Single Crystal Graphene: The next manufacturing frontier

We don’t often think about crystals being capable of bending without breaking, but a single crystal of graphene will be rather flexible. In the world of graphene language is important and it will help you dear InvestorIntel reader to find out why this is the case…

The current state of the art for making graphene

Commercially available graphene is available in tonne quantities. These are manufactured as platelets, nano platelets or nano sheets. They are usually sold as powders dispersions and pastes that can be used as additives in products such as rubber tyres, carbon composites and paints.

Larger sheets of graphene can be made at square centimetre scale by the chemical vapour deposition (CVD) method grown on surfaces such as solid copper and silicon. These surfaces are not completely smooth and this creates imperfections in the resulting graphene layer making it polycrystalline. This CVD graphene is essentially a batch process and not currently suitable for making the material on anything other than sample scales. Graphene sheet made by this method has been found to be suitable for flexible touchscreens, but does not have the strength needed for other uses.

So at the moment graphene can be made in very tiny pieces or as imperfect samples.

On perfection…

The size and perfection of the sheet is necessary to realise the amazing properties of graphene. Think about the metaphor

of a chain. We all know that a chain is only as strong as its weakest link. CVD graphene could not realise the promised strength of the perfect material because the defects introduce weak links across the sheet. Now imagine a chain where all the links are separate. It doesn't matter what are the properties of the individual links, it cannot be used as a chain unless the links are embedded in some glue like material. This is one of the reasons nanoplatelets are used as additives in composite materials.

Close to perfection

Perfection in graphene terms is a sheet of carbon where all the atoms are connected by bonds to form hexagons. This pattern is uninterrupted and continuous through the entire sheet, be it on the nano-scale, metre-scale or kilometre-scale. This is what scientists mean by a single crystal. In essence there is a continuous two-dimensional chain of bonds throughout the whole material.

If you think perfection is impossible, you would have been right until a few weeks ago. Researchers at Peking University in China have made single crystal graphene on copper foil that they claim is almost perfect at 99.9% alignment.

However, the graphene must be removed from the solid growth surface and this separation damages the sheet, and makes graphene by a batch process. The continuous manufacture of single crystal graphene is not quite there yet. The next step will probably be when the researchers start to perfect the growth of graphene on liquid surfaces as we outlined in a previous column entry.

So What…

Well, if you could make single crystal graphene by a

continuous process a myriad of amazing industrial products would result.

Just one example: Architects would be freed to create a whole new range of super tall skyscrapers. Elevator technology is one of the main constraints placed on the height of skyscrapers. At the time of writing the tallest building is 828m (0.8Km) high.

A layered graphene elevator tether ribbon would allow people to be carried right to the top of tall buildings in one smooth action without having to change elevators which would bring in a new age of kilometre and mile high buildings. All this is foreseeable now the manufacturing frontier has been extended into single crystal graphene technology.

Graphene manufacturing: A global lead indicator?

The world of graphene is a fast evolving place but just what is all this activity about? Looking at patents filed is one way, and the most recent analysis of worldwide patents found that there were 25,855 individual patent publications that involve graphene. But this is not the full story, read on to find out more…

Patent activity

The graphene patent analysis sounds impressive (and it is impressive) but it does not tell us everything we need to know. Patents are published some 18 months after the application date. Looking at patent activity as a predictor of the future is a bit like driving a car forward by looking in

the rear view mirror.

Scientific publications activity

Much of the work on graphene is being done by universities and associated academic institutions. A large part of the rewards system for academic researchers is the number and quality of the scientific papers they produce. So academic researchers will tend to make public their projects. Finding current work that relates to making graphene is surprisingly difficult, however people are making progress in this area.

A team funded by the University of South Australia looked at the various ways that sheet graphene could be manufactured for use in organic solar cells. This team used data up to June 2016 and found that Chemical Vapour Deposition (CVD) was the overwhelming method for making graphene in laboratory. They found that while good progress has been made, much more remains to be done to achieve low-cost high-quality manufacture of graphene. Manufacturing high quality graphene is not easy.

Lead and lag indicators

Most measures tell us what has happened. Both patent and scientific publications are by their nature reports of activity in the past. This means they are lag indicators.

What we need is a lead indicator that shows us the direction of travel of graphene manufacturing activity. Lead indicators are harder to find than their lag counterparts.

Global nanotechnology conference content as a lead indicator

To gain an insight I turned to a reliable source of information. Dr Denis Koltsov runs a UK-based consulting firm, focusing on technology and innovation, called BREC Solutions

Ltd. He keeps a close watch on developments in nanotechnology in general and graphene in particular.

One of the facets he monitors is the number of conferences that take place around the world. These are planned up to two years in advance. While the exact content becomes vague the further ahead one looks, the broad themes expressed in the conference plans are usually a good guide and this gives an insight into the work being done by graphene researchers around the world.

So, using these broad themes as a metric, what is planned ahead? According to the BREC nanotechnology Newsletter number 55, there are 107 conferences on nanotechnology that feature graphene in some way between August 2017 and March 2019.

Looking at the plans for each conference I classified the content in terms of pure research, applications for graphene, and graphene manufacturing. Some conferences have a mix of all three while others focus on just one theme, usually fundamental research. The results are revealing.

The bulk of the work being reported continues to be fundamental research into the properties of graphene. Applying graphene to solve various problems is the next most common conference theme. Actually making graphene is not being discussed to the same extent. Of the 107 conferences around the world, just four have content that can be associated with manufacturing graphene. Of these four conferences, one is in the UK, one in the USA and two are in China.

So What…

It seems that the global graphene research effort is still exploring the fundamental properties of the material, there is yet much to learn. Applications of graphene are possibly

driven by patent activity around the world by various universities hoping to make some kind of return on research investment– we will know whether this is the case when the patents are published over the next two years.

Actually making high quality sheet graphene is very hard to do and requires significant amounts of long-term, consistent, funding over years. Most funded work seems to be for much shorter-term projects. However progress is being made, as we revealed in our column last month, by the team at Peking University in China. Perhaps this will stimulate others to build on their work.

This lead indicator reveals we have to wait some time to see global conferences dedicated to the manufacturing of graphene. When this starts to happen we will know that graphene has grown from its teenage years and come of age to fulfil the world changing promise of this wonder material.