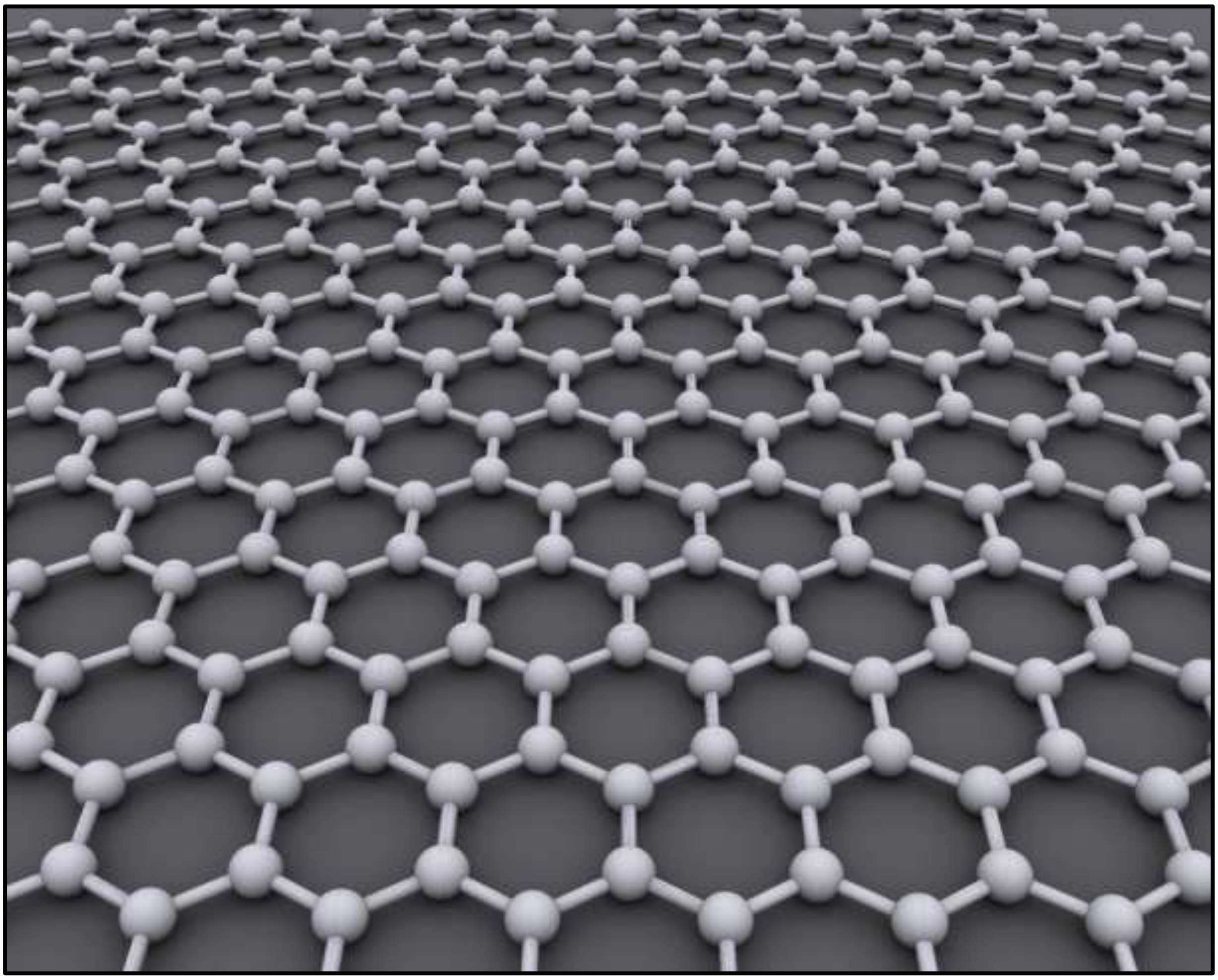
Limerick Institute of Technology Engineering Week Presentation 2019

Leaving Certificate Engineering Prescribed Topic 2019

"Basic Principles of Operation and Applications of Nanotechnology"



Presented by:

David Sims
Department of Electrical and Electronic Engineering
Limerick Institute of Technology

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1 Introduction

The National Nanotechnology Initiative describes Nanotechnology as the understanding and control of matter at the Nano scale, at dimensions between approximately 1 and 100 nanometres, where unique phenomena enable novel applications. 1 nanometre = 1 x 10-9 metres, written as 1nm, and is 0.001 of a micron (µm), or 0.000,001 of a millimetre (mm).

2 History of Nanotechnology

The idea of nanotechnology originates with the Nobel Prize winning theoretical physicist Richard Feynman. In his 1960 article, "There's Plenty of Room at the Bottom", Feynman questioned if one day we might "ultimately – in the great future – we can arrange the atoms the way we want; the very atoms, all the way down!" Feynman set two challenges for Nano scale technology, for which he awarded $1,000 each, worth approximately the equivalent of €7,500 in today's money.

The first challenge was to create a motor that could be completely contained within 0.25 cubic centimetres, this was completed the same year by William McLellan using conventional tools such as a microscope, a watchmaker's lathe and a toothpick.

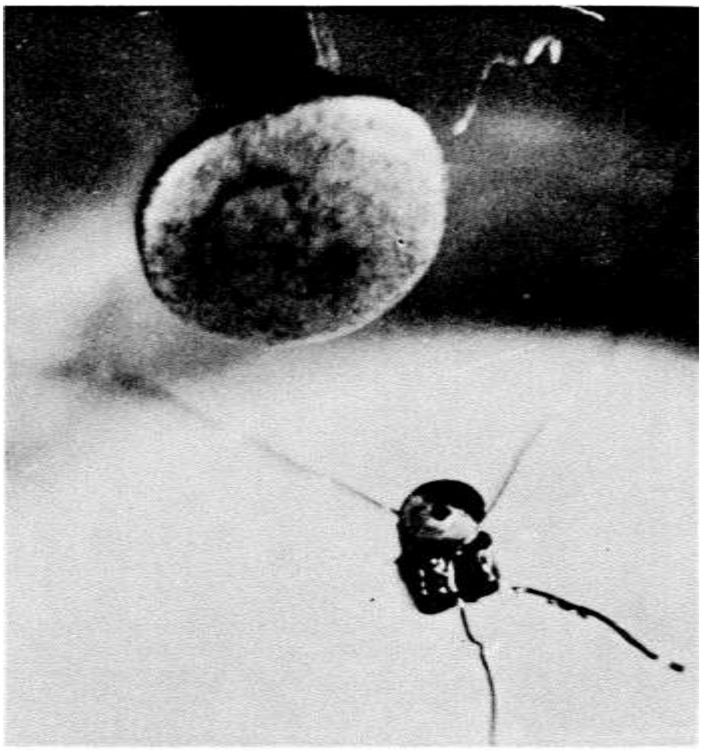

Figure 1 The McLellan Micromotor photographed under the head of a pin

The second challenge was to write text at 1:25,000 scale, small enough that it can be read by an electron microscope, which would be small enough to fit the entire 1960 edition of the Encyclopaedia Britannica on the head of a pin.

25 years later, in 1985, the second challenge was completed when Tom Newman inscribed the opening paragraph of "A Tale of Two Cities" at 1:25,000 scale.

Despite conceptualising the field, beyond a few articles published around the claiming of the prizes that Feynman issued, he had little influence on the development of nanotechnology. Future technologists would rediscover his work as they developed their own ideas.

The term Nanotechnology was coined by Japanese scientist Taniguchi Nori in 1974, but it was not used again until K. Eric Drexler independently devised the term in his 1986 book "Engines of Creation: The Coming Era of Nanotechnology."

Drexler's book, and usage of the term Nanotechnology was concerned with the idea of using Nano scale factories to manufacture materials atom by atom. In his 1992 book "Nanosystems", he mentions with regret that the term had been diluted to mean any technology operating at Nano scale. This interpretation of the term is now the overriding usage of the term Nanotechnology today.

In 1981 the scanning tunnelling microscope (STM) was invented at IBM Zurich by Gerd Binning and Heinrich Rohrer, both of whom were later awarded the Nobel Prize for Physics in 1986. This new type of imaging allowed the imaging of surfaces at atom scale, with a resolution of between 0.1 and 0.01 nanometres. They can reach magnifications of up to x500,000.

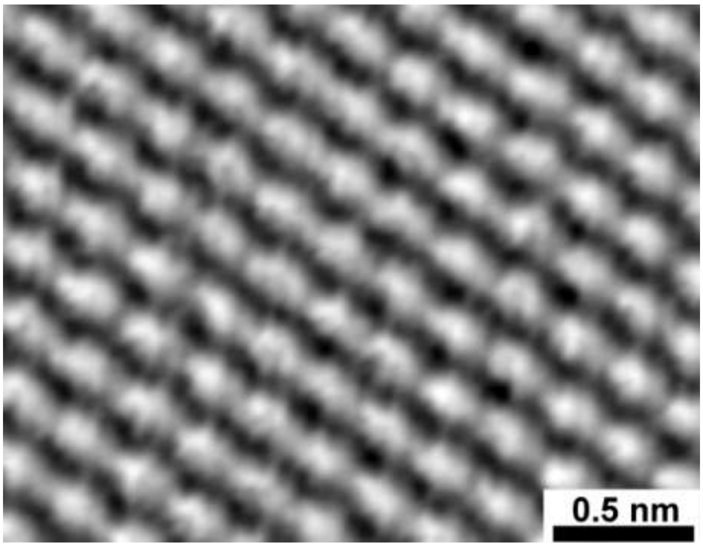

Figure 2 Image of a graphene surface at an atomic level obtained by an STM.

In 1989 IBM researcher Don Eigler was the first to manipulate atoms to spell out "IBM" using a scanning tunnelling microscope.

Graphene, the main nanotechnology material that we will discuss later, was first observed by an electron microscope in 1962. It wasn't until 2004 that the material was rediscovered by Andre Geim and Konstantin Novoselov at the University of Manchester, who won the Nobel Prize for Physics in 2010 for their work in isolating the material.

2.1 Nanotechnology in Antiquity

While deliberate uses of nanotechnology are a recent development, accidental uses have occurred several times throughout history.

While the original process of creating Damascus steel has been lost, in 2006 a research team in Germany discovered that it contained carbon nanotubes which may have contributed to the reputation that Damascus steel has for being tough and resistant to shattering. It has been proposed that the process of forging and annealing is responsible for the Nano scale structures in the steel.

The Lycurgus Cup is a cup from Roman times made of glass that contains nanoparticles of silver and gold in colloidal form which cause the glass to appear different colours depending on which direction light passes through it. The nanoparticles reflect different wavelengths of light resulting in a different colour when lit from inside the cup.

3 Visualising Nano scale

One nanometre is one billionth of a meter. One nanometre equals 10 angstroms. For comparison, the diameter of the earth is 12,742 km and one billionth of that diameter is 1.27 centimetres.

Figure 3 A marble approximately one billionth the size of the earth

Examples of Nano-scale

- A single gold atom is about a third of a nanometre in diameter
- One nanometre is the length your fingernail grows in one second
- A strand of human DNA is 2.5 nanometres in diameter
- The smallest feature size on microprocessors shipping today is 14 nanometres
- Particles of cooking oil smoke are 30 nanometres
- The size of an airborne virus particle is 50 nanometres
- The largest size particle that can fit through a surgical mask is 100 nanometres
- A human hair is approximately 80,000 to 100,000 nanometres wide
- A sheet of paper is approximately 100,000 nanometres thick

The National Center for Electron Microscopy in the US produced the following graphic that illustrates the size and scale of nanotechnology.

Figure 4 The Scale of Things

4 Graphene

Graphite is a naturally occurring form of Carbon that is widely used as a dry lubricant; a material that is solid yet reduces friction between surfaces. It is a major component in pencil 'lead' and it is one of the few non-metallic conductors. Graphite is composed of sheets of graphene. Graphene can be found as a constituent element of other allotropes (forms) of carbon, such as graphite and diamond.

Each sheet of graphene is a single atom thick two-dimensional layer of carbon atoms tightly packed in a hexagonal formation. While the bonds between the atoms in graphene are stronger than those in other carbon forms such as diamonds, graphite is soft and malleable and more flexible, i.e. a lower Young's Modulus, because the bonds take the form of a two-dimensional lattice instead of three-dimensional lattice as in diamonds. This allows the sheets of graphene to be easily separated and gives graphite its malleable property.

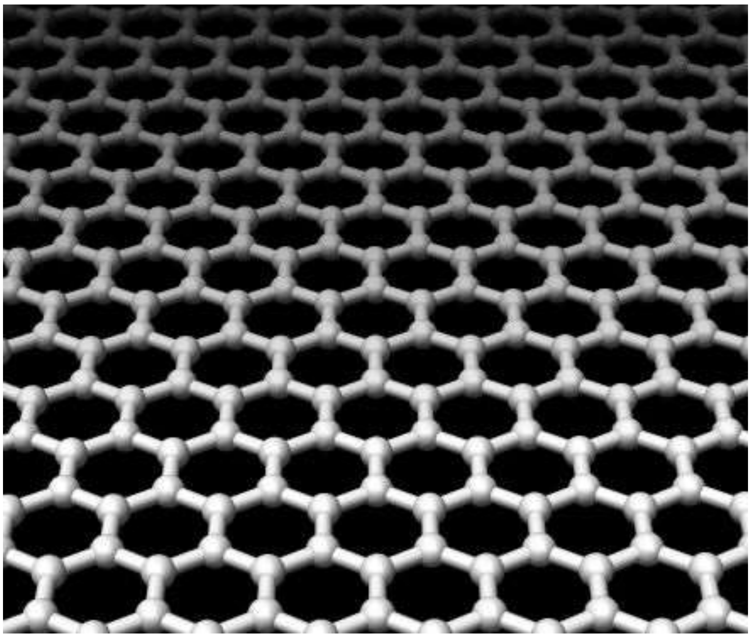

Figure 5 The Hexagonal Structure of Graphene

The strength of the covalent bond between the carbon atoms gives graphene a very high tensile strength.

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Due to the two-dimensional nature of the material each atom that comprises it is exposed on the surface of the sheet, it has no inside. The arrangements of the atoms means that they are only bonded with three other atoms, allowing a fourth bond to be completed with another substance. This makes graphene ideal for use in composite materials.

Currently graphene is difficult to produce in large quantities, which makes it incredibly expensive. Currently pure flakes of cost graphene more than gold.

4.1 Properties of Graphene

- Graphene conducts electricity better than copper, it is one of the best conductors on Earth
- It is 200 times stronger than steel but six times lighter
- It has a tensile strength of 130 GPa, the strongest material ever tested
- It is almost perfectly transparent since it only absorbs 2.3% of white light
- It impermeable to gases
- Graphene can self repair when carbon atoms are exposed to a hole in a sheet

4.2 Carbon Nanotubes

Carbon Nanotubes are a form of carbon with a cylindrical structure. They are a member of the fullerene family of atomic structures that also includes spherical Bucky balls. Nanotubes are commonly composed of single or multiple walls, each wall a seamless sheet of graphene. Multi-walled nanotubes contain concentric tubes of graphene. The chirality or angle in which the graphene is connected to form the nanotube determines its properties. You can see examples of this in Figure 6.

4.3 Properties of Carbon Nanotubes

- Carbon Nanotubes can either be metallic or semi-conducting in their behaviour depending on the chirality of the nanotube
- Due to the properties of graphene, nanotubes are extremely strong
- Nanotubes have the highest strength-to-weight ratio of any known material
- Nanotubes are capable of developing a strong magnetic field due to their sharpness

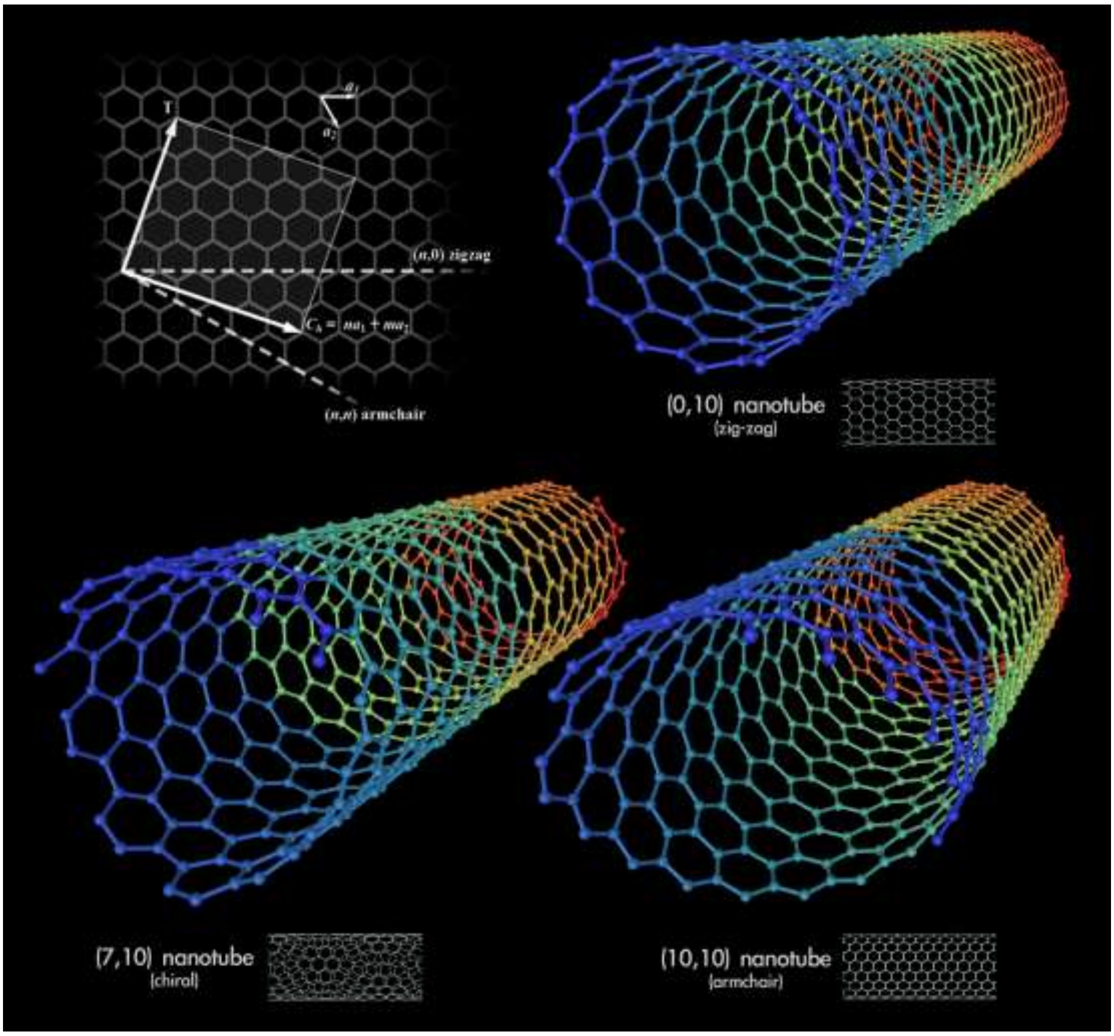

Figure 6 Types of Carbon Nanotubes

4.4 How to Make Graphene

You can replicate the work of the Nobel Prize winning physicists at home with just a few household items.

Requirements

- A sheet of paper
- A pencil
- Sellotape

Instructions

- Use the pencil to deposit a thick layer of graphite on the sheet of paper
- Use a piece of sellotape to peel a layer of graphite from the paper
- Use another piece of sellotape to peel a layer of graphite from the first piece of sellotape and repeat the process over and over with fresh sellotape each time
- Eventually you will be left with a single, almost transparent, layer of the graphite which will be graphene

5 Applications of Graphene

Since graphene is still a relatively new discovery, the limits of its applications are not yet known but the following are some of the current and most promising applications.

5.1 Graphene Filtration

Graphene has the potential to create clean drinking water. Graphene oxide membranes can create a perfect barrier for liquids and gasses. Water can only pass through a graphene membrane when the layer of water is one atom thick. It is hoped that graphene filters will be able to remove salt, chemicals and pesticides from water.

Figure 7 LifeSaver are testing graphene water filters (ft.com)

5.2 Composites

The unique properties of graphene, which we discussed earlier, make it extremely attractive material to use in combination with others. This is also one of the simplest uses of graphene as it can make compounds lighter, stronger, conductive and more flexible.

Use of graphene in aircraft has the potential to reduce their weight, making them more fuel-efficient and due to its conductivity, more resistant to lightning strikes.

Graphene is already used in sporting goods, from golf clubs to mountain bikes in order to give the composite materials some of the properties of graphene. In 2017 British Company Dassi released the first bike with a frame that contains 1% graphene, making the frame lighter, stronger and more flexible. Dassi claim that by using that small amount of graphene, they have made the frame 30% lighter.

Figure 8 Dassi Bike Frame with Graphene (dassi.com)

5.3 Energy

Due to its conductivity, graphene could be used to dramatically increase the life of Lithium-Ion batteries and even make them smaller and quicker to charge.

Huawei have created a phone battery lined with graphene that increases the maximum temperature that the battery can operate.

Electric car companies such as Tesla are heavily rumoured to be developing batteries using graphene in order to increase the range and reduce the charging time of electric vehicles.

Graphene's transparency and conductivity make it ideal for applications in the area of solar power.

5.4 Biomedical

The uses of graphene and graphene oxide in the biomedical area are still emerging but they have shown a remarkable number of properties that will prove useful in biomedical applications.

Graphene oxide has antibacterial properties and has shown biocompatibility with mammalian cells and could be used as a scaffold for growing tissue.

Researchers at Boise State University are attempting to bioengineer cartilage tissue with graphene in order to better absorb impact at the joints and to enable greater flexibility of the tissue.

5.5 Sensors

Due to the surface exposing each atom, graphene is an ideal material for the creation of sensors.

Magnetic sensors, humidity and photo detectors at micrometre scale have been built using graphene.

5.6 Electronics

Graphene is seen as the next step in increasing the miniaturisation of technology, replacing silicon as the basis for computer chips and integrated circuits.

Graphene has enabled the creation of flexible displays for mobile phones.

6 Future Applications of Nanotechnology

While Feynman's vision for molecular nanotechnology as manufacturing has yet to be realised, the first important steps have been made. Graphene will pave the way for the advancements needed to make the Nano scale factory a reality.

6.1 Nanobotics

Nanobots are the pinnacle of Nanotechnology, they will enable the Nano scale factories of the future. It is envisaged that swarms of Nano-robots or a 'utility fog' could work together to create structures of a much larger size. Nano-robots could build copies of themselves as needed to complete tasks, repair themselves and repurpose their materials when their task is complete.

At present only basic mechanisms have been recreated at Nano scale, such as an atom-sized motor and a magnetically controlled 'Nanoswimmer' that can swim through biologic fluid. It is envisaged that the nanoswimmer could eventually be used for targeted drug delivery.

6.2 Subatomic manipulation

Picotechnology (atomic scale) and Femotechnology (subatomic scale) are exciting areas for futures applications of this technology.

Alchemy, attempting to transform one element into another, such as turning lead into gold, has been an obsession of humans for millennia. This could lead to the creation of theorised elements or the creation of new elements.

7 Potential Dangers of Nanotechnology

While the hype around graphene and nanotechnology is overwhelmingly positive, there are possible dangers that are being investigated.

7.1 Nano-pollutants

Researchers at Lund University found Nanoparticles of plastic have ended up in the brains of fish, causing brain damage and altering their behaviour. Given that huge amounts of plastic end up into the oceans this is a huge cause for concern.

Nanoparticles of tattoo ink were found in the lymph nodes due to the human body trying to remove the ink particles from the body.

Experiments have shown that nanoparticles can pass the blood-brain barrier in some mammals.

Some forms of Carbon nanotubes may be as harmful as asbestos, and have been shown to cause mesothelioma in rats.

7.2 Future Risks

The increasing miniaturisation of electronics, sensors and other materials could give rise to privacy concerns. Covert surveillance using nanotechnology is a real possibility.

Nano scale weapons and bio-weapons could be developed that could be almost impossible to detect.

While still decades away from realisation, there are huge ethical concerns with the development of Nano scale robots, which encompass all of the previous risks while adding the nightmare scenario of roaming bands of renegade nano-bots, often called "Grey Goo", consuming matter of all kind and creating copies of themselves.

8 Summary

Advantages

- Nanotechnology will be used as the next generation of materials engineering, producing stronger, lighter and more flexible materials.
- Graphene has the potential to purify water and to filter harmful gasses from the air.
- Graphene can help reduce the size of electronic and mechanical components resulting in smaller devices.
- Future advancements will reduce the cost of manufacturing goods and increase their longevity.

Disadvantages

- Currently Graphene is expensive and difficult to produce in large quantities.
- Nano particles cause pollution and health risks, we don't understand the full impact yet.
- Graphene and nanotechnology may cause economic upheaval like the kind seen during the Industrial Revolution.
- Privacy and Security becoming increasingly difficult to monitor when the scale of the devices used is so small.

9 More Resources

National Nanotechnology Initiative – http://nano.gov

Understanding Nano – http://understandingnano.com

University of Manchester – https://www.graphene.manchester.ac.uk/

Wikipedia Nanotechnology – https://en.wikipedia.org/wiki/Nanotechnology

9.1 References

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Picture of the McLellan Motor, "The World's Smallest Motor", Engineering and Science. December 1960.

Cover Image, "The ideal crystalline structure of graphene is a hexagonal grid." By AndrewAIUS, CC BY-SA 3.0

A diagram showing the types of carbon nanotubes. (Created by Michael Ströck (mstroeck) on February 1, 2006. Released under the GFDL).

The Hexagonal Structure of Graphene, Public Domain, Dr Thomas Szkopek

Graphite STM Image, Public Domain, Frank Trixler

10 List of Engineering Courses in L.I.T.

Department of Electrical and Electronic Engineering:

Course	Level	Course Code	CAO Points
Craft Apprentice Programme - Electrical Trade	6	FETAC67	n/a
Electrical Engineering - Higher Certificate	6	LC272	n/a
Electrical Engineering – B.Eng.	7	LC271	241
Electronic Engineering – B.Eng.	7	LC279	221
Industrial Automation & Robotic Systems – B.Eng.	7	LC277	226
Renewable and Electrical Energy Engineering – B.Eng.	7	LC278	215
Electrical Engineering - B.Eng. (Honours)	8	LC275	284
Electronic Engineering – B.Eng. (Honours)	8	LC376	353
Industrial Automation & Robotic Systems - B.Eng. (Honours)	8	LC375	309
Renewable & Electrical Energy Engineering - B.Eng. (Honours)	8	LC374	313

Department of Mechanical and Automobile Engineering:

Course	Level	Course Code	CAO Points
Craft Apprentice Programme – Mechanical Automation & Maintenance Fitting	6	FETAC75	n/a
Craft Apprentice Programme – Motor Mechanics	6	FETAC75	n/a
Agricultural Mechanisation – Higher Certificate	6	LC284	201
Automobile Technology – Higher Certificate	6	LC281	201
Agricultural Engineering – B.Eng. (One year add on)	7	A7284	n/a
Mechanical Engineering – B.Eng.	7	LC285	240
Precision Engineering – B.Eng.	7	LC283	211
Road Transport Technology & Management – B.Eng.	7	LC286	231
Automotive Engineering & Transport Management - B.Eng. (Honours)	7	LC380	(new)
Mechanical Engineering - B.Eng. (Honours)	8	LC288	301
Precision Engineering - B.Eng. (Honours)	8	(T.B.C.)	(new)
Process & Engineering Management - B.Eng. (Honours) (One year add on)	8	A8286	n/a

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