Activation of NV color center using hydrogen ion irradiation

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1. Introduction

Nitrogen-vacancy (NV) color center is attractive candidate for quantum bit (Qubit) because its electron spin can be easily detected and modified at room temperature.[1-3] In order to realize optical quantum computing system, the position and properties of NV color center should be controlled. Single color center can be placed at the resonator using single ion implanter or low fluence ion implantation method. Although nitrogen ion were implanted at the suitable point, few percent of nitrogen became NV color center. NV color center consists nitrogen atom and adjacent carbon vacancy. Single atom and low fluence implantation cannot produce sufficient vacancies for forming NV color center. Therefore additional vacancies should be formed around stopping range of implanted nitrogen. We tried to fabricate additional vacancies using hydrogen ion irradiation method.

2. Experimental

Optical grade (N : below 50 ppm) and electronic grade (N : below 5 ppb) CVD diamonds were used in this study. 100 keV N^+ and 200 keV H^+ ions were implanted at the CVD diamond. The fluence of ions were varied from 1×10^{14} to 5×10^{17} ions/cm^2. The stopping range and damages were calculated using Stopping and Range of Ions in Matter (SRIM) code. The ion implantation was performed at KOMAC. The implanted diamond was annealed at 900℃ for 30 minutes in vacuum. Optical properties of NV color center was observed using photoluminescence (PL) measurement. Structure of diamond was confirmed by x-ray diffraction (XRD) and Raman spectroscopy. Surface roughness was also observed using atomic force microscopy (AFM).

3. Results and discussion

Figure 1 shows stopping range of N^+ and H^+ ion implanted samples. Implanted nitrogen and hydrogen ions were distributed around 120 nm and 900 nm below the surface. Because the difference of stopping range between nitrogen and hydrogen was about 700 nm, implanted hydrogen would not affect the formation of NV color center. Implanted hydrogen ions just produce additional carbon vacancies. When the fluence of nitrogen was above 1×10^{13} ions/cm^2, the ions can produce sufficient carbon vacancies for forming NV color centers. However, in case of single ion implantation or low fluence implantation for quantum computing area, implanted ions do not produce sufficient carbon vacancies.

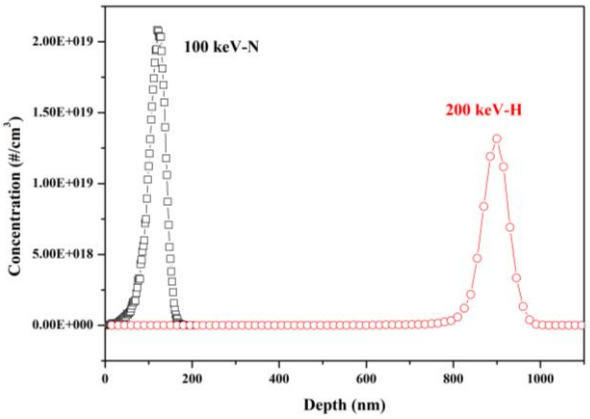

Figure 1. SRIM results of 100 keV-N^+ and 200 keV-H^+ ion implantation

Displacement per atom (DPA) of N^+ and H^+ ions implanted samples were also calculated using SRIM code as shown in Fig. 2.

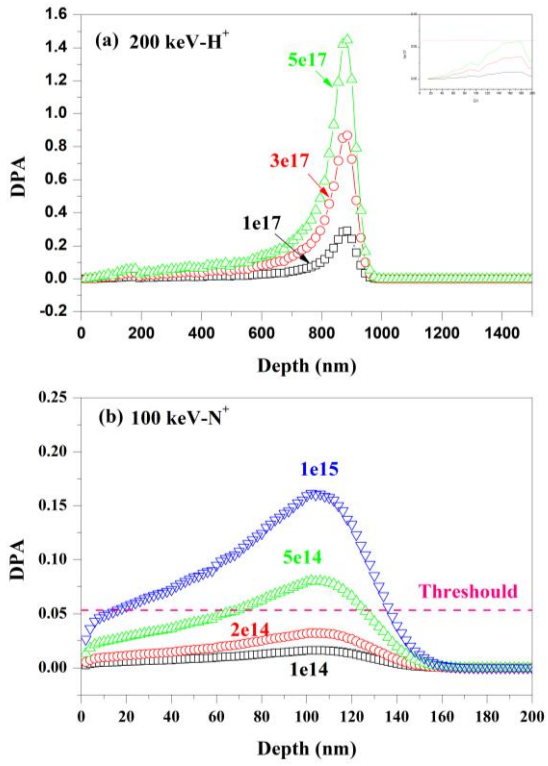

Figure 2. DPA calculation of ion implanted diamond (a) 200 keV-H, (b) 100 keV-N

When the fluence of nitrogen ion was above 5×10^{14} ions/cm^2, the carbon vacancies were produced above threshold dpa.[4] Therefore, the diamond cannot recover the diamond structure after annealing process. That is consistent with PL data as shown in Fig 3.

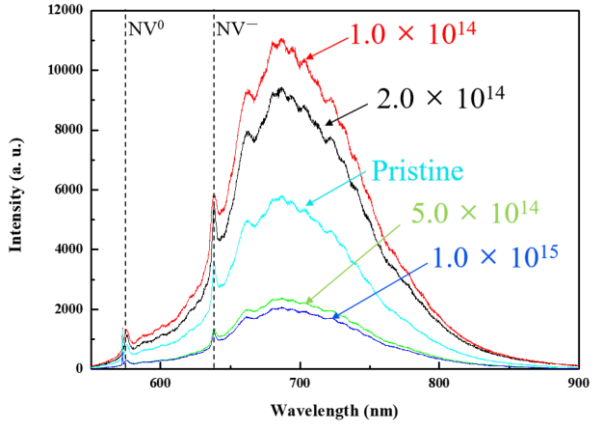

Figure 3. PL data of nitrogen implanted diamond

Because we used optical grade CVD diamond in this experiment, clear PL signal was observed even if that was a pristine sample (just annealed). When the fluence was below 5×10^{14} ions/cm^2, the PL intensity of NV center was higher than pristine sample. It seems that additional carbon vacancies, which was produce by nitrogen implantation, lead to activate NV color center. And implanted nitrogen ion also can become NV color center after annealing process. However, according to Fig. 3, low fluence sample shows higher PL intensity than high fluence samples. Interestingly, at the fluence of 5×10^{14} ions/cm^2, the PL signal became lower than pristine sample. As we mentioned above, when the nitrogen fluence was above 5×10^{14} ions/cm^2, the dpa of implanted diamond exceed threshold damage density. Therefore, the damaged diamond structure cannot recover after annealing process. PL results in Fig. 3 are consistent with this interpretation.

Additional carbon vacancies should be produced below the threshold damage density. The suitable fluence of hydrogen irradiation was also estimated using SRIM code. When the hydrogen ions were irradiated below 5×10^{17} ions/cm^2, the crystal structure of damaged region would be recovered (Fig 2. a).

In order to fabricate single NV color center, the low fluence(~10^9 ions/cm^2) nitrogen implantation was conducted at KOMAC. There are not sufficient carbon vacancies, so additional hydrogen ion irradiation was performed. After ion irradiation, the samples were annealing at high temperature. Optical properties and structure of diamond will be discussed.

4. Conclusion

We tried to fabricate single NV color center using ion implantation technique. In order to fabricate single NV color center, low fluence implantation technique should be conducted. Although single nitrogen ion would be implanted at suitable position, the nitrogen does not became NV color center. Additional carbon vacancies was produce using high energy hydrogen ion irradiation. The appropriate fluence of hydrogen ion was estimated using N^+ implantation experiment and SRIM simulation.

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