Flexible and Stretchable Electronics: Current Status and Future Scope

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Review Article

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ABSTRACT

Flexible and stretchable electronics have been subjects of interest for decades to scientists and industrial manufacturers. On-going research is trying to prove instrumental towards making this a reality with through technical verifications and analysis. These should then be suitable for production. Starting with metals and semiconductor substrates, interest has now veered to organic polymers and graphene. However, problems still remain. This review article discusses the properties of different materials and possible processes by which stretchable devices can be manufactured in the near future.

INTRODUCTION

Flexible electronics is basically designing electronic circuits on suitable substrates. Flexibility requires thin films since the strain is proportional to film thickness and inversely proportional to the bending radius.

Stretchability is defined as the value at which a material starts to deform proportionally to the force applied elastically. These materials should be able to withstand extension >> 1%. Stretchable electronics materials should thus have high conductivity, good thermal and mechanical stability, low porosity for water vapor and oxygen. For manufacture, the devices should be able to withstand high process temperatures, measured by low weight loss at high temperatures. For medical applications materials used should also be biocompatible.

These materials are considered to have a wide range of applications, from sensors, displays, wearable electronics, and foldable devices to engineering use.

Stainless steel was used for a long time in amorphous silicon solar cells. It has the property of withstanding high temperatures yet being very stable itself [1].

Glass is another material which is highly common nowadays in the manufacturing of LED's, LCD's, etc. The foil which has thickness 30 µm and has optical transmittance >90%. But, due to its fragility, it makes a bit difficult to manufacture but much easier than stainless steel to handle [1]. In recent years the organic substances such as PEDOT (Poly 3,4-ethyldioxythiophene) which is synthesized with PSS (Poly 4-styrene-sulfonate) to get PSS: PEDOT. Often these substances are coated with Parylene (para-xylene) to be used in medical implants and other applications. Another material which has aroused great interest since its discovery in 2006 is graphene which is believed to be an alternative and perhaps a replacement for silicon. Single layer graphene shows great electron mobility, excellent resistivity (10^{-6} Ω.cm). Graphene can be transferred to different substrates by the most commonly used process of Chemical Vapour Deposition (CVD) often coating with Polymethyl Methacrylate (PMMA). Such materials have been examined to find a definitive method for industrial applications benefitting the medical and other industries.

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STRETCHABLE SUBSTANCES AND PARAMETERS

The most novel material used in commercial flexible electronics is the PSS: PEDOT [1]. It is difficult to assess the conductivity for this substance because by any process the increment of charge carriers does not affect it directly and a dispute remains whether the increased charge carriers or the new strengthened mobility of them causes a direct effect on its conductivity [2]. However, it is a widely used printable conductor, but its conductivity is 104 times lower than most metals. Composite films of polyaniline and single-wall carbon nanotubes have better conductivity than PEDOT: PSS (2 S/cm) [3]. As discussed earlier the metal-graphene mitigates these problems to a certain extent. The striking electrical characteristic of graphene is a zero overlap semi-metal that has electrons and holes as charge carriers. In graphene, only 3 electrons are subjected to chemical bonding leaving an electron that may be called as highly free or of high mobility ranging from practical 15000 to more than theoretical 200000 cml/VS [4]. Due to these unique properties, it is now slowly superseding PSS. It was synthesized with PEDOT to form Graphene Poly (3,4 ethyldioxythiophene) (PEDOT) (**Figure 1**).

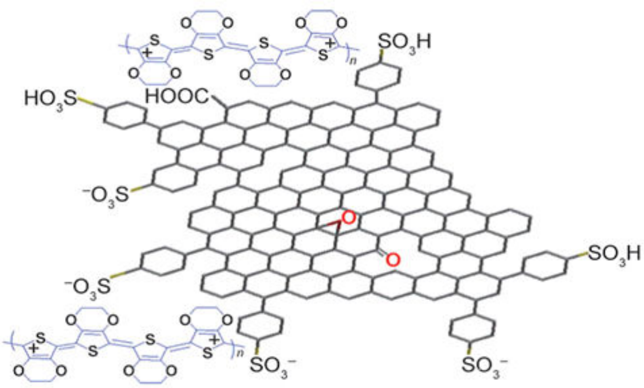

Figure 1. Part Structure of Graphene-PEDOT [5].

Many experiments have been conducted in the recent past with the Graphene PEDOT to confirm its properties for use in flexible electronics. Among these experiments, combinations with various elements were done to get a measurement of its conductivity, thickness of the sheets when combined with the elements, mass loss above a certain temperature, thermal stability, etc. If flexible substrates have to find a strong foothold in the near future then the most important factor will be their conductivities. Fortunately, for this hybrid material, the conductivity was fairly good and remained unchanged even after external factors like bending. Such should be the quality of substrates always so that in the future these materials can be manufactured quite easily. As graphene serves as an ideal metal with perfect configurations for flexible electronics more such hybrids should be experimented and tried out for practical purposes. Although the PSS-PEDOT may be commercially available for flexible electronics applications graphene-based hybrids should now be tried and tested.

COMMERCIALLY USED FLEXIBLE SUBSTANCES AND THEIR METHODOLOGY

Making impermeable thin-film barrier coatings have become the major challenge to making flexible OLED displays. Polymeric substrates needed a barrier on the substrate side (passivation) and on top (encapsulation) of the device to ensure long life. The barrier through which the light is emitted needs to meet the additional criteria of high optical transparency of 85% to 90% over the visible spectrum, control of optical microcavity effects and, if on top of the OLED, low stress to avoid shear damage to the OLED, dense and conformal coating to avoid through layer and edge leakage, and low process temperature. Multilayer organic/inorganic barrier coats have been proven to extend the operating life of OLEDs [1-5].

The need for a strong encapsulate is felt for the manufacture of all these. Parylene is a transparent, chemically stable polymer with low permeation rate of oxygen and water vapor. It has been considered a good candidate to be used as a barrier layer for FOLED (Flexible OLED). Due to its excellent homogeneous and conformal coverage, with no formation of pinholes and micro-cracks, it is an ideal encapsulant for OTFTs (Organic Thin Film Transistors) [6].

ENCAPSULATING AGENTS AND THEIR ROLES

Among the various types of Parylene available Parylene-C is most commercially viable and suitable for such operations. Parylene-C exhibits static and dynamic coefficients of friction in the range of 0:25 to 0:33 and this allows the use of this

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material as a dielectric and/or encapsulant in flexible OTFTs [6]. It has an effective chemical barrier layer. The Parylene coating gives a continuous transparent and conformal film. Para-xylylene film is applied to substrates in an evacuated deposition chamber by a process known as Vapor Deposition Polymerization (VDP) [6]. Apart from this variety, the commercially available parylene variants include Parylene N and Parylene HT [7-10]. Parylene N has a linear structure and a highly crystalline nature. It has the highest dielectric strength of about 7000. The dielectric constant of Parylene N determines the capacitance higher dielectric constant results in higher capacitance and higher electric field at the surface of the dielectric [6]. Parylene N is used as the dielectric in these types of applications and apart from the medical applications of Parylene, this variety serves best for other electronic applications and uses.

STRETCHABLE ELECTRONICS APPLICATIONS IN BIOMEDICAL FIELD

Stretchable electronics play a big role in medical applications as they are integrated with the brain, heart, skin, etc. Reduction of stiffness is crucial for achieving systems that not only are safe but also provide high-fidelity data streams. Flexible electronics using the NM concepts described previously permit high-speed multiplexing, high temporal resolution, as well as conformal electrode-tissue interfaces over large areas. So, to increase their function in brain analysis is quite an extent. Furthermore, high-density systems with submillimeter spacing between the electrodes yield insights into new neural mechanisms, whereby unusual clockwise and counterclockwise spiral patterns of excitation propagate in a manner correlated to signs of micro-seizures [3]. Similarly, for the heart, such electronic systems play a pivotal these days. Electrodes for electrical mapping integrate on the balloon surface with classes of serpentine interconnects [3]. This mode of operation is particularly useful for balloon ablation catheters, where the assessment of ablation can be achieved quickly without the need for separate diagnostic devices. In addition to electrical and temperature sensors, contact sensors and stimulation electrodes are also supported on this platform. Contact sensors can report the moment when the balloon skin and endocardial tissue touch, thereby providing important feedback (without X-ray imaging) on how to adjust and maneuver inflated balloons to achieve optimal occlusion of the PVs during ablation procedures [3].

DEFECTS RISING IN MATERIALS OF FLEXIBLE ELECTRONICS AND THEIR REMEDIAL MEASURES

Graphene-like materials which include carbon nanotubes indicates a lot of defects which arise from their growth or imperfections. These defects arise through certain processes carried out on it such as Chemical Vapour Deposition (CVD). The in-plane defects can be detected through micro Raman spectroscopy so goes for the cases of doping graphene for various technological purposes. Pristine graphene is said to show more crack defects than does graphene oxide. Overlapping of grain boundaries in graphene is posited as one of the main defects in graphene manufacturing as it reduces the quality and the other important features of it to a great extent. The overlapping takes place due to the fusion of two graphene domains of different orientations. Another crucial defect which arises is the catalytic metal etching defect which reduces the conductance of monolayer graphene. There are several methods to overcoming these defects. One of them is to arrange one graphene sheet over the other to improve the stretchable quality of graphene. The mechanical characteristics of this type of arrangement of graphene enable it to conform easily to softer substances. However, the factor for stretchability has been violated in conforming it to a softer substrate. In many experiments, it has been seen that silicon and PDMS (Poly Di Methyl Siloxane) due to mechanical operations a strain is created on the substance which allows it to form a wave-like a pattern. Although this method is commonly accepted the cost of SiC is relatively high and so cannot be considered as a manufacturing element in the least. The correct method for transferring graphene on these substrates to be taken for absolute commercialization has not been decided as yet.

PRINTABLE BATTERIES IN FUTURE STRETCHABLE ELECTRONICS APPLICATIONS

If the vision of a stretchable and wearable device be seen then a compatible power source should be considered. For that matter, a thin, lightweight battery is best suited for the purpose. The development of such batteries has been restricted to designing or synthesis. The perfect material for the battery is yet to be found. In this context, graphene batteries have generated quite an interest among scientists and researchers. As is well-known Lithium-Ion Batteries (LIB) are the most widely used power sources for portable devices at present due to their high operating voltage, light weight and large charge-storage capability resulting in high power density. However, presently for large scale and sensor applications, the cost may be too high [11-13]. The main difference between a graphene battery and a LIB is the composition of the respective electrodes primarily the cathode. The anode uses carbon allotropes in some cases, generally being made up of a metallic material and graphene. The energy density of these batteries is half of what the normal batteries are. So, this type of battery generates the most interest among manufacturers (Figure 2).

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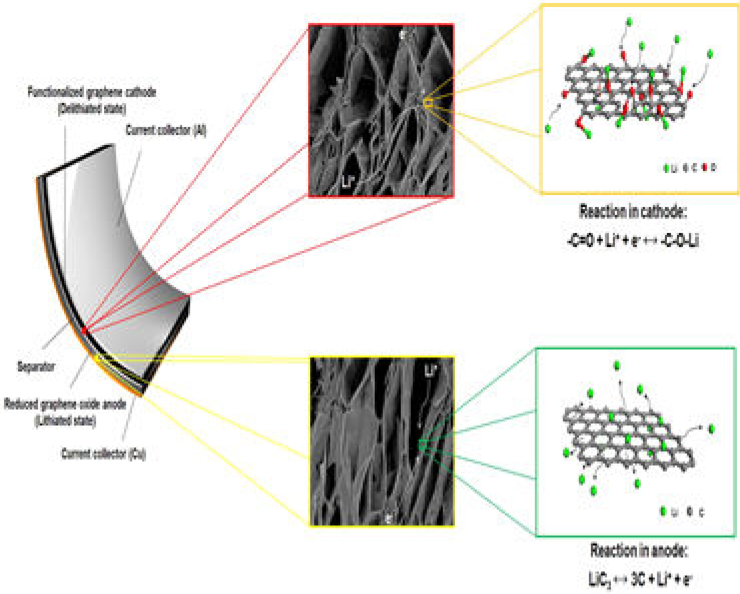

Figure 2. The process for manufacturing a graphene battery [13].

In contrast to the graphene and lithium counterparts recently a team of scientists focused on developing an advanced zinc battery using bismuth oxide as an additive for the electrodes.

PRINTING METHODS AND TECHNIQUES

Printing usually uses common printing equipment suitable for developing patterns on substrates. Painting is considered as a method of printing too. Commonly Al paints were considered as a viable source for printing batteries but due to the highly explosive nature and high property of oxidation of the substance, it was eventually discarded. Careful selection of the types of ink used for printing has to be done nicely. Among the various forms of inks, available researchers have chosen zinc-silver oxide mixing it with isoprene and polystyrene (SIS). Zn/Ag_2O chemistry has an aqueous chemistry. In this case, the non-reaction of the chemistry gives an advantageous position for the manufactures to consider this to be a viable option for an ink material. There are various other processes for printing like gravure, stencil, screen, and inkjet. Among them, inkjet and stencil printing are taken as the standard methods for printing in experiments and research all over [14-18]. In the inkjet printing method, two processes are mainly applied by the printer to successfully print a pattern. These processes are i>thermal process ii>piezoelectric process properly in all its applications [19-25]. The applications of these batteries vary widely from sensors to RFID tags. The biometric sensors which require a constant power source to be fully active have a big requirement for this. When such sensors are introduced into the human body for detection and monitoring of glucose level, blood pressure, etc. these batteries if are printed on the chip or integrated with it are going to serve as the power storage for these sensors. A sensor in the brain of an individual needs to be active always and so the power source needs to be that much supportive. These batteries serve the purpose very well. Batteries integrated with the main substrate like graphene or any graphene polymer will be able to form the future of stretchable electronics [26-30].

FUTURE SCOPES IN DEVELOPMENTS FOR FLEXIBLE AND STRETCHABLE ELECTRONICS

The materials which are to be used for the above-mentioned integration of stretchable electronics into the manufacturing of effective devices in the future have to be cost-effective to a great extent. Among all the materials considered for use, graphene serves the best purpose for stretchable applications surpassing the conventional silicon. As discussed above the popular Silicon Carbide (SiC). Singularly occurring graphene in nature cannot be put into manufacturing directly [31-33]. Its synthesis and preparation methods are at the moment not inexpensive in the least. If in the near future these methods are made cheap then mass production of the material will be made possible [34]. Developing polymers integrated with graphene is one of the best methods for manufacturing because not only will it be cost effective but also easily manageable [35]. In any such stretchable device, a constant power source is required and

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hence the battery material has to be incorporated within the device as such [36-38]. For this probably the material graphene has to undergo more experimenting for its successful combination with these suitable elements. Upon accomplishing that only can the necessary circuits be printed on the produced material to highest effectiveness. Such can be the process to develop future smartphones which can be wrist bound or smart sensors for medical purposes [39].

CONCLUSION

Graphene is being considered as the material needed for stretchable applications these days. If the strain constraints are relieved and the printing processes are enhanced and made viable for industrial production then we can presciently say that the market for stretchable electronics will develop. The preparation and synthesizing of graphene, the confirmation of a suitable battery for the constant power source for the devices is to be decided finally.

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REFERENCES

1. Wong WS and Salleo A. Flexible electronics: materials and applications. Springer, New York. 2009.
2. Benfdila A and Lakhlef A. Graphene material and perspectives for nanoelectronics. J Nanoelectron Optoe. 2018;13:1437-1443.
3. Thomas S, et al. Why does the electrical conductivity in pedot: pss decrease with pss content. A study combining thermoelectric measurements with impedance spectroscopy. J Polymer Sci Part B: Polymer Phys. 2012;50:976-983.
4. Kumar V and Khandelwal G. Graphene-based flexible and stretchable bioelectronics in health care systems. J Anal Pharm Res. 2016;3:00053.
5. Yanfei Xu, et al. Hybrid material of graphene and poly (3,4-ethyldioxythiophene) with high conductivity, flexibility, and transparency. Nano Res. 2009;2:343-348.
6. http://paduaresearch.cab.unipd.it/3451/
7. Sushmitha K and Reza H. Oskouei parylene coatings in medical devices and implants: A review. Universal J Biomed Eng. 2015;3:9-14.
8. Dae HK, et al. Flexible and stretchable electronics for bio-integrated devices. Annual Review of Biomed Eng. 2012;14:113-128.
9. Seung ML, et al. Graphene as a flexible electronic material: mechanical limitations by defect formation and efforts to overcome Elsevier materials today. Materials Today. 2015;18:336-344.
10. Dae HK and John A. Rogers stretchable electronics: materials strategies and devices advanced materials. Adv Materials. 2008.
11. Singh N et al. Paintable Battery. Sci Rep. 2012;2:481.
12. Se HK, et al. Printable solid-state lithium ion batteries: a new route toward shape-conformable power sources with aesthetic versatility for flexible electronics. Nano Lett. 2015;15:5168-5177.
13. Kim H, et al. All graphene battery: bridging the gap between supercapacitors and lithium ion batteries. Sci Rep. 2014;4:5278.
14. https://www2.eecs.berkeley.edu/Pubs/TechRpts/2015/EECS-2015-33.html.
15. https://pubs.rsc.org/en/journals/journalissues/nr#!recentarticles&adv.
16. Meyer et al. High density interconnect and flexible hybrid assemblies. IEEE Transactions on Advanced Packaging. 2001;24:3.
17. Fortunato et al. High-performance flexible hybrid fets based on cellulose fiber paper. IEEE Electr Device Letters. 2008;29:9.
18. https://docplayer.net/41475254-The-flexible-hybrid-electronics-paradigm.html.
19. Changzhou Y, et al. Flexible hybrid paper made of monolayer Co_3O_4 microsphere arrays on rGO/CNTs and their application in electrochemical capacitors. Funct Mater. 2012;22:2560-2566.

20. Park J. Nanotechnology-enabled flexible hybrid electronics. J Electr Electron Syst. 2016;5:202.

21. Lele P, et al. Ultrathin two-dimensional MNo_2/graphene hybrid nanostructures for high performance, flexible planar supercapacitors. Nano Lett. 2013;13:2151-2157.

22. Yuan JH, et al. Design of stretchable electronics against impact. J App Mechanics. 2016;83.

23. Zhigang Wu, et al. Opportunities and challenges in flexible and stretchable electronics: A panel discussion at ISFSE2016. Micromachines. 2017;8:129.

24. Yang, et al. Flexible conducting polymer/reduced graphene oxide films: Synthesis, characterization, and electrochemical performance. Nanoscale Resear Letters. 2015;10:222.

25. Dohyuk Yoo, et al. Direct synthesis of highly conductive PEDOT: PSS/graphene composites and their applications in energy harvesting systems. Nano Resear. 2014;7:717-730.

26. Liu Y, et al. High performance flexible all-solid-state supercapacitor from large free-standing grapheme pedot/pss films. Sci Rep. 2015;5:17045.

27. Sato S, et al. Graphene novel material for nanoelectronics Fujitsu. Sci Tech. 2010;46:103-110.

28. Benfdila A and Lakhlef A. Graphene material and perspectives for nanoelectronics. J Nanoelectron and Optoe. 2017.

29. http://www.ijaet.org/.

30. Lei Liao, et al. High-κ oxide nanoribbons as gate dielectrics for high mobility top-gated graphene transistors. App Physical Sci. 2010;107:6711-6715.

31. https://pubs.rsc.org/en/content/articlelanding/2016/cp/c6cp04566a#!divAbstract

32. Xu S, et al. Stretchable batteries with self-similar serpentine interconnects and integrated wireless recharging systems. Nat Commun. 2013;4:1543.

33. https://e3s-center.berkeley.edu/wp-content/uploads/2017/07/Johnson_Kevin.pdf.

34. Michael Wendler, et al. Development of printed thin and flexible batteries. Sci and Tech.

35. https://pubs.acs.org/doi/abs/10.1021/acsenergylett.7b01086.

36. Gaikwad, et al. A flexible high potential printed battery for powering printed electronics. Appl Phys Lett. 2013;102:233302.

37. https://lecturenotes.in/notes/17127-note-for-introduction-to-nanotechnology-in-by-nawab-masid

38. http://blogs.cimav.edu.mx/daniel.glossman/data/files/Nanotecnolog%C3%ADa/Nanomaterials %20Handbook.pdf.

39. http://doi.contentdirections.com/mr/mgh.jsp?doi=10.1036/0071467343.