Graphene Technology in the Space Industry

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I. INTRODUCTION

Since its discovery in 2004, graphene has captivated the scientific community's interest. Graphene is a material made of a single layer of carbon atoms in a hexagonal pattern. Because of this unique structure, graphene has many useful properties. It is recognized as the toughest 2D material to exist, as it is 200 times stronger than steel measuring the same dimension [2]. Additionally, graphene can stretch up to 20% more of its original size. It also has a lower electrical resistance compared to all other material at room temperature, resulting in excellent conductive properties [2]. The impressive features of graphene allow it to be used in a multitude of ways. For example, it can be rolled into tubes, layered, woven, or folded as illustrated in Figure (1) [2]. Its flexible but durable nature allows it to be integrated into everything from clothing to spacecraft.

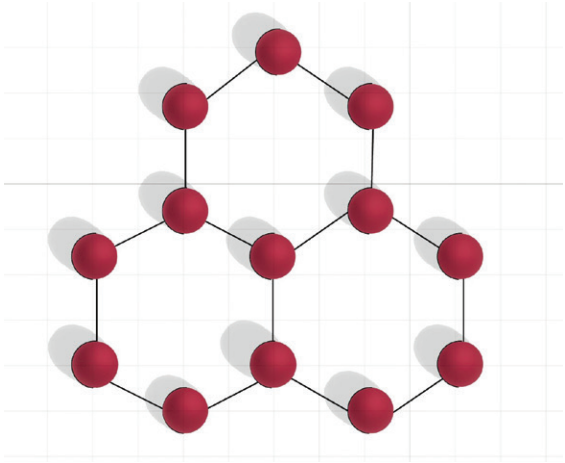

Figure (1) shows the structure of graphene.

Additionally, because of its superb electrical capacity, graphene is being incorporated into electronic systems such as sensors, radars, and circuits [3]. Graphene enables these devices to work more efficiently by negating the effect of a system's lost energy. This means that spacecraft can become more energy efficient, saving time and money. Furthermore, scientists are working on applications for graphene in other sectors such as ballistic defense and electronics. This paper focuses on graphene in the space industry—where scientists are making breakthroughs.

II. UTILITY IN THE SPACE INDUSTRY

Technology in the space industry has improved exponentially since humans launched the first satellite into space in 1957 [4]. Since then, the United States, Europe, and Russia have continuously developed revolutionary technology for space exploration. From breakthroughs in engineering, medicine, and materials, space exploration has ushered in a sense of innovation across the world.

Though graphene was not invented solely for space exploration, it has quickly become one of the most revolutionary materials utilized in this regard. Graphene gained its popularity in the space industry from 2010-2015 [2]. During this five year period, the world was beginning to understand how revolutionary the material really was. There then came a significant limiting factor in the growth of graphene: it was nearly impossible to produce on a large scale. Companies and government organizations such as NASA became involved in the race to mass produce graphene

effectively. In 2018, researchers from the Department of Energy discovered a method to make graphene known as chemical vapor deposition (CVD)[5]. This is a common method of creating nanomaterials that requires hot chemical gas to be reacted with a solid element or substance. CVD has been refined and developed into a science over the past few years. This means large scale graphene synthesis is now realistic [5].

III. INFRASTRUCTURE & EQUIPMENT

One of graphene's primary uses is to build the industrial parts of spacecraft. 'Monolithic' epoxy--rigid epoxy that is commonly used in construction and engineering--does not have the thermal capabilities nor the strength to withstand harsh conditions in space. To strengthen the epoxy, graphene nano-platelets are mixed with carbon nano-tubes to create an epoxy that is 260% stronger than the standard monolithic epoxy [6]. It is also 190% less susceptible to tension forces [6]. This creates more durable and flexible seals in spacecraft.

Graphene is being used to improve the daily lives of astronauts. Space suits integrated with graphene have shown resistance to radiation. Researchers tested elements and materials such as boron, beryllium, and carbon dioxide in space suits, but none were effective at shielding radiation [7]. The graphene integrated suit showed a 34% reduction in cosmic ray exposure [7]. This is important because the next big space mission is to put a human on Mars. With advanced space suits made with graphene, astronauts will be better protected from the harsh Martian environment, inevitably bringing peace of mind to said astronauts and allowing them to conduct safer research.

New radiation sensors are also being developed from graphene with the intent to keep astronauts safe. In fact, in 2019 the European Space Agency launched a rocket to experiment with graphene sensor 3D printing [8]. The objective was to enable astronauts to create critical sensors or to sustain a long spaceflight if equipment was damaged. Printing today focuses on sensors and electronic displays. However, its continued development brings it closer to creating batteries and super capacitors [8]. Graphene sensors are used to detect cosmic radiation and space junk. They are also integrated into Space-to-Earth communications [tectales].

Lastly, graphene is used as a shock absorber. It can absorb and distribute kinetic energy faster than any other material on Earth. It distributes kinetic force in a perfect elastic wave so that one area of the impact is not damaged excessively [9]. This property is useful for building parts of spacecraft that often encounter debris.

IV. RISE IN SOLAR PANELS

Solar cells emerged in 1954 when engineers were searching for a power source to be used by telephones in a remote location [10]. The first solar cell these engineers developed operated at only 1% efficiency [11]. Since then, solar cells have not improved much. The typical industrial solar cell operates at 10-15% efficiency [3]. New studies with graphene solar cells show that they operate at up to 30% efficiency [12]. These solar cells will produce 2-3 times the amount of energy when compared to their traditional counterpart while occupying half the space.

Graphene is ideal for collecting electrical energy. Its high conductivity allows the sheets of material to act as bridges, accelerating electron transfer. One layer is 97% transparent, and remains 88% transparent when layered five times [13]. In space, they are far more durable and temperature resistant than conventional crystalline silicon solar cells. In fact, in addition to traditional solar cells integrated with graphene, Chinese researchers have also developed a graphene composite film that converts light to electricity. [14]. The graphene film takes advantage of its hexagonal structure, enacting it to behave like a highway for electrons. This highway accelerates electron transfer [14]. This new film currently remains in the testing phases but is expected to have a higher efficiency than solar cells. It is anticipated to be used in solar sails which will be discussed in the next section.

These solar applications of graphene can be utilized as energy sources in spacecraft. Most satellites are powered by solar cells. Solar cells are heavy and add unnecessary weight and cost to space missions. Due to graphene's impressive electrical properties, engineers are developing flexible graphene solar cells [12]. These solar cells will be much lighter. They will also be able to attach to different surfaces—perfect for spacecraft application.

V. DEVELOPMENT OF SOLAR SAILS

Though solar sails sound like they belong in a science fiction movie, they are a promising technology that can revolutionize space travel. Unlike traditional rocket fuel, solar sails are light, easy to launch, and need no fuel. Much like solar cells, solar sails work by converting photons from light into electrical energy, much like solar cells [15]. If photons hit the sails, the spacecraft will accelerate. In 2020, the European Space Agency developed solar sails using graphene technology [15]. They began by taking small sheets of graphene and shooting them with laser beams. When the graphene accelerated in response to being struck with the photons from the laser, it propelled itself forward [15].It reacted with more vigor than other materials being tested for

solar sails, such as lightweight polymers like Mylar. It directs itself exactly like a sailboat—changing the angle of its sail to adjust its course [16]. It can also move in different ways by changing its center of mass.

VI. INTRODUCTION INTO ROCKET FUEL

Students and researchers at Purdue University recently formulated a different method to launch rockets. A new propellant made of graphene foam is being successfully tested for its propulsion capabilities. By combining the graphene foam fuel with traditional solid fuel, the launch was more fuel efficient [17]. The foam works well because it is porous and allows air to circulate better, further igniting the launch [17]. The key to the foam's success is in its structure. It has a 3D tunnel-like structure that allows for quick heat transfer throughout the material. [17]

Similarly, nanofluids (oils or fluids containing nanoparticles of a nanomaterial such as graphene) have become a popular alternative to traditional rocket fuel. The nano particles in the fluid creates a nanostructure to allow heat to transfer faster through the material [18].

Isrosene, a nanofluid made with graphene, is one of the top performing nanofluid rocket fuels[5]. According to the Indian Space Research Organization, once the fuel was mixed with graphene, it improved its heat transfer efficiency by 49% [5]. Improving heat transfer allows for more effective burning rates. This reduces the amount of fuel used which lowers the weight of the rocket, allowing the rocket to carry a larger payload.

Solar sails made of polymers have already been implemented and used in spacecraft. Researchers predict that it will soon be possible to make solar sails up to a kilometer wide out of graphene. If solar sails are largely implemented in the future, they will enable spacecraft to travel further than traditional fuel [16].

VII. WHAT THE FUTURE HOLDS

SpaceX launched a mission in early April 2022 to test how graphene sensors react to a zero-gravity environment. The sensors were designed by Dutch and Chilean students and researchers [19]. Because this launch took place recently, results of the experiment are still pending, however, the sensors are expected to be more sensitive to cosmic activity than average spacecraft sensors [19].

Other companies and organizations have launched similar campaigns to that of SpaceX. The Cambridge Graphene Center has partnered with the European Space Agency and a company called Graphene Flagship to test their graphene devices in space [20]. While SpaceX's mission is focused on sensors made of graphene, this mission tests graphene's use in cooling systems on

spacecraft. Engineers have designed loop pipes (fluid pumps with no mechanical parts) with graphene to help regulate their temperature [20]. Having no mechanical parts also prevents breakdowns and machine failures. These two advantages prolong the lifespan of spacecraft—saving money, time, and energy for the companies.

A team out of the University of Manchester is currently developing advanced rocket living spaces enhanced with graphene. Integrating graphene within the infrastructure of spacecraft living spaces helps regulate the extreme temperatures of space [21]. Graphene's strength also helps protect the spacecraft from micrometeorites and space junk. This keeps astronauts safe and healthy. Engineers on the same team are designing plans for a graphene enhanced Earth-like habitat on other planets such as Mars. [21].

CONCLUSION

Graphene has made significant strides in advancing existing technology over the past decade. What was once thought to be an impossible material has changed the way that we think about the future of the space industry. From solar sails to space suits, graphene has revolutionized the limits of space exploration. If humans are to expand across the galaxy, as NASA and SpaceX believe, graphene technology will play a large role in our success. This unassuming, yet powerful material may yet be the key to unlocking humanity's dreams of reaching distant galaxies.

When Earth will one day face another apocalyptic event, space travel will become the only option for survival. By developing graphene technology in the space industry, engineers give life a chance to endure on, even in the worst scenarios.

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