuum. After the annealing process, the surface graphite was removed by acid treatment. Figure 3 shows the PL mapping image of the sample. Single color centers were observed, and the distance of individual color centers was above 1 micrometer as shown in Fig. 4 (b). It is clear evidence for ion implantation with 10^8 ions/cm^2. In case of ion implantation with a fluence of 10^{10} ions/cm^2, the ensemble color centers were observed as shown in Fig. 4. (a). We have verified the ultra-low fluence by fabricating and measuring single NV centers.

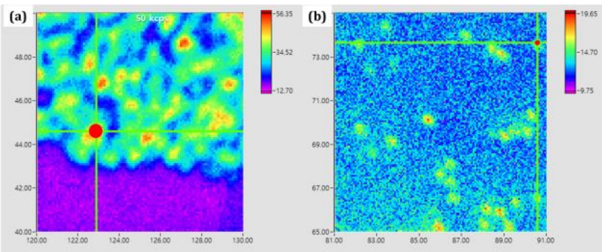

Figure 4. PL mapping image of NV centers: (a) ensemble NV centers, (b) single NV centers.

3. Conclusions

We have developed the ultra-low fluence ion implanter in 2023. System verification was carried out by creating and measuring single color center in diamond. Ultra-low fluence ion beam has been provided quantum information scientists for more than 20 days per year since 2024. It can provide scientists with 9-ion species and new ion species are developed every year for quantum information science. Quantum entanglement can be studied using N_2^+ and $^{13}C^+$ ion implantation methods. We have extracted the N_2^+ and $^{13}C^+$ion beams. The fluence verifications of these ions are now conducting. We are also developing a micro-implanter for enhancing the lateral position accuracy of color centers. The micro-implanter will be verified later this year.

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