GC Antiviral / Viricidal Graphene Inks

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Forward by the Data Science Foundation

This paper is being published to support the work Graphene Composites is doing to develop coronavirus-killing graphene materials. It is not a data science paper but a request for support from the data science community. The following message was received, and we decided to publish the message and the supporting paper and invite you to contact Sandy Chen at Graphene Composites if you can help

The Request:

I am writing to inform you that we have been urgently working on a graphene ink that can be applied to fabrics including N95 face masks and other personal protective equipment (PPE). The key difference is that whereas most PPE traps or filters bacteria and viruses, this graphene ink-treated PPE should kill them – providing significantly increased protection against coronavirus.

Once we have developed and tested this coronavirus-killing graphene ink technology, we will work with existing manufacturers to integrate it into masks and other PPE. **We ask you, our investors, to please get in touch if you know of any organisation that might be able to join us in fighting this pandemic - by emailing me at sandy.chen@graphenecomposites.com.** A leading US Ivy League university has joined our team, and we are in discussions with leading local and federal authorities in the US – we would like to generate similar momentum in the UK and Europe.

If you are interested, we can send you a white paper that outlines how the graphene ink would work and how it would be developed and deployed. To be clear, this white paper is not a confidential document, so please feel free to pass it onto anyone who might be able to help.

We regard this coronavirus pandemic as the defining crisis of our lifetimes. To paraphrase the Greek playwright Aeschylus, it is in times of crisis that we realise that the fabric of civilisation is woven thin. In this crisis, we – GC and our partners – will work as one to strengthen this social fabric.

The Whitepaper:

Summary

Although existing personal protective equipment (PPE) can filter out 95% of harmful bacteria and viruses, few can actually kill coronaviruses in particular. Research has shown that combining graphene oxide (GO) with known antivirals significantly enhances their virus-killing performance.

Graphene Composites (GC) is a leader in graphene and other nanomaterials technologies. Adapting an existing graphene ink project, we would seek to produce antiviral graphene inks that would be applied to fabrics to not only filter or trap coronaviruses – but to kill them.

These antiviral (and potentially viricidal) graphene ink-treated fabrics could be used in masks, other personal protective equipment (PPE) and hospital field tents.

We would work with existing PPE manufacturers to incorporate antiviral graphene inks into their products. We would aim to have preliminary batches available for testing within three months – with a path to large-scale production within months.

Antiviral/viricidal graphene inks in PPE

Producing antiviral graphene inks for fabrics

Our end-product goals are masks and other PPE that have the ability to kill viruses and bacteria as the users (doctors, nurses) breathe. This will require a consistent, extremely effective fabric layer (or layers) that is also breathable.

This will most likely require a relatively low concentration of graphene/GO with high loadings of anti-virals. This combination should be able to achieve a high degree of anti-viral performance in a cost-effective and scaleable way.

A potentially attractive fabric is cellulose (e.g. paper or cotton) – particularly because of its ease and low cost of manufacture. A graphene-based antibacterial paper has been developed that could provide the template for this materials process ("Graphene-Based Antibacterial Paper" by Hu, Peng et alia).

Working with existing PPE manufacturers

We will work with any manufacturers of PPE to incorporate our antiviral/viricidal graphene/GO inks into their existing production processes. The aim is to deliver significantly higher performance – aiming to not just filter and capture the coronavirus, but to kill it.

Project plan

1. **Adapt existing project**

   GC have an existing project in graphene/GO fabric inks, developed in conjunction with Brown University in the US and the UK Centre for Process Innovation. We would re-purpose this project to focus on developing a graphene/GO anti-viral ink – working closely with Brown University and other partners.

2. **Develop and test antiviral/viricidal graphene inks**

   GC and its partners would produce sample batches of graphene/GO/antiviral inks, and then test them against the Covid-19 coronavirus and other viruses.

3. **Incorporate into existing PPE production process**

   GC's Production and Quality Manager is highly experienced in ISO 9001 and other quality control processes. GC would work closely with PPE manufacturers to incorporate the antiviral graphene/GO fabric inks into their manufacturing processes.

4. **Full-scale production**

   GC personnel have decades of experience in scaling up nanomaterials technologies from R&D into full-scale production.

Background: Graphene oxide and antivirals/viricidals

Graphene and graphene oxide

Research studies have shown that the two-dimensional structures, sharp edges, and negatively-charged surfaces of graphene oxide (GO) can kill bacteria and viruses by disrupting their plasma membrane (for bacteria) and/or by oxidising them ("Antibacterial Activity of Graphite, Graphite Oxide, Graphene Oxide, and Reduced Graphene Oxide: Membrane and Oxidative Stress" by Liu, Zeng et alia).

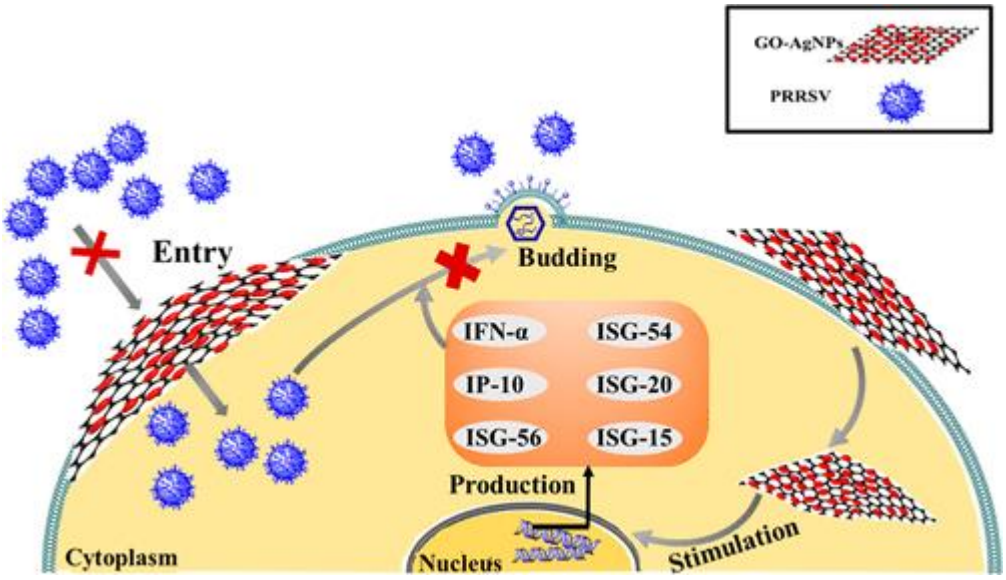
In addition, the high surface areas of graphene and graphene oxide enable them to be loaded with high levels of antiviral agents – making them ideal drug carriers. And crucially, the combination of graphene/GO and antiviral agents has been shown to both increase their antiviral performance as well as reduce their toxicity – enabling significantly higher antiviral performance ("Synergistic antiviral effect of curcumin functionalized graphene oxide against respiratory syncytial virus infection" by Yang, Li et alia, 2017).

GC's aim is to develop graphene/GO inks that are loaded with these anti-virals, with the main goal being to use the antiviral combination that is most effective against coronavirus. These inks would then be applied to fabrics that would then be used in masks, other PPE and field hospital tents.

Specific graphene/GO and anti-viral/viricidal combinations are detailed below.

Graphene oxide and silver nanoparticles

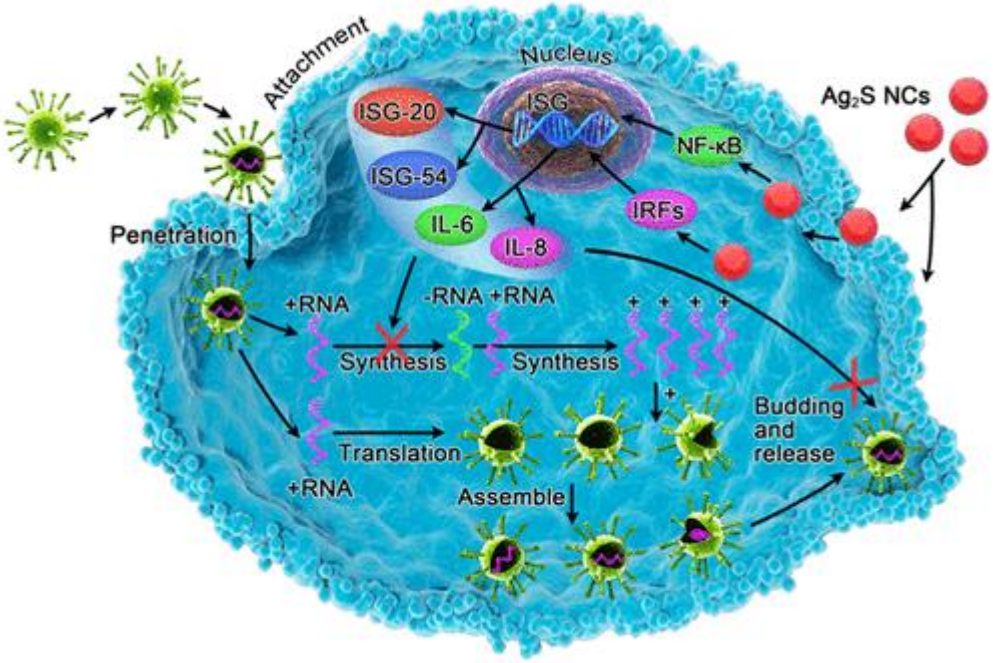
(Abstract from "Antiviral Activity of Graphene Oxide–Silver Nanocomposites by Preventing Viral Entry and Activation of the Antiviral Innate Immune Response" by Du, Lu, Liu et alia)



"Developing nanomaterials-based antimicrobial agents has shown a widespread promise. In this study, silver nanoparticle-modified graphene oxide (GO-AgNPs) nanocomposites were self-assembled via interfacial electrostatic force. By using the porcine reproductive and respiratory syndrome virus (PRRSV)

as a pattern, the antiviral effect of the as-prepared GO-AgNPs nanocomposites on the replication of virus was investigated. The results indicated that exposure with GO-AgNPs nanocomposites could obviously suppress PRRSV infection. It was found that GO-AgNPs nanocomposites exhibited a better inhibitory effect compared with AgNPs and GO. By selecting the porcine epidemic diarrhea virus (PEDV) as a contrast virus, GO-AgNPs nanocomposites were proven to have a broad antiviral activity. Mechanism studies showed that GO-AgNPs nanocomposites might prevent PRRSV from entering the host cells, with 59.2% inhibition efficiency. Meanwhile, GO-AgNPs nanocomposite treatment enhances the production of interferon-α (IFN-α) and IFN-stimulating genes (ISGs), which can directly inhibit the proliferation of virus. Taken together, this study reports a new type of antiviral agent and provides a promising pharmaceutical agent for treating infection by the highly pathogenic PRRSV. Moreover, it may provide novel ideas for the research and development of antiviral formulations based on nanocomposites and extend their applications in biological systems."

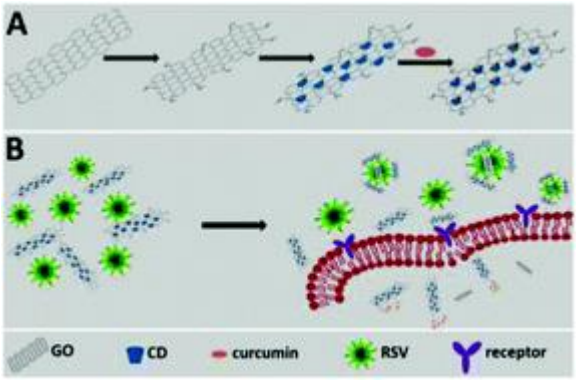
(Abstract from "Glutathione-Capped Ag2S Nanoclusters Inhibit Coronavirus Proliferation through Blockage of Viral RNA Synthesis and Budding" by Du, Liang et alia)



"Development of novel antiviral reagents is of great importance for the control of virus spread. Here, Ag2S nanoclusters (NCs) were proved for the first time to possess highly efficient antiviral activity by using porcine epidemic diarrhea virus (PEDV) as a model of coronavirus. Analyses of virus titers showed that Ag2S NCs significantly suppressed the infection of PEDV by about 3 orders of magnitude at the noncytotoxic concentration at 12 h postinfection, which was further confirmed by the expression of viral proteins. Mechanism investigations indicated that Ag2S NCs treatment inhibits the synthesis of viral negative-strand RNA and viral budding. Ag2S NCs treatment was also found to positively regulate the generation of IFN-stimulating genes (ISGs) and the expression of proinflammation cytokines, which might prevent PEDV infection. This study suggests the novel underlying of Ag2S NCs as a promising therapeutic drug for coronavirus."

Curcumin functionalised graphene oxide

(Abstract of paper: “Synergistic antiviral effect of curcumin functionalized graphene oxide against respiratory syncytial virus infection” by Yang, Li et alia, 2017)



“The respiratory syncytial virus (RSV), which is considered as the major viral pathogen of the lower respiratory tract of infants, has been implicated in severe lung disease. In this contribution, we developed a β-cyclodextrin (CD) functionalized graphene oxide (GO) composite, which displayed excellent antiviral activity and could load curcumin efficiently. RSV, a negative-sense single-stranded enveloped RNA virus, was employed as a model virus to investigate the antiviral activity of multifunctional GO. Proved by the tissue culture infectious dose assay and immunofluorescence assay, the curcumin loaded functional GO was confirmed with highly efficient inhibition for RSV infection and great biocompatibility to the host cells. The results showed that the composite could prevent RSV from infecting the host cells by directly inactivating the virus and inhibiting the viral attachment, and possessed prophylactic and therapeutic effects towards the virus. Our data indicate that the composite may provide new insights into antiviral therapy for RSV infection.”

Hypericin-loaded graphene oxide

(Abstract from “Hypericin-loaded graphene oxide protects ducks against a novel duck reovirus” by Du, Xiao, Fu et alia, 2019)

“Novel duck reovirus (NDRV) disease is a serious infectious disease for poultry, for which no effective therapy has been established. Therefore, development of novel antivirals against NDRV is urgently needed. In present study, we developed a complex wherein hypericin (HY), which shows broad-spectrum antiviral activity, was loaded onto graphene oxide (GO), which has a high drug-loading capacity and low cytotoxicity. The antiviral activity of the complex (GO/HY) was studied in DF-1 cells and in ducklings infected with the NDRV TH11 strain. GO/HY showed a dose-dependent inhibition of NDRV replication, which may be attributed to direct virus inactivation or inhibition of virus attachment. Western blotting and indirect immunofluorescence assay (IFA) showed markedly suppressed protein expression in GO/HY-treated NDRV-infected DF-1 cells. Moreover, GO/HY prolonged the survival time of the ducklings by reducing pathological lesions caused by the infection and inhibiting viral replication in the liver and lungs. These results suggest that GO/HY has antiviral activity against NDRV both in vitro and in vivo.”

Graphene Composites and graphene inks

Graphene functionalisation

In order for graphene and graphene oxide to disperse in inks (instead of clumping together), it is necessary to functionalise them, i.e. attach chemical hooks to the edges and/or surfaces.

GC and its key personnel and partners have decades of experience in graphene/GO functionalisation. Prior to joining GC, the GC Chief Technology Officer was Principal Scientist in the Graphene Application Centre and National Formulation Centre at the UK Centre for Process Innovation (CPI), which is a part of the UK Government's High Value Manufacturing Catapult network. CPI is both a partner and an investor in GC.

Producing graphene inks

The graphene/GO inks would be produced by dispersing graphene or GO in a solution of either alcohol or water at a specific concentration that is designed leave a thin layer of nano-sheets that are aligned (or mis-aligned if needed) in a specific pattern according to the requirements of the specific antiviral agent.

The production process involves graphene/GO functionalisation in a plasma reactor, and then attaching/loading the anti-viral onto the surfaces and/or edges of the nano-sheets of graphene/GO.

There is also a milling process, whereby the treated graphene/GO sheets are dispersed and aligned (or misaligned) so that the materials performance is consistent and effective.

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