Graphene fibers Introduction

Graphene, as the thinnest, hardest, most conductive and new nanometer carbon material, has been praised as "black gold" and "king of new materials" in the industry . Graphene not only has excellent electrical properties (electron mobility up to 200,000 cm2/Vs at room temperature), light weight, good thermal conductivity (5000 W/mK), large specific surface area (2630 m2/g), young's modulu s (1100 GPa) and rupture strength (125 GPa), but also has some unique properties, such as quantum hall effect, quantum tunneling effect, etc . Since 2004, when professor Geim's group at the university of Manchester successfully obtained graphene by mechanical stripping, it has attracted worldwide attention and attracted numerous researchers to pursue the dream of new materials . Graphene can be widely used in lithium ion battery electrode materials, supercapacitors, solar battery electrode materials, thin film transistor preparation, sensors, semiconductor devices, transparent display touch screens and transparent electrodes, etc. (as shown in figure 1).Graphene is combined with ordinary fiber, which has special functions such as antibacterial, anti-mite, anti-heat, anti-cutting, anti-static, anti-ultraviolet, far-infrared heating and conduction cooling.

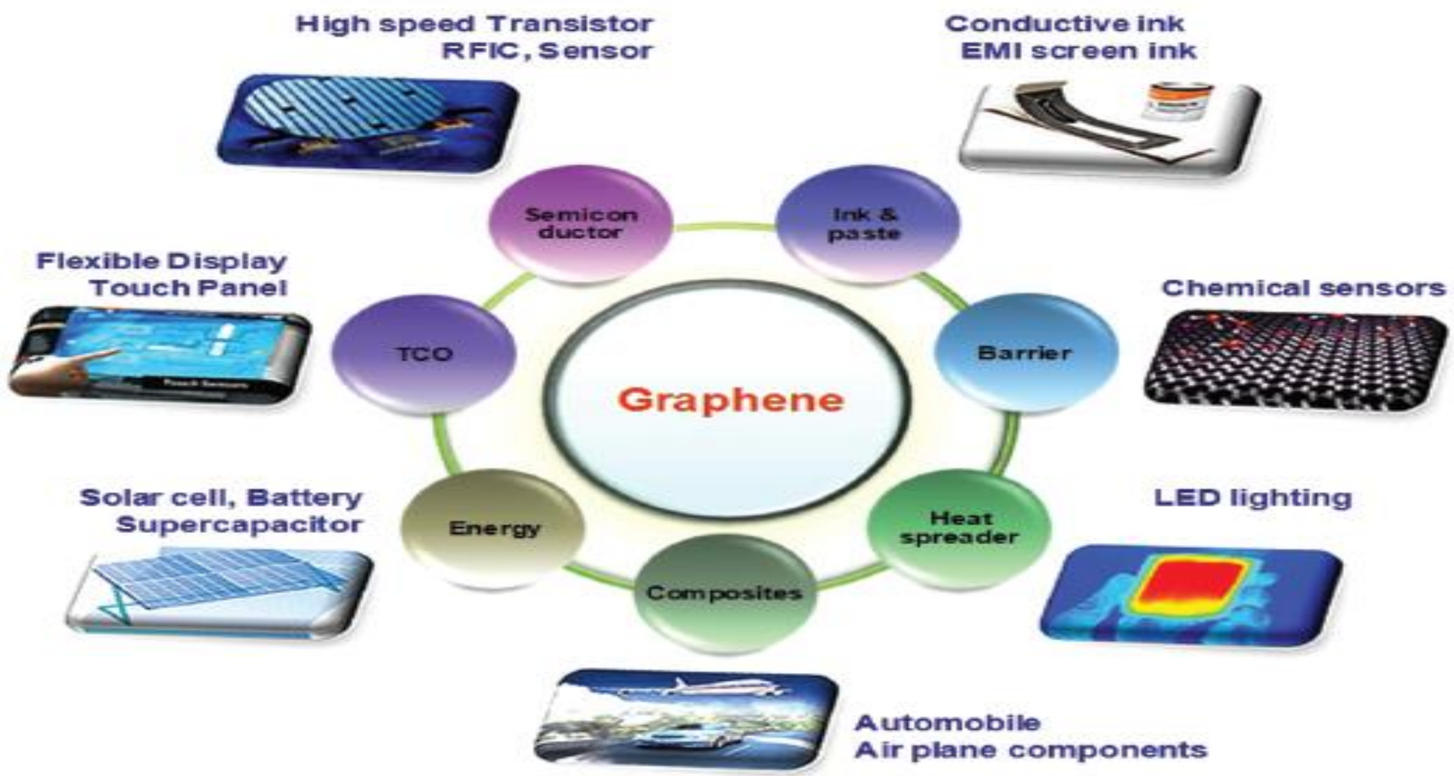


Figure 1 Overview of graphene applications

main varieties of chemical fibers

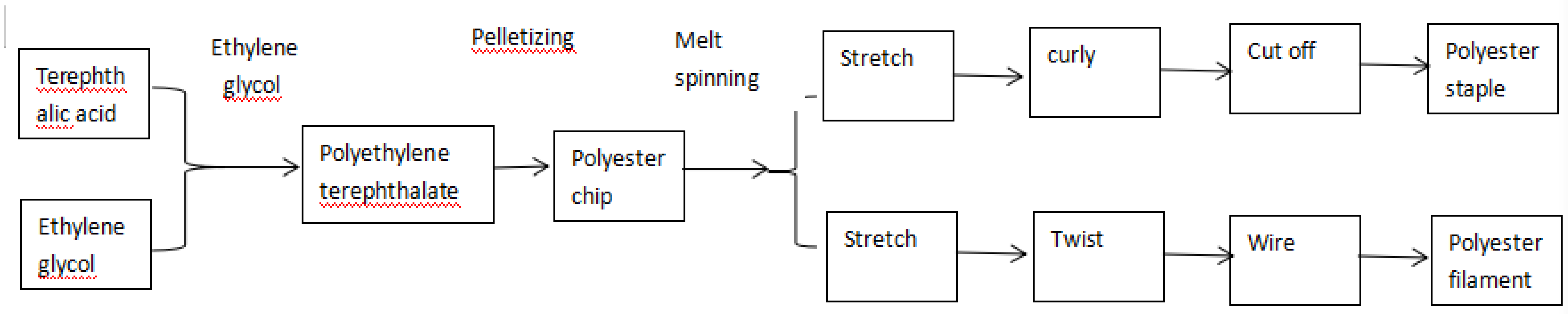
Scientific name		Trade name	English abbreviation	Application area
Department of polyester	Poly (ethylene terephthalate) polyester fiber	Polyester	PET	Clothing, bedding, all kinds of decorative fabrics, defense special fabrics and other textiles
Aliphatic polyamides	Polyamide 6 fiber nylon6	Nylon 6	PA6	Clothing, silk, umbrella, fishnet wire, curtain wire, etc
	Polyamide 66 fiber nylon66	Polyamide 66	PA66	Automobile, machinery industry, electronics and other fields
Polyacrylonitrile system	Polyacrylonitrile fiber acrylic	acrylic fibers	PAN	Clothing, apparel and other fields
Polyvinyl alcohol	Polyvinyl acetal fiber vinylon	vinylon	PVA	Knitted fabrics such as coats, cotton sweaters, pants, sweaters, etc
Department of polyolefin	Polypropylene fiber propylene	polypropylene fibe r	PP	Areas such as carpet and industry

	ultra high molecular weight polyethylene fi ber	polyethylene fibre	UHMWPE	Protective clothing, helmet, bulletproof material, rope etc
Chlorine fiber	Polyvinyl chloride fibre	polyvinyl chloride fibre	PVC	Stage curtains, upholstery fabrics, overalls, etc
Polyurethane system	Spandex polyurethane fiber	spandex	PU	Clothing, elastic, health care products, etc
Aromatic polyamides	Polyphlorodibenzoyl m-phenylenediamine fiber nomex	Fanglun 1313	PMIA	High temperature conveyor belt, transfer printing blanket, automotive hose, etc
	Polyp-p-benzoyl p-phenylenediamine fiber kevlar	Fanglun 1414	PPTA	Tire cord, rubber reinforcement materials, special ropes and body armor
regenerated cellulose fib	Viscose	viscose acetal fibr	/	Underwear, textile and other

re		e		fields

Polyester and its production technology

1. Manufacturing technique



Polyester is the trade name of polyethylene terephthalate fiber, which is called triton in the UK and dacron in the us. Advantages: is a late development of synthetic fiber, but because of its mechanical strength, wear resistance, acid and alkali resistance, not easy to mold and decay, chemical stability and other characteristics, nearly half a century of rapid development, output has ranked the first synthetic fiber. Polyester can be made into filament or staple fibers, with almost half the output.

Polyester is made from terephthalic acid (TPA) and ethylene glycol (EG).Polyethylene terephthalate can be synthesized by chemical synthesis. The synthetic polyethylene terephthalate is cast into a strip and cut into granules to form colorless and transparent solid particles, usually called polyester resin or polyester chips, which can be dried and then spun. Polyester is fusioned at a temperature of 285~290℃.The polyester melt extrudes from the holes in the spinneret to form a stream of mucus, which cools in the air to form the primary fiber. The processing of polyester varies with the production quality. When producing polyester filament yarn, it is necessary to twist through drafting, heat setting, winding and packaging. Polyester staple fiber processing generally includes cluster, drafting, oiling, crimping, heat setting, cutting, packaging and so on.

2 Properties of polyester

2.1 Physical properties

2.1.1. Color: usually milky white with mercerization. For matte products, TiO_2 can be added before spinning; for pure white products, whitener should be added; for colored silk, pigment or dye should be added to the spinning melt.

2.1.2. Surface and cross section shape: the surface of conventional polyester is smooth, the cross section is approximately round, if the opposite spinneret hole can be made into a variety of special cross section shape of fiber.

2.1.3. Density: the density of polyester is 1.333g/cm^3 when it is completely amorphous; At complete crystallization, the density is 1.455 g/cm^3.Polyester usually has high crystallinity and density of 1.38-1.40g /cm^3, similar to wool (1.32g /cm^3).

2.1.4. Moisture recovery rate: in standard condition, the moisture recovery rate of polyester is 0.4%, lower than that of acrylic (1%-2%) and acrylic (4%).Due to the low hygroscopicity of polyester, its wet strength decreases less and the fabric can be washed and worn well. But the static electricity phenomenon is serious when processing and wearing, fabric permeability and hygroscopicity is poor. Polyester usually has high crystallinity and density of 1.38-1.40g /cm^3, similar to wool (1.32g /cm^3).

2.1.5. Thermal properties: softening point Ts of polyester is 230-240°, melting point Tm is 255-265°, decomposition point Td is about 300°, polyester can burn in the fire, crimp, and melt into beads, black smoke and aroma. In dyeing and finishing, the temperature should be controlled above the glass transition temperature and below the softening point temperature. The heat setting temperature in the printing and dyeing factory is generally 180 ~ 220℃, and the temperature of dyeing, finishing and ironing of garments should be lower than the heat setting temperature, otherwise the setting effect will be destroyed due to the intensification of molecular chain activities. Due to the low hygroscopicity of polyester, its wet strength decreases less and the fabric can be washed and worn well. But the static electricity phenomenon is serious when processing and wearing, fabric permeability and hygroscopicity is poor. Polyester usually has high crystallinity and density of 1.38-1.40g /cm^3, similar to wool (1.32g /cm^3).

2.1.6. Light resistance: the light resistance of polyester is second only to that of acrylic fiber. Polyester only has a strong absorption band in the light wave region at 315nm, so its strength only loses 60% after sunlight exposure for 600h, which is similar to that of cotton fiber.

2.1.7. Electrical properties: polyester has poor conductivity due to its low hygroscopicity. The dielectric constant is 3.0-3.8 in the range of -100~160°, making it an excellent insulator.

2.2 mechanical property

2.2.1 High strength: the dry strength is 4~7 dN/ Tex, and the strength does not decrease in wet state. Under proper heat treatment conditions, the higher the tensile degree of polyester in the spinning process, the higher the orientation of fiber, the higher the breaking strength of fiber, and the lower the elongation at break. Conversely, it is possible to obtain fibers with low strength and high elongation. In other words, different kinds of fibers with high strength and low elongation or low strength and high elongation can be made by changing the stretching and heat treatment conditions.

2.2.2 Elongation: moderate, elongation is generally 20%-50%。

2.2.3 High modulus: in large varieties of synthetic fibers, the initial modulus of polyester is the highest, and its value can be as high as 14-17 GPa. Therefore, the size of polyester fabric is stable, not deformed and not out of shape.

2.2.4 Resilience: very good, polyester resilience is close to wool, when the elongation rate of 5%, after removing the load elongation can almost completely recover, so polyester fabric is more wrinkle resistance than other synthetic fabrics.

2.2.5 Wear resistance: the wear resistance of polyester is second only to nylon and more than other synthetic fibers.

2.3 Chemical stability

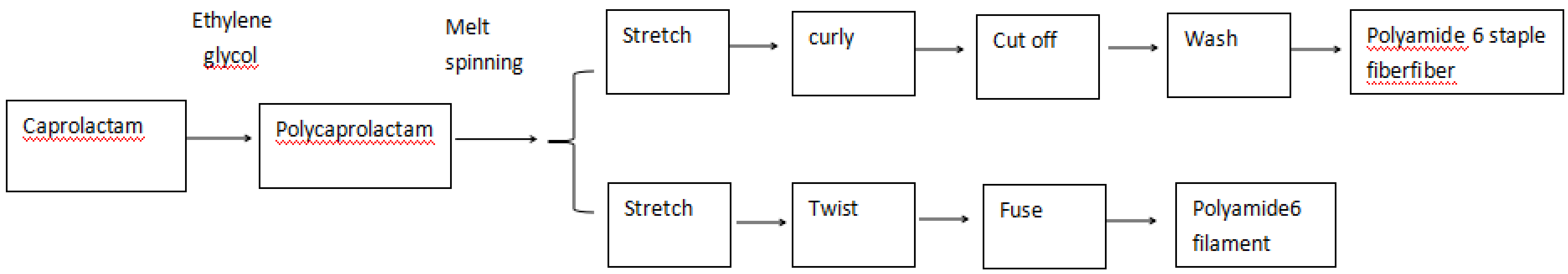
2.3.1 Acid resistance: polyester is stable to acid. After soaking for 24 h at 100° in 5% hydrochloric acid solution or 72 h in 70% sulfuric acid solution at 40°, its strength has no loss, but it cannot resist the long-term action of concentrated nitric acid or concentrated sulfuric acid at room temperature.

2.3.2 Alkali resistance: polyester esters on large molecules by the role of alkali hydrolysis, in the room temperature or high temperature dilute alkali, can destroy the fiber, only the low temperature dilute alkali is more stable.

2.3.3 Solvent resistance: generally has a strong resistance to non-polar organic solvents, polar solvents at room temperature also has a strong resistance.

Nylon and its production technology

1、Manufacturing technique



Polyamide fiber is one of the main varieties of synthetic fiber, which is called polyamide fiber. Foreign names are nylon, nylon, capron and so on. Nylon is the first synthetic fiber to achieve industrial production of the variety. Nylon production is mainly filament, nylon filament by stretching and twisting, can be made into stretch silk. The production of stretch wire adopts twisting method, nylon filament wire in a machine once complete twisting, heat setting, untwisting three processes, the production of stretch wire. Stretch yarn made of stretch silk has high elasticity and wear resistance. It is mainly used in knitwear, such as gloves, socks, sportswear and stretch shirts.

2 Properties of nylon

2.1 physical properties

2.1.1 Density: the density of polyamide fibers is relatively low. Among all fibers, the density is only higher than that of polypropylene and polyethylene fibers.

2.1.2 Optical properties: polyamide fiber has optical anisotropy, and the birefringence number varies greatly with the stretching ratio. After stretching, polyamide 66 has a longitudinal refractive index of 1.582 and a transverse refractive index of about 1.519.Polyamide fiber 6 has a longitudinal refractive index of 1.580 and a transverse refractive index of about 1.530.Polyamide fibers have high surface gloss and usually need to add matting agent TiO_2 for matting before spinning.

2.1.3 Light resistance: the light resistance of polyamide fiber is poor, in a long time of sunlight and ultraviolet light irradiation, the intensity of the decline, yellow color, usually in the fiber to add light resistance agent, can improve the light resistance.

2.1.4 Heat resistance: the heat resistance of polyamide fiber is not good enough. After 5h at 150°, the fiber will turn yellow and its strength and elongation will decrease. The thermal stability of polyamide 66 is better than that of polyamide 6.Polyamide fiber has good low temperature resistance, even at -70°, the elasticity of little change.

2.1.5 Electrical properties: low dc conductivity of polyamide fiber, easy to produce static electricity in the process.

2.1.6 Hygroscopicity: the hygroscopicity of polyamide fiber is lower than that of natural fiber and artificial fiber. The hygroscopicity of nylon 6 is slightly higher than that of nylon 66.

2.2 Mechanical property

2.2.1 Breaking strength: polyamide fiber has high strength due to its high crystallinity, orientation and intermolecular force. Generally, the breaking strength of polyamide fiber filament for textile is 4.4~5.7 cn/dtex. The moisture absorption rate of polyamide fiber is low, and its wet strength is about 85-90% of that of dry fiber.

2.2.2 Elongation at break: the elongation at break of polyamide fibers varies with varieties, with strong filaments approximately 20-30% and ordinary filaments 25-40%.Polyamide 6 staple fibers are a little higher about 40-50%

2.2.3 Initial modulus: the initial modulus of polyamide fibers is lower than that of most other fibers and therefore tends to deform during use. Under the same conditions, the initial modulus of polyamide 66 fibers is slightly higher than that of polyamide 6 fibers, close to that of wool and polyacrylamide fibers.

2.2.4 Elasticity: polyamide fiber has excellent elasticity: polyamide 6 filament has an elastic recovery rate of 99% at 10% elongation, while polyester filament has an elastic recovery rate of 67% at the same elongation, while viscose filament has an elastic recovery rate of only 32%.

2.2.5 Abrasion resistance: polyamide fiber is the fiber with the best abrasion resistance among all textile fibers. Its abrasion resistance is 10 times of cotton, 20 times of wool and 50 times of viscose fiber

2.2.6 Resistance to multiple deformation or fatigue: due to the good elasticity of polyamide fiber, its knotting strength and resistance to multiple deformation is very good. The knotting strength of ordinary polyamide filament is 80-90% of the breaking strength, which is higher than other fibers. Polyamide fibers deform nearly as much as polyester, but more than all other chemical fibers and natural fibers. Under the same experimental conditions, the resistance of polyamide fibers to this deformation is 7-8 times higher than that of cotton fibers, and dozens of times higher than that of viscose fibers.

2.3 Chemical properties

2.3.1 Dyeability: polyamide fibers are easier to stain than natural fibers and synthetic fibers, although not as dyeable as synthetic fibers.

2.3.2 Acid and alkaline resistance: polyamide fiber is alkali resistant, but poor acid resistance and oxidation resistance, good resistance to reducing effects.

一、Main quality control indicators of graphene fiber:

1、Linear density: thickness of graphene fiber, also known as fiber size, is divided into three units: denier (D), Tex (Tex) and Dtex (Dtex). The conversion relation of these three is as follows:

$$1\ \text{tex} = 10\ \text{Dtex}$$

$$1\ \text{tex} = 9\ \text{D}$$

$$1\ \text{D} = \frac{10}{9}\ \text{Dtex} \approx 1.1\ \text{Dtex}$$

Note :(1) the linear density of graphene nylon DTY is 70D ≈ 77 Dtex = 7.7 Tex.

(2) general description of fiber: 70D/24F means that the fiber has a thickness of 70D and each yarn has 24 strands.

2、Fracture strength: refers to the tensile fracture strength per unit fineness in cn/tex and is read as per centimeter . The calculation formula is as follows:

$$\text{Breaking strength} = \frac{\text{breaking force}}{\text{Linear density}}$$

Note :(1) the DTY strength of graphene nylon is about 4 cn/tex, and the strength of high-strength graphene nylon is about 8 cn/tex.

(2) in general, the composite fiber strength obtained by adding colored masterbatch to the fiber will decrease compared with the original fiber, while the composite fiber strength will not decrease after adding graphene masterbatch to nylon or polyester, but will increase or remain unchanged.

3. Elongation at break: refers to the ratio of elongation length to original length when the fiber is stretched to fracture, expressed as a percentage, which refers to the elastic size of the fiber.

二、Functional indicators of graphene fibers:

1. Antibacterial performance: it is mainly expressed by the bactericidal rate (refers to the ability to kill bacteria instantly) or the bactericidal rate (refers to the ability to inhibit the growth of bacteria for a long time).The antibacterial properties of the fibers were mainly tested against three bacteria, staphylococcus aureus, escherichia coli and candida albicans .This is because bacteria are divided into gram-positive bacteria and gram-negative bacteria, staphylococcus aureus is the representative of gram-positive bacteria, escherichia coli is the representative of gram-negative bacteria .Candida albicans is a representative fungus.

The assessment criteria are as follows:

The bactericidal rate was > 95%, and the antibacterial effect was significant.

50% < fungicidal rate < 95%, the sample antibacterial effect is obvious;

The bactericidal rate is less than 50%, and the antibacterial effect of the sample is not obvious.

Note: the fungicidal rate or bacteriostatic rate of the graphene fiber of our company can reach 99.9%, indicating that it has excellent antibacterial effect. Another expression is the antibacterial activity value. The antibacterial activity value is greater than 3, indicating that it has excellent antibacterial effect.

2. Anti-mite performance: there are many kinds of mites, and we mainly tested the resistance of fibers to dust mites. Because the living conditions of dust mites are similar to human beings, there are a large number of dust mites in daily life, such as mattresses, blankets, plush toys, quilts, etc., and dust mites are obviously harmful to human bodies, causing asthma, allergic rhinitis, eczema and other diseases.

The evaluation criteria for mite control performance of national standard are:

When the inhibition rate was ≥95%, the samples had strong anti-mite effect.

When the inhibition rate was ≥80%, the samples had strong anti-mite effect.

The samples had anti-mite effect when the inhibition rate was ≥60%.

Note: the inhibition rate of graphene fiber in our company reached 94.90%, indicating that it has good anti-mite effect.

3. UV resistance: mainly represented by UV protection coefficient UPF, uv-a barrier and uv-b barrier.

The American standard uv performance evaluation criteria are as follows:

When UPF≥40, the sample has excellent uv protection performance.

When 25≤UPF≤39, the samples have good uv protection performance.

When 15≤UPF≤24, the sample has good uv protection performance.

Note: the UPF of our graphene fiber has reached 107.5, the uv-a barrier rate has reached 98.85, and the uv-b barrier rate has reached 99.18, indicating that it has excellent UV protection performance.

4. Far-infrared properties: fibers with far-infrared properties have the effect of warmth and health care, because graphene fibers emit 6-14 feet of far-infrared wavelength close to human body, which can effectively activate somatic biomolecules, improve blood circulation, and achieve the effect of warmth and health care.The main evaluation indexes are far infrared emissivity and far infrared radiation temperature rise.

The evaluation criteria in national standards are: Far-infrared emissivity ≥0.88

Far-infrared radiation temperature rise ≥1.4℃

Note: the far infrared emissivity of our graphene fibers is 0.89, and the radiation temperature rise is 2.8℃.

5. Food grade: there are seven items in total, which refer to whether the concentrations of harmful substances that can be dissolved after dissolving in different solvents of graphene fibers can meet the standards.

Note: our graphene nylon can meet the food grade standard.

The evaluation criteria in national standards are:

6. Antistatic performance: the antistatic performance of graphene fiber is in the development stage, and the experimental results have reached the standard, but the data is not stable enough.

Polyamide (PA) - graphene composite fiber

Product name	Test content	Test item	Test criteria	Test organization	Test result	Conclusion	Remark
GO-PA6	antibacterial test	staphylococcus aureus	AATCC100: 2012	ITS	sterilizing rate ＞ 99.9%	remarkable antibacterial effect	The bactericidal rate was > 95%, and the antibacterial effect of the samples was significant 50% < fungicidal rate < 95%, the sample antibacterial effect is obvious The bactericidal rate is less than 50%, and the antibacterial effect of the sample is not obvious
		escherichia coli			sterilizing rate ＞ 99.9%		
		Candida albicans			sterilizing rate ＞ 99.9%		

GO-PA6 Cloth	Uv test	Uv protection coefficient UPF	AATCC183: 2004	TUV-SUD	107.51	excellent uv protection	When UPF≥40, the sample has excellent uv protection performance When 25≤UPF≤39, the samples have good uv protection performance When 15≤UPF≤24, the sample has good uv protection performance
		Uv-a blocking rate			98.85		
		UV - B blocking rate			99.18		
GO-PA6	Far-infrared test	Far infrared emissivity	GB/T30127: 2013	Wuhan quality inspection institute	0.89	far-infrared calorific property	When far infrared emissivity ≥0.88. And the far-infrared radiation temperature rise ≥1.4℃ Textiles have
		Far infrared radiation heats up			2.8		

							far-infrared calorific properties
GO-PA6 Cloth	Anti mite test	dust mite	GB/T24253	TUV-SUD	94.9%	strong anti-mite effect	When the inhibition rate ≥95%, the samples had a stronger anti-mite effect When the inhibition rate was ≥80%, the samples had strong anti-mite effect The samples had anti-mite effect when the inhibition rate was ≥60%

（PET）- Graphene composite fiber

Product name	Test items	Test item	Test criteria	Test House	Test result	Conclusion	Remark
GO-PET	antibacterial test	MRSA	ISO20743:2013	Micro spectrum technology	Antimicrobial activity value ＞5.9	remarkable antibacterial effect	The antibacterial activity value was > 3, and the antibacterial effect of the sample was significant. 1.3 < antibacterial activity value < 3, the antibacterial effect of the sample was obvious; 0.3 < antibacterial activity value < 1.3, the sample has a slight antibacterial effect
		escherichia coli			antibacterial activity value＞6.3		
GO-PET	Far-infrared test	Far infrared emissivity	GB/T30127:2013	Wuhan inspection	0.89	far-infrared calorific property	When far infrared emissivity ≥0.88

		Temperature raises		institute	2.6		Moreover, when the temperature rise of far-infrared radiation is ≥1.4℃, the product is prevented from having far-infrared calorific property

Graphene Antibacterial Mechanism

Graphene is a two-dimensional carbon nanomaterial consisting of carbon atoms with sp2 hybridized orbitals forming a hexagonal honeycomb lattice. Graphene and its derivatives, such as graphene (G), GO (GO) and reduced GO (rGO), have unique two-dimensional surface chemical structures and sharp physical edge structures, among which GO is the most studied class of antibacterial and antiviral graphene materials [1,2].According to reports, graphene material antibacterial antiviral ability mainly based on the following several mechanisms of hybrid synergy: 1) physical cutting, Nano knife (Nano - Knives), also known as graphene material physical sharp edge can be effectively cutting surface of bacteria, viruses, destroy the cell wall and membrane structure, caused by intracellular material leakage and metabolic disorders, eventually killing bacteria, virus, is one of the main antibacterial antiviral mechanism of graphene materials [3, 4];2) Insertion and Extraction of membrane surface components. Graphene materials have a large specific surface area and hydrophobicity, which can effectively adsorb phospholipid molecules on the surface of bacteria and viruses by contact or Insertion, thus destroying their cell membrane structure and causing bacterial virus death [5].3) physical capture (Wrapping). Graphene materials isolate bacteria from surrounding media by Wrapping, thus blocking their proliferation and exerting bacteriostatic effect [6].4) oxidative stress (ROS). During contact with bacteria, both surface defects and sharp edge structures of graphene can induce bacteria to produce reactive oxygen species, thus leading to normal physiological and metabolic disorders and bacterial death [7,8](figure 1).In addition to the above main antibacterial and antiviral mechanisms, charge conduction is also an important antibacterial mechanism of graphene, which conducts bacterial surface charge through graphene, destroys the physiological activities and functions of the cell membrane, causes bacterial metabolic disorders, and thus promotes bacterial death [9].

Since 2010, based on the good antibacterial properties of graphene, a large number of researches on graphene and its composite antibacterial materials have been reported, further confirming the great potential of graphene materials in antibacterial applications. At the same time, as a new application direction, the antiviral effect of graphene materials has also been gradually paid attention to and shown good antiviral application ability [10].At present, specific antibacterial and antiviral properties of graphene materials are still controversial [11].According to the report and enhope's own experimental antibacterial test results, the antibacterial properties of some graphene materials show certain selectivity to different types or types of bacteria or viruses, which are manifested as high resistance to some bacteria, low resistance to some bacteria and even promotion of their proliferation [12].This may have something to do with the physical and chemical properties of the graphene materials used and the characteristics of the bacteria themselves. In addition, there are many kinds of graphene in the laboratory and the market at present, and the quality and performance parameters are very different, which have greatly hindered the development of antibacterial and antiviral application of graphene materials. Therefore, a lot of research work is still needed to further improve and clarify the specific application technology of graphene materials.

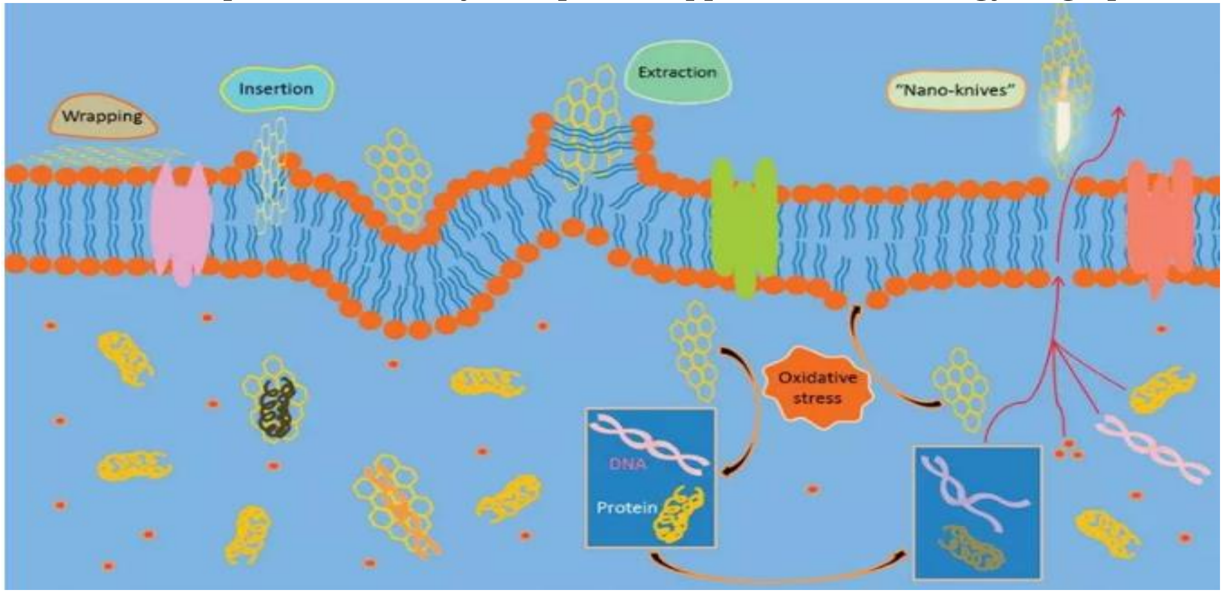


Figure 1. Main antibacterial mechanisms of graphene

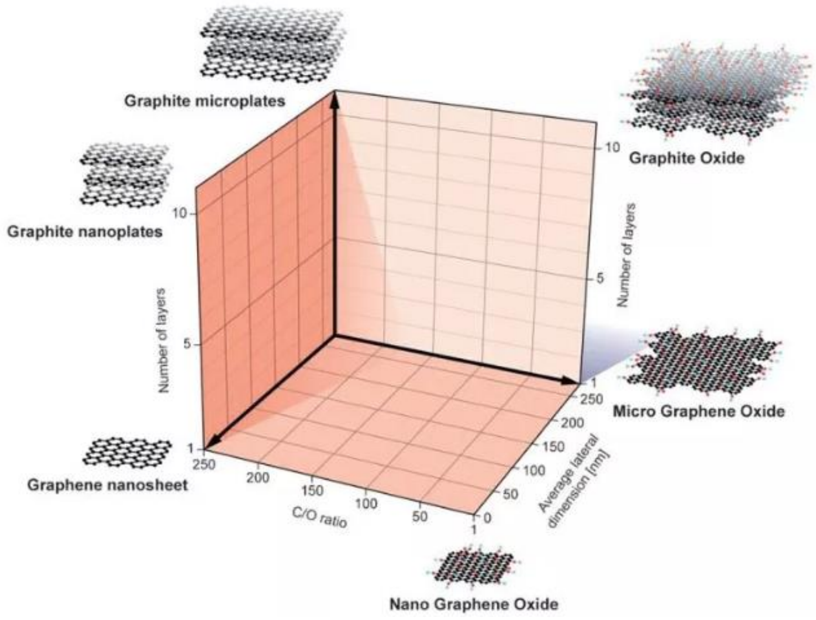


Figure 2. Graphene physical and chemical factors influencing antibacterial properties of graphene materials

The antibacterial and antiviral properties of graphene materials are affected by the physical and chemical l properties, biological factors and abiotic factors of graphene materials. The physical and chemical properties of graphene materials are mainly influenced by the number of graphene layers, transverse size and chemical composition (carbon-oxygen ratio) [13] (figure 2).The results showed th at the lower the number of layers of graphene, the stronger the antibacterial ability, which may be related to the increase of specific surface area of graphene, the increase of defects, and the stronger edge cutting effect [14].By mixing GO with escherichia coli of different transverse sizes, Chen yuan et al. found that the antibacterial effect of GO on escherichia coli increased with the increase of the transverse size of GO, which was related to the more effective capture of bacteria by large size GO [15].However, the increased transverse size of the graphene material has the potential to further weaken the cutting effect of the graphene edge on bacteria and viruses, thus affecting the actual killing effect. Fan lizhen et al. studied the antibacterial effect of graphene materials with different surface carbon/oxygen ratios on e. coli, and the results showed that the higher the oxygen content, the stronger the antibacterial ability [16].The structure and physiological conditions of bacteria and viruses themselves also affect the antibacterial ability of graphene materials. Studies have shown that the antibacterial performance of graphene materials against gram-positive staphylococcus aureus is better than that of gram-negative e. coli, which may be related to the outer membrane structure characteristics of gram-positive and gram-negative bacteria [17].External conditions, such as dispersion medium, polymer material and surface charge, will affect the antibacterial and antiviral ability of graphene materials. In the medium dispersion medium, biomolecules bind and coat the surface of graphene, thus blocking the antibacterial effect of contact between graphene and bacteria to some extent, thus weakening the antibacterial property of graphene materials [18].

Qiangsheng graphene technology co., ltd. has independent intellectual property rights for the production of graphene technology, which can prepare a variety of graphene and its derivatives with different transverse sizes, layers and surface chemical composition, including graphene, go, modified go, etc. At the same time, based on existing graphene materials, the company further developed a series of graphene composite fiber products. Based on the above graphene raw materials and composite fiber technology, it has good antibacterial properties by referring to the national/international standards for antimicrobial testing.

References

1）绍文尧，闫梦文，谢全灵。氧化石墨烯抗菌机理研究进展。化工技术与开发。2016，10：32-39.

2）H.E. Karahan, Y. Wang, W. Li, F. Liu, L. Wang, X. Sui, M.A. Riaz, Y. Chen., Antimicrobial graphene materials: the interplay of complex materials characteristics and competing mechanisms. Biomaterials Science. 2018, 6:766-773.

3）S. Ye, K.Shao, Z. li, N. Guo, Y. Zuo, Q. Li, Z. Lu, L. Chen, Q. He, H. Han., Antiviral Activity of graphene Oxide: How Sharp Edged Structure and Charge Matter. ACS Applied Materials & Interfaces. 2015, 7:21571-21579.

4）V. Palmieri, M. Papi, C. Conti, G. Ciasca, G. Maulucci, M.D. Spirito., The future development of bacteria fighting medical devices: the role of graphene oxides. Expert Review of Medical Devices. 2016, 11: 1013-1019.

5）V.T.H. Pham,V.K. Truong, M.D.J. Quinn, S.M. Notley, Y. Guo, V.A. Baulin, M.A. Kobaisi, R.J. Crawford, F.P. Ivanova., Graphene Induces Formation of Pores that Kill Spherical and Rod-Shaped Bacteria. ACS Nano. 2015, 8: 8458-8467.

6）F. Perreault, A.F.D. Faria, S. Najati, M. Elimelech., Antimicrobial Properties of Graphene Oxide nanosheets: Why Size Matters. ACS Nano. 2015, 7: 7226-7236.

7）S. Liu, T.H.Zeng, M. Hofmann, E. Burcombe, J. Wei, R. Jiang, J. Kong, Y. Chen., Antibacterial Activity of Graphite, Graphite Oxide, Graphene Oxide, and Reduced Graphene Oxide: Membrane and Oxidative Stress. ACS Nano. 2011, 9: 6971-6980.

8）S.Gurunathan, J.W. Han, A.A. Dayem, V. Eppakayala, M.R. Park, D.N. Kwon, J.H.Kim., Antibacterial activity of dithiothreitol reduced graphene oxide. Journal of Industrial and Engineering Chemistry. 2013, 19: 1280-1288.

9）J. Li, G. Wang, H. Zhu, M. Zhang, X. Zheng, Z. Di, X. Liu, X. Wang., Antibacterial activity of large-area monolayer graphene film manipulated by charge transfer. Scientific Reports. 2014, 4: 4359.

10）A.R. Deokar, A.P. Nagvenkar, I. Kalt, L. Shani, Y. Yeshurum, A. Gedanken, R. Sarid.,Graphene-Based “Hot Plate” for the Capture and Destruction of the Herpes Simplex Virus Type 1. Bioconjugate Chemistry. 2017, 28: 1115-1122.

11）H.M. Hegab, A. ElMekawy, L. Zou, D. Mulcahy, C.P. Saint, M.G. markovic., The controversial antibacterial activity of graphene –based materials. Carbon. 2016, 105: 362-376.

12）O.N. Ruiz, K.A.S. Fernando, B. Wang, N.A. Brown, P.G. Luo, N.D. Mcnamara, M. Vansness, Y.P. Sun, C.E. Bunker., Graphene Oxide: A Nonspecific Enhancer of Cellular Growth. ACS Nano. 2011, 10: 8100-8107.

13）H.E. Karahan,C. Wiraja, C. Xu, J. Wei, Y. Wang, L. Wang, F. liu, Y. Chen., Graphene Materials in Antimicrobial Nanomedicine: Current status and Future Perspectives. Advanced Healthcare Materials. 2018, 7: 1701406.

14）J. Qiu, H.Geng, D. Wang, S. Qian, H. Zhu, Y. Qiao, W. Qian, X. Liu., Layer-Number Dependent Antibacterial and Osteogenic Behaviors of graphene Oxide Electrophoretic Deposited on Titanium. ACS Applied Materials & Interfaces.2017, 9: 12253-12263.

15）S. Liu, M. Hu, T.H. Zeng, R. Wu, R. Jiang, J. Wei, L. Wang, J. Kong, Y. Chen., Lateral Dimension-Dependent Antibacterial Activity of Graphene Oxides Sheets. Langmuir.2012, 28: 12364-12372.

16）M.H. Wang, Q. li, X. Li, Y. Liu, L.Z. Fan.,Effect of oxygen-containing functional groups in epoxy/reduced graphene oxide composite coatings on corrosion protection and antimicrobial properties. Applies Surface Science. 2018, 448: 351-361.

17）O. Akhavan, E. Ghaderi., Toxicity of Graphene and Graphene Oxide Nanowalls Against Bacteria. ACS Nano. 2010, 10: 5731-5736.

18）L. Hui, J.G. Piao, J. Auletta, K. Hu, Y. Zhu, T. Meyer, H. Liu, L. Yang., Availability of the Basal Planes of graphene Oxide Determines Whether It Is Antibacterial. ACS Applied Materials & Interfaces. 2014, 6: 13183-13190.