Material Preference Analysis of Highly Thermally Conductive Flexible Substrates Based on Material Ethics

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ABSTRACT
With the development of space technology and the civil economy, society is placing higher demands on flexible substrates. In this paper, from the perspective of material ethics in engineering design, the idea of engineering ethics is implemented in material preferences and green material practices are observed in the experimental process. The most suitable materials for making high thermal conductivity flexible substrates were identified through experimental analysis and comparison, and preliminary samples of high thermal conductivity flexible substrates were finally produced. This paper demonstrates the importance of material ethics in engineering design and can effectively address the negative effects of material mixing, while exploiting the flexibility and thermal conductivity of graphene-based polyimide. It was concluded that rGO is the most suitable raw material for highly thermally conductive flexible substrates, and the process was chosen to make sandwich samples of graphene and polyimide by hot pressing technology.

Keywords: *engineering ethics, graphene, high thermal conductivity, flexibility*

1. INTRODUCTION

1.1. Background of research on high thermal conductivity flexible substrates.

(1) Preparation and performance study of high thermal conductivity polymer matrix composites. New highly thermally conductive polymer-based composites were prepared using aluminium oxide (Al_2O_3), graphene and boron nitride (BN) nanosheets as thermally conductive fillers and epoxy resin and polyvinylidene fluoride (PVDF) as the matrix [1].

(2) Preparation of graphene-based flexible thermally conductive materials and study of their thermal conductivity. Graphene oxide, which has the best thermal conductivity at present, was used as the base material, and carbon fibres (CF) and carbon nanotubes (CNTs) were used as additive materials for the film [2].

1.2. Research themes and specific contents

The aim of this paper is to develop a flexible substrate with excellent thermal conductivity for the heat dissipation of electronic components such as aerospace. The performance of a highly thermally conductive flexible substrate is inextricably linked to its materials and processes.

The research in this paper mainly covers the following aspects: (1) Exploring the process of combining graphene and polyimide for moulding. (2) Fabrication of substrates using different processes and measurement of their performance data. (3) To analyse the effect of the manufacturing process on the properties and to investigate the relevant patterns.

1.3. Research significance

(1) Demand for civil electronic products. A major core technical problem of flexible display is the flexibility of the substrate and thermal performance protection, the development of high thermal conductivity of the flexible substrate has become a must in the field of technology.

(2) Aerospace needs. In order to meet the heat dissipation requirements of high-power devices, lightweight, highly thermally conductive materials with good mechanical properties are receiving increasing attention.

2. ANALYSIS ON THE EXISTING PROBLEMS AND INNOVATIVE IDEAS

At present, the main substrates in the field of flexible electronics are ultra-thin glass substrates, metal foil substrates and polymer substrates. Among them, the flexibility and mechanical properties of glass substrates are relatively poor, not suitable for flexible display requirements; metal foil substrates have a certain degree of electrical conductivity, and the surface roughness is relatively high, when the substrate is bent will cause the conductive devices on the substrate off and failure; polymer substrates are more suitable for flexible requirements, but the thermal conductivity of ordinary polymer substrates is relatively poor, so it is not suitable for the application of high heat-generating integrated circuits. The thermal conductivity of ordinary polymer substrates is poor, making them unsuitable for use in integrated circuits that generate high heat. Other new paper substrates are not yet mature and have poor water and oxygen resistance, so they account for very little of the research and market direction [4].

In this paper, a hot-press bonding technique between independently flexible graphene films and polyimide films is used, which effectively addresses the negative effects of material blending, while exploiting the flexibility and thermal conductivity of graphene-based polyimide.

3. RELEVANT MATERIAL PROPERTIES

3.1. Graphene

Mechanical properties: Graphene is one of the strongest materials known and is also very ductile and bendable, with a theoretical Young's modulus of 1.0TPa and an intrinsic tensile strength of 130GPa. reduced graphene modified with hydrogen plasma also has very good strength, with an average modulus of 0.25TPa [5]. Graphite paper made from graphene flakes has many holes and is therefore brittle, however, functionalised graphene obtained by oxidation and then made from functionalised graphene is exceptionally strong and tough.

Electron effects: Graphene has a carrier mobility of approximately 1.5m2/(V-s) at room temperature, which is more than 10 times that of silicon and more than twice that of indium antimonide (InSb), the substance with the highest known carrier mobility. Under certain conditions such as low temperatures, the carrier mobility of graphene can even be as high as 25m2/(V-s). Unlike many materials, the electron mobility of graphene is less affected by changes in temperature, with single-layer graphene having an electron mobility of around 1.5m2/(V-s) at any temperature between 50 and 500K.

Thermal properties: Graphene has very good thermal conductivity. Pure, defect-free single-layer graphene has a thermal conductivity of up to 5300 W/(m-K), which is the highest thermal conductivity of any carbon material to date, higher than the 3500 W/(m-K) of single-walled carbon nanotubes and the 3000 W/(m-K) of multi-walled carbon nanotubes. It also has a thermal conductivity of 600 W/(m-K) when used as a carrier. In addition, the ballistic thermal conductivity of graphene can shift the lower limit of ballistic thermal conductivity per unit circumference and length of carbon nanotubes down [6].

3.2. Introduction to polyimide films

The color of the film is yellow and transparent, with a relative density of 1.39 to 1.45. It has outstanding resistance to high temperature, radiation, chemical corrosion and electrical insulation, and can be used in air at 250 to 280°C for a long time. The glass transition temperature is 280°C (Upilex R), 385°C (Kapton) and above 500°C (Upilex S) respectively. 200MPa tensile strength at 20°C, more than 100MPa at 200°C. especially suitable for flexible printed circuit board substrate and various high temperature resistant electrical insulation materials. High mechanical properties The tensile strength of homopolymer polyimide films is approximately 250 MPa, while that of biphenyl polyimide films can reach 540 MPa. The tensile strength of fibres made from copolyimide can reach 6 GPa, which is second only to the expensive carbon fibres. Moreover, the coefficient of thermal expansion of polyimide can reach 10-6/°C, almost the same level as metal, and even some individual products can reach 10-7/°C.

Dielectric strength There are carbonyl and amino groups in the polyimide structure, and the conjugate system of adjacent groups and ether bonds reduces the polarity of the molecule, making polyimides have good insulating properties. Polyimides modified with the introduction of other atoms can have a dielectric constant as low as 2.5, a bulk resistivity of 1017 Ω-cm, a dielectric loss of 10-3 and a dielectric strength of 100 kV/mm-300 kV/mm, and can maintain over 90% of their performance over a fairly wide range of temperatures and frequencies.

4. THE SCREENING ANALYSIS OF HIGH THERMAL CONDUCTIVITY FLEXIBLE SUBSTRATE MATERIALS

4.1. Screening principles as well as specifications

Engineering ethics involves the coordination of engineering and technology, the coordination of engineering and humanities, and the coordination of engineering and social development. Engineering ethics emphasizes engineering and technology talents as the centre, caring for human life safety, one's own safety and the safety of others, paying attention to the safety and reliability of industrial production, ensuring excessive quality, protecting the natural environment and green development, treating the natural environment as the root of engineering activities, making industrial production and the natural environment harmonious, sustainable and balanced development, advocating fair and just social positive energy, paying attention to one's At the same time need to pay attention to others, common development and common progress.

Enhance the concept of green materials and advocate intrinsically safe design. Green materials and intrinsically safe design have similar concepts, and both advocate governance from the source of process design. Green materials refers to the development of new green materials in combination with the innovation of clean production process technology and equipment to minimise environmental pollution and energy and resource consumption, which focuses on achieving governance at source by improving the atomic economy of chemical reactions. Intrinsically safe design means taking measures such as major hazard identification, quantitative risk assessment, intrinsic safety review and reasonable risk control to actively eliminate and avoid chemical process risks caused by human error and equipment failure as far as possible, so as to maximise intrinsic safety and minimise engineering risks.

4.2. Screening methods

4.2.1. Graphene material selection - graphene oxide (GO) vs. reduced graphene oxide (rGO)

Graphene Oxide Graphene oxide flakes are the product of chemical oxidation and exfoliation of graphite powder. Graphene oxide is a single atomic layer that can readily be expanded in lateral dimensions to tens of microns. The structure therefore spans the scales typical of chemistry and materials science in general. Graphene oxide can be considered a non-traditional, soft material with polymeric, colloidal, thin-film, and amphiphilic molecular properties.

Reduced graphene oxide By reducing graphene oxide, these oxidised functional groups are removed in order to obtain a graphene material. This graphene material is known as reduced graphene oxide, often abbreviated as rGO. rGO can also be obtained from graphite oxide, a material made from multiple layers of graphene oxide, which undergoes a series of reductions to graphene oxide and then to rGO. We wish to compare the characterisation of rGO and GO to explore more suitable materials.

4.2.2. Raman spectra

For GO, it can be seen from Figure 1 that the G-peak, which is the main characteristic peak of graphene, appears at 1580 cm-1. This peak can effectively reflect the number of layers of graphene, and the more developed the structure of the graphite lamellae, the stronger this peak is, but it is highly susceptible to stress. The more developed the structure of the graphite lamellae, the stronger this peak is, but the more susceptible it is to stress. The intact graphite lamellae consist entirely of hexagons of carbon atoms, and when pentagons and heptagons or other local defects are present, a defect peak, the D-peak, is generated, which is located at 1350 cm^-1. The crystallisation of carbon nanotubes can be characterised qualitatively by the ratio of the intensities of the G and D peaks, R=ID/IG, the smaller the R value, the better the surface crystallisation. The peak near 2700 cm-1 is the second-order D-peak, which is used to characterise the interlayer stacking of carbon atoms in graphene samples, and its frequency is also influenced by the wavelength of the laser.

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The ID/IG of reduced graphene is larger than that of graphene oxide, indicating greater defectivity and better electron conduction properties.

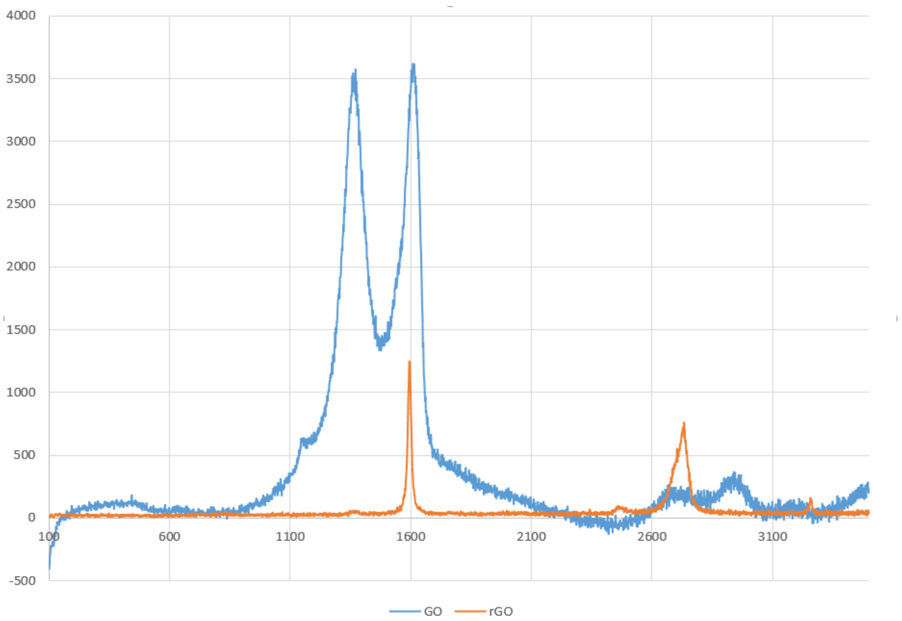


Figure 1 Raman spectra of GO and rGO

4.2.3. X-ray diffraction

Graphene oxide was analysed by X-ray diffraction, as shown in Figure2, the peak of graphene oxide appeared at 11.62°, which is a crystal plane diffraction peak, and the crystal plane spacing of graphene oxide was calculated by Bragg's formula as 0.76 nm, and the diffraction peak at 26.53° was also produced due to incomplete oxidation of graphene.

The reduced graphene oxide was analysed by X-ray diffraction, as shown in the figure, after the reduction of graphene oxide, the diffraction peak of graphene appeared at 26.23°, close to the position of the diffraction peak of graphite, but the diffraction peak of graphene broadened and weakened due to the interlayer exfoliation of the monolayer graphite, which reduced the size, decreased the integrity of the crystal structure and increased the disorder, and the diffraction peak at 54.31° was due to the incomplete oxidation of graphene. The 54.31° diffraction peak is a result of incomplete graphene oxidation.

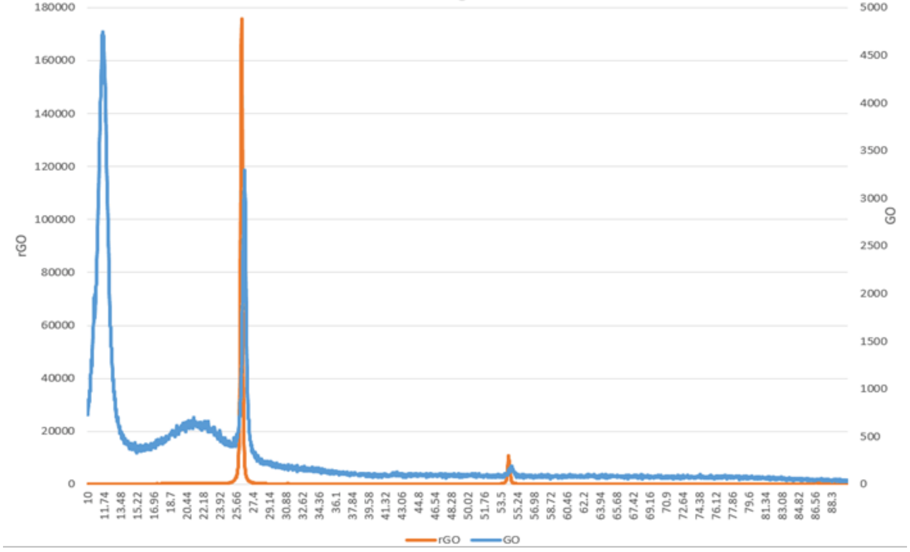


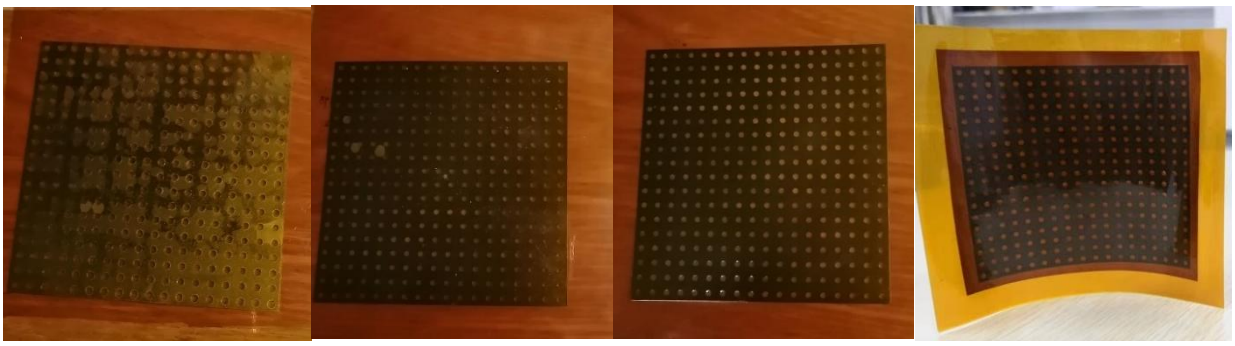
Figure 2. X-ray diffraction of GO and rGO

4.3. Fabrication of graphene precursors for high thermal conductivity substrates

There were three main difficulties encountered during the experimental process. Firstly, there was no previous research in China that led to uncertainty about the specific parameters; secondly, there was the possibility that air bubbles would be generated during the hot pressing process, which would affect the properties of the film. Thirdly, during the hot pressing process, air bubbles may be generated, which may affect the properties of the film (Figure 3).

Another problem is that the bond between the layers of ordinary graphene flakes is weak and can be easily peeled off, and the samples are not flexible or have poor thermal conductivity. The author therefore punched holes in the graphene flakes to increase the bonding area between the top and bottom layers, ensuring that the bond was strong enough to withstand multiple bends.

The initial sample contained many air bubbles and the bond was very poor, and it fell apart after a few bends. The author analysed this as a result of low pressure and insufficient holding time, and then experimented again to obtain a sample with only a few air bubbles. On this basis, the author considered attaching copper and followed the previous laminate structure, replacing the polyimide film at the bottom with a copper foil, and successfully produced a precursor for the graphene-based highly thermally conductive substrate.



Large bubbles, poor adhesion	Individual bubbles	Graphene-polyimide	Graphene-polyimide - copper

Figure 3. Sample making process

4.4. Screening results

Material selection: The thermal conductivity of graphene is around 4840~5300. It is also less dense, more resistant to high temperatures, and has a higher specific strength and specific modulus. It is due to these properties that I chose graphene as the main material for thermal conductivity, while graphene has the disadvantage of being brittle and having poor interlayer bonding, so I chose a soft polyimide film as the protective layer. The two are combined in the sandwich structure shown in the diagram to form a graphene-polyimide composite. This ensures that the finished product has good reliability while making full use of the high thermal conductivity of graphene, without breaking very easily.

Graphene-polyimide composites are obtained at a temperature of 190°, a pressure of 2mpa and a hot pressing time of 20 minutes. The results of the performance tests on similar products were good and showed that 80% of the performance was maintained after 20,000 repeated bends at 90°.

At a temperature of 195°C, a pressure of 3 MPa and a pressing time of 20 minutes, I have produced a copper-clad substrate precursor with a calculated thermal conductivity of around 1200.

5. CONCLUSION

After several experiments, this paper has now concluded that rGO has better thermal conductivity and heat dissipation properties, and that it is more appropriate to use rGO as a highly thermally conductive flexible substrate material. At the same time, air bubbles in the material bond would lead to a dramatic reduction in the bonding force between the layers, which would greatly reduce the performance of the product, so a technique was needed that could apply a uniform force. The hot pressing technique was my first choice due to its advantages of heat transfer, uniform and controlled force application, simplicity and ease of operation.

Under the background of new engineering construction, insisting on the foundation of moral education and integrating engineering ethics education into the whole process of cultivating engineering talents is an important way to cultivate high-quality engineering talents. University students should always pay attention to engineering ethics elements such as safety ethics, environmental ethics, laws and regulations in engineering design and material preference. Therefore, in the future, the author will actively search for common points in engineering ethics theory and material selection, further promote the integration and development of these two theories, and promote a design theory and specification that contains both engineering ethics and sustainable design ideas, which is of great practical significance to new industrial design activities in the future. Engineering ethics can be used to monitor and regulate industrial design, binding individuals to learn and implement sustainable design theory as their core theory. The ethical theory of engineering can act as a layer of spiritual assurance for the realisation of sustainable design.

AUTHORS' CONTRIBUTIONS

This paper is independently completed by Gaonaonao Xue.

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