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"TECHNOLOGY, TRADE, AND MILITARY-CIVIL FUSION: CHINA'S PURSUIT OF ARTIFICIAL INTELLIGENCE, NEW MATERIALS, AND NEW ENERGY"

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Vice Chairman Cleveland, Commissioner Lee, and Members of the Commission, thank you for the opportunity to appear before you today to discuss the two-dimensional material, graphene, and China's efforts to establish dominance in this space.

The National Graphene Association (NGA) is the sole trade association in the U.S. advocating for the commercialization of graphene. With twenty corporate partners and over two thousand members, NGA is expediting the commercialization of graphene through an ecosystem that spans industry, academia, national and international standards bodies, and federal policymakers. Most recently, the NGA held a high-level two-day summit here in Washington, D.C., with Senator Roger Wicker (R-MS), Chairman of the Senate Committee on Commerce, Science, and Transportation, supporting the summit and providing the opening keynote on the second day. This was the first conference where industry, academia, and government were all represented and discussed the imperative need for U.S. leadership in graphene commercialization.

Graphene Overview

Though graphene is generating a lot of excitement and attention presently, the existence of this material has been known to the scientific community for over 70 years. However, it was not until 2004, when graphene was first isolated by researchers from the University of Manchester, that its true significance was discovered. So, what is graphene? It is a two-dimensional, single atomic layer of carbon and is the thinnest and strongest material ever discovered. In fact, graphene's properties were considered so revolutionary upon its isolation, that the two research scientists, Konstantin Novoselov and Andre Geim, were awarded the Nobel Prize in Physics six years later. Below are some of the key properties identified:

- 200 times stronger than steel;
- Conducts electricity better than copper;
- Transparent – allowing 97.3% of light to pass through;
- Flexible – stretching up to 25% of its length;
- Conducts heat better than any other metal;

Though graphene's discovery was revolutionary, the process used to isolate graphene was relatively simple in its execution. The researchers used flakes of graphite (the same material used in pencils) and sticky tape to isolate graphene. The sticky tape was placed on the graphite, peeled off and then applied to a separate surface. Tape was reapplied to the remaining graphite, and the process repeated until a single layer of graphene was all that remained. A great visual for understanding this is to think of a deck of playing cards. The full deck represents the graphite and each card represents a single layer. Peel off each card (or layer) until the bottom card representing the single, atomic, layer is all that remains. This process is a form of exfoliation and it produces the most artisanal form of graphene; yet it is also the most uneconomical process for making graphene commercially.

There are two primary forms of graphene – graphene film and graphene powder. Graphene film is suitable for high tech sensors, electronics and photonic and photovoltaic devices while graphene powders are suitable for composites and other applications where graphene powders are used as structural additives. For commercial production, there are two primary methods to make graphene – exfoliation, the process originally used to isolate graphene, and chemical vapor deposition (CVD). These processes are referred to as "top down" and "bottom up" methods. Exfoliation (top down) is the predominant method used to produce graphene. The process starts with bulk graphite, breaking it down until you get nanoplates, which are small pieces of graphene. However, instead of using sticky tape as the Nobel Prize researchers did, the top down process uses electrochemical exfoliation, high pressure milling, or incorporating oxidizing agents to make graphene.

CVD (bottom up) uses a gas (i.e.; methane) that contains carbon. The gas is super-heated to nearly 1,000 degrees and blown over a metal surface, usually copper. This process aids in separating the carbon and hydrogen in the gas allowing the carbon to settle onto the metal. Interestingly, as the carbon settles onto the copper, it begins assembling atom-by-atom to form a layer of graphene. Once the metal is covered, the chemical reaction ceases. CVD is the method used to produce graphene film for use in electronic devices. The difficulty with CVD, in the past at least, has been scaling the process in a manner to make it cost effective for the end-user. However, scalability is becoming less of an obstacle than it once was given technological advances in the manufacturing process.

Potential Graphene Applications

Energy

Graphene-enhanced lithium-ion batteries are shown to have superior performance, increased output, longer lifecycles, and greater operating tolerance at higher temperatures than "plain" lithium-ion batteries. Graphene-based supercapacitors offer energy storage at higher levels and can hold hundreds of times the amount of electrical charge as standard capacitors, providing a suitable replacement for electrochemical batteries in many industrial and commercial applications. Graphene's superior conductivity also makes it a feasible candidate as an alternative to the rare and expensive cadmium telluride typically required for photovoltaic panels.

Water Desalination

Graphene membranes have proven to be quite effective in desalination of seawater, with commercial products on the market showing promise to produce safe drinking water with less energy than the reverse-osmosis technique currently used to treat seawater.

Automotive

Graphene's use in automotive applications gained prominence in 2018 when XG Sciences announced that its collaboration with Ford Motor Company had yielded graphene enhanced polyurethane foam parts. The addition of graphene resulted in improvements in noise reduction, heat endurance, and strength of these parts. Graphene is also showing the potential to reduce the weight and increase the strength of automotive composites and tires.

Communications

Samsung is currently investigating the use of graphene for handset batteries. In addition, Huawei is currently using graphene as part of the cooling system for the newest version of its "Honor" handset line.

Infrastructure

Graphene is showing significant promise in the both concrete and asphalt. Data consistently shows that a small addition of graphene can reduce the weight, increase the strength, and increase the overall life of roads and other critical infrastructure.

Aerospace

Graphene's properties are showing unique applicability for composite parts, fire retardant technologies for aircraft interiors, and conductive coatings to provide better protection against lightning strikes. Furthermore, graphene is showing promise in space applications such as using a solar sail as a propulsion system.

Coatings

Graphene can improve the anti-corrosion properties of coatings by a factor of five. Of its many properties discussed previously, graphene is also impermeable, lending a significant benefit to coatings used in harsh environments. This is particularly important for the maritime industry. Moreover, conductive ink has been developed using graphene that allows for the creation of electronic circuits on a variety of surfaces.

Sensors

Graphene-based sensors can be used to detect gas and other biological agents as well as explosives. Its heat and conductive properties can be used in coatings to detect changes in temperature and wirelessly submit those changes to a handheld receiver. Biomedically, graphene can be used to detect changes in the human body.

Apparel and Sporting Goods

Many retail graphene enhanced products have surfaced over the past 18 months. Callaway Golf balls, Head tennis rackets, Inov8 running shoes, Anker wireless earbuds are but a few. Great Britain even used a graphene-enhanced sled for the Skeleton event in the 2018 Winter Olympics.

This is not an exhaustive list of potential applications, but only a sampling of what is currently being investigated and commercially developed. Given graphene's unique properties, its ability to impact nearly every sector of the economy cannot be understated.

Global Focus on Graphene

The realization and proof of existence of the first truly two-dimensional material launched one of the fastest paced research topics in history. The resulting massive global investment in graphene research has established an extensive base of knowledge and a large intellectual property and patent pool for this material and its myriad applications. In fact, since its discovery in 2004 and subsequent Nobel Prize award in 2010, graphene has advanced from initial discovery to commercial development at a tremendous rate.

This rate of progress in the graphene industry is nothing short of astonishing. In December of 2018, a team of researchers published an extensive analysis of patents filed in the field of graphene providing evidence of how quickly this field is advancing and which country is leading. The research team determined that over 50,000 patents have been filed in the graphene field, with over half of those patents filed in the last three years (2015-2017).[1] While the U.S. holds just over 6,000 patents in graphene, it is China that dominates the field with 32,142 patents - over 60% of total patents filed. South Korea is second with just over 7,000 patents. It is worth noting, however, that the U.S. and South Korea are believed to hold more "high-value" patents with leading companies such as IBM, Lockheed Martin, and Samsung holding a number of these patents.[2] The researchers also point to a number of other key factors in the patent analysis. First, the U.S. and Japanese patents are mainly held by companies while China and Korea patents are tied more to "universities or research institutes". Second, when looking at the various stages of a technology (emerging, growth, maturity, saturation), the analysis points to China with a distinct advantage among the top 20 patentees in the growth stage of graphene.[3]

Though the U.S. has invested substantially in understanding the fundamental science of graphene and supporting academic research - many government agencies (National Science Foundation, Department of Energy, Department of Defense, National Institute of Standards and Technology, and many others) have developed an extensive base of scientific knowledge - the path from the laboratory to developing viable commercial products is not as well coordinated nor developed in the U.S. with some criticism pointing to siloed efforts in research and development and a lack of

[1] Yang, X., Yu, X., Liu, X., (2018) Obtaining a Sustainable Competitive Advantage from Patent Information: A Patent Analysis of the Graphene Industry. Sustainability 2018, 10, 4800.
[2] Ibid.
[3] Ibid.pp 16-17.

general information on what the U.S. is really doing commercially.[4] Furthermore, there is no high level U.S. government policy on the strategic and economic importance of building and supporting a stable U.S. graphene industry.

In contrast, the U.K. and Europe have undertaken significant steps to transition graphene from the lab to commercialization. In 2013, the United Kingdom and European Union's European Regional Development Fund provided £61 Million to create a National Graphene Institute (NGI). That same year, the European Commission allocated €1 billion to develop the Graphene Flagship, the E.U.'s biggest research initiative designed to take graphene from the lab into European industries and generate economic growth through commercialization of graphene. Furthermore, the United Kingdom recently dedicated another facility called the Graphene Engineering and Innovation Center (GEIC) to "rapidly accelerate the development and commercialisation of new graphene technologies."

China's Focus on Graphene

China's interest in graphene is well known. In 2015, President Xi Jinping visited the National Graphene Institute as part of his state visit to the U.K. while Huawei had previously entered into a partnership with the NGI to conduct additional graphene research.[5] Graphene is also specifically mentioned in China's 13th Five-Year plan (2016-2020) as part of its goal to develop strategic emerging industries. Finally, in 2018, China formally established the Beijing Graphene Research Institute which will focus on "technological research and industrialization".[6]

China's progress in graphene is equally as astonishing as the development of the graphene industry itself. As previously mentioned, China holds just over 60% of all patents filed in the graphene field. The number of Chinese companies focused on graphene is estimated to be in the thousands. Furthermore, a large body of published graphene research continues to grow year over year with Chinese researchers dominating the amount of global publications in the graphene space – garnering 44% of world-wide publications between 2012 – 2015.[7]

An ongoing concern in examining China's pursuit of advanced materials like graphene is the issue of dual-use – that a technology or application will have military as well as civilian uses. For graphene, the immediate identification of specific dual-use technologies is not as easily recognized. Nearly every potential commercial application that has been identified for graphene's use can be easily translated to potential military applications as well. Anti-corrosion coatings could be used on naval vessels. Composite armor could be made lighter and stronger with the addition of graphene. Graphene based inks that allow for electronic circuits could be

[4] It wasn't until Ford announced in 2018 that it had collaborated with XG Sciences on graphene enhanced polyurethane foam parts that graphene's commercial viability became "real".

[5] https://www.manchester.ac.uk/discover/news/chinas-president-xi-jinping-visits-the-national-graphene-institute/

[6] http://www.chinadaily.com.cn/m/beijing/zhongguancun/2018-10/30/content_37173414.htm

[7] Shapira, P., Gök, A., Yazdi, F. (2015) Graphene Research and Enterprise: Mapping Innovation and Business Growth in a Strategic Emerging Technology

imbedded in battlefield clothing as antenna for communications or flexible sensors that could detect the presence of biological or chemical agents.

The difficulty in easily identifying graphene technologies in terms of dual-use is not unique. Commercial technologies are advancing at such a rapid pace and scale that the line between civilian and military use is no longer easily identified. There is a reason why the Defense Department created its Defense Innovation Unit to work with commercial industries in identifying new technologies for military purposes. Europe has shown concern regarding dual-uses of graphene and in 2017, the European Defence Agency commissioned a study to determine potential dual-use graphene-based technologies. The areas identified for study are the same areas where graphene has significant commercial possibilities such as "sensors, biomedical, filters/membranes, optoelectronic devices, energy, and camouflage/signature management." The first working group meeting for EDA's study was held in May 2018.[8]

It is clear, at least in media coverage, that China is touting graphene's use for defense purposes. In 2016, it was reported that China was testing graphene for armor and bullet proof vests. Just last year, reports surfaced with graphene touted as a significant part of the armor for China's new attack helicopter.[9] While it is possible the reports may exaggerate what role graphene is playing in a particular weapons platform, the likelihood is that it is being used for weight reduction and/or an increase in strength of the armor material. But it does beg the question of strategic priorities – is the U.S. focused more on retail applications of graphene while China is focused on defense applications?

As far as distinct commercial products, one product, in particular, stands out in the area of coatings. The Sixth Element (Changzhou) Materials Technology Co used its graphene-zinc anti-corrosion paint "to cover several bridges and wind-turbines steel towers." The significance is described in the use of graphene – "adding 1% of graphene, one could reduce the zinc content in current anti-corrosion coatings from ~80% to 25%, and the corrosion protection time is doubled."[10] The Sixth Element is also the same company supplying the graphene for Huawei's handset technologies.

Chinese companies are also actively engaging in commercial collaborations with institutions like the National Graphene Institute or with foreign graphene companies directly. For instance, U.K. based graphene company, Versarien, has entered into two separate collaboration agreements with unnamed Chinese aerospace companies. The Chinese government is also offering monetary support to encourage municipalities and provinces to create graphene cities or industrial parks and identify foreign companies or researchers to relocate or create a graphene-based startup in these areas. Chinese companies, individual investors, and financial holding companies are

[8] https://www.eda.europa.eu/info-hub/press-centre/latest-news/2018/05/29/work-starts-on-graphene-roadmap-in-defence

[9] http://www.defense-aerospace.com/articles-view/release/3/196658/china-adds-graphene-armor-to-z_10-attack-helicopter.html

[10] https://www.graphene-info.com/graphene-enhanced-anti-corrosion-system-deployed-bridges-and-wind-power-towers-across-china

actively pursuing U.S. and other foreign graphene companies and scientists offering millions of dollars and state of the art facilities to relocate or establish graphene manufacturing facilities in China. One significant result of these directed efforts by China is a reduction in the talent pool available in the U.S.

Dr. James Tour of Rice University, one of the top experts in graphene, has testified before Congress and has recently spoken at NGA's American Graphene Summit, about the real threat of losing the next generation of great scientific minds to China and other countries that are able to provide funding and resources to support continued work in this field. He spoke of a "brain drain" in the U.S. – some of best and brightest research minds choosing to go back to their home country. And he contributes this exodus to the limited amount of funding for the younger researchers. For example, Dr. Tour stated that he used to have 1 out of every 3 proposals funded. Today, the figure is about 1 in 10. If a senior research scientist is facing such reductions, the younger researchers are facing as much as 1 in 20 proposals that may receive funding. The last comment Dr. Tour made is he expects that in less than 10 years, U.S. students will choose to go to China for graduate school.

Dr. Tour's remarks are indicative of the potential problem the U.S. would have in gaining a leadership role in the commercialization of graphene. If the best and brightest research minds are, indeed, leaving the U.S. for other countries – that knowledge translates directly into commercialization efforts. I have had some personal conversations with young researchers, two of whom are studying here in Northern Virginia and are doing some interesting work in the sensors space. They're U.S. students and are eager to move their research to commercial application here in the U.S. The ultimate question from Dr. Tour's perspective is – will there be any funding for them?

Lastly, China maintains significant domestic graphite resources providing a competitive advantage in the development of its own graphene and graphene-based applications. According to the U.S. Geological Survey, in 2018, China produced 70% of the world's graphite and between 2014 and 2017, China accounted for 37% of U.S. graphite imports. In contrast, the U.S. produced no graphite and North America (Canada and Mexico) only accounted for 5% of the world's graphite production in 2018.[11] In examining China's rapid growth in graphene patents, its large domestic graphite supply clearly provides Chinese companies and researcher institutes greater opportunities for new advances and developments – especially as exfoliation from graphite remains the most common form of producing graphene. As the U.S. graphene market continues to develop, the requirements for graphene powder will naturally increase resulting in continued commercial dependency on imports of graphite from foreign sources. It is not difficult to imagine that the percentage of graphite imported from China would increase.

A China that possesses a significant lead in graphene patents, dominates the supply and production of the critical source material necessary to produce graphene, and actively attempts to

[11] https://www.usgs.gov/centers/nmic/graphite-statistics-and-information

procure the best foreign minds in graphene science, should pose a serious concern to U.S. policymakers.

The real obstacle to the advancement of graphene in the United States is a lack of coordinated focus from the U.S. government and a dedicated infrastructure that allows for the integration of graphene into already existing technologies and industries. There are many companies in the United States (and worldwide) that can manufacture graphene raw material by the ton annually. Price and scale of production are no longer impeding factors for the use and advancement of graphene. However, there is a dire need for technology transfer assets to support market entry for both small businesses and corporations.

Recommendations:

The U.S. government must adopt a grand strategy for graphene commercialization - a large-scale integrative and collaborative effort amongst industry, academia, and government to support and accelerate commercialization of graphene in the U.S. This will require the development of, and sufficient funding for, a commercialization program similar to what the U.K. and EU have undertaken. It is an effort that will require conjoined work and parallel efforts to develop international standards, best practices, assessment of environmental and safety studies, development of a national commercialization roadmap, and dedicated outreach efforts with large U.S. end-user industries to foster acceptance and industrial use of graphene.

A critical component of this strategy will be support for emerging companies focused on graphene production. Most U.S. graphene companies are startups, or very small businesses, with insufficient resources compared to their international competitors who are subsidized by their respective governments. A comprehensive incubator program would provide critical resources such as a physical base of operations or access to technical expertise and testing equipment and funding. Critical information could be shared amongst these small companies with research institutions, end-user industries, and government agencies to further commercial advances.

Fortunately, the U.S. can rely on its allies' experiences to inform how to construct a large-scale well-funded commercialization program. To assist the U.S. in moving forward with this type of large-scale program, NGA is actively working with industry, academia, and policymakers to implement the first steps necessary to get this type of program on a proper footing. Specifically, the U.S. should:

1) Develop increased situational awareness of the graphene efforts that are already ongoing at the federal level and what potential applications (or problems to be solved) may require graphene and graphene-based technologies. A common refrain from graphene companies is that they can produce the material in various forms, but they are unaware of what the end-user, especially at the federal level, is looking for in terms of applications. Senator Roger Wicker (R-MS) took the first step in this area by requiring the Department of Defense, in the 2019 National Defense Authorization Act (NDAA), to report on department wide efforts in the graphene field. The report is expected in the near term, but a comprehensive look at all federal work in this field is still needed.

2) Formally establish U.S. policy focused on the economic and national security importance of graphene commercialization. Similar to the FY19 NDAA, Senator Wicker also took a first step in this area and included report language in the FYI9 CJS Appropriations bill that recognized "the emergence of graphene as an innovative material with significant commercial and national security potential." In addition, the language encouraged the National Institute of Standards and Technology (NIST) to continue to fund and pursue graphene research activities and designate industry and academic institutions with expertise, existing capabilities, and infrastructure related to the commercial application of graphene.

In May, the National Graphene Association took the initiative to establish a Graphene Academic Council to assist in beginning these collaborative efforts. This follows on NGA's creation of a Graphene Industry Council in 2018 and a Standards Committee to collaborate on efforts to ensure international standards, which play a crucial role in ensuring that the development of new technologies and the improvement of existing technologies, are consistent in terminology and definitions.

Conclusion

Now that a solid base of graphene knowledge has been established and the science of graphene has been explored in detail, the next few years will be pivotal for commercialization as the material is prime for utilization by many large-scale industries. Graphene-based companies and other supporting organizations will be in the most need of federal support and funding. Failure of the U.S. to develop a comprehensive strategy to lead and support the commercialization and continued development of graphene technologies will create a strong dependency on graphene technologies and source materials developed by U.S. competitors. This should pose a significant concern for U.S. economic and national security in future years – a concern that can be addressed by taking the actions mentioned above in short order.