Evaluating the Efficiency of Graphene Electrical Conductivity when Adhered to Copper and Nickel

Thousand Oaks High School
AP Research STEM

Introduction

Graphene

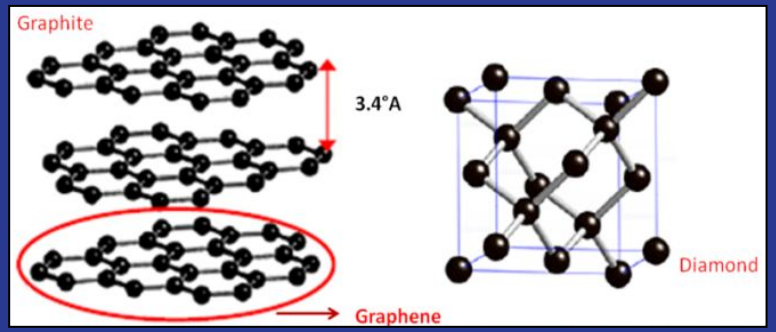


Fig 1. Shows the molecular structure of graphite (multilayer graphene) compared to that of a diamond (Singh et. al. 2012).

- 2004: Discovery of Graphene
- Hexagonal Molecular Structure: Hard
- 2D: Flexible
- Superconductor: Heat & Electricity

(Balandin et al., 2008)

Methods of Growth

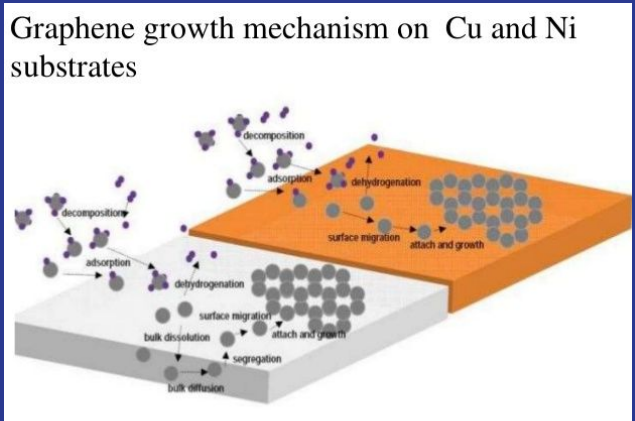


Fig 2. Chemical Vapor Deposition of graphene onto nickel (the white section) and copper (the orange section). Figure from Google Images (free).

- Micromechanical Cleavage (Scotch Tape Method)
- Chemical Vapor Deposition (CVD)
- Nanotube Slicing

(Grandthyll, 2012)
(Woehrl, 2014)

Methods of Adhesion

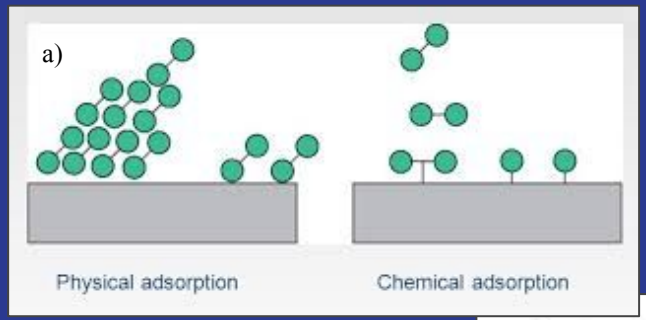
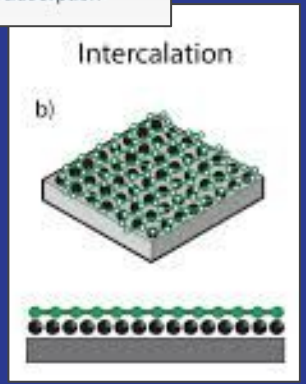


Fig 3a. Shows examples of both the physical adsorption (physisorption) and chemical adsorption (chemisorption) of two materials. 3b. Shows an example of intercalation of two materials. Figure from Google Images (free)



- Intercalation: Insertion Adhesion
- Adsorption: Surface Adhesion
  - Physisorption
    - Only Cu
  - Chemisorption
    - Only Ni

(Huang et al., 2011)
(Khomyakov et al., 2009)

Fermi Energy

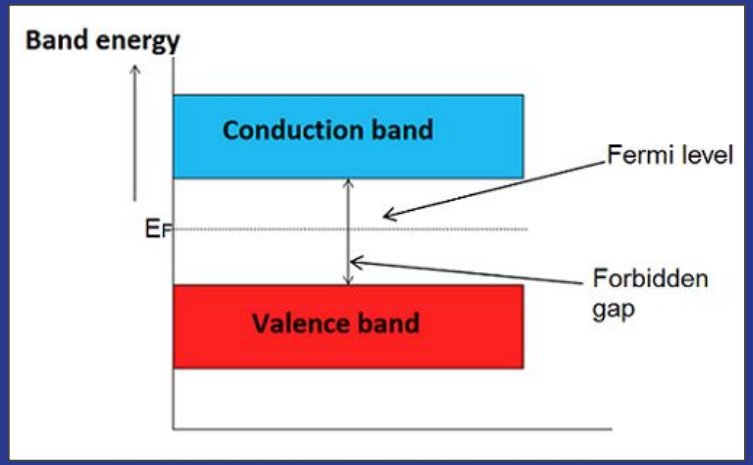


Fig 4. The Fermi level of a material is the highest possible energy of electrons at absolute zero (0k). As temperature increases, so does the maximum possible energy of electrons, and if a materials electron energy level passes into the conduction band at room temperature (295.5 k), then that material is considered to be a conductor. Figure from Google Images (free).

- Fermi Energy used to measure electrical conduction
- Measured in Electron Volts (eV)
- Represents Highest Electron Value at Absolute Zero (0k)
- If Band Energy is Above Conduction Band, Material is a Conductor

(Hwang et al., 2012)

Reasons for Adhesion

- Increasing Efficiency of Electronics
- Strengthening Structures and Devices

Purpose

To determine the most effective way to adhere graphene to nickel and copper in order to preserve graphene’s conductive qualities after the adhesion.

Primary Research Question

Are the methods of graphene adhesion equally effective at maintaining graphene’s high capability for electrical conduction?

Hypothesis/Null

- Alternate: All methods of graphene adhesion are not equally effective at maintaining graphene’s high capability for electrical conduction.

- Null: All methods of graphene adhesion are equally effective at maintaining graphene’s high capability for electrical conduction.

Secondary Research Question

Will intercalation be the most effective method of adhesion because graphene will be more closely connected to copper and nickel when it is intercalated within the metal rather than being adhered just on the surface?

Hypothesis/Null

- Alternate: Intercalation will not be the most effective method of adhesion.
- Null: Intercalation will be the most effective method of adhesion.

Previous Work

- Graphene bonds poorly with Cu, Au, Ag, and Pt.
- Graphene bonds strongly with Ni, Ti and Co.
- Graphene retains its properties when weakly bonded to the metals
- Progressively loses these properties as bonds grow stronger.

(Khomyakov et al., 2009)

Method: Systematic Review

- Systematic Review of Relevant, Peer Reviewed Literature
  - Obtained from CSUCI Library, TOHS
    - Received from Various Databases
    - New Journal of Physics, Nano Letters, etc.
  - Keywords: Graphene, Intercalation, Absorption, Adhesion

Results

First, the Fermi Levels of Each Pure Material Were Calculated in Order to Create a Standard for the Adhered Models

Material	Fermi Energy (eV)
Copper	7
Nickel	6.97
Graphene	8.25

Fig 4. Data received from Hsu and Khomyakov. There first column represents the pure material being tested and the second column shows the average Fermi energy of each material in electron volts (eV).

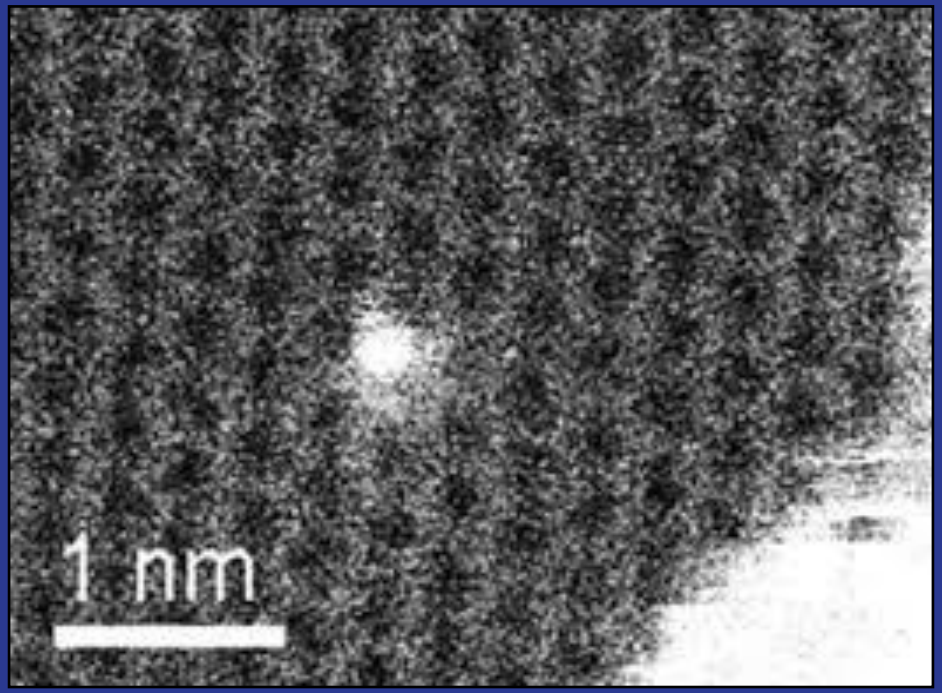


Fig 5. Electron microscopy of graphene that shows the electron structure of this section of graphene (Voloshina, 2014)

Next, the Fermi Energies Were Calculated for All Types of Adhesion

Type of Adhesion	Fermi Energy (eV)
Cu Intercalation	7.55
Ni Intercalation	6.4
Cu Physisorption	8.08
Ni Chemisorption	6.25

Fig 6a. Table showing average fermi energy for each form of graphene-metal adhesion

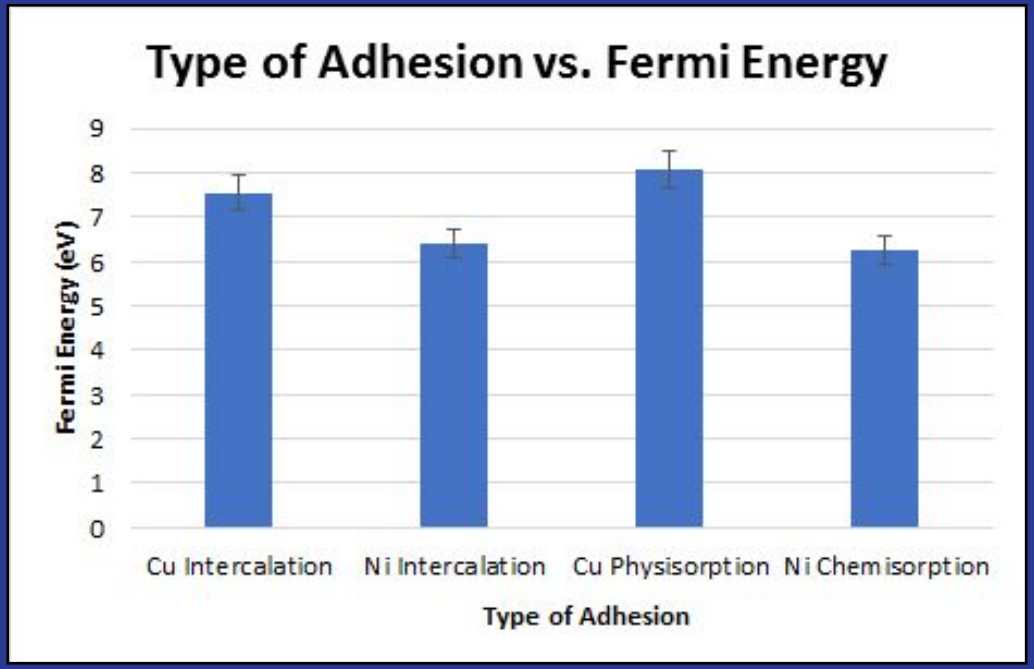


Fig 6a. Graph of Fermi level tests of graphene-metal adhesions: Graphene intercalation is shown before graphene adsorption due to the order in which the data was found. The error bars are based of of the standard deviation of the data set.

Discussion

Graphene

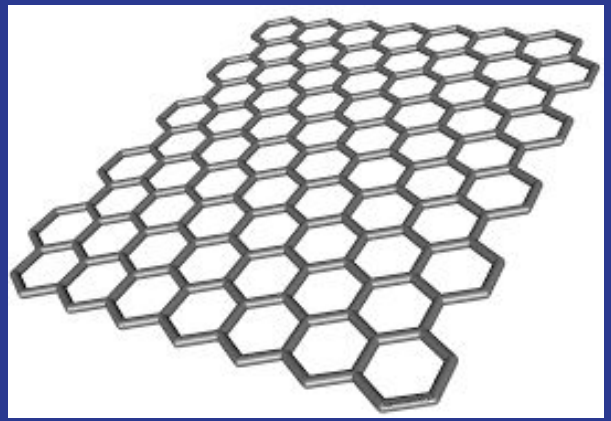


Image of Molecular Structure of Graphene. Figure from Google Images (free).

- New Material with Unique Properties
  - 2D, Hard, Conductive
- Graphene Adhesion to Metal
  - Improves Electronics Conduction
  - Strengthens Structures/Devices

Pure Materials

Material	Fermi Energy (eV)
Copper	7
Nickel	6.97
Graphene	8.25

Adhered Materials

Type of Adhesion	Fermi Energy (eV)
Cu Intercalation	7.55
Ni Intercalation	6.4
Cu Physisorption	8.08
Ni Chemisorption	6.25

- Pure Graphene > All
- Cu Adhesion > Pure Cu
- Pure Ni > Ni Adhesion

T - Test Results: $p > 0.05$

Conclusions & Further Work

Conclusions

- The graphene - Cu adhesions benefits Cu conduction
- The graphene - Ni adhesions hinders Ni conduction
- The T - Test results confirm both null hypotheses

Further Work

- Collect more data on fermi energy of pure and adhered graphene
- Test graphene adhesion to more materials
  - Different metals
  - Nonmetals
- Test effect on other graphene properties
  - Hardness
  - Heat Conductivity

Acknowledgements

- Dr. Nikki Malhotra
- Dr. Zin Htway
- Dr. Frank Müller
- Dr. Alexander Grüneis
- Emily Htway
- Michelle Magnusson

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