# Science AMA Series: We're the NanoHAC group from Imperial College, here to talk about graphene, nanotubes, and other really small materials. AUA!

NanoHAC [1] and r/Science AMAs[1]

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**Abstract**

Hi Redditors! We are the Nanostructured Hierarchical Assemblies and Composites group, aka NanoHAC, from Imperial College London. Nanomaterials, in particular graphene and carbon nanotubes, have exceptional properties as individual nanoscale objects but there are a ton of challenges in exploiting their characteristics in usable, real-life, macroscopic materials. Our research uses chemistry and engineering to tackle the hurdles inherent in the processing and assembly of these materials, from purification, to changing their surface chemistry, to making composites, to creating hybrid nanostructures, and much more. Here to answer your questions are Dr Adam Clancy (nanotube processing, functionalisation and assembly), Dr Noelia Rubio Carrero (the same, but with graphene), Sandra Fisher (studies the nanomaterials in nanocomposites), Dr Hannah Leese (turning nanomaterials into components for electronics), and Dr Hin Chun Yau (self-assembling nanomaterials into structures). We are here to answer any questions you have on carbon nanomaterials, their uses and future directions, being a scientist, music, baking the ideal lemon drizzle cake, the best pubs in London, or anything else you fancy! We'll be answering questions from 1-3 pm ET (or 5-7pm GMT for us here in the UK), so feel free to ask us anything! EDIT: Hi all, we're packing up for the night. If you have any more questions, feel free to ask and we'll try to answer them.

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NANOHAC R/SCIENCE

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How big will the impact of Graphene be on battery life in the future?

NeutralPotato

To start with, let me just point out that batteries isn't my main area of expertise, so any battery scientists, please leap in and correct me if I get it wrong.

The increased surface area of the anode (bit where you store lithium when the battery is charged) can make a big difference, and people are already wiping the floor with typical battery performance in terms of power density (amount of charge you can put in per gram of battery). However, unless you want a 2d nanometer thin, meters wide battery, you need to assemble the graphene into a 3d structure that limits stacking of graphene (i.e graphite which is what is in normal lithium ion batteries). As a nanocarbon-but-not-battery researcher looking in, doing this assembly in a cheap and industrially scalable manner appears to be the biggest challenge at the moment.

As for solid numbers, my Galaxy 5 Neo battery weighs 45.02 g and says it holds 38.8 kJ of energy, so has an energy density of 862 kJ per kg. The best number I could find in a quick search for a graphene-based battery is 9360 kJ per kg (so 10.9 times better). It is worth pointing out that the numbers there aren't just from adding graphene, but also incorporating emerging battery technology (here, lithium-sulphur batteries). There may well be better numbers out there too but 10x better seems about right. Still, even though the technology exists, you wont find it in your iphone until it makes economic sense to do so.

Tl;dr, Pretty big. Graphene can be used to help make batteries that hold 10x more energy, the technology already exists and will only get more impressive in time.

I've often heard that graphene can do anything except come out of the lab. How long do you foresee before significant graphene-based devices become commercially viable?

KingKha

Adam: Ooh, difficult question. There are a couple of small companies trying to get things to market already, but at a guess I'd say 3 years or so until stuff is mass produced in phones. However, personally I think the "significant" devices will take advantage of graphene not being a metal, nor a semiconductor, but something unique (called a zero-bandgap semiconductor). Much of the current work is into playing with graphene to make it into a transistor or conductive, transparent film, etc, improving on things which already exist. I think it will become really significant when someone makes a new electrical component which does something to electronics (or photonics) that nothing has ever done before, reinventing how electronics works. No idea when that'll be though

Hi there! 1st year Nanotechnology engineering student at Waterloo here. My questions are: 1) How do you see the nano field expanding in the next 5-10 years? 2) What is the most promising use you're currently working on for carbon nanotubes? 3) Do you think Nanotechnology will have mainstream industrial jobs in the foreseeable future? Thanks!! Excited to hear about your work

Wannabebillnye

1) The 'nano-field' is currently expanding on a day-to-day basis and particular improvement will be heavily focused on development of next generation nano-electronics. As the technology of carbon nanotube and semi-conducting nano-materials production and purification mature, a range of wearable electronics with integrated nanomaterials as sensors, high-speed & compact computer processor and functional nano-building block will start to emerge

2) It's a tie between multifunctional composites (light, strong, tough, and electrically interesting) and carbon nanotubes based electronics. Plus a few bits which are still to early to talk about (sorry!)

3) There are currently thousands of jobs working on nanotechnology and it is guaranteed to keep increasing. You can be synthesising nanomaterials, integrating nanomaterials into devices (ie. thin film solar panel, smart textile, flexible display), working on nano-medicine, making nano-materials incorporated composite etc.

4) Good luck! I hope you enjoy nanotechnology as much as we do!

Will carbon nanotubes soon be economically viable on a large scale, such as in the following technology:

http://www.kurzweilai.net/converting-atmospheric-carbon-dioxide-into-carbon-nanotubes-for-use-in-batteries

strangeattractors

Well, multi-walled carbon nanotubes (like those in that article) have been economically viable for a long time and are used in loads of applications from phone screens to tennis rackets. *Single* walled carbon nanotubes are the ones which are a) better at pretty much everything and b) previously expensive. Recently (in the last couple of years) this has started to change and people are now making scalable single-walled ones. The bottle neck is now not making to bloomin things, but making something useful.

Hello, thanks for doing this interesting AMA!
I have a couple of questions:

- How far away are we from CNT-based transistors with commercial application (availible to the general public at affordable price)?
- How do you see the future of computing, under the assumption of CNTs being widely used? Are the estimates of 5-10 times improvement in speed and reduction in energy requirements realistic?
- What would (each of you) say the most frustrating part of your work is except the salary, of course?

noiwontfixyourpc

Unfortunately we still have a long way to go until we can have CNT-base transistors installed into our desktop computers. Obviously the exact time scale is unknown but even an optimistic rough estimate would be no less than 5 years. The major challenges for CNT transistor are electronic-type sorting (isolating semi-conducting CNTs and getting rid of the metal ones that will short-circuit the transistor), aligning them, and connecting the CNTs to the terminals. Don't forget, the ultimate CNTs transistor should be 1 CNT per transistor which can truly miniaturise the device into the nanoscale.

There is no doubt that CNT transistor are much better than conventional silicon based transistors (the mobility and on-off ratio are at least 10x higher). The energy required per transistor is lower but more importantly, as CNTs are excellent thermal conductors, there will be less heat which makes using it cheaper/easier/more reliable.

Hi, I went to an IBBS research seminar by Dr Terry Tetley last week on nanoparticles and lung health. It was an interesting seminar as I didn't have any previous knowledge on that subject area.

Rather than that what is the coolest thing you guys found about nanoparticles.

REdINKStTone

Personally, I think the coolest thing is the ability to nucleate crystals of proteins. From a fundamental perspective, the crystallisation is difficult and the nanomaterials are not only very effective, but by changing the nanomaterial geometry we can can see the mechanism of crystalisation. From a non-fundamental perspective, they look awesome so my mum is impressed.

What was the most surprising property of any of the materials you research

Demonlynchmob

Hannah: There have been several surprises, but two of the most surprising within the research I have undertaken is 1. The behaviour of water nanoconfined inside carbon nanotubes: depending on the diameter, water molecules can structure to form ice, or flow quicker than any theoretical model ever predicted possible 2. The observation that functionalised nanocarbons can assist in the crystallisation of proteins – proteins are complicated large molecules that really don't like to crystallise – but it is vital for future drug development to obtain their structures and carbon nanomaterials seem to be able to help!

Do you think that the properties of graphene could make it suitable as shielding for spacecraft (especially to prevent cosmic radiation)?

Also what suggestions would you have for a team who wants to go about testing shielding properties of graphene?

0riginal_Poster

Interesting question, I'd never considered cosmic radiation shielding and honestly have no idea if it would be beneficial. NASA back in 2002 said hydrogen-rich materials such as polypropylene were the best and ideal graphene has no hydrogen, but I wouldnt want to make a strong case either way as it starts becoming particle physics, of which I only have a basic understanding.

For suggestions, as cosmic radiation consists primarily of high energy protons, my recommendation would be to find a collaborator who can led you their particle accelerator (or very powerful hydrogen sourced anode ray tube).

When it comes to the synthesis of graphene, nanotubes and other small materials, which of the two methods (bottom up vs top down) shows a more promising result?

Prot00ls

I would say that it really does depend on the application. Bottom up approaches can give you molecular building blocks (imagine Lego®), where you can tailor precisely and identical materials, but scale up is slow and making large, high quality materials has so far been limited. The top down approach allows us to scale up our technologies and get them closer to working, viable applications.

will graphene make super light body armor like Mithril from Lord of the Rings possible anytime soon?

petermobeter

Hannah: Graphene definitely has the potential to make super light materials…and maybe armour, there are some encouraging results out there in literature – although we have not measured such properties in the group.

Noelia: Yeah, Graphene can be between eight and ten times stronger than steel when absorbing impacts, however, the graphene was partially cracked after the impact. Maybe if graphene could be combine with a suitable matrix we could create an armour stronger than Mithril!; If this doesn't work we can always try to use graphene to create an improved Aragorn's sword :-D

Adam: … it's called Anduril

Graphene and nanotubes are remarkable for their qualities and stability. On the other hand their stability may prove to be a problem in the future when production becomes popular.

Are you concerned about proliferation of those materials and its impact on biosphere in the future similar to the plastics today?

perliczka

Studies have shown that carbon nanotubes and graphene are not toxic in a living environment. However, this could be different when exposed to much higher concentrations of these nanomaterials…
Carbon nanotubes have shown accumulation in the liver after intravenous injection. The question is how long these materials would be in a living organism. If the carbon nanotubes are functionalised and/or oxidised the degradation would be much quicker compared to non-functionalised materials.

I read an article on graphene and was fascinated with something it said, regarding properties of graphene- you can have a sheet on graphene 1 atom thick and still feel and and touch it and even pick it up.

I can't wrap my mind around how that works- what would it feel like to hold something an atom thick, how it looks from the side, etc, I just really interested me.

Mallago

from the side you cant see it - our eyes can only make out things about 0.05 mm wide and it is about 150,000x smaller than that (0.35 nm). Even seeing it from the top down can be difficult because of how thin it is. As for picking it up, Ive never tried. You'd almost certainly break it and it's really annoying to make

Have you guys have had difficulty with research funding in the EU? (If it follows through) and how has the Precautionary-Principle been enforced with the research you are doing?

Silphex

Not particularly - the UK government has said they will pay their share of any projects that end after Brexit, but even that doesnt apply to any projects we are working on. The difficulties may well come later though. The biggest issue post-Brexit may be losing access to highly skilled EU scientists who would have applied to our world--class universities but dont want to deal with getting a visa. If we dont have the best scientists applying, we wont do the best research, and Brexit may well restrict the number of applicants for each job. It depends on the agreement they reach; "Brexit means Brexit" isnt a statement filled with specifics.

Hey! Thanks for doing this ama. I'm currently doing research on neutron absorption in nuclear reactors, and I've been specifically interested in the aspect of graphene and C-nanotubes being used to filter deuterium and tritium. 1) Could you maybe explain some of the benefits and drawbacks of graphene as a method of isotope separation (specifically, how fast/efficient it is, and how easy it is to scale up)? 2) Also, have you contributed to any research regarding neutron scattering in graphene/C-nanotubes? Thanks!

nightman2112

Ah yes! a niche application - I saw the Manchester group give a talk on this last year. First thing, it is very early days in the research but it looked promising. The hydrogen had to pass through a proton carrier (Nafion iirc), which was the limiting factor for speed, plus there was always H2 and HD slipping through. But when compared to electrolysis or kinetic isotope effect reactions it gave pretty good numbers. As for neutron scattering, we've used it to show when we've individualised nanomaterials in solution, but have used it as a tool, not specifically researched the inherent scattering effects.

Hi! I have been wondering about techniques used when making graphene. So what are the most promising looking methods mass prodising graphene? Or are there any?

Almostegnigeer

Broadly speaking there are 4 ways:

1) use scotchtape to peel individual layers off graphite (makes great graphene but is slow and gives you very small amounts)

2) Grow a single layer of carbon on a sheet of metal (called CVD) which will probably be the way we make it industrially. Makes decent graphene.

3) Put soap and graphite in a blender - quick, cheap, scalable, and easy but gives few-layered graphite, not really graphene (plus its covered in soap)

4) Boil graphite in a mix of acids to get water soluble graphene oxide, then heat up in hydrogen to remove the oxygen - Gives very heavily damaged graphene but is easy to do

from wikipedia:

Nanotori are predicted to have many unique properties, such as magnetic moments 1000 times larger than previously expected for certain specific radii.

What is your opinion on nanotori? How come this form develops these special properties and what is the correct type of torus (hole to diameter ratio) to get the most out of it?

showbro

Nanotori are a very niche material with only a handful of people reporting their synthesis in the last 20 years. So far they have mainly been of interest to molecular physicists and computational scientists who have calculated their electromagnetic properties of a defect free nanotori of known tube diameter and ring diameter. The interesting properties electronically come from quantum confinement in two scales plus some stuff about magnets I dont understand (I'm a chemist). The reason they arent so well studied is that even with nanotubes you still cant completely control the diameter (and thus electronics) of the materials, and nanotori are harder to make let alone control the synthesis.

Is graohene able to conduct electricity?

Asciencyimagination

Yes, incredibly well

Hi, there have been a lot of things in the media about electronics incorporating CNTs and Graphene, etc. But how about commerical vehicle manufacturing? I have heard of replacing carbon fibre with CNT in an article but other than that, nothing has really come up.

Pikachubro

Intrinsically, CNT composites should be stronger than carbon fibre composites, but CF research had a 100 year head start. Matching the strength has been done, but they are currently smaller scale things than entire vehicles, but the main advantages are things like making tougher materials (which CF cant do) and avoiding 'catastrophic failure' where damage builds up invisibly before the whole thing shatters. I'd also be cautious of saying replace - we're aiming to compliment CF. Fibreglass is basically just worse CF and aluminium is a load weaker than either, but we still find uses for all these materials in vehicle manufacture.