Efficiency of Graphene Electrical Conductivity when Adhered to Copper and Nickel

Introduction

In 2004 Professor Sir Andre Geim and Professor Sir Kostya Novoselov of Manchester discovered graphene, an isolated single atomic layer of carbon.

Graphene's carbon hexagonal molecular structure makes it one of the hardest known materials. Additionally, the two-dimensional carbon hexagonal molecular structure of graphene is a superconductor of both heat and electricity (Balandin et al., 2008). Because of these properties, scientists and engineers implement graphene materials into sensitive electronic devices, such as computer chips, to make them smaller and more efficient.

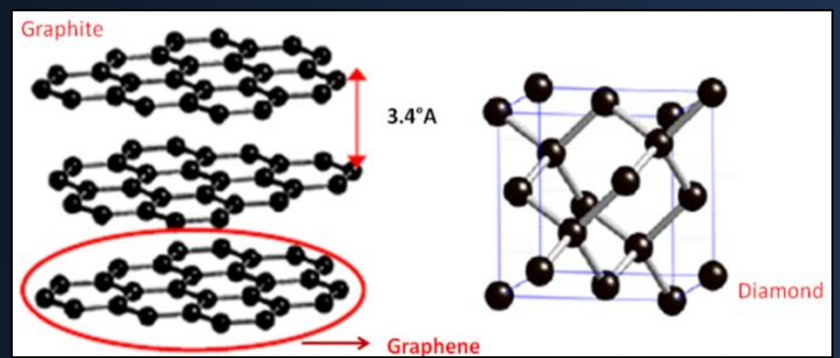

Fig 1. Shows the molecular structure of graphite (multilayer graphene) compared to that of a diamond (Singh et. al. 2012).

To use graphene for these types of science and engineering projects, it is necessary to adhere graphene to different types of metals to ensure stability and function. Previous work in which graphene was grown on copper showed graphene bonds poorly to copper. However, stronger bonds form with the metals nickel (Khomyakov et al., 2009).Graphene retains most of its properties, including its strength and conductivity, when weakly bonded to the metals but progressively loses these qualities as bonds grow stronger (Khomyakov et al., 2009).

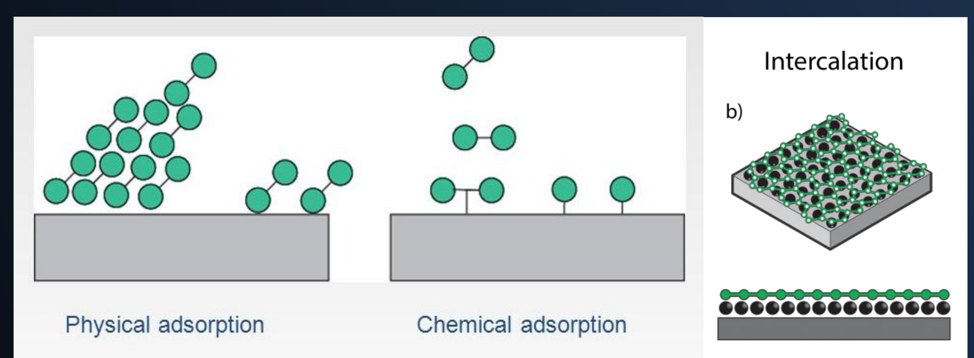

Fig 2a. Shows examples of both the physical adsorption (physisorption) and chemical adsorption (chemisorption) of two materials. 2b. Shows an example of intercalation of two materials. Figure from Google Images (free)

Purpose

This study was done to identify the most effective way to adhere graphene to nickel and copper to preserve graphene's conductive qualities after the adhesion.

Abstract

Graphene is a relatively new material with multiple unique properties. It is a single-atomic carbon layer with a hexagonal molecular structure. Graphene has a hardness greater than diamond and is a superconductor of both heat and electricity. However, since graphene is a relatively new material, little is known about the effects of other materials on its properties. This is a study of the electrical conductivity of graphene when graphene is adhered to copper and nickel. The intent is to determine which adhesion method most effectively preserves graphene's electrical conductivity. The effectiveness of the adhesion methods are compared using the Fermi energy of each product of adhesion. Through a systematic review, results indicate weaker adhesions to graphene are more effective at preserving the electrical conductivity of graphene.

Research Question and Hypotheses

Research Question (1): *Are the methods of graphene adhesion equally effective at maintaining graphene's high capability for electrical conduction?*
Alternate Hypothesis (1): *All methods of graphene adhesion are not equally effective at maintaining graphene's high capability for electrical conduction.*
Null Hypothesis (1): *All methods of graphene adhesion are equally effective at maintaining graphene's high capability for electrical conduction.*
Research Question (2): *Will intercalation, the insertion of a material into a layered structure, 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?*
Alternate Hypothesis (2): *Intercalation will 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.*
Null Hypothesis (2): *Intercalation will not 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.*

Methods

- **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

Before being adhered, graphene was found to have a Fermi level of about 8.25 eV (Yoon, 2012). Comparatively, pure copper had a Fermi level of 7.00 eV and nickel had a Fermi level of 6.97 (Table 1; Hsu, 2012 and Khomyakov, 2009). The results, as indicated in Table 2, show Cu-graphene intercalation has a downward Fermi shift of 0.7eV, Ni-graphene intercalation has a downward shift of 1.85 eV. Cu-graphene physisorption has a downward shift of 0.17 eV, and Ni-graphene chemisorption has a downward shift of 2.0 eV. The standard deviation of the results was calculated to be about 1.5.

Results (Continued)

Table 1. 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).

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

Table 2. Table of data from Fermi level tests of graphene-metal adhesions: Graphene intercalation is shown before graphene adsorption due to the order in which the data was found.

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

Discussion

The results indicate that the weaker bonding adhesions preserved the electrical conductivity of graphene the most. This means that in graphene-Cu bonds, intercalation preserved graphene's conductivity, and in graphene-Ni bonds, chemisorption preserved graphene's conductivity. However, all bonds were less effective than pure graphene, and in graphene-Ni bonds, each bond was less effective than pure Ni.

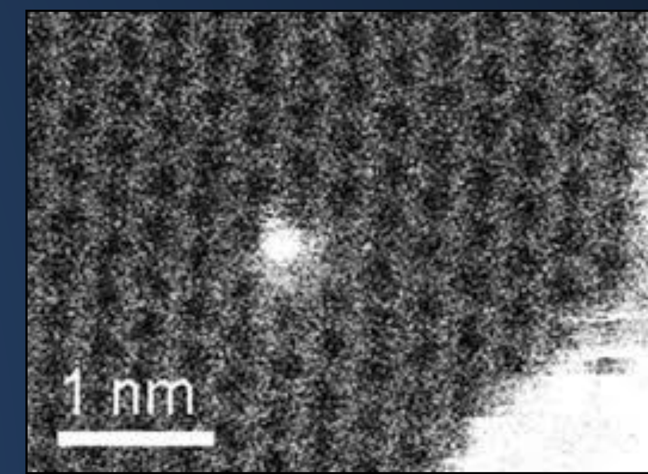

Fig 6. Electron microscopy of graphene that shows the electron structure of this section of graphene (Voloshina, 2014)

Conclusion

Based on the results, weaker forms of adhesion such as adsorption on copper and intercalation with nickel preserve the conductive qualities more than stronger forms of adhesion.

Further Work

Further work on graphene adhesion to metals need to include more research on the Fermi levels resulting from different forms of adhesion metals other than copper and nickel. Additionally, further work can be done to test the effect of graphene-metal adhesions between different graphene properties. Finally, further work can be done on the effect of nonmetals to graphene.

Acknowledgements

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