

Graphene for healthcare



Graphene for healthcare

By

Del Stark and Jon Evans

© Del Stark Technology Solutions and JE Science Ltd, March 2014

All rights reserved: no part of this publication may be reproduced or transmitted in any form or by any means, electronic, mechanical, photocopying, recording, or otherwise without the prior written permission of the Publisher. This report may not be lent, resold, hired out or otherwise disposed of by way of trade in any form of binding or cover other than that in which it is published, without the prior consent of the Publisher. While all reasonable steps have been taken to ensure that the data presented are accurate, Del Stark Technology Solutions and JE Science Ltd cannot accept responsibility for error or omissions.

Executive summary

This technical briefing details the latest research and development activities being conducted into the healthcare applications of the single atom-thick sheets of carbon known as graphene. The briefing contains a list of all the journal papers published in 2013 and the beginning of 2014 reporting healthcare applications of graphene, including links to the online paper abstract and the website of the lead author or the main department, institute or university they are affiliated with. It also provides a list of all the graphene patents filed over the past couple of years that mention healthcare applications, together with links to the online patent abstract and the website of the main applicant.

At the moment, the majority of this research and development is being conducted by Asian-led teams, providing 56% of the journal papers and conference presentations profiled in this briefing and an astonishing 81% of the patent applications. China is the single most prolific country, with Chinese-led teams providing 39% of the journal papers and 66% of the patent applications. Other countries heavily involved in researching the healthcare applications of graphene include the US and South Korea.

This research is mainly at an early stage, as evidenced by the biocompatibility of graphene-based materials still being a major research topic and many of the healthcare applications detailed in the patents being purely speculative. The precise level of toxicity posed by graphene to human cells and tissues is still unclear, with different studies producing contradictory findings. There is, however, a growing understanding that the biocompatibility of graphene depends on a whole host of different factors. These include the size and structure of the graphene-based materials, which can include pristine graphene, graphene oxide, graphene hydrogels and graphene quantum dots, as well as whether and how their surfaces are chemically modified and even the type of cells they interact with.

The healthcare applications currently attracting most research interest are drug delivery, accounting for 31% of the journal papers and taking advantage of graphene's huge surface area, and biosensors, accounting for 20% of the journal papers and taking advantage of



graphene's impressive electrical properties. Nevertheless, scientists are also exploring a wide variety of other healthcare applications, including providing scaffolds for cell growth, enhancing blood circulation in the brain and preventing blood clotting around medical implants, driven by graphene's full suite of impressive physical properties.

Graphene-based biosensors are furthest along the path to commercial development, being the subject of 38% of the patents, whereas drug delivery is the subject of just 16%. Many of the scientists interviewed for this briefing, all of whom are actively conducting research into the healthcare applications of graphene, also believe that biosensors will most likely be the first commercialized application. This is because most graphene-based biosensors are designed to detect biomolecules in samples of bodily fluid such as blood and urine. As these biosensors don't need to enter the body, the potential cellular toxicity of graphene is not an issue.

The interviewed scientists believe that graphene-based materials offer a great deal of potential for the healthcare sector, although probably mainly in the long term. Questions over the biocompatibility of graphene-based materials will need to be resolved before they can be utilized for applications inside the body, but current research does suggest several ways for reducing the toxicity of these materials.



Contents

Executive summary	1
Contents	3
Introduction	5
Expert view: Gil Gonçalves	8
Research	11
___ Biocompatibility	11
___ Biomedical devices.....	15
___ Biosensors.....	15
___ Cancer therapy.....	20
___ Clinical applications.....	22
___ Contrast agents.....	24
___ Drug delivery.....	24
___ Scaffolds	30
___ Other industrial applications	33
Research analysis	34
Expert view: Manzoor Koyakutty.....	41
Patents.....	43
___ Biocompatibility	43
___ Biomedical	43



_____ Biosensors.....	60
_____ Cancer.....	76
_____ Drug delivery.....	82
_____ Tissue engineering	88
Expert View: Elena Polyakova.....	92
Commercial analysis.....	94
Expert View: Gregory Burwell.....	99

