Creation and Study of Vacancies in Hexagonal Boron Nitride

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Abstract

Using ion implantation techniques to induce Boron vacancy is a proven way to create near room temperature, photostable quantum emitters in hexagonal boron nitride. These emitters have promising applications as their spin states are optically addressable and have the highest recorded brightness among the known quantum emitting materials. Despite these useful properties, the creation of these quantum emitters and their properties require further investigation. We are studying how irradiation dose affects the density and depth of negatively charged boron vacancy by creating defects using a Helium Ion Microscope and characterizing the defect density through RAMAN spectroscopy. Understanding these relationships could help further optimize the intentional creation and manipulation of VB- defects in hexagonal Boron Nitride.

Motivation

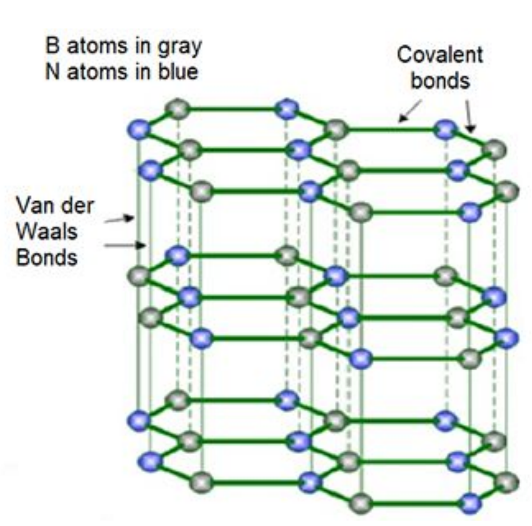


Figure 1. Molecular model of Hexagonal Boron Nitride [4]

- Hexagonal Boron Nitride (hBN) can host various defects. However, negatively charged Boron vacancy (VB-), when boron is removed from the lattice structure, proves to be of most interest [1]
- Quantum emitters in hBN have the highest recorded brightness of any quantum emitter to date and, in contrast to other quantum emitters, show high coherence at room temperature [2].
- Controlled engineering of VB- using focused ion beam implantation has been recently demonstrated using Xe, Ar, and N [3].

Methods

Sample Preparation and Characterization

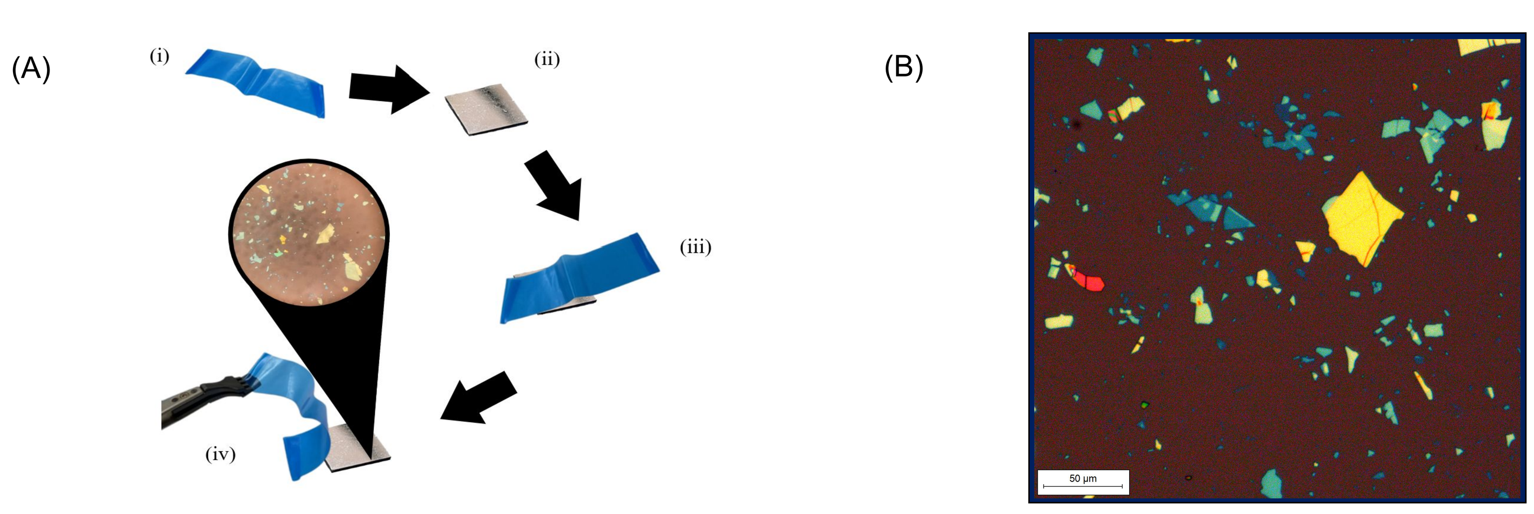


Figure 2. (A) (i) hBN is exfoliated onto vinyl tape (ii) a silicon wafer is cleaned (iii) the tape is applied directly to the wafer and is gently massaged to ensure adhesion of crystals (iv) the tape is briskly removed exfoliating hBN crystals onto the wafer. (B) The crystals' thicknesses were approximated by their color as outlined by *Anzai et al.* Yellow is approximately 90-100nm thick while the dark blue matches more closely the color of the wafer below, indicating it is much thinner [5].

TRIM Simulation

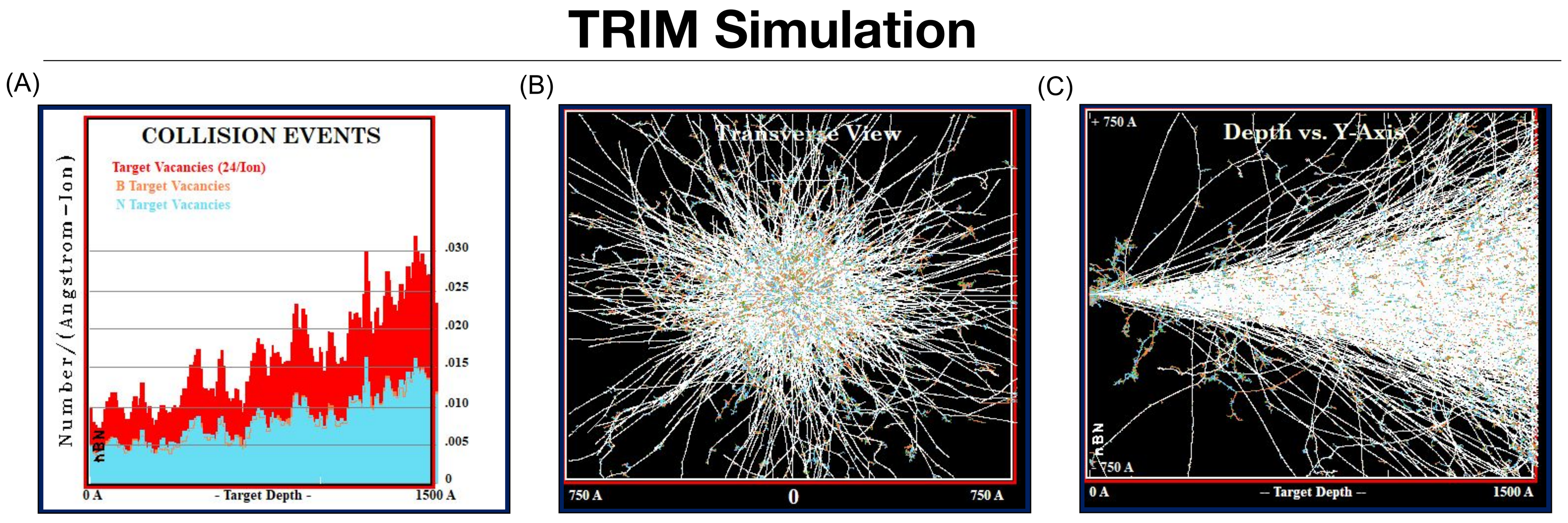


Figure 3. The Transport of Ions in Matter (TRIM) simulation, was used to gain an approximation of the ion penetration depth, trajectories, and vacancy distribution for the set implantation energy of 24 keV. (A) This graph shows the distribution of both Nitrogen and Boron Vacancies based on depth. (B) and (C) show two different angles of the trajectories of He ions along with displaced B and N atoms.

Ion Implantation and Raman Spectroscopy

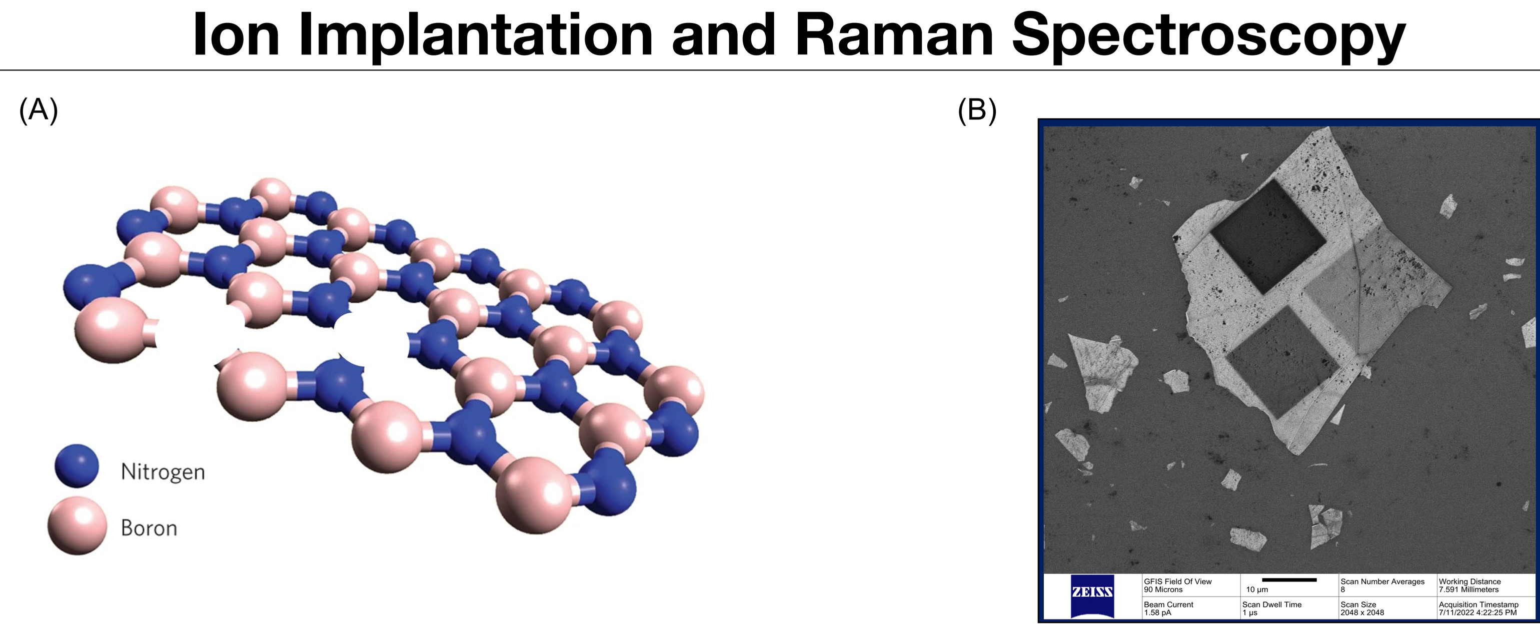
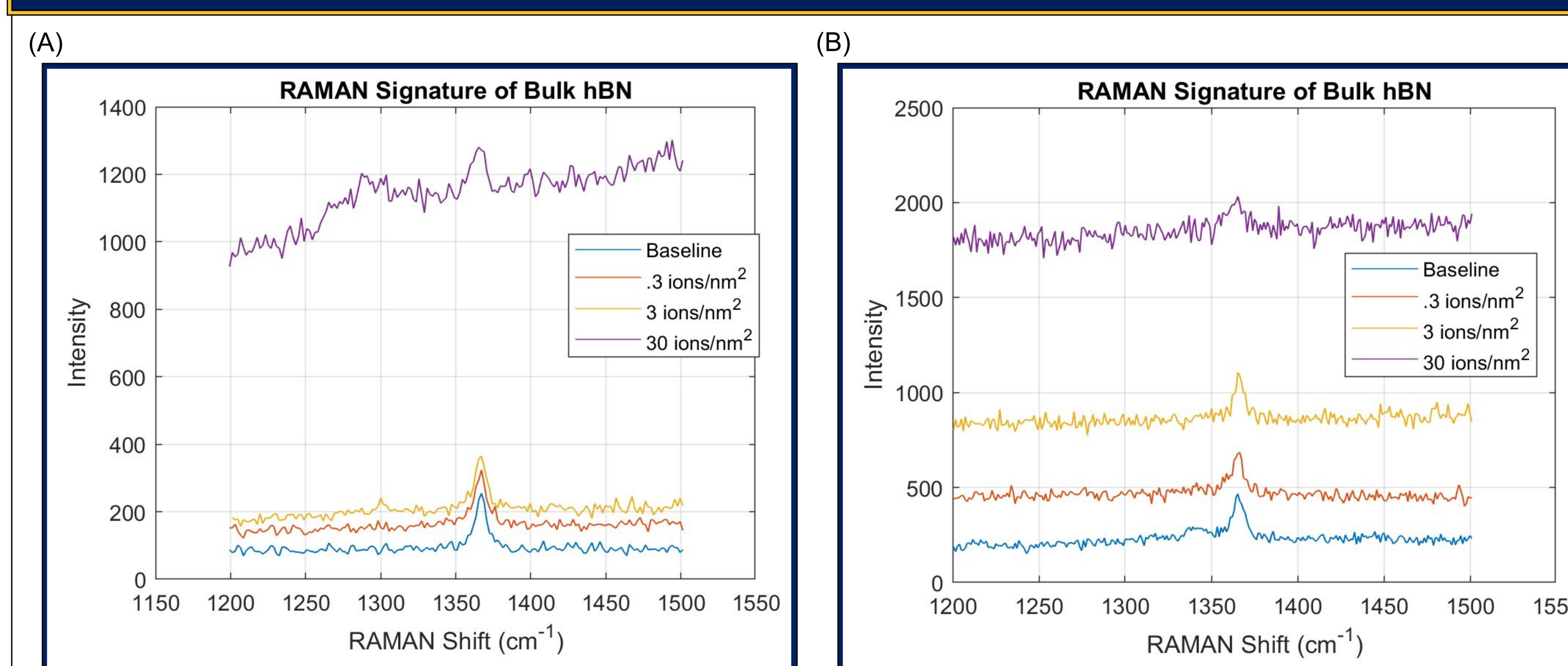
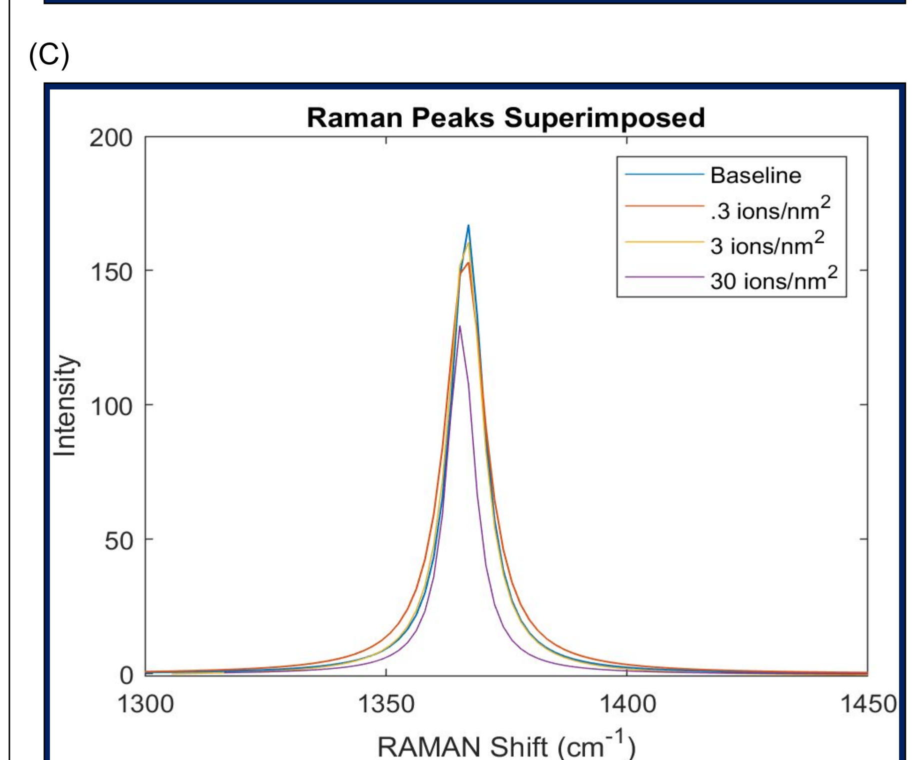


Figure 4. (A) a focused ion beam of Helium were used to damage the hBN crystal to create vacancies. This picture shows both Boron and Nitrogen Vacancies. This damage allows the crystal additional vibrational modes which can be measured using Raman Spectroscopy [6]. (B) a Helium ion microscope picture of our sample (also seen in fig. 2(B)) after radiation . The darkness of the irradiated region corresponds with the size irradiation dose.

Results





- The baseline intensities for the 514nm and 633nm spectra increase with dose despite the constant laser intensity
- Disorder in the spectra increase with ion dose
- There is an evolution of a second peak for the 30 ions/nm^2 514nm measurement, centered at ~1292cm^{-1}
- The peaks for the baseline, .3, and 3 ions/nm^2 doses are all centered at 1367.13 cm^{-1} while the highest dose is shifted to 1365.33 cm^{-1} . This shift is associated with increased defect density [7].
- The relative heights of the superimposed peaks don't perfectly correlate with dose like in the literature; however, the baseline is the tallest and the highest dose peak is the shortest [8].

Figure 5. (A) Raman spectra of the different irradiated regions measured with a 514nm laser. (B) Raman spectra of the same irradiated regions as (A), but measured with a 633nm laser. (C) The Raman peaks from (A) fit to Lorentzian curves for comparison.

Conclusion

Through TRIM simulation and Raman spectroscopy, we gained a better understanding of the creation of vacancy defects in hBN.
Future Work:
Further experimentation should be done at more doses so that a better trend can be established with respect to ion dose and height of the main peak.

References

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