Development of Smart Textiles and Next Generation Wearable Electronics

Pooja Kale[1], Suranjana Gangopadhyay[2]
[1&2] Department of Textile Manufacturing, Veermata Jijabai Technological Institute, Matunga, Mumbai 400019, India.

Abstract: *Textile material has potential to be used as sensor element, antennae and interconnections in a wearable bioinstrumentation system. Currently application of this technology involves use of heavy and rigid electronic parts which compromises wearer's comfort. Energy supply devices are essential corner stone for wearable electronics. In future different technologies are expected for integration of sensors and electronics in clothing, it is opportune to review the common features and the challenges associated with various textile electronic materials. Different technologies for improving clothing comfort are reviewed in this paper along with experimental results.*

Keywords: *Wearable electronics, Power generation fabrics, bio-mechanical energy, energy harvesting, motion sensors, Protective clothing.*

1. Introduction

Development of more advance smart flexible electronic with wearers comfort is a big challenge which was fulfil up to some extent by fabrication of smart textile with collective features of lightweight, flexibility, breathability and washability which provides novel way of designing functional next generation wearable electronics.This technology have wide range of application as body conformal antennas for integrated radio equipment into clothing, power and data transmission, a personal area network, flexible photovoltaic integrated into textile fabrics,smart footwear to let you know where you are and to convert and conserve energy and as a phase change materials for heating and cooling of the individual. Another application is the weaving of sensors into parachutes to avoid obstacles and steer the parachutist or the cargo load to precise locations [1]. Distributed networks of sensing and computing elements are equipped in cars and homes, which results in a user and context aware environment. Wearable electronics and intelligent textiles are used for a medical application like continuous and long-term monitoring of patient.

Now a days conventional gel electrodes are replaced with textrodes due to its non-irritating property [2]. In conventional gel electrodes irritation caused both by the adhesive part and the gel used. Sensors, antenna and interconnections are fabricated from textile material and are integrated in the textile clothing to overcome inconvenience due rigid electronic parts due to which comfort and mobility was improved [3]. Yarn super capacitors are charged through TENG cloths and are fabricated as self-power generating cloths. Textile fabric converted into energy storing devices was an insulator and not a current collector nor the active material in an electrochemical energy storing device.

Highly conductive fabrics were obtain through electroless deposition of Ni coating on polyester yarn used as a current collectors for electrodes in all solid state yarn supercapacitor [4]. Scalable fabrication technology was used for construction of reliable and sustainable power generation fabrics this wearable power textile was capable of harvesting energy effectively from human biomechanical movement [5]. Flexible electronic devices are mainly fabricated from bendable wearable material like Conductive fibers, liquid metallic blends and polymers [6-9]. Wearable application require small size, light weight and low profile antennas, which must present stable electrical properties, low power consumption, reasonable impedance match and desirable radiation [10]. Natural rubber is a possible alternate flexible material which is biocompatible, low cost, and water/weather resistant and environment friendly. These aspects are discussed in details in the following sections.

2. Textile Sensors

Explication to overcome the inconvenience by integration of sensors interconnects and processing and transmission circuitry in textile clothing is the integration of sensors in textile clothing and wireless monitoring of physiological activities like measurement of respiration rate and ECG.

2.1 Fabrication of Sensors

As an alternative to conventional gel electrode knitted or woven stainless steel textrodes were used due to its less skin irritation [2].This textrodes are integrated in respibelt which was made up of Lycra yarn and place around the abdomen or thorax. Due to breathing circumference and length of the respibelt gets changed up to 2cm, which results in inductance and resistance variation this signals are converted to analog signals and transferred to base station through inductive links. Surpass results are obtain three-electrode ECG configuration circuit over a two-electrode ECG circuit. Data analyses and storage is carried out with the help of microprocessor, Algorithm for ECG and respiration rate are stored in microprocessor which latter easily read out on computer. A driven right leg (DRL) topology was implemented, because of its known high common mode rejection ratio (CMRR).As textrodes have increased sensitivity to motion artifacts digital and analog filters are used to eliminate motion artifacts and drifts [11].

Integration of sensors in textile clothing is a challenging task because the wearers comfort is mainly depends on the mobility and flexibility of clothing. This can be overcome by reducing size of electronic parts and circuitry and by developing textile motion sensors, which was possible due to use of flexible textile material. Liwen Li was found that when 1X1 rib knitted fabric engineered from silver coated conductive yarn connected with the circuit of an electric organ. The resistance of conductive knitted fabrics reduced with the increase in stretching and the current is obtained by measuring the resistance transversely passing the fabric. The corresponding change in resistance could change the voice intensity of the trumpet [12]. In this case factors which impact resistance of knitted fabric are fabric texture, loop transfer, contact resistance and loading speed of the conductive knitted fabric. 1X1 rib texture has different geometric structure and electric property than plain knitted texture.

2.2 Stretchable Human Motion Sensors

Shayan Seyedin was engineered a conductive elastomeric multifilament from polyurethane and dimethyl sulfoxide strain sensing textiles in different knitted structures with simple alterations in the loop configuration and stitch insertion in the knit structure which can detects large strain up to 200% with high stability up to 500 stretching cycles. This strain sensing textiles can be directly worn on various body parts and monitor a moments like bending and kicking [3]. Electromechanical testing shows that knitted fabric fabricated from multifilament have Positive GF (~ 350) at 100% applied strain, which is 7 times higher than the monofilament (~50) [3].

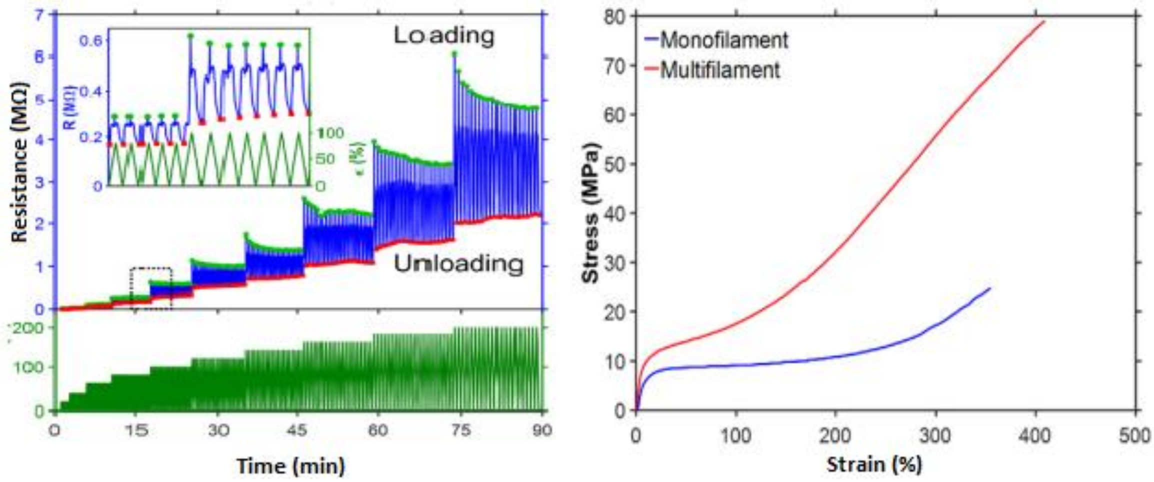


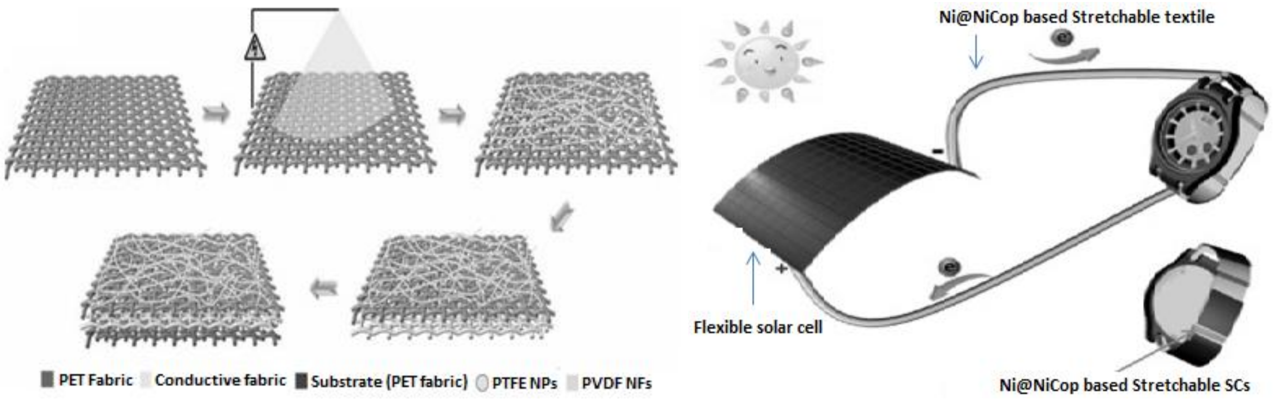
Figure 1. a. Strain sensing response of the PU/PEDOT: PSS multifilament during the cyclic stretching-relaxation test [3], and b. Representative tensile stress-strain curves of PU/PEDOT: PSS monofilament and multifilament [3]

Figure 1a shows Electromechanical testing (measuring the change in resistance with applied strain) revealed that the multifilament's could detect different magnitudes of applied strain and could respond reproducibly to applied strains as high as 200% while monofilaments had a lower strain sensing limit of 100% applied strain in cyclic testing. An electromechanical property shows that the resistance of the multifilament's increase with stretching and decreased upon relaxation. Figure 1b indicates the stress strain curve for multifilament. Elastic recovery of multifilament was similar to monofilament.

3. Power Generation and Energy Storage Fabric for Electronic Textiles

The self-power generation fabric can harvest versatile biomechanical energy from human motions and convert them effectively into steady electricity. With an effective area of 16 cm2, this textile could deliver a power density of 80 mW /m2 at load of 50 M which was sufficient to drive low energy consumption electronics [5]. Those also serve as a highly sensitive sensor of human movements and postures. Qian Qiu fabricate a triboelectric material by simultaneous electro spinning and electrospraying techniques and convert this into composite material i.e. single electrode based triboelectric nanogenerator fabric(TENGs).This fabrics can harvest energy from daily body movement like walking and running. Figure 2a shows detailed fabrication process of power generation fabric. Water Vapour Transmission rate was 8.8 kg m-1 d-1, which shows they have outstanding breathability. Power textiles can be tailored into any desired size and exhibit excellent durability, which ensure the practical application.

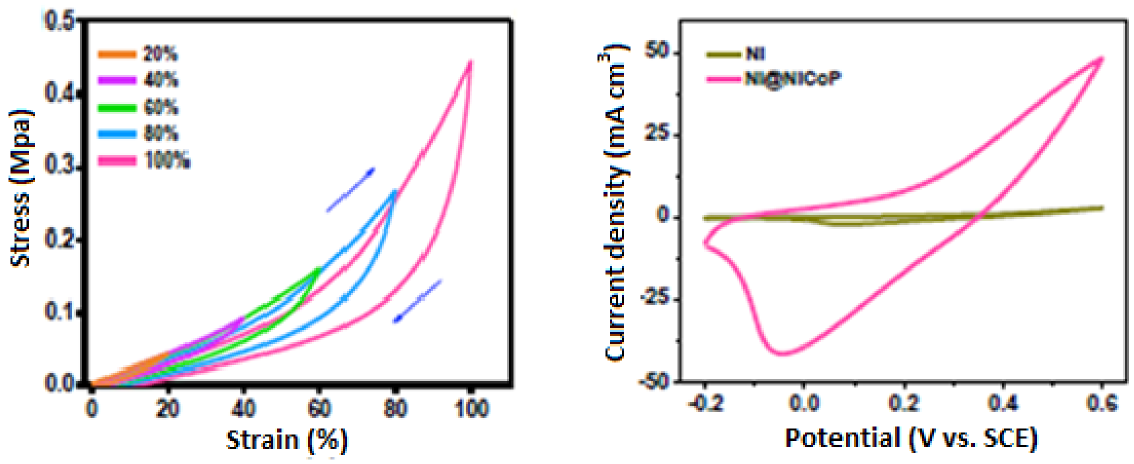
Stretchable textiles with good conductivity and great energy storage capacity are necessary for future wearable electronic clothes. Stretchable nickel, cobalt, phosphorous coated spandex textiles were develop by two step electroless deposition by typical polymer assisted metal deposition(PAMD) process which gives good conductivity and electrochemical performance. These fabrics can delivers a low square resistance of 0.19 Ω $\square^{-1}$ and high conductivity of 526 S cm^{-1}.Conductivity and stability are enhance due to outer NiCoP alloy layer. Stretchable asymmetric supercapacitor (ASC) is engineered from Ni@NiCoP stretchable textiles. These textiles are converted into self-powered system which was then assembled on lab coat and supplies a continuous power for an electronic watch under sunlight or in absence of sunlight [13].Figure 2b shows schematic illustration of self-powered system.



a. b.

Figure 2 a. Fabrication of power generation fabric [5], and b. Scheme illustrating the self-powered system [13]

The original spandex textile can be stretched to maximum length of 318%, while the Ni@NiCoP ST can only reach the highest strain of 265%.The maximum stress of the Ni@NiCoP ST was larger than pure spandex, this results are due to coating of metal and alloys which elevate the strength of the stretchable textile but restrict some elasticity of the polymer fibers. Figure 3a shows the stress strain behavior of Ni@NiCoP spandex textile. Figure 3b present cyclic voltammetry curves of the Ni@NiCoP stretchable textiles compared with Ni stretchable textiles shows that NiCoP owns greater energy storage capacity than Ni.



a. b.

Figure.3 a. Strain cycling behaviour of the Ni@NiCoP coated spandex textile, and b.CV curves of Ni and Ni@NiCoP coated spandex textile at a scan rate of 100 mV s^{-1}

4. Conclusion

In this review paper we have identified different fabrication techniques and applications of self-powered stretchable textiles and motion sensors. Self-powered stretchable textiles are fabricated by coating different conductive polymer layers on textile surface by PAMD technique and simultaneous electrospinning and electrospraying. These active coating layers are act as a conductive layer for flow of electric power. ASC was fabricated by placing PAM based hydrogel electrolytes in between two conductive layers. This stretchable supercapacitor was responsible for energy storage ability of textile. By simultaneous electrospinning and electrospraying techniques triboelectric material was fabricated which was further converted in triboelectric nanogenerater by using two sided conductive tape and integrated into clothing. Power Density of 80 mW /m ^{2} was produced by triboelectric nanogenerater, which is sufficient to drive various wearable electronics. Motion sensors are fabricated from flexible and conformal textile material i.e., knitted structure for better performance in which resistance varies during loading and unloading of the textile structure which mainly cause due to human motions like walking, running, kicking etc. This textiles acts as an motion detecting sensors which are used for monitoring different physiological activities in human and in electric musical organs for controlling voice intensity.

5. References

[1] Tilak Dias.:*Electronic Textiles,*Woodhead Publishing,978-0-08-100201-8,(2005).
[2] M. Catrysse.; R. Puers.; C. Hertleer.;L. Van Langenhove.;H. van Egmond.;D. Matthys.: Towards the integration of textile sensors in a wireless monitoring suit, *Sensors and Actuators,* A 114 (2004).,pp.302–311,0624-4247.
[3] Shayan Seyedin.;Sepehr Moradi.;Charanpreet Singh.;Joselito M. Razal.: Continuous production of stretchable conductive multifilaments in kilometerscale enables facile knitting of wearable strain sensing textiles *Applied Materials Today*, **Vol**.(2018)11., pp. 255-263,2352-9407.
[4] Xiong Pu.;Linxuan Li.;Mengmeng Liu.;Chunyan Jiang.;Chunhua Du.;Zhenfu Zhao.; Weiguo Hu.;Zhong Lin Wang.:Wearable Self-Charging Power Textile Based on Flexible Yarn Supercapacitors and Fabric Nanogenerators, *Advance Materials*, **Vol.** (2016) 28.,pp.98-105,201504403.
[5] Qian Qiu.;Miaomiao Zhu.;Zhaoling Li.;Kaili Qi.;Xiaoyan Liu.;Jianyong Yu.;Bin Ding.:Highly flexible, breathable, tailorable and washable power generation fabrics for wearable electronics, *Nano Energy,* https://doi.org/10.1016/j.nanoen.2019.02.010.
[6] Liyakath, R. A., A. Takshi, and G. Mumcu.: Multilayer stretchable conductors on polymer substrates for conformal and reconfigurable antennas, *IEEE Antennas and Wireless Propag. Lett*, **Vol. (2013)**12, pp. 603–606.
[7] Hayes.;G. J.,Ju-Hee So.;Qusba.;A.Dickey.;G. Lazzi.:Flexible liquid metal alloy (EGaIn) microstrip patch antenna, *IEEE Trans, Antennas Propag*, **Vol**.60 (2012)No. 5.,pp.2151–2156.
[8] Hazra.;C. K. Ghosh.;S. K. Parui.:Effect of different semi conductive substrate materials on a P-shaped wearable antenna,*Int. J. of Adv. Res. in Comp. and Comm. Eng. (IJARCCE)*, **Vol.**2(2013)No. 8.,pp.3071–3074.
[9] J.Xi.;H. Zhu.;T. T. Ye.: Exploration of printing-friendly RFID antenna designs on paper substrates, *IEEE Int. Conf. on RFID*, (2011),pp.38–44.
[10] Saadat Hanif Dar.;Jameel Ahmed.;Muhammad Raees.: Characterizations of Flexible Wearable Antenna based on Rubber Substrate, *International Journal of Advanced Computer Science and Applications*, **Vol. 7**(2016) ,No. 11.,pp.190-195.
[11] Johan Coosemans.; Bart Hermans.; Robert Puers.: Integrating wireless ECG monitoring in textiles,*Sensors and Actuators,*A 130–131 (2006)., pp.48–53,0924-4247.
[12] Liwen Li.;Kun Yang.; Guangli Song.; Liang Zhang.; Juan Guo.:Research and Application of the Property of Conductive Knitted Fabrics,*Modern Applied Science*,Vol.3(2009)No 11.,pp.84-88.
[13] Peng Suna.;Meijia Qiua.; Mingyang Li.;Wenjie Mai.;Guofeng Cui.;Yexiang Tong.:Stretchable Ni@NiCoP textile for wearable energy storage clothes, *Nano Energy,* https://doi.org/10.1016/j.nanoen.2018.10.067.

6. Corresponding Address

Miss. Pooja Vasantrao Kale
Ph.D Research Scholar
Department of Textile Manufacturing,
Veermata Jijabai Technological Institute, Matunga, Mumbai,INDIA
Pin: 400019,
E-Mail: pooja.kale07@gmail.com