How to read a scientific article (that you think is too complicated)
Systematic Post-assembly Modification of Graphene Oxide Paper with Primary Alkylamines

Sasha Stankovich,†,‡ Dmitriy A. Dikin,† Owen C. Compton,‡ Geoffrey H. B. Dommett,‡ Rodney S. Ruoff,*,†§ and SonBinh T. Nguyen*,†

†Department of Mechanical Engineering and ‡Department of Chemistry and The International Institute for Nanotechnology, Northwestern University, 2145 Sheridan Road, Evanston, Illinois 60208-3133. †Current address: Department of Mechanical Engineering and the Texas Materials Institute, The University of Texas at Austin, 1 University Station, C2200, Austin, TX 78712-0292

Received February 12, 2010. Revised Manuscript Received April 16, 2010

Graphene oxide paper can be systematically modified with alkylamines in both solution- and vapor-phase, with the latter process being significantly slower. After removal of physisorbed amine, the increases in gallery spacing, physical thickness, and mass of amine-modified papers can be directly correlated to the length of the intercalated alkyl chain. While the tensile strength of the modified papers slightly decreases with increasing amine lengths, their “effective oxide moduli” were essentially unchanged, suggesting that graphene oxide is the sole contributor to the stiffness of amine-modified papers.

Introduction

The bottom-up assembly of nanosized building blocks offers a versatile route to the fabrication of a variety of functional macrostructures that are inaccessible via conventional top-down synthetic techniques, especially in the case of hybrid and nanocomposite materials. In particular, flexible paper- or foil-like assemblies have been formed from exfoliated lamellar clays,1 carbon nanotubes,2 stacks of expanded graphite platelets,3 platelets of graphene oxide,4 and platelets of reduced graphene oxide,5 to afford materials that exhibit excellent mechanical, electronic, and, in some cases, optical properties. We have recently reported the preparation of graphene oxide paper,6 also by pressure-assisted assembly of aqueous suspensions of graphene oxide platelets,6 which are produced by the exfoliation of graphite oxide (GO). Flow-directed filtration of water-dispersed graphene oxide induces self-assembly of individual platelets into a stacked lamellar structure with near-parallel platelet axes.

(epoxy, hydroxyl, carbonyl, and carboxyl groups (oxygen, carbon, and hydrogen planes and edges),7–10) this paper shows that these non-covalent functional groups can be covalently modified with amine-functionalized graphene oxide papers (AGOs). We have previously prepared AGOs from commercially available reduced graphene oxide paper by several methods.

In spite of the rich chemistry and unique properties offered by oxygen-containing functionalities,11 further structure-property relationships in chemically modified AGOs have been largely unexplored. Recent work focusing only on modifying AGOs with small molecules has already demonstrated the importance of the chemical functional groups (covalently attached to the oxide surface) on its mechanical properties. Further, the rich chemistry and unique properties of graphene oxide combined with its large surface area,3,12–16 make it a good candidate for chemical modification.
Scientific papers can be tricky, but you don’t need to read the whole thing to get the gist of the research therein.

For starters, you’ll need to understand:
• How the paper is structured
• What you *need* to read in the beginning
• What to do if you’re stuck
• What to do if you’re still interested at the end
How is the paper structured?

Most scientific papers follow the general structure outlined below. Some fields of research follow slightly different structures – keep an eye on the papers in your field and you’ll start to see the patterns.

• Title/Authors – This is the basic information for the article, pretty self-explanatory
• Abstract – A general run-down of all of the contents of the paper
• Introduction – The “why” of the research project – putting this research in the context of the greater research community
• Methods – How did the researchers do what they did? Why did they do it that way?
• Results – This is what happened when they did the research and what they think it means.
• Discussion – This is how the results fit into the corpus of other research of this sort. This is also where the authors talk about why what happened (Results) is important (or not).
• Conclusions – Usually provides an overview of the research. Also provides the reader with the answer to the “who cares?” question – why is the research important?
Do I need to read all of that?

• The short answer is NO!
• Follow these steps to get a simple overview of the paper:

1. Read the abstract
2. Read the beginning and end of the introduction
3. Look at the figures and tables including the captions
4. Read the Conclusions section (or last couple of paragraphs of the paper)
1. Read the Abstract

The abstract will basically tell you everything important about the paper. In this case, the paper indicates that the researchers:

1) modified graphene oxide paper with something called alkylamines
2) found that variability in the products depended on something called the alkyl chain (including a reduction in paper strength)
3) found that “effective graphene oxide moduli” were unchanged

…but wait! I don’t know what those terms mean!
1. Read the Abstract

No problem – look ‘em up!

Use basic sources such as dictionaries and Wikipedia to get a sense for what the complex terms in the paper mean.

Don’t forget to search for the terms in the paper itself to see if you can use context to figure things out...
1. Read the Abstract

Systematic Post-assembly Modification of Graphene Oxide Paper with Primary Alkylamines

Sasha Stankovich,†,‡ Dmitry A. Dikin,† Owen C. Compton,† Geoffrey H. B. Dommett,‡ Rodney S. Ruoff,*,†,§ and SonBinh T. Nguyen*,†

†Department of Mechanical Engineering and ‡Department of Chemistry and The International Institute for Nanotechnology, Northwestern University, 2145 Sheridan Road, Evanston, Illinois 60208-3133. §Current address: Department of Mechanical Engineering and the Texas Materials Institute, The University of Texas at Austin, 1 University Station, C2200, Austin, TX 78712-0292

Received February 12, 2010. Revised Manuscript Received April 16, 2010

Graphene oxide paper can be systematically modified with alkylamines in both solution- and vapor-phase, with the latter process being significantly slower. After removal of physisorbed amine, the increases in gallery spacing, physical thickness, and mass of amine-modified papers can be directly correlated to the length of the intercalated alkyl chain. While the tensile strength of the modified papers slightly decreases with increasing amine lengths, their “effective graphene oxide moduli” were essentially unchanged, suggesting that graphene oxide is the sole contributor to the stiffness of amine-modified papers.

No problem – look ‘em up!

Graphene oxide paper – “...a composite material fabricated from graphene oxide... The material has exceptional stiffness and strength, due to the intrinsic strength of the two-dimensional graphene backbone and to its interwoven layer structure which distributes loads... graphene oxide paper is an electrical insulator; however, it may be possible to tune this property, making the paper a conductor or semiconductor, without sacrificing its mechanical properties.” (from Wikipedia)

Gallery spacing – Refers to the spacing between layers of graphene. Figured this out by doing a quick search for “spacing” in the paper and deducing the meaning by context.

Alkylamine – this is an amine (ammonia derivative) with an alkyl group attached. Figured this out by looking in the dictionary! A quick search for “alkylamine” in the paper shows that the authors have previous information suggesting that alkylamines will be useful for this type of work (see the first paragraph of Results and Discussion).

Moduli – refers to the “stiffness” of the material. Figured this out by doing a quick search for “moduli” in the paper and found that the authors are referring to Young’s Modulus, which I then looked up in Wikipedia.
Graphene oxide paper was modified using alkylamines. The length of the alkyl chain (in the alkylamine) is correlated with changes in the structure of the resultant graphene paper – specifically, longer alkyl chains resulted in more distance between graphene sheets and decrease in tensile strength. However, the flexibility of the graphene paper was not affected.

WOW! Now we know the basics of the paper. Lets dig a little deeper...
2. Read the beginning and end of the introduction

**Introduction**

The bottom-up assembly of nanosized building blocks offers a versatile route to the fabrication of a variety of functional macrostructures that are inaccessible via conventional top-down synthetic techniques, especially in the case of hybrid and nanocomposite materials. In particular, flexible paper- or foil-like assemblies have been formed from exfoliated lamellar clays,\(^1\) carbon nanotubes,\(^2\) stacks of expanded graphite platelets,\(^3\) platelets of graphene oxide,\(^4\) and platelets of reduced graphene oxide,\(^5\) to afford materials that exhibit excellent mechanical, electronic, and, in some cases, optical properties. We have recently reported the preparation of graphene oxide paper,\(^4\) also by pressure-assisted assembly of aqueous suspensions of graphene oxide platelets,\(^6\) which are produced by the exfoliation of graphite oxide (GO). Flow-directed filtration of water-dispersed graphene oxide induces self-assembly of individual platelets into a stacked, layered structure with near-parallel platelet arrangement, yielding a self-supporting, mechanically strong paper upon drying. Since the assembled graphene oxide platelets retain all their oxygen-containing functional groups...

**Beginning:**

Herein, we report a systematic study on the intercalation of primary alkylamines in both solution and vapor phase into graphene oxide paper. The modified materials exhibit a direct relation between the intercalated alkyl chain length and gallery spacing, physical thickness, sample mass, and tensile strength. Surprisingly, in spite of the large interlayer spacings produced by intercalation of amines, the Young’s moduli of the modified papers remained constant.

**End:**

The **beginning** and the **end** of the Introduction are most likely to give us background into why the research was conducted (beginning) and either an introduction of the goals of the research or a complete overview of the research including results (end).

At this point, there is a lot of junk in the middle of the introduction that is probably confusing and not relevant to getting a gist of the paper...so ignore it for now.
2. Read the beginning and end of the introduction

**Introduction**

The bottom-up assembly of nanosized building blocks offers a versatile route to the fabrication of a variety of functional macrostructures that are inaccessible via conventional top-down synthetic techniques, especially in the case of hybrid and nanocomposite materials. In particular, flexible paper- or foil-like assemblies have been formed from exfoliated lamellar clays, carbon nanotubes, stacks of expanded graphite platelets, platelets of graphene oxide, and platelets of reduced graphene oxide, to afford materials that exhibit excellent mechanical, electronic, and, in some cases, optical properties. We have recently reported the preparation of graphene oxide paper, also by pressure-assisted assembly of aqueous suspensions of graphene oxide platelets, which are produced by the exfoliation of graphite oxide (GO). Flow-directed filtration of water-dispersed graphene oxide induces self-assembly of individual platelets into a stacked, layered structure with near-parallel platelet arrangement, yielding a self-supporting, mechanically strong paper upon drying. Since the assembled graphene oxide platelets retain all their oxygen-containing functional groups

---

**Beginning:**

Nanotech fabrication show promise not seen in ‘top-down’ assembly methods

Nano-paper is especially cool (e.g. graphene oxide) for mechanical, electrical, and optical stuff

The beginning of the complicated and (for now) not relevant stuff. E.g. “Blah, blah, blah, what we’ve done before and why we’re qualified, blah, blah.”

**End:**

Herein, we report a systematic study on the intercalation of primary alkylamines in both solution and vapor phase into graphene oxide paper. The modified materials exhibit a direct relation between the intercalated alkyl chain length and gallery spacing, physical thickness, sample mass, and tensile strength. Surprisingly, in spite of the large interlayer spacings produced by intercalation of amines, the Young’s moduli of the modified papers remained constant.

**How handy! A concise overview** of the research project presented in this paper, using slightly different language from the abstract!
2. Read the beginning and end of the introduction

**Introduction**

The bottom-up assembly of nanosized building blocks offers a versatile route to the fabrication of a variety of functional macrostructures that are inaccessible via conventional top-down synthetic techniques, especially in the case of hybrid and nanocomposite materials. In particular, flexible paper- or foil-like assemblies have been formed from exfoliated lamellar clays,\(^1\) carbon nanotubes,\(^2\) stacks of expanded graphite platelets,\(^3\) platelets of graphene oxide,\(^4\) and platelets of reduced graphene oxide,\(^5\) to afford materials that exhibit excellent mechanical, electronic, and, in some cases, optical properties. We have recently reported the preparation of graphene oxide paper,\(^6\) also by pressure-assisted assembly of aqueous suspensions of graphene oxide platelets,\(^6\) which are produced by the exfoliation of graphite oxide (GO). Flow-directed filtration of water-dispersed graphene oxide induces self-assembly of individual platelets into a stacked, layered structure with near-parallel platelet arrangement, yielding a self-supporting, mechanically strong paper upon drying. Since the assembled graphene oxide platelets retain all their oxygen-containing functional groups.

Herein, we report a systematic study on the intercalation of primary alkylamines in both solution and vapor phase into graphene oxide paper. The modified materials exhibit a direct relation between the intercalated alkyl chain length and gallery spacing, physical thickness, sample mass, and tensile strength. Surprisingly, in spite of the large interlayer spacings produced by intercalation of amines, the Young’s moduli of the modified papers remained constant.

**Beginning:**

Now we have a really good idea of what the paper is about based on the Abstract and the last paragraph of the Introduction.

**End:**

AND we have a good idea of why this research is important based on the first part of the Introduction.
3. Look over the figures and tables, including the captions

Based on what we know so far, we can now go through, VERY QUICKLY, and see what the figures and tables show.

If something is too complicated, just move on to the next item. You’ll see that you already know a lot about the results from looking at the Abstract and Introduction!
3. Look over the figures and tables, including the captions

Neat! This figure shows how the alkyl chain length affects gallery spacing (remember that from the Abstract?)

Oooh! Pictures of graphene oxide of different thicknesses!
3. Look over the figures and tables, including the captions

Ah, yes, a reduction in tensile strength (y-axis) with increase in alkyl chain length (x-axis) – as mentioned in the Abstract

Modulus (x-axis; flexibility) and alkyl chain length. No change in modulus with increase in alkyl chain length except at C12 (long) alkyl chain lengths...

Kinda complicated, but we figured it out!
3. Look over the figures and tables, including the captions

Figure 6. XRD patterns of dodecylamine-modified graphene oxide paper produced by (1) solution-phase intercalation (24 h) and vapor-phase intercalation after (2) 12 h and (3) 2 weeks. None of the samples were exposed to a methanol wash. Peaks marked with (*) denote the residual character of unmodified graphene oxide paper.

Figure 7. SEM images taken at different magnifications to illustrate incomplete intercalation of dodecylamine vapor into graphene oxide paper after 12 h of exposure. The contrast between the unmodified and intercalated layers can be attributed to the accumulated charging in the amine-modified layers.
4. Read the Conclusions

We’ve got this thing mostly figured out. Let’s just look over the Conclusions section to see if there are any more interesting tidbits.

Conclusions

In conclusion, we have demonstrated that post-assembly modification of graphene oxide papers with primary alkylamines can be successfully achieved via solution- or vapor-phase intercalation, with the latter process being significantly slower. After removal of physisorbed amines from the gallery, modified papers systematically exhibit direct correlations between the length of the intercalated alkyl chain and intergallery spacing, physical thickness of the paper, sample mass, and tensile strength. The tensile strength of the amine-modified papers suffers slightly as the length of the amine increases, with longer chains increasing the gallery spacing and making the paper weaker. However, the stiffness of the modified papers remains relatively unaffected, with little change in “effective graphene oxide modulus”. These results suggest that graphene oxide paper can be used as an effective storage medium (for charges and chemicals) retaining its good mechanical stiffness in spite of intergallery loading.

Here, they reiterate what they did. We pretty much understand this stuff, but if we were still confused, we could look here for clarification.

This is helpful. The authors give an overview of why this research is important: graphene oxide paper can be used to store stuff between layers while retaining most of its physical properties!
Now what?

Well, now you’re done. You’ve got the gist of the paper, understand the results, and have a sense for why its important.

If there was anything you read that really piqued your interest, you can go back and thoroughly read the Introduction, Methods, Results, or Discussion sections. Otherwise, take some notes and move on to the next paper.

Congratulations Scientist!
FAQ

Q: *Will this method work for every paper?*
A: NO! There will definitely be cases for which no matter how closely you follow these guidelines, the paper will still be too complicated. If you run into one of those papers, it is probably too specialized for your work at this point, so you can either move on to a different paper or, if you’re ambitious, find an expert to help you (professor, TA, or even a librarian!).

Q: *Do all papers have the same structure?*
A: No, some fields of research have pretty different paper structures, but in most cases, some or all of the components are there, they just aren’t labeled as clearly.

Q:
A: