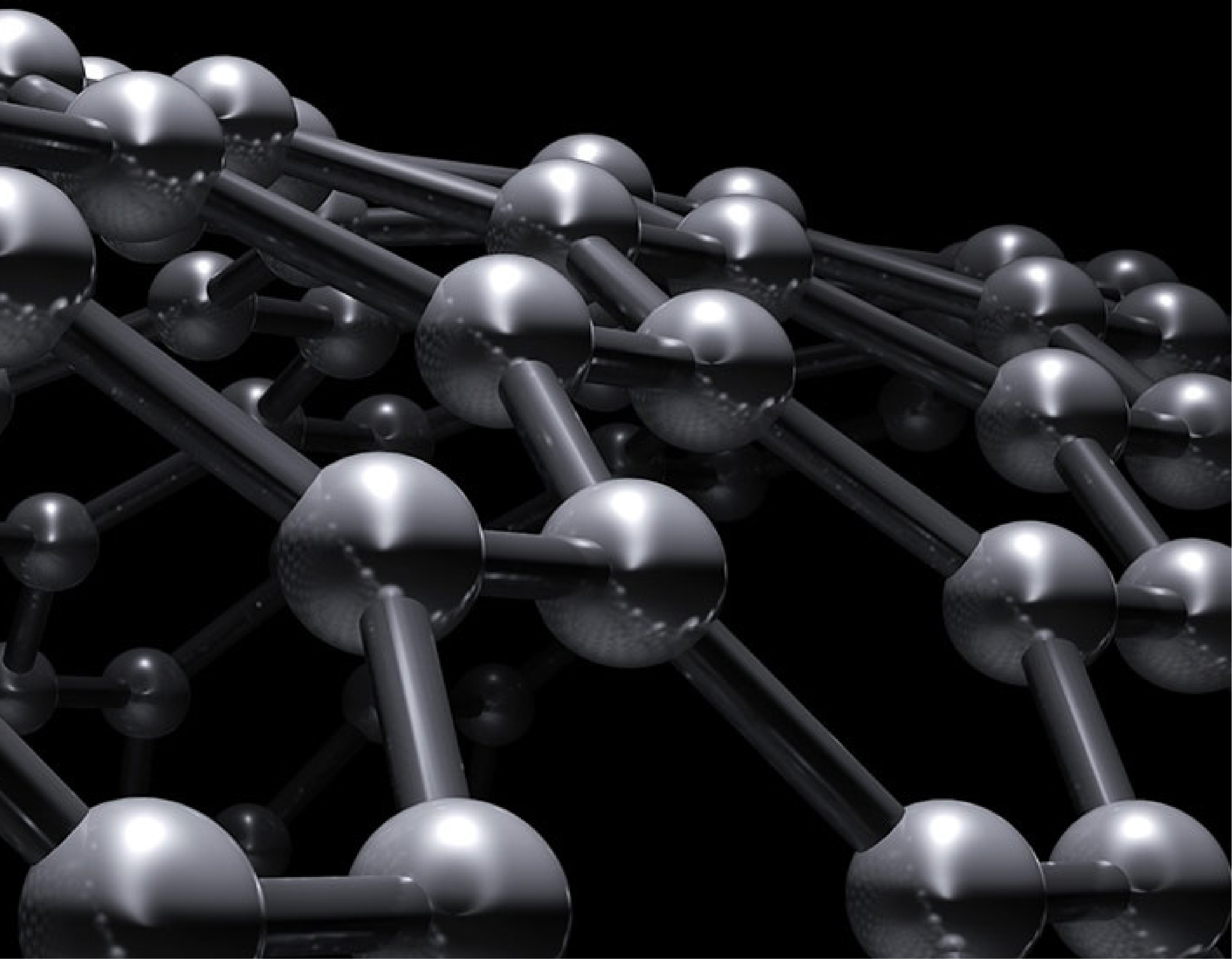
HIPCO FIBER



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Introduction

Carbon is a versatile material capable of forming Structures that are both simple and complex with ease. This ability of carbon has made it the material of choice for life on earth. The material is abundant on earth and nearby planetary bodies. Just when we thought that we knew everything; It had a few more tricks up its sleeve. While observing Starlight, Professor Kroto found that there were lines of carbon that did not seem to match any known forms of carbon. He met Richard Smalley at a conference at Rice University, and they began talking about the strange new forms of carbon. At that time, Dr.Smalley had access to the world's most powerful laser and used it to fire various materials to see what they were made of. The experiments yielded the first conclusive evidence of a new form of carbon called fullerenes. These unique football-shaped molecules played a pivotal role in kickstarting nanotechnology.

Further developments in fullerenes led to the discovery of carbon nanotubes. Especially single-walled carbon nanotubes. These unique molecules seem to have the ability strength and properties that were unmatched by any known material. These were the fictional diamond tubes the authors had always predicted but had been incredibly difficult to manufacture. Studies on the properties of the carbon nanotubes revealed that they had strength higher than any material known to humanity. They also had unique electrical properties, the ability to withstand radiation, and the ability to self-repair any ability to form complex chain molecules like their precursor carbon. The tubes' diameter is usually in the range of several tenths to a few tens of nanometers (billionths of a meter, or ten-thousandths the diameter of a human hair) for the common, single-walled variety of tubes; concentrically nested tubes, or multiwalled tubes, can be significantly wider and are likewise being explored for their potential utility.

Materials scientists have been touting these and other properties of nanotubes since the early 1990s, promising a revolution in aerospace and other sectors. Lab tests show that carbon nanotubes have hundreds of times the tensile strength of an equivalent diameter span of steel, yet with just a sixth of steel's density. Binding these nanotubes with resin into fibers, weave those fibers into sheets, and curing those sheets into shapes, and the resulting structures — are super strong and superlight compared to aluminum and conventional composites. Indeed it has the potential to revolutionize performance and open new designs for aircraft and satellites.

HiPCO® Nanotubes

At The initial stage of production, the produced material is a mix of single-walled carbon nanotubes (SWCNT), amorphous carbon, and catalyst. It is essential to purify this nanotube for better results in fiber production. These raw nanotubes are purified using the halogen purification method which is a patented process by NoPo. And this process plays an important role in the quality of fiber produced. In this method, the catalyst and the other carbonaceous materials are removed to obtain a material with the main 85 percent of CNT.

Properties	**Analysis Results**	**Explanation**
Morphology	Dry powder of nanotubes bundled in ropes	Visual appearance.
TGA Residue as Fe	<15wt%	TGA is used to measure the Fe content. The residue content will be Fe_2O_3. Which is ~12% so the Fe catalyst in the purified material is ~8.4%
Average SWNT Diameter	0.8-1.2nm	RBM of Raman analysis gives the average diameter of Nanotubes. The wavelength ~272cm_{-1}. Analyzed using TEM.
Bulk Density	0.05g/cm_3	Packing box
Moisture Content	<0.5 wt%	In the TGA thermogram the weight loss ~150°C identifies the moisture content.

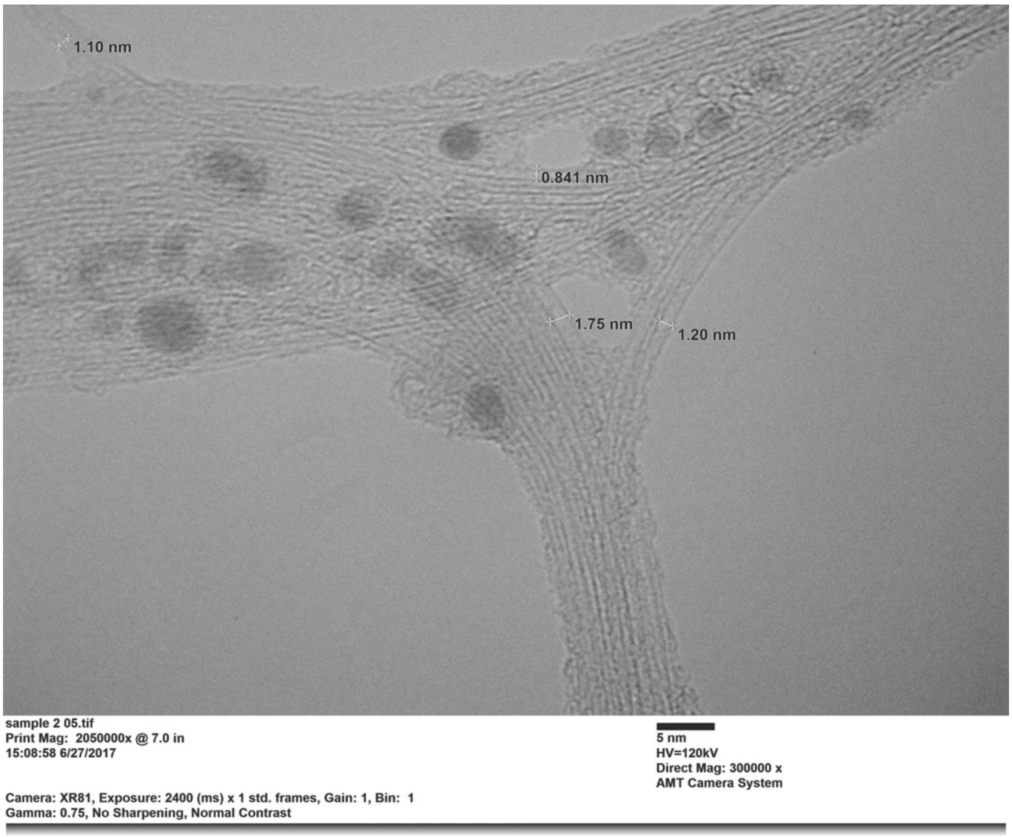


Image of HiPCO® nanotubes using Transmission electron Micorscope (TEM)

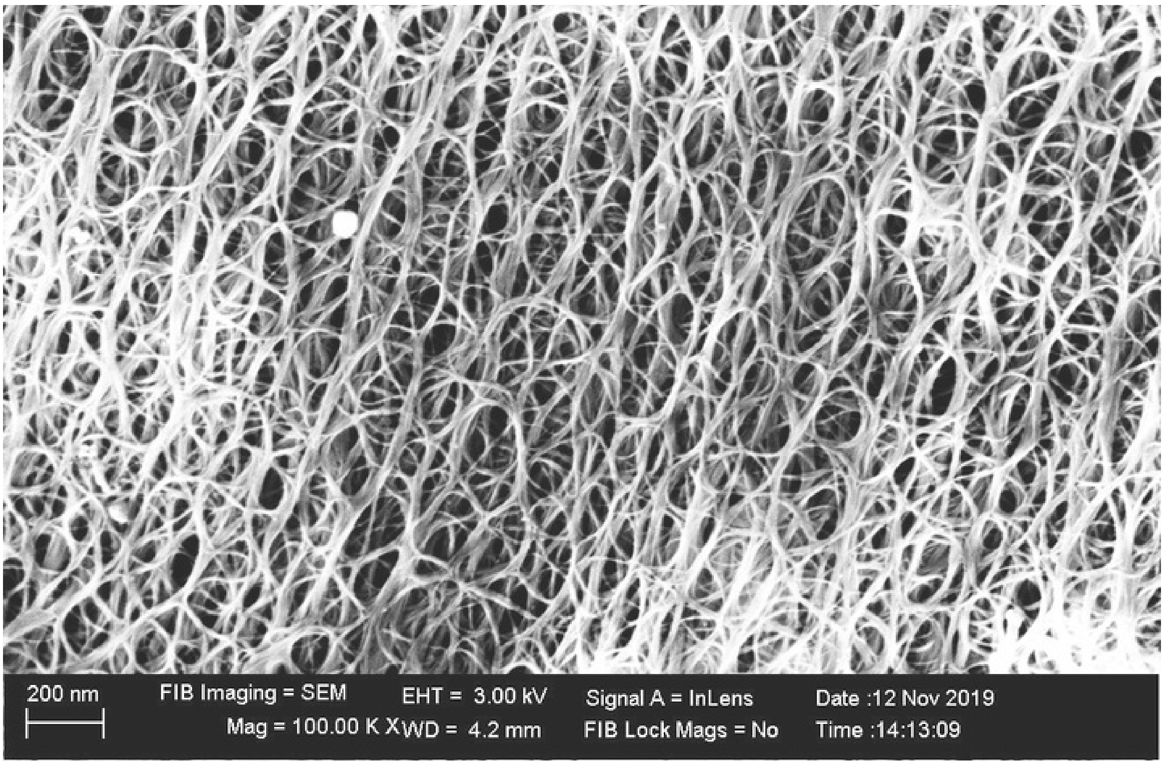


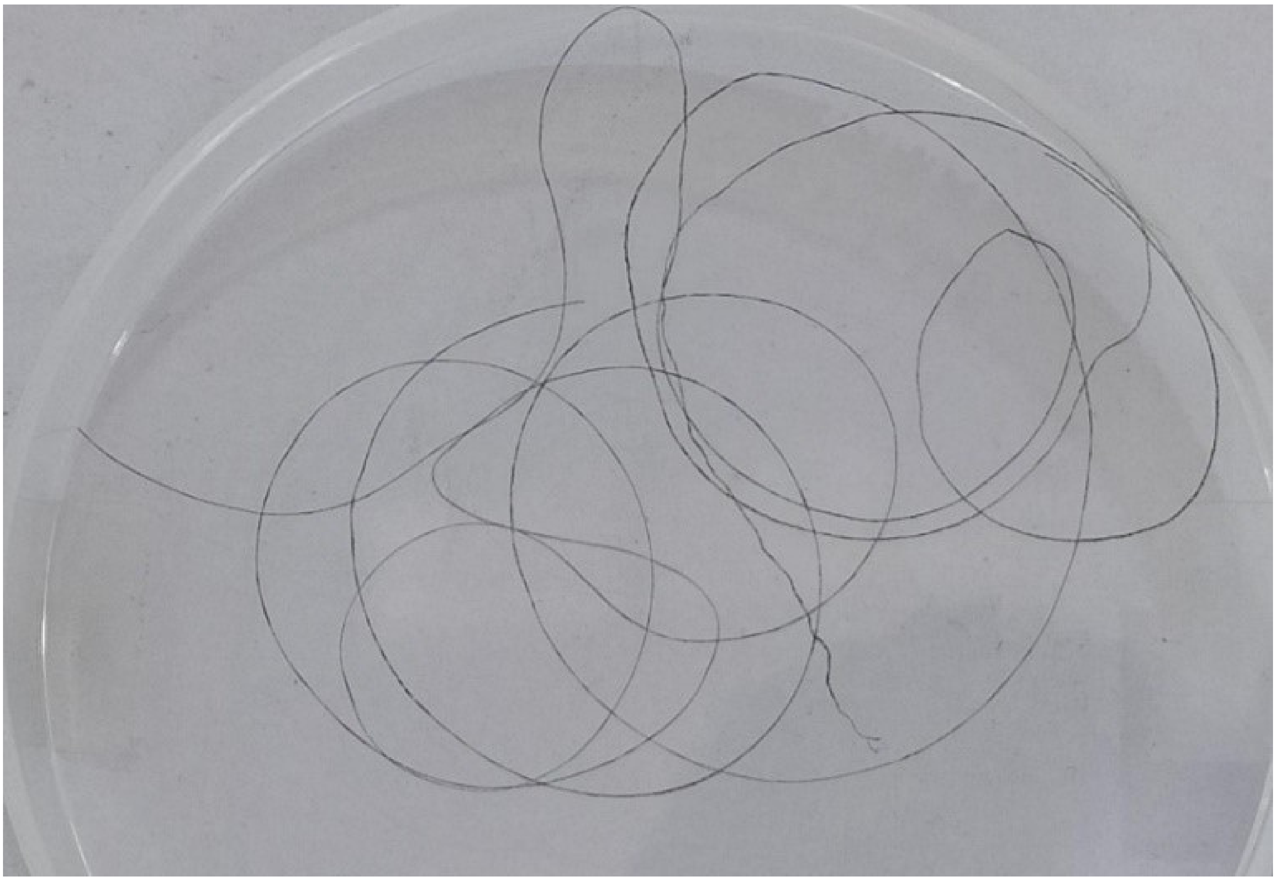
Image of HiPCO® nanotubes using Scanning electron Micorscope (SEM)

HiPCO Fibers

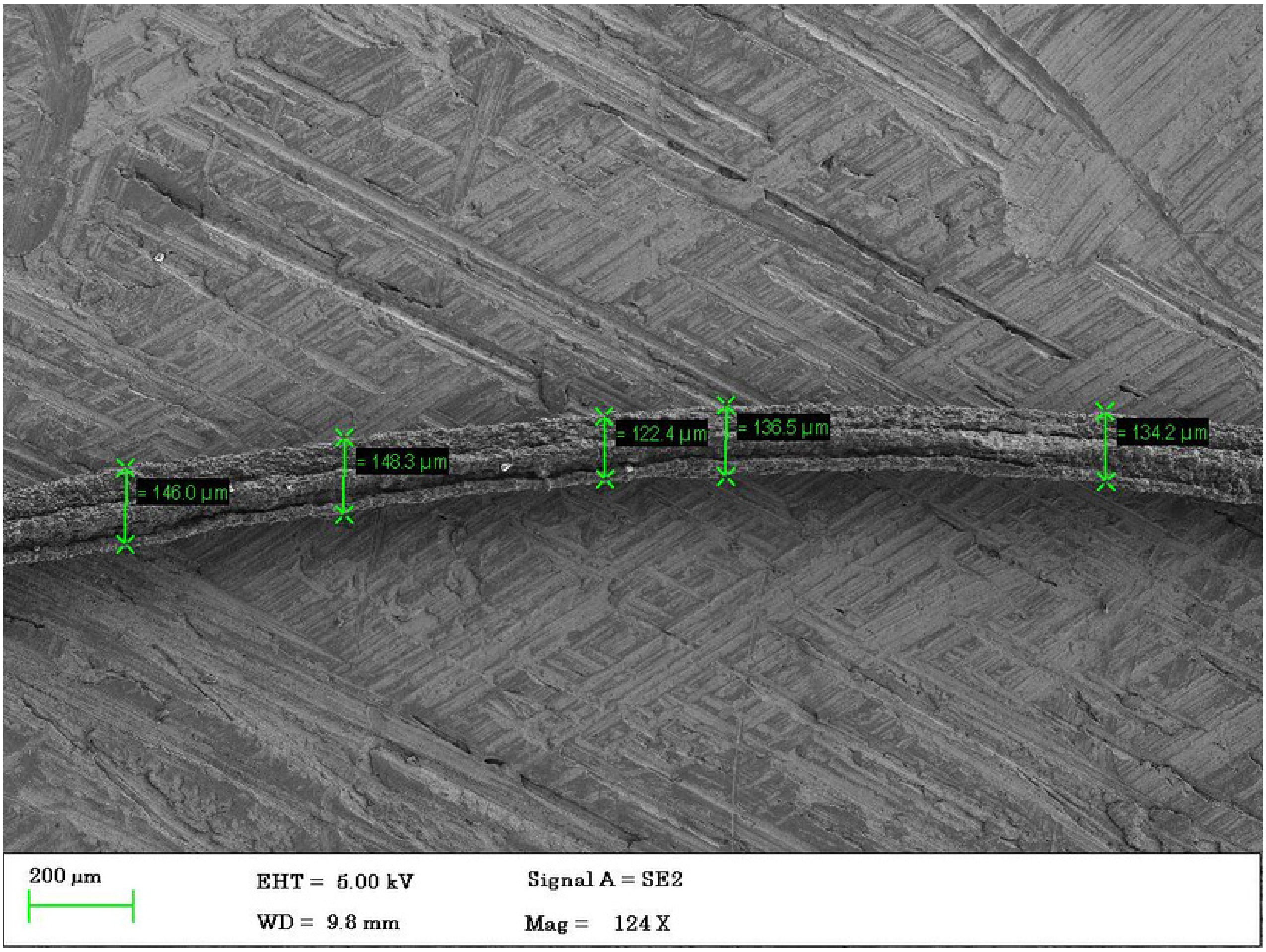
HiPCO® fibers are produced using HiPCO® single-walled nanotubes by aligning each SWCNT side by side to form a long fiber. The aim is to transfer the tensile strength of a single HiPCO® nanotube (127 GPa) to the macroscale fiber. The current focus is to produce a fiber of 7 μm in diameter or even lower. Currently, the diameter of the fibers achieved by us is around 20- 140 μm, and the maximum tensile strength achieved is 650 MPa and 10 % conductivity of copper.

Production of a good quality fiber from HiPCO® nanotubes can only happen with a combination of certain variables. These nanotubes are the ones with the smallest diameter known so far in this world and from previous studies, smaller nanotubes have exhibited maximum tensile strength. And arranging these nanotubes side by side using a wet spinning process can result in fibers with maximum strength. For that, all the variables affecting the fiber strength need to be identified and it is already been identified. These variables need to be narrowed down by conducting a large number of experiments.

https://www.sciencedirect.com/science/article/abs/pii/S0008622317303354



Pristine HiPCO® fibers produced in NoPO

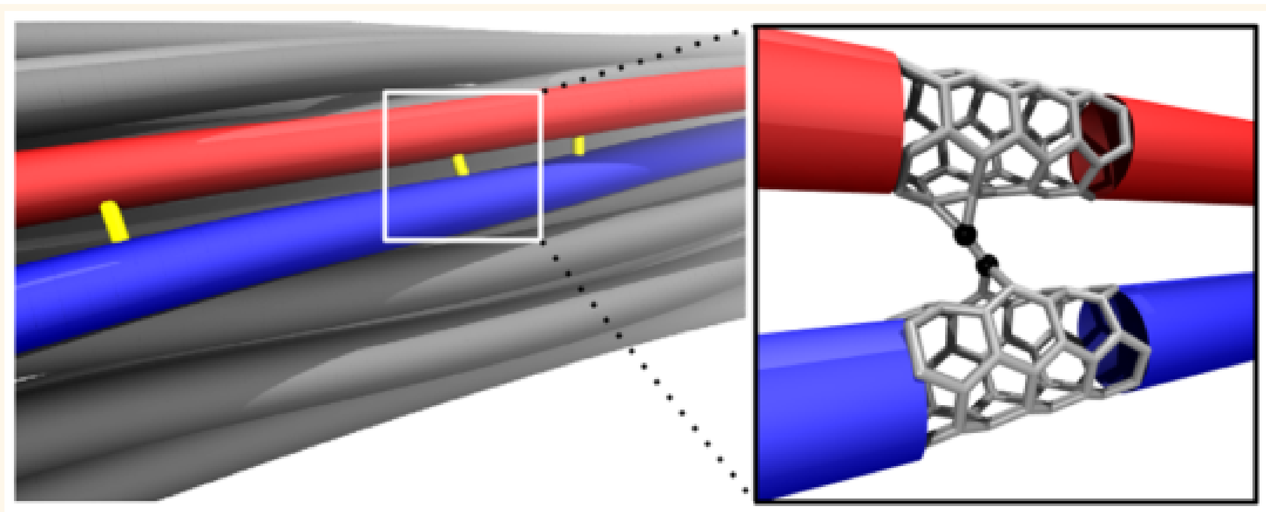


SEM image of fiber produced using HiPCO® nanotubes with dia of 140 µm

Production statistics

Carbon nanotube fibers consist of millions of individual carbon nanotubes held in place by a combination of nanotube-nanotube entanglements and van der Waals interactions.

A 7 μm cross-section of fiber consists of around 50 million HiPCO® SWCNT arranged parallel to each other. This arrangement gives the fiber the strength which makes it stay intact. With additional crosslinking of these fibers, more bonds can be created between these CNTs giving the nanotubes additional strength as per the 2022 paper by Boris Yakobson. We have experimentally demonstrated the crosslinking between nanotubes and thus doubling the strength of fibers. And it is expected that the strength can be improved to 10 - 12 times with extremely high-quality fibers thus reaching tensile strength higher than 10 Gpa



Compared to other fibers which use nanotubes from Meijo. A 7 μm cross-section has only 5.4 million nanotubes which is 10 times less than HiPCO® fibers. So it is believed that the extra addition of nanotubes in HiPCO® fibers will aid in the improved strength and electrical conductivity.

https://pubs.acs.org/doi/10.1021/acsnano.0c08588

As per rough calculations, 1 g of the nanotube can produce 41 KM of 7-micrometer fibers and 200 m of 100-micrometer fibers.

CNT weight	**Fiber diameter (µm)**	**Length of fiber (m)**
1 g	7	41000
1 g	20	5000
1 g	100	200

HiPCO® Fiber Application

As per the current production rate, 200 mg of SWCNT can be processed each week. Thus producing 40 m of 100-micrometer fiber, this 40 m fiber itself can be used for certain immediate applications. As the production capacities increase new applications could be accommodated.

These are some of the general applications of the CNT fibers and further several other applications based on the amount of production is listed.

Table 3 Various application fields and main roles of CNTFs

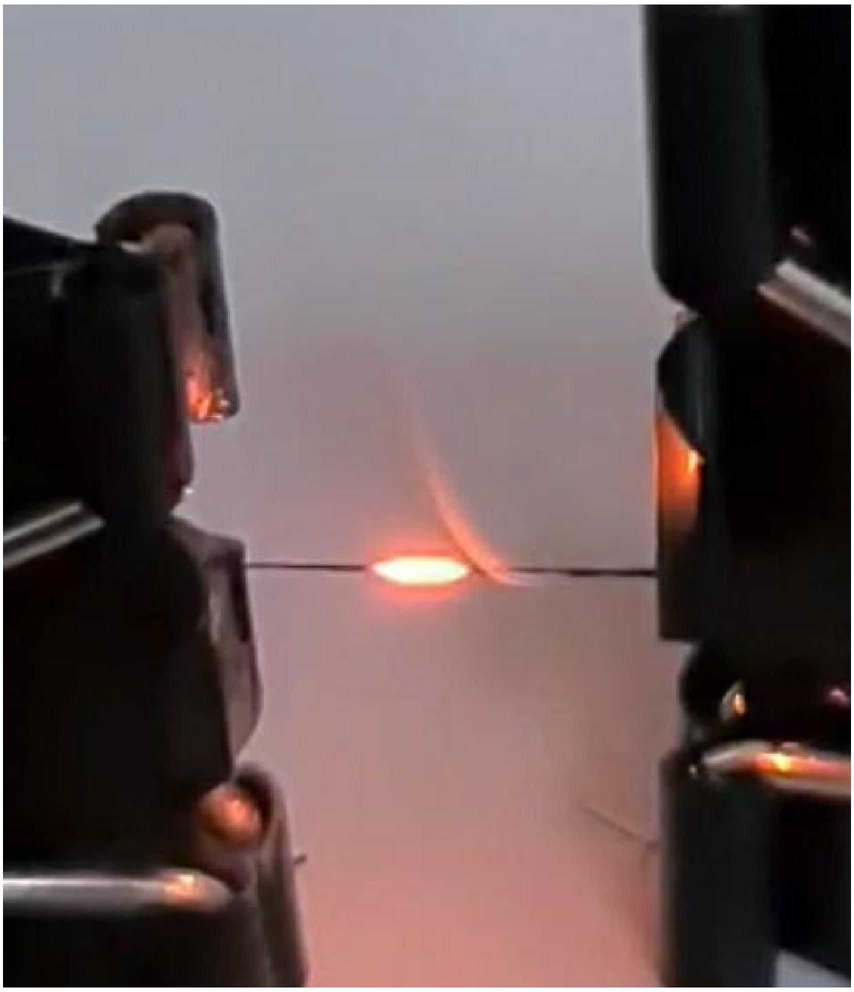
	Application	Main contents (role and need)
1	Composite materials	CNT/PVA yarns are used as high-strength and heatable fabrics
2	Battery	CNT sheet composites are useful as binder-free anodes, and CNTFs are employed in wire-shaped lithium-ion batteries as self-standing electrodes
3	Capacitor	CNTF is suitable for wearable energy storage devices because it has a flexible and porous structure and can be applied as a template for electrode materials
4	Actuator	CNT with high electrical conductivity and Young's modulus is suitable as a material for actuators, and CNTF is also a highly promising material
5	Solar cell	Ultralight and strong CNTFs are widely applied as working and counter electrodes because of their good electrical conductivity and mechanical flexibility
6	Artificial muscles	CNT sheets are useful components of artificial muscles that provide giant elongation rates in wide temperature ranges
7	Sensor	CNTF is suitable as a material for wearable sensors due to its brush-like structure, alignment, and conductivity
8	Field emission	CNTF is suitable as a field emission material due to its large aspect ratio and high electrical and thermal conductivities
9	Transparent speaker	Transparent, flexible, stretchable CNT film loudspeakers have a small heat capacity due to the thermoacoustic effect, thus they have a wide frequency response range and a high sound pressure level
10	Touch panels	Touch panels assembled by depositing Ni, Au on CNT films and produced by a roll-to-roll process are superior in flexibility and wearability
11	Mirage effect	Transparent CNT sheet with low thermal capacitance and high heat transfer ability enables high-frequency modulation, thereby providing a rapidly changing gradient of refractive index in the surrounding liquid or gas
12	Light source	Highly conducting and oriented CNT sheets used as a planar incandescent light source that emits polarized radiation
13	Thermal transport	The intercalation of iodine molecules can raise the inter-tube interfacial electrical and thermal transport and thus increase the electrical and thermal transport performance of the fibers
14	LCD application	CNT films composed of numerous parallel CNTs as the aligning layer can readily align liquid crystal molecules

https://doi.org/10.1007/s43207-020-00106-0

200 mg/Week

Resistive Heater

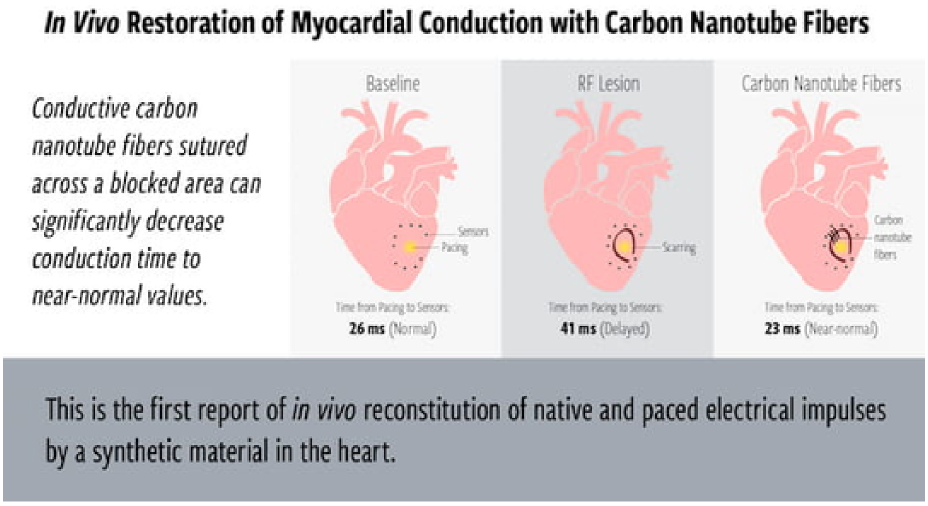
Fiber heating experiements conducted using HiPCO® fiber.



Carbon nanotube fibers with considerably high resistance can be used as resistive heaters. It glows continuously with high intensity when a low amount of current passes through it. This property of fibers can be used in satellites as a fuse.

1 g/Week

Biomedical Application

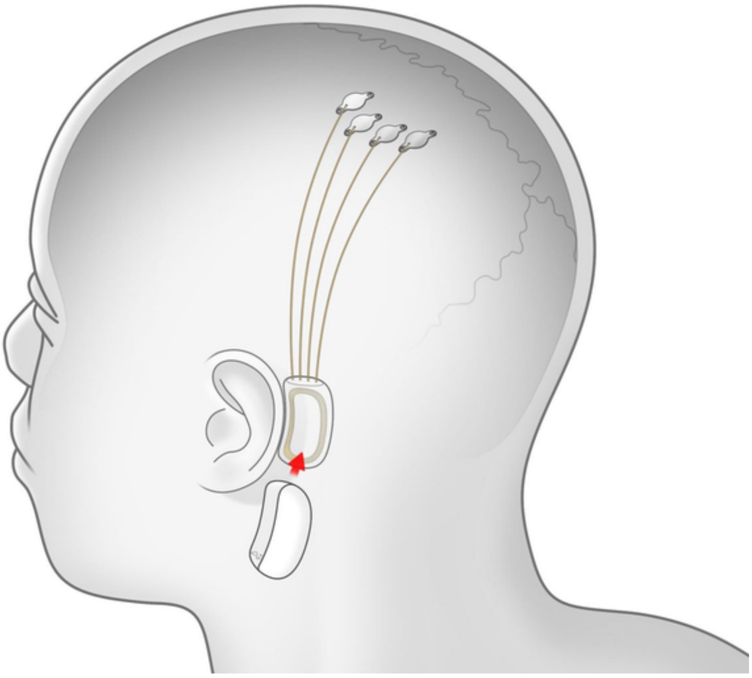


HiPCO fibers showing good conductivity has much potential application in the biomedical field. Carbon nanotube fibers (CNTfs) combine the mechanical properties of suture materials with the conductive properties of metals and may form a restorative solution to impaired myocardial conduction.

Scientists at Texas Heart Institute (THI) report they have used biocompatible fibers invented at Rice University in studies that showed sewing them directly into damaged and tissue can restore electrical function to hearts.

https://www.ahajournals.org/doi/full/10.1161/CIRCEP.119.007256

Neuronal Connection to Brain



According to various studies CNT fibers acts far superior than the metal electrodes.Because they provide a two-way connection, they show promise for treating patients with neurological disorders while monitoring the real-time response of neural circuits in areas that control movement, mood and bodily functions.

Interestingly, conductivity is not the most important electrical property of the nanotube fibers. These fibers are intrinsically porous and extremely stable, which are both great advantages over metal electrodes for sensing electrochemical signals and maintaining performance over long periods of time. Caleb Kemere shows a brain atlas as he discusses new research aimed at using carbon nanotube fibers invented at Rice as electrodes for deep brain stimulation of patients with neurological disorders like Parkinson's disease. The flexible fibers are much smaller than the metallic electrodes they would replace and far more effective in stimulating and recording signals from neurons.
HiPCO fibers have greater potential as the nanotubes are small in diameter. Fibers with diameters as less as few micrometers with considerable strength and conductivity can be produced.

https://blog.dexmat.com/cnt-fibers-superior-links-to-brain

5 g/Week

High strength Tether

The high strength factor of SWCNT can be applied to the making of super-strong tethers. The current target is to produce a 100 μm tether that can lift 20 kg of weight. Thus the combination of these tethers can be used for film production as stunt ropes.

These can reduce the post-production costs considerably and also smoothen the process. The current requirement is been made by Christopher Nolan. Once this becomes a norm in the industry it would be followed by many.

CNT fibers can replace High-strength tethers used for aerospace applications. Especially in satellites where weight reduction is a cost-reducing factor. With improved conductivity, it can be used as a cable in macro drones and also can accelerate the microsat technology.

Electrical Conductivity

The electrical conductivity of CNT technology is vital to its overall success in electrical interconnect applications. In the early research and development phase, the resistivity of electrically charged CNTs was about 200 times that of copper. More recently, that value dropped down to only 20 times that of copper. Now samples from manufacturers are getting closer to 10 times the resistivity of copper. The current objective for leading developers of this technology is to bring it down to five times that of copper. If that happens, it will be a real game-changer.

10 g/Week

Antennas

In summary, CNT thread antennas fabricated from moderately conductive CNT fibers match the radiation efficiency of copper control antennas while saving about an order of magnitude in antenna weight. To capture the trade-off between weight savings and radiation efficiency, we normalize the radiation efficiency by the weight of the radiating element (copper wire or CNT thread), which we call the specific radiation efficiency. By this metric, CNT thread antennas are 20 times more efficient than copper wire.

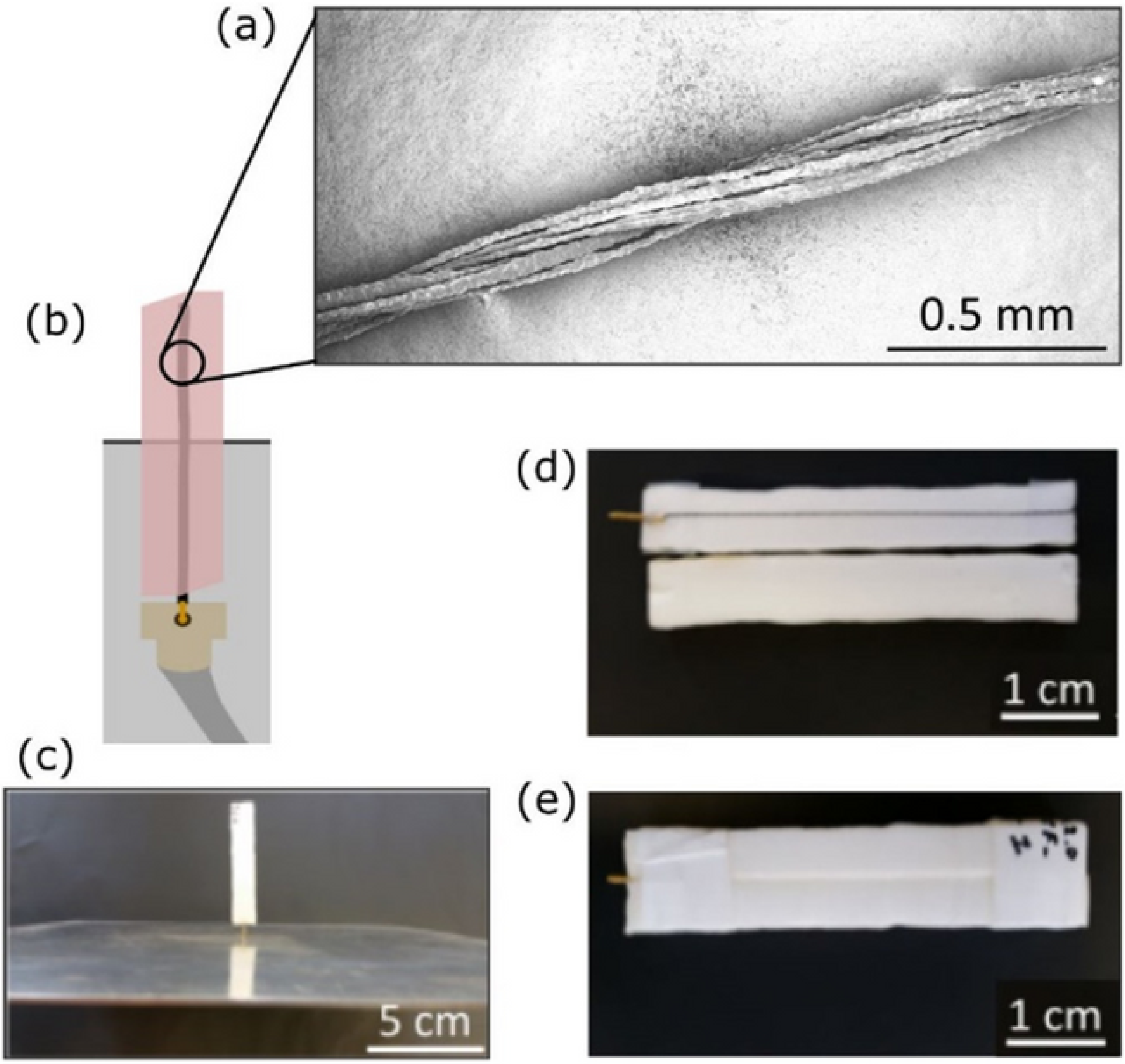


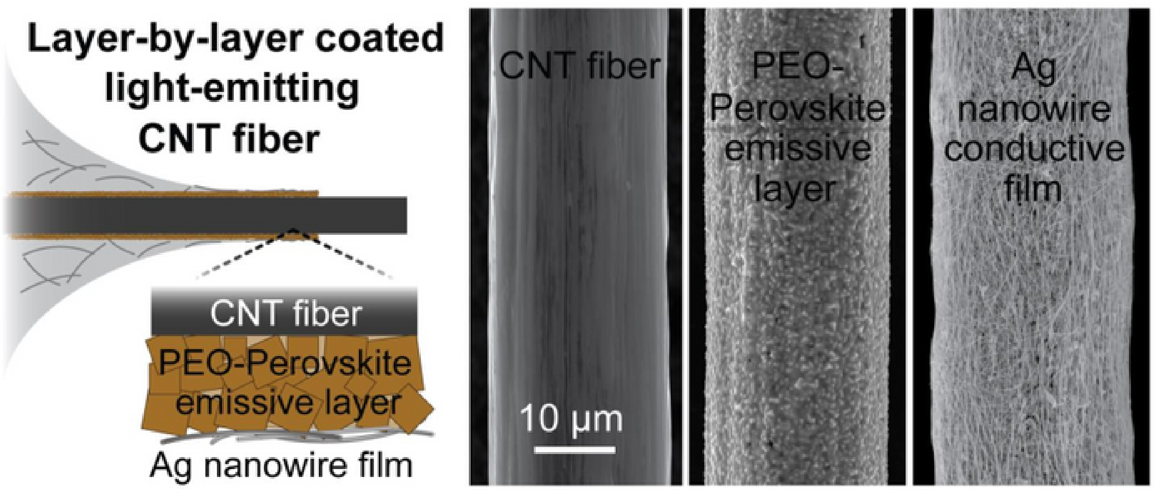
FIG. 1. Experimental configuration for testing CNT thread monopole antennas. (a) SEM micrograph of the 8 filament high-twist CNT thread, (b) schematic representation of the monopole antenna, (c) Rohacell HF/CNT antenna plugged into the Al ground plane, (d) CNT thread attached to brass pin connector, and (e) Rohacell HF/CNT thread final assembly.

This demonstrates that at wireless communication frequencies, copper wire antennas can be replaced with CNT thread antennas without impacting performance while decreasing weight. Although copper wire thinner than 30 AWG could provide identical performance at lower weight at these frequencies, such an antenna would be extremely susceptible to mechanical damage due to copper’s high ductility and low tensile strength. While not problematic for stationary antennas, e.g., in-ground stations, mechanical robustness is important for antennas in weight-sensitive mobile assemblies, such as aircraft or satellites. Mechanical robustness and flexibility are even more critical in wearable electronics, where copper’s and other metals’ poor fatigue behavior poses significant challenges for researchers vying to integrate antennas into clothing.

As a light source

Fibers with diverse functionalities including sensing, energy generation and storage, light emission, localized data processing, and communication are promising building blocks for the emerging and rapidly growing field of fiber and textile electronics. However, conventional material systems and current processing techniques alone are insufficient to accommodate these fiber-shaped devices. Improved understanding of active fiber assembly and new designs and fabrication processes are therefore essential to achieve electrically-active devices with small diameter, lightweight, and high mechanical strength.

A design in which carbon nanotube (CNT) fibers are used as the backbone for electrically-active fiber-shaped devices. The CNT fibers, which are formed through a scalable and cost-effective solution-spinning process, concurrently provide the desired mechanical properties and electrical performance, all while having a low density. It is shown that a solution coating technique can be implemented to sequentially form the desired device layers conformally around the CNT fiber producing a multilayered coaxial architecture.



Field Emission

Carbon nanotube (CNT) fiber-based emitters have shown great potential to deliver stable, high current beams for various potential applications. Because of joule heating, CNT field emitters are heated to high temperatures during field emission.

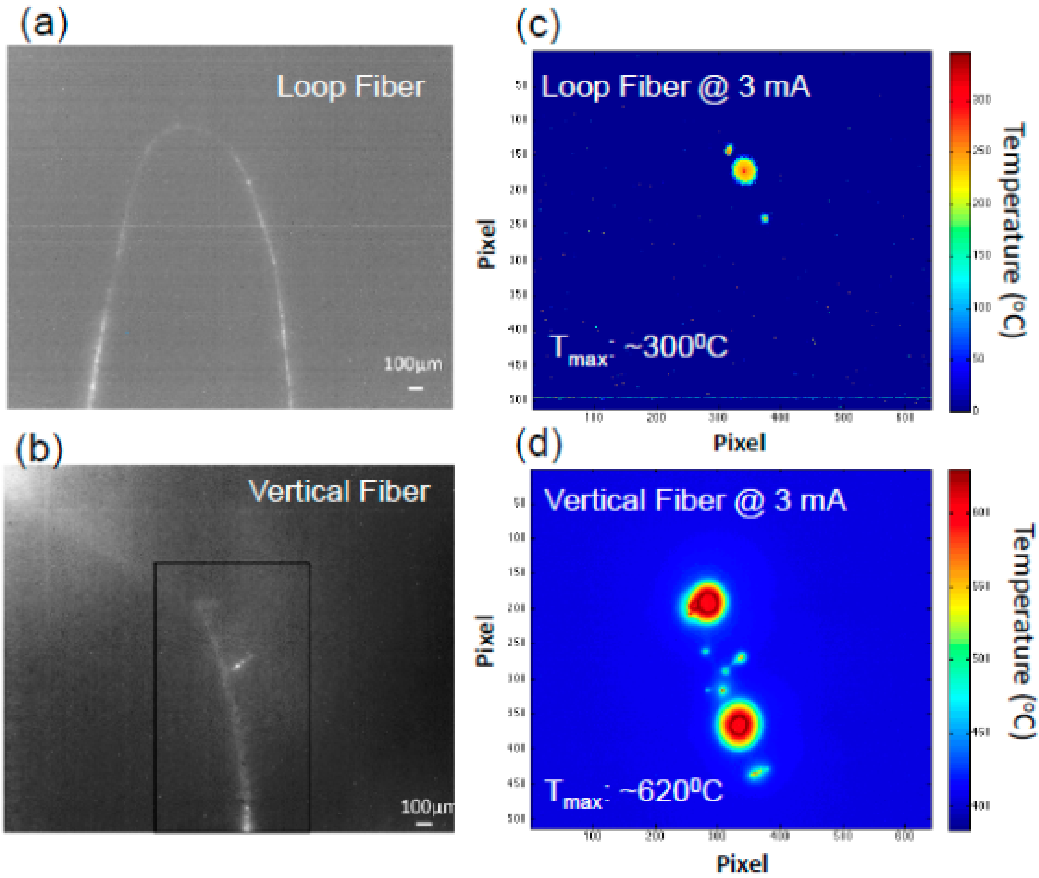


Figure 6. Optical image of the (**a**) looped CNT fiber and (**b**) single vertical CNT fiber. Temperature distribution of the (**c**) looped CNT fiber and (**d**) vertical CNT fiber, obtained from the IR camera.

100 g/Week

Wearable sensors

The wearable textile sensor technology is one of the key technologies in the fourth industrial revolution, which can respond to versatile environmental stimuli and even simultaneously communicate with users. In particular, wearable chemical sensors that detect invisible yet harmful environmental gases or vapor phase substances near the users can be utilized in various high-technology applications including military, medical analysis, industrial safety, and air pollution tracking applications. For the wearable chemical sensors, fiber-shaped sensing materials with superior properties could be integrated into smart textiles in various forms by weaving functional components into conventional fabrics, which cannot be achieved with typical solid-state gas sensors or recently reported sensing materials prepared on flexible films or papers. Therefore, the design and synthesis of the fiber-shaped electric components with incorporated sensing functionality are important in wearable sensing technology.

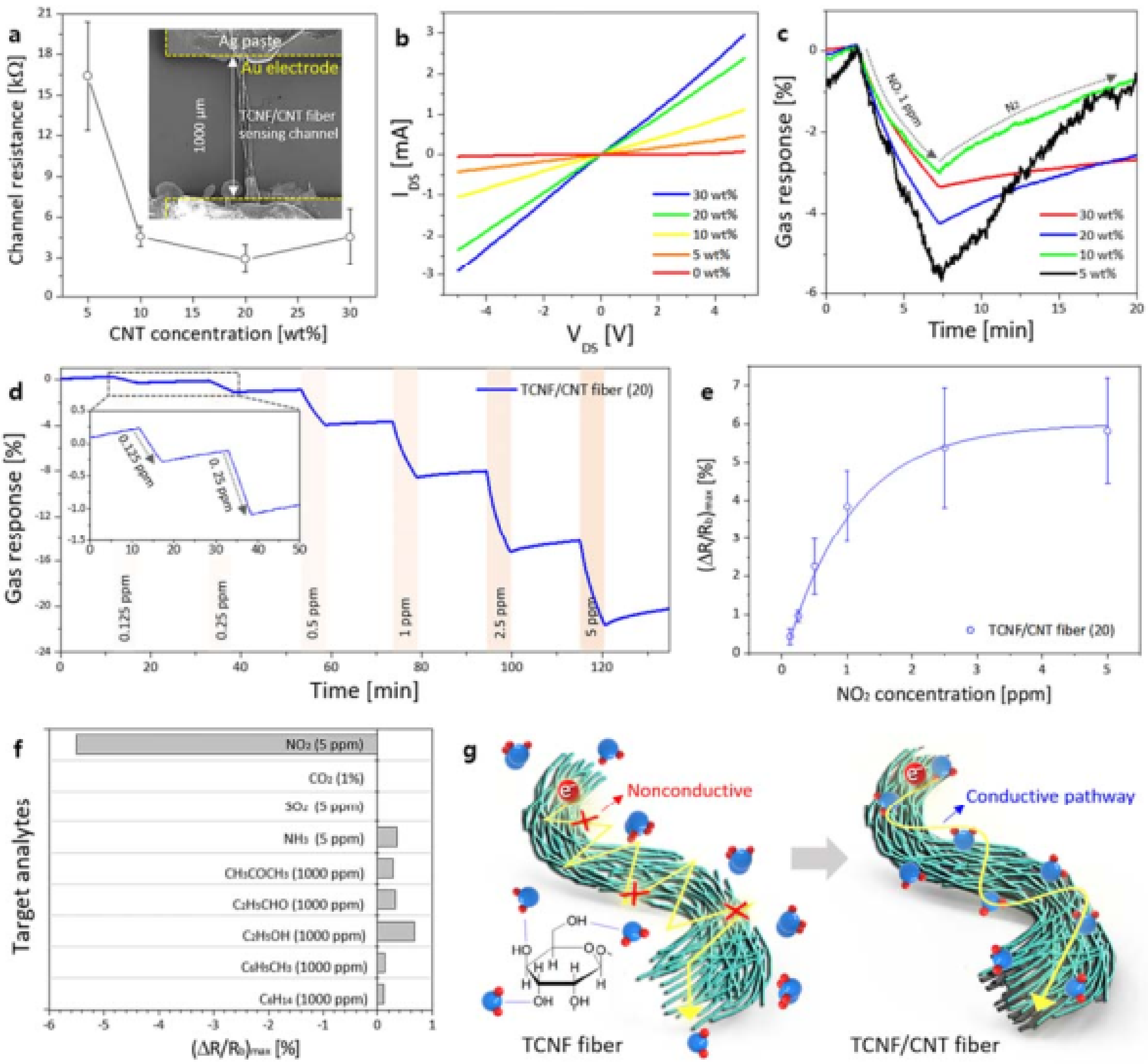
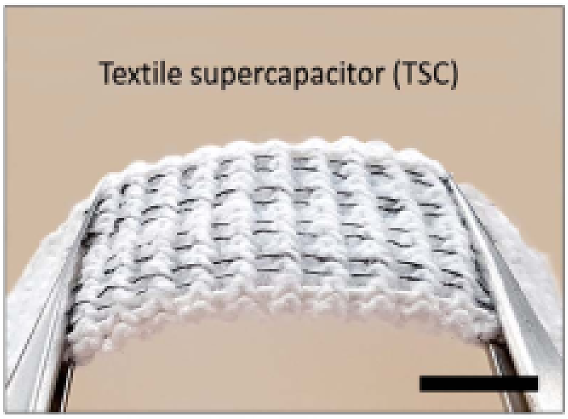


Figure 3. Device characteristics and gas sensing performances of the TCNF/CNT fiber gas sensors. (a) Channel resistance variations of the TCNT/CNT fiber sensing devices with various CNT concentrations (0, 5, 10, 20, 30 wt%). Inset: SEM image of the TCNF/CNT fiber sensing channel integrated with Au electrodes. (b) *I–V* curves of the TCNT/CNT fiber sensing devices with various CNT concentrations (0, 5, 10, 20, 30 wt%). (c) Real-time NO_2 sensing behaviors of the TCNF/CNT devices with various CNT concentrations (0, 5, 10, 20, 30 wt%). (d) Real-time sensing behavior of the TCNF/CNT (20) sensor in the range of 0.125–5 ppm of NO_2. (e) $(\Delta R/R_b)_{max}$ of the TCNF/CNT (20) sensor in the range of 0.125 to 5 ppm of NO_2. (f) $(\Delta R/R_b)_{max}$ of the TCNF/CNT (20) sensor for various analytes including hexane, toluene, ethanol, propionaldehyde, acetone (1000 ppm), NH_3, SO_2, NO_2 (5 ppm), and CO_2 (1%). (g) Sensing mechanism of the TCNF/CNT fiber.

Super Capacitor

In this study, it was identified that fiber supercapacitors have both high specific capacitances and increased potential windows. The first utilized strategy was to trap pseudocapacitive guest materials within vascular, high electrical conductivity networks of twist-spun CNT yarns, which maximized the weight percent of the guest without significantly hindering accessibility of the electrolyte to the guest. The second strategy was to use an asymmetric electrode configuration that comprised a MnO2 containing cathode yarn and reduced graphene oxide (rGO) containing anode yarn

In summary, asymmetric yarn supercapacitors have high energy density and can be woven into textiles. The rGO embedded CNT yarn electrode which contains 90.1 wt% rGO shows excellent charge storage capability (172 mF cm 2) which contributes to enhancing the overall electrochemical performance of the asymmetric supercapacitors. By combining with MnO2 embedded CNT yarn cathode, the wide voltage windows up to 2.1 V at aqueous electrolyte, and 3.5 V at organic electrolyte were obtained.



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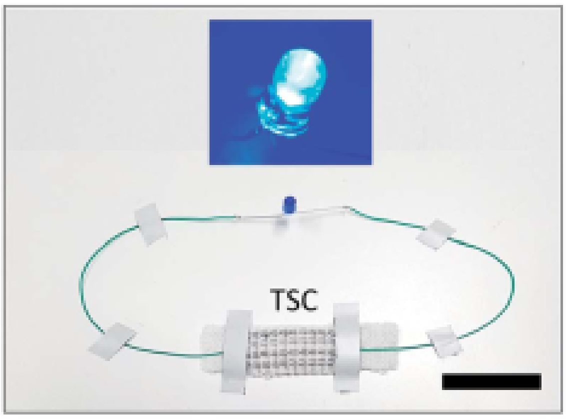
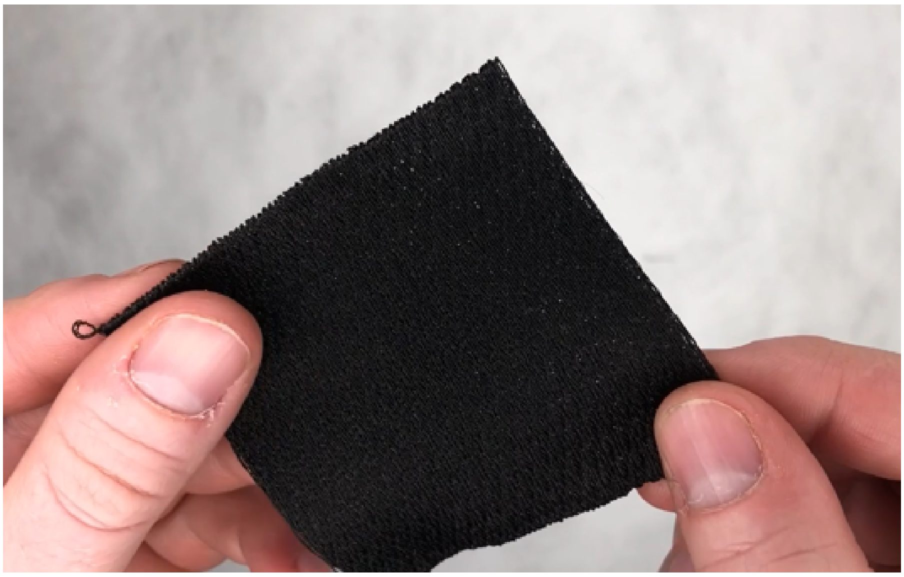


1 Kg/Week



Ballistic armor

To function well, ballistic armor needs to have several characteristics. A bullet impact does damage by putting a lot of kinetic energy into a very small package; the location the bullet hits will experience a high concentration of force. The first task of ballistic armor is to prevent the bullet from passing through the material entirely, and in order do to this the fibers need to have high tensile strength and high total toughness – measurements of how much stress (force on a fiber divided by the cross-sectional area of that fiber) and how much total energy input fiber can withstand without breaking.

CNT fibers possess some of the other properties that are beneficial for ballistic armor, such as thermal stability and excellent chemical resistance. The property that really sets them apart from existing ballistic fibers is their electrical conductivity - both aramids and UHMWPE fibers are insulators. This could allow for the creation of ballistic vests that are also smart clothing: armor equipped with biometric sensors, heating elements, or other electrical functionality.

https://blog.dexmat.com/carbon-nanotube-fibers-for-ballistic-armor

Cable batteries

1D cable structures offer high mechanical flexibility. CNTs can be assembled into continuous 1D fibers by using wet or dry spinning techniques. Thus, cable batteries based on CNT fibers with desirable electrochemical and mechanical properties have been developed.
Liu et al.fabricated a cable lithium-ion battery (LIB) with an ultrahigh-energy density of 215 mWh cm^{-3}. CNT fibers were produced from macroscale CNT films, which served as the core of the cable in the center and were wrapped with insulating materials, anode, cathode, and separator layer by layer. The CNT fiber core not only provides high electrical conductivity but also strengthens the mechanical properties of the assembled cable LIB. The cable LIB with a diameter of ~2 mm and a length of ~1200 mm demonstrated high flexibility.

In another study, a facile oxidation step was used to convert Fe catalysts in CNT yarns to electrochemically active Fe_2O_3 nanoparticles, Carbon layers around Fe catalysts were eliminated by partial oxidation because of their relatively lower degree of graphitization. The resulting Fe_2O_3 nanoparticles were distributed homogeneously on CNT surfaces without apparent agglomeration. A cable LIB was demonstrated using the Fe_2O_3/CNT anode coupled with a $LiFePO_4$/CNT cathode. A unique advantage of cable batteries is that they can be further woven into flexible textiles to power lightweight and flexible wearable electronics.

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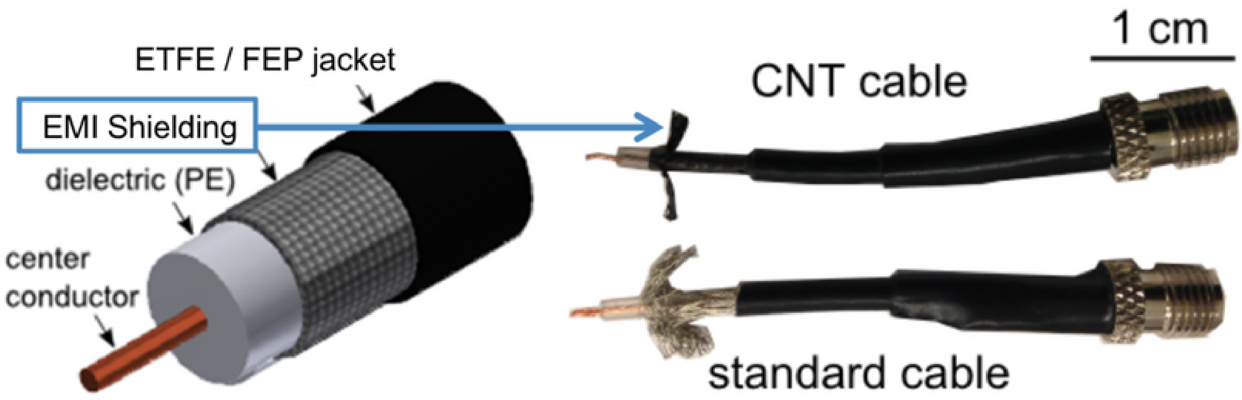
10 Kg/Week

Conductive textile thread

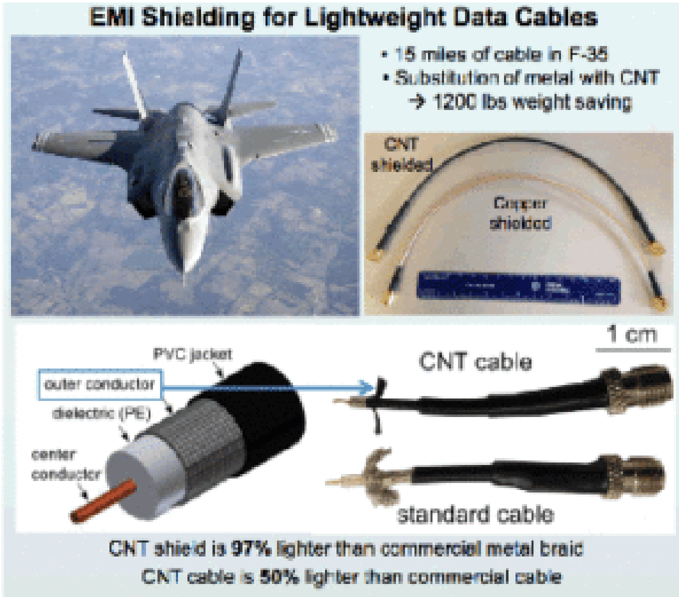
CNT yarn can be handled like a textile thread, it can potentially be combined together with textile yarns to make clothing with complex electronic functionality without sacrificing comfort or weight. Additionally, because they have such a high surface area, CNT yarns are excellent at interfacing electrically with the human body, whether that be through contact with body fluids or through “dry” contact with the skin. This means that they can potentially be used to make smart clothing that monitors the health of the wearer, or tracks movement and muscle contraction.

100 Kg/Week

Carbon Nanotube Fibers and Films



Carbon nanotubes (CNTs) are advancing as the most promising solution for reducing the weight of spacecraft wires. CNTs combine high strength, electrical and thermal conductivity with low density, which makes them ideal for applications where weight reduction is a priority. Compared to a copper wire with the same diameter, a CNT fiber has **6 times higher strength, more than 6 times lower density, and at least 25 times higher flexure tolerance**, all of which are essential qualities for conductors in aerospace applications. The image above shows a standard copper braid cable shield compared to a CNT shield for an RG-316 cable. CNT film/tape shields are 95% lighter than the copper double braid shields while offering comparable shielding effectiveness and insertion loss properties.



The CNT film shielded cables also have the following advantages:

• Overall cable weight reduction of CNT shielded vs. Cu double braid shielded cable without connectors is over 50%.

• CNT film shield is 100 microns thick compared to 500 microns thick Cu double braid shield.

• It is easy to apply CNT film to coaxial cables as well as twisted pair type cables.

• CNT film shielded cables survive at least 1000 flex cycles with a minimum bend radius of at least 7.5X the jacketed cable diameter

Electrical Applications

One immediate application evaluated by the defense industry is the replacement of copper-based 1553 database cables with CNT conductors and shields. The weight savings they offer can be upwards of several pounds, which is an especially significant advantage for space applications, as each pound of payload typically costs upwards of $10,000 to launch into space. Electrical testing has already been conducted to determine the signal integrity loss of CNT conductors and shields and has returned surprisingly good results, showing little signal loss degradation on lengths up to 10–15 feet, which will only improve as the conductivity of CNT materials continues to improve.

In addition to the space market, two helicopter manufacturers in the United States are conducting independent test studies to determine the viability of CNT materials for use in the rotary wing market.

1 Tonne/Week

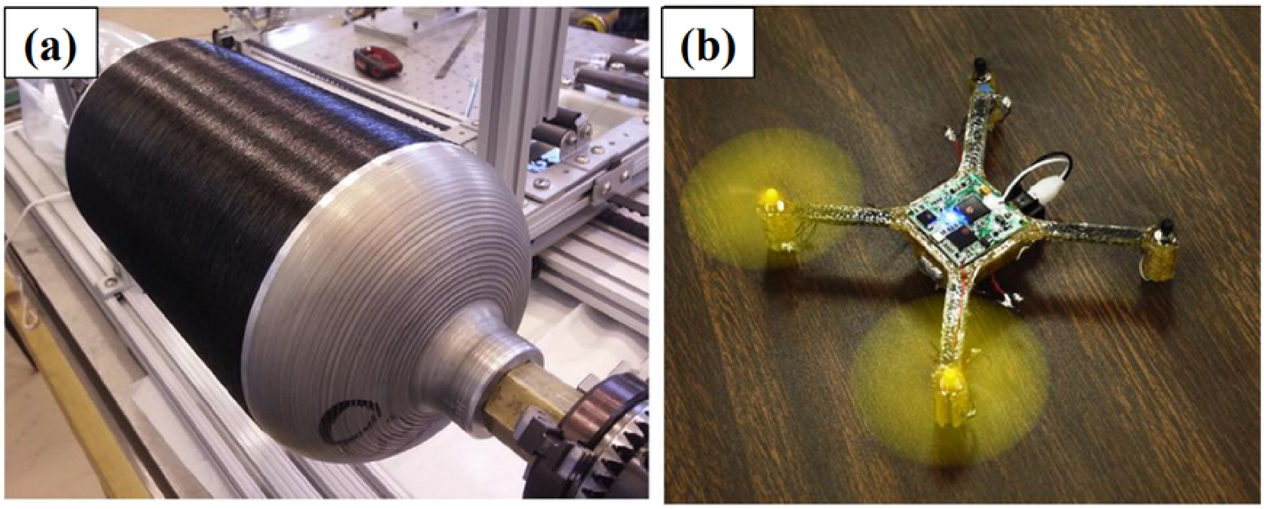
High Strength Composites

Carbon nanotube fibers appear to be a ready component for composite material. It provides strengthening, stiffening, and flexibility that can meet demands for advanced composites. CNT fibers appear to be key material in the aviation, automobile, sports, energy, and defense industries in the near future.

NASA has already successfully built high-performing CNT composite overwrapped pressure vessels (COPVs), and claims through separate research that certain CNT composites have exhibited up to 200 GPa tensile strength, 1,400 GPa modulus, and 20% failure strain — this is compared to a reported 6.9 GPa tensile strength, 324 GPa modulus and 2% failure strain for high-strength carbon fibers like Toray (Tokyo, Japan) T1100GC and Hexcel (Stamford, Conn., U.S.) IM10. The main applications dealing with aerospace that can be immediately implemented are

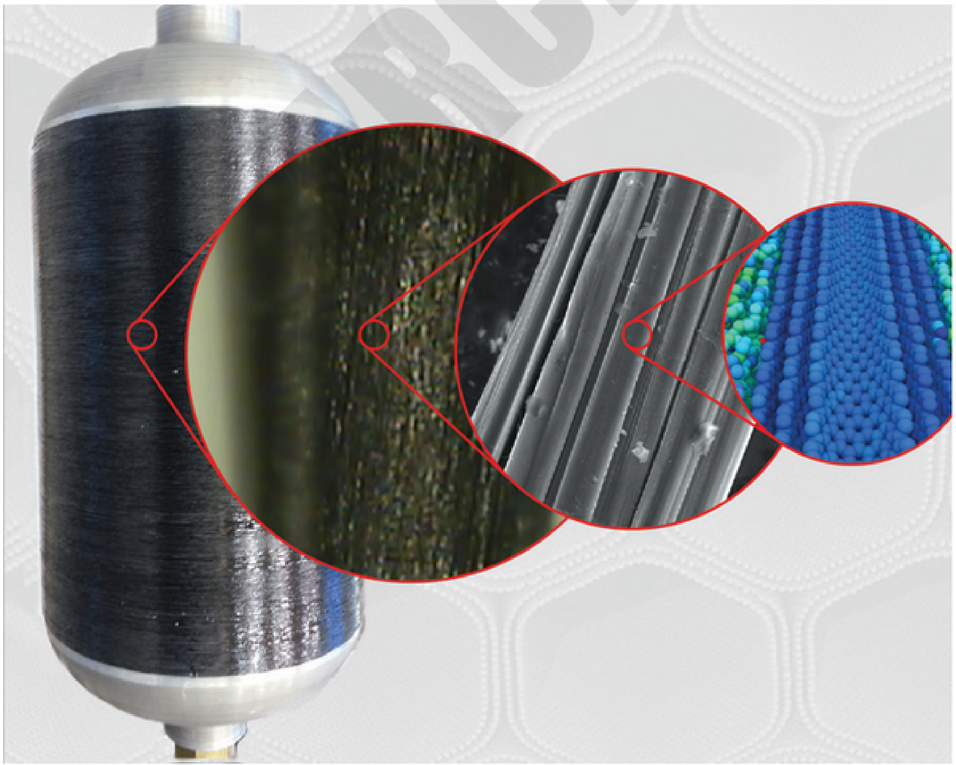
- **Heat Blankets**
- **Sensing devices**
- **Strength and lightweight**
- **EMI shielding**

Recently usage of composite CNT fibers has been reported for composite overwrapped pressure vessels (COPVs). COPVs are used for tension-dominated applications where thin walled liners are wrapped with composites and are commonly used for gas and propellent storage in spacecraft and launch vehicles. Improvement of the strength-to-weight ratio of composites used in COPVs could yield tremendous savings in weight which in turn help in minimizing the mass of launch vehicles and spacecraft.



As shown in the above picture overwrapping of aluminum rings with thermoset CNT yarns, the mechanical properties of the CNT composite overwrapped aluminum rings (CCOARs) were measured under static and cyclic loads at the room, elevated, and cryogenic temperatures. Wrapping of about 10 wt.% of CNT/Epon 828 over Al rings resulted in a ~ 200% increase in hoop tensile properties compared to that of the bare Al ring in addition the composite overwrap sustained load during the stress-rupture cycle without mechanical degradation.

CNT yarns are also been used as feedstock in the latest technologies such as 3D printing which are widely used for the fabrication of geometrically complex parts. Gardner et al reported the usage of CNT yarns as multifunctional feedstock for additive manufacturing. As shown in the Figure a quadcopter frame is manufactured using continuous CNT yarn reinforced polyetherimide (Ultem) by additive manufacturing. The development of printable CNT yarn filament with a high-performance polymer matrix depicts the potential to fabricate tailored components taking advantage of CNT yarn properties.



Demonstration flight article wrapped with carbon nanotube composite. Zoom shows carbon nanotubes used and simulation developed to support process development.

Copper replacement in Motors

Carbon nanotube fibers and yarns have gained the attention of the electric motor and power generation industries due to the incredible combination of properties offered by CNT materials. Carbon nanotube fibers and yarns offer a highly flexible, strong, and lightweight option for motor winding constructions. Carbon nanotubes also offer higher conductivity than copper at the molecular level, although it has not yet been demonstrated that CNT yarns can achieve this level of conductivity on the scale of macroscopic fibers.

Current state-of-the-art CNT fibers have a conductivity that is 15 - 20 % that of copper; considering this, further improvement is needed before CNT fibers can be a competitive material for most types of magnet wire. There may be an advantage to be gained by using CNT fibers in motors that operate at higher frequencies because copper's electrical performance is reduced at higher frequency operation compared to that of CNT fibers.

The flexibility of CNT fibers is vastly superior to copper, being more comparable to that of a textile thread with the ability to survive millions of flex cycles. Combined with its high strength, this level of flexibility can allow for an increase in packing efficiency of motor windings and enable faster, more reliable installation methods to create improved magnet wire constructions. CNT fibers and yarns are also by far the lightest option for a magnet wire, being 9 times lighter than copper wire and 3 times lighter than aluminum wire.

One of the primary drawbacks to using CNT yarns as motor windings is the cost of the material; these fibers are currently one of the higher-priced alternatives to aluminum and copper and are more expensive than gold and silver. As demand for carbon nanotubes fiber increases and advances in production techniques evolve, carbon nanotubes fibers may start to become more of a competitor in the magnet wire space when in terms of price per pound.