Exploring the Properties and Applications of Carbon Allotropes

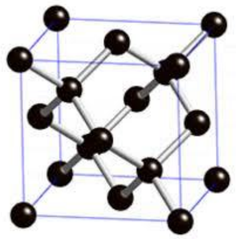
Ishaan Agarwal[1], Oliver Cunningham[1], Raiden Mosier[1], Hrish Patel[1], Pranav Praveen[1], Hana Warner[2]

[1]Bellaire High School, [2]Harvard John A. Paulson School of Engineering and Applied Science

Two common allotropes (structures) of carbon include diamond and graphene. While both are composed of exclusively carbon atoms, they have vastly different material properties as a result of differences in their structure. The purpose of this exploration is to allow for future investigations and applications of the properties of these forms of carbon to everyday life.

Diamond

- Diamonds are formed when carbon sources are subject to extreme pressures and temperatures, resulting in a "cube-in-a-cube" uniform lattice of pure carbon.



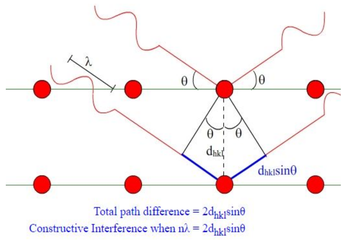
- Due to this lattice, diamonds are very resistant to abrasion (scratch resistance: rubbing diamond against other materials does not deform the structure). However, they are not tough: any alteration or deformation of the lattice structure as a result of compressive force causes the entire structure to collapse and shatter.

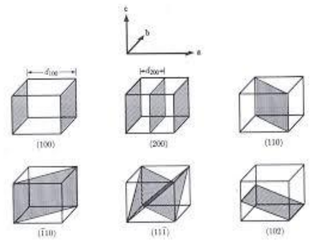
Applications

X-ray diffraction allows imaging of lattice structures, which explain many properties about a material (like conductivity, toughness and hardness, density, etc.). Knowledge about these properties allows the precise use of materials for different purposes, as well as the synthesization of new materials (like graphene!) that have properties not found in nature.

X-Ray Diffraction

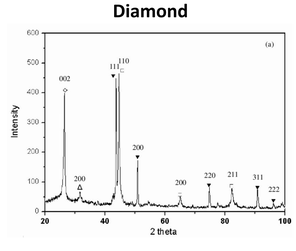
- A method where a laser is directed at a lattice material in order to determine properties of atoms and bonds.
- **Bragg's Law:** nλ=2dsinθ. When the distance dsinθ is proportional to the wavelength λ, the rays will constructively interfere, increasing intensity and forming peaks.



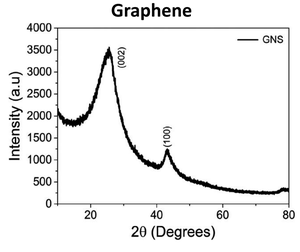


- Explaining the Graphs
  - The graph has axes of 2θ and intensity.
  - The numbers at peak intensities correspond to different planes within the structure. X-rays will constructively interfere on certain planes depending on the arrangement of atoms. A higher intensity indicated more aligned atoms.

Diamond

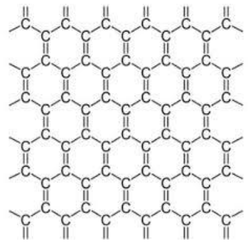


Graphene



Graphene

- The structure of graphene was discovered from graphite. Graphene consists of one layer of hexagonal carbon atoms bonded together.



- Because of its hexagonal composition, its tensile strength and elastic modulus (toughness) is one hundred times stronger than steel while being significantly lighter (pure carbon instead of iron).

Acknowledgements and References

This work was completed as part of the Quantum Engineering Research and You (QuERY) program at Bellaire High School, supported by the Harvard Quantum Initiative and MIT CQE-iQuISE (Center for Quantum Engineering, Interdisciplinary Quantum Information Science and Engineering program).

Gong, Jian Ru. Graphene Simulation. 2011. InTech, pp. 21–38.

Cervenka. "Harder than Diamond, Stronger than Steel, Super Conductor ... Graphene's Unreal." The Conversation, 19 Mar. 2012.

N-diamond: An intermediate state between rhombohedral graphite and diamond? - Scientific Figure on ResearchGate.

Preston. "Structure of Diamond. 1945. *Nature, 155*, pp. 69–70.

Scientific American. "How Can Graphite and Diamond Be so Different If They Are Both Composed of Pure Carbon?" Scientific American, 9 Oct. 2007.

University of Cambridge. "Bragg's Law." Doitpoms.ac.uk, 2023.