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Polymer resin coating over dielectric elastomer for effective stretchable RF devices

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Stretchable dielectrics exploit their inherent elasticity to enable new types of transducers that convert mechanical energy into electrical energy. Electric power can be altered by simply stretching or shrinking a low cost material, and hence is more desirable now-a-days. The challenge of a material to be sustainable for lifelong is a great task for varying environmental conditions. It could be overcome by making functional coatings over the substrate. The challenge includes choosing resins that stretch along with the substrate uniformly without affecting its dielectric properties. In this article, the effect of different polymer coatings over the dielectric elastomer Lycra is investigated. Elastomeric coatings with the polymer resins silicone, TPU and Epoxy were made by doctor blade method. Dielectric properties measurements and Tensile strength tests pointed out the effectiveness of the coated substrates in stretchable RF devices. SEM micrograph images show the sustainability of the resin coated fabric for varying environmental conditions.

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1. Introduction

The stretchable electronic devices with electrical to mechanical energy conversion and vice versa is under increased demand since the reconfigurable devices are capable to dynamically modify their frequencies and radiation patterns in a controlled and reversible manner during the operations such as stretching, compression, bending, twisting and other types of extreme mechanical deformation.

Among all the innovations in this regard, the fabrication into stretchable RF devices are certainly the most challenging: this technology needs the stretchable materials with dielectric and stretch properties suitable for RF devices implementation. Typically, polymers are chosen as materials to embed the stretchable electronic components or circuits. Polymers containing amide or carbonyl groups can shape hydrogen bonds between neighbouring chains; the in part decidedly charged hydrogen ions in N-H groups of one affix are emphatically pulled in to the mostly contrarily charged oxygen particles in C=O groups to another. These strong hydrogen bonds result in the high elasticity and high melting point of polymers containing urethane. The main challenge is to replace hard and rigid substrates with soft and elastic ones. The diverse systems utilized as a part of erosion assurance of metals, conducting polymers and nano materials, nano composites and carbon based materials in corrosion [1].High temperature and low temperature processing of microchip manufacturing and coatings in nanoscale range [2]. The significant modification of fire performance of the textile materials can be achieved by simply tailoring the surfaceand flame retardant coatings [3]. Two or more layers of polymer coated textile with one layer as textile and the other, a polymeric resin. Combination of the properties of different layers determines the overall performance of the system [4]. Commercially available paraffin wax as stretchable water coating for low cost and ultra-flexible electronics [5].

The demand for stretchable and reversibly deformable electronics is getting increased day by day, due to its compatibility as well as low cost to process in determined frequency range. Types of reconfigurable antennas and their uses are described in [6] and the antenna with PIN diode based reconfiguration also is studied. Reconfiguration mechanism based on liquid metal displacement can be more effectively performed [7]. Thin stretchable polyurethane called PDMS was used as substrate material for elastic antennas with conducting layers were made by depositing Au nano film (50/100 nm) [8]. Creating complicated electronic circuits onto the elastomeric substrate by combining flexible useful islands and stretchable interconnects in an elastomeric matrix [9]. The wearable textile antennas or fabric antenna which says the background information and application by making embroided or metal patches onto the fabric [10]. Stretchable PDMS as the substrate and the fabric Lycra was made conductive by simply dipping the stretched mode of the fabric onto PANI/CNT solution, resulting in conductive fabric which is used as conductive patch for the pre- designed antenna [11]. Stretchable and reversibly reconfigurable antenna for frequency reconfiguration within specific range using the substrate EVA and Ag elastomeric cloth as conductive [12].

Different types of fabric materials were investigated for stress and strain in biaxial woven fabric with the yarns aligned along warp and weft directions [13]. The effect of spandex and cotton yarns on dynamic recovery fabric for linear density significant wale and course directions [14]. Enhancement of transport properties in PET films by inserting an active layer (A) containing oxygen scavenger between the two inert layers [15]. Synthesis of PUU as chain extender by entrapping curcumin thereby forming CURPUU elastomers for tunable thermo-mechanical properties [16]. Lycra fabric as an effective substrate for tunable and reversibly deformable applications in patch antenna [17].

According to our knowledge, the research regarding stretchable electronics is blooming or by deeply stating that there is little research reconfigurable stretchable systems [6–12]. Our previous studies on studies of the properties of fabric materials [13–17] pointed the fabrics, their coatings and physio – chemical measurement system either with or without additives. Layering and coatings of different materials and different temperature range of the polymers with performance analysis [1–5].

From all the above studies, there is a great need for a stretchable electronic system, which is re-configurable as well as low in cost which made this work to consider extremely stretchable fabric Lycra for stretchable RF devices applications. As the fabric is water penetrable, the properties of the embedded devices vary based on the changes in environmental conditions. Hence, it was made waterproof by coating the fabric with polymer resins that are water proof, self – adhesive and stretchable. The level of adhesiveness of the resins over the fabric substrate was assessed by SEM analysis. The dielectric measurements were carried out to assess and point out the suitability of the coated fabric for stretchable and reconfigurable RF applications.

2. Experimental

2.1. Materials

Fabric lycra, which is known for its exceptional elasticity, made up of a long chain polymer called polyurethane also used in shape memory materials. Because of its superior strength in the durability, Lycra has gained interest quickly. It also has a better resistance to dry heat & oil, in comparison to rubber. The level of comfort and wicking ability found in the fabric are unparalleled. Hence, the fabric Lycra with stretchability up to 716% is used as substrate to be coated with resins.

The selected polymers for coating onto the Lycra fabric are RTV silicone (Anabond Limited, India) with low thermal conductivity over the range of -50 to 250ºc, ability to repel water and excellent elongation up to 350% an tensile strength 15 – 25(Kg/Cm2), Synthetic polyurethane based resin (Anabond Limited, India) a one component polymer which reacts with atmospheric moisture for curing and has high flexibility, Epoxy based resin (Anabond Limited, India) makes strong bonding with the substrates and the latent, a curing agent present in it is hardened into a solid one with increased cohesive strength.

For the preparation of the RF substrates, the commercially bought Lycra fabric is boiled with 1.0 mol/L NaOH aqueous solution for 1h, and washed with Deionized water (DI) and dried at 100ºC for one hour in a hot air oven to remove surface impurities, if any. The resin samples are coated on either sides of the fabric Lycra by doctor blade method, with the blades held at 50 to 70º angle in both forward and reverse metering ways, and are air dried for 30 minutes. However, out of all the three resins selected, the silicone resin could be coated one side at a time due to its high viscous nature and hence the substrates were named based upon the layers of coating with their corresponding names.

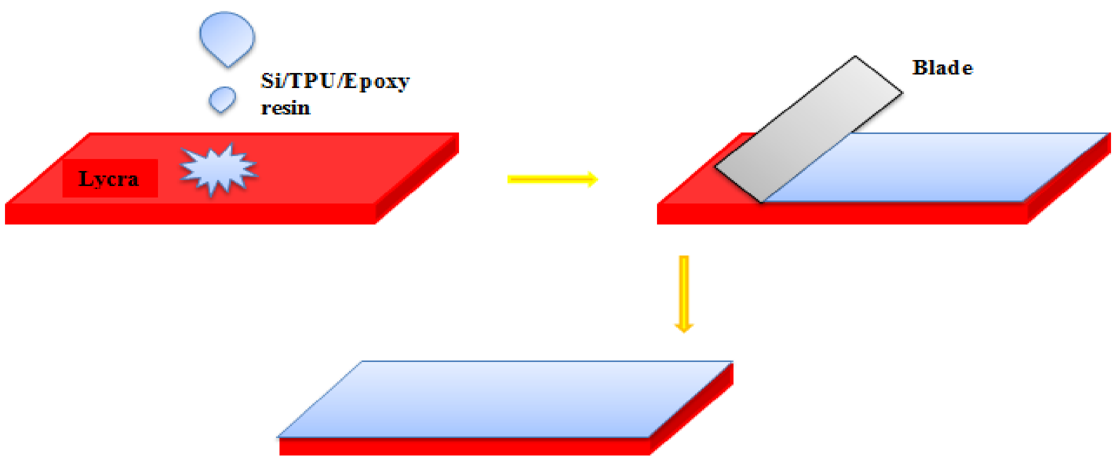


Fig. 1. Steps of coating by doctor blade method (color online)

2.2. Dielectric characterization

Dielectric analysis of the produced substrates was performed using a Suspended ring resonator optimally designed for 2GHz. The samples were placed one by one between the two plates of the resonator which were held perpendicular to each other and their corresponding resonant values were noted in VNA (Virtual Network Analyzer). The dielectric constant of the samples were calculated by the formulas

$$\sqrt{\varepsilon_r} = \frac{C}{2 f_r L} \tag{1}$$

ε_r is the dielectric constant of the material; C is the speed of the light, f_r is the resonant frequency measured from the peak, L is the length of the substrate used. The loss tangent (tan ɗ) is calculated by,

$$\tan \delta = \frac{1}{Q} \tag{2}$$

where Q is the Quality factor,

$$Q = \frac{f_{res}}{f_{3dB,U} - f_{3dB,L}} \tag{3}$$

F_{res} is the Resonant frequency and $f_{3dB,H}$, $f_{3dB,L}$ are 3dB frequency Upper and Lower limit.

Table 1. Dielectric properties of the coated and uncoated samples

Material	Thickness	Dielectric Constant	Loss Tangent
Lycra	0.4 mm	3.38	0.045
Single sided Silicone Laminated Lycra	0.55 mm	4.16	0.024
Double sided Silicone Laminated Lycra	0.7 mm	3.7	0.055
Epoxy coated Lycra	0.55 mm	2.7	0.0629
TPU coated Lycra	0.50 mm	3.6	0.053

2.3. Physico – Chemical characterization:

2.3.1. Scanning Electron Microscopy

Scanning electron microscopy (SEM) is a strategy in microscopy that allows resolution better than that of the optical microscope (about 100 Å) on examination of the specimen's surface. SEM was performed on samples for structural morphology study inorder to determine the structural equality and level of coating for each of the resins. This study further helps to comfy the performance evaluation of coated fabrics as dielectric substrates.

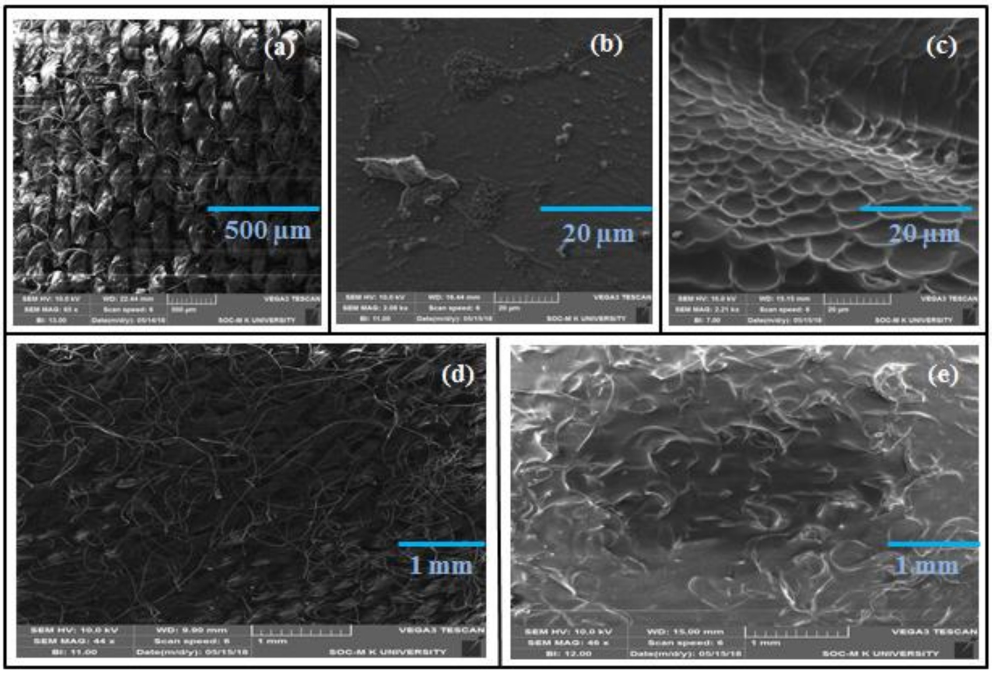


Fig. 2. (a)Unlaminated Lycra with clearly visible pores (can be easily affected by environmental conditions) (b) Coated on one side with silicone resin (c) Coated on both the sides with silicone resin (d) Coated with epoxy resin (e) Coated with TPU resin

2.3.2. Tensile strength measurements

Mechanical Tensile strength measurements were carried according to ASTM standard D 1776 using Universal Testing Machine (UTM) with the force 33 N and loading rate 10 mm/min.

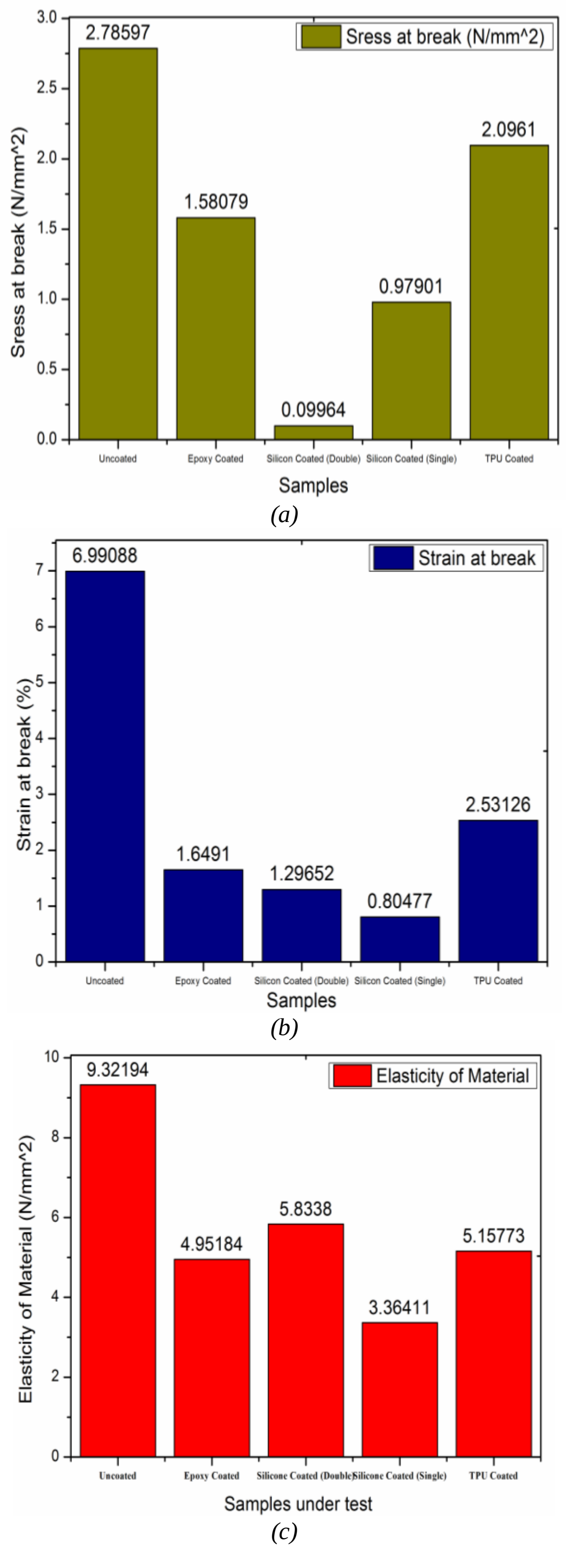


Fig 3. (a) Stress at break; (b) Strain at break; (c) Elastic modulus (color online)

The test samples were cut in the dimension 1 cm × 9 cm and are inserted one by one into the clamps of which are preset with the distance 20 mm. Pulling one clamp at a uniform rate and the load is applied through the other clamp, which moves in a considerable way to actuate a load measuring mechanism so that the rate of increase of either load or elongation is usually not constant. The samples are stretched in accordance with contradictory force applied on both the clamps. The procedure was continued until the samples were torn.

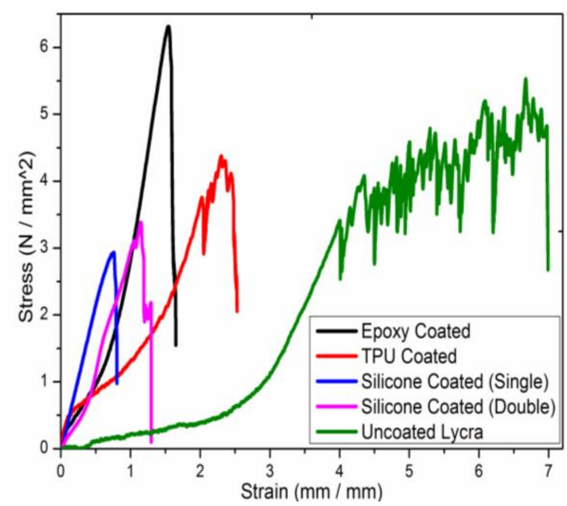


Fig. 4. Stress vs Strain curve (color online)

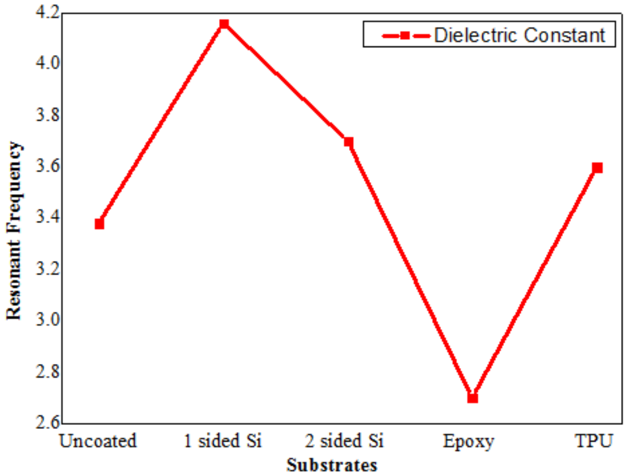
3. Results and discussion

3.1. Dielectric characterization

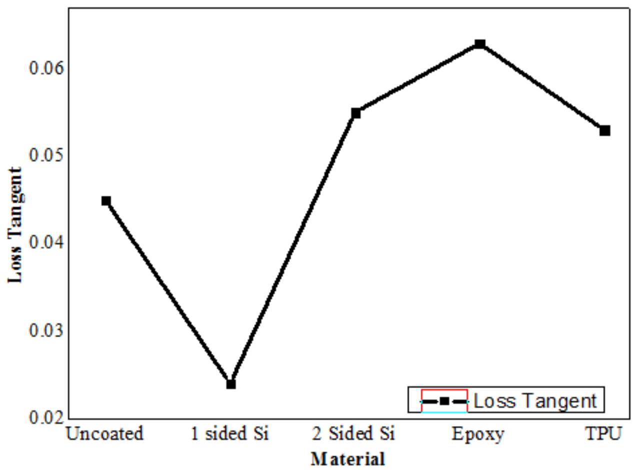
Dielectric characterization was done for single layered and bi – layered coatings of silicone, Epoxy and TPU in order to investigate the effectiveness of the corresponding coatings over the stretchable substrate Lycra and of their suitability for RF devices. Data are shown in Table 1.The thicknesses of the coated substrates vary depending on the viscosity of the coated resins. We have chosen resins with viscosity values to be not high; as the coated substrates explicitly announce the thickness after the coating process is made. The thickness of the coated substrates were maintained to be almost similar to that of the uncoated one, as there is possibility of the dielectric properties of substrate Lycra could be manipulated by the coated resins.

The dielectric constant and Loss tangent of the substrate affects device’s performance. Hence, the substrate with low dielectric constant and very low loss tangent are much desired. As the fabric Lycra not only has the properties to be a good dielectric for RF devices, also is super elastic to prove the variation in dielectric performance based on mechanical alteration it is chosen for study. The close observance to comparison analysis in Fig. 5 shows that the one sided Silicone coated Lycra has higher dielectric constant. On the other side, since it has very low loss tangent it suits RF application. In two sided

Silicone Coated Lycra substrate, both the values are normalized to best suit with the application. The variation in properties of the substrates purely depends upon the type and level of bonding the resin with the materials and the additives present that influences the adhesive behaviour. The epoxy resin coated substrate shows comparatively higher loss tangent value and very low resonant frequency and can be used for RF applications. TPU coated Lycra substrate shows both the dielectric values similar to that of the uncoated one and hence is also suitable. Moreover, the experimental dielectric values of the samples are found to be good in agreement with the expected values.



(a)



(b)

Fig. 5.Comparison analysis of (a) Dielectric Constant (Resonant Frequency) (b) Loss Tangent (color online)

3.2. SEM Analysis

SEM image analysis exhibits the level of adhesiveness and quality of adhesion of the resins coated upon the substrate. Fig. 2 shows the micrographs of the mono layered and bi layered samples. The silicone coated on single side exhibits the resin spread equally along the substrate on one side and double side silicone resin coating proves the equal distribution along the stretchable fabric substrate on both the sides with good adhesion quality compared with the former. The Epoxy coated fabric was shown to be the best in adhesion with the substrate and the uniformity was unwarranted due to its limited capacity of coverage with the yarn. Thermo Poly Urethane resin coating on the fabric substrate was good in adhesion, with linear uniformity, equal and limited coverage with the fibre yarns. However, the absence of voids in the SEM micrographs express their capacity of good inter layer adhesion.

3.3. Tensile strength properties

In order to demonstrate the mechanical performance of the samples in a better way, the mono layered and bi-layered coatings of silicone, Epoxy and TPU with commercially bought Lycra fabric are compared in Fig 3 and Fig 4. For Elastic modulus E, stress at break σ, strain at break Ɛ and stress strain analysis.

The stress vs strain curve shows the better analysis of tensile strength properties of uncoated and coated fabrics. It shows the gradual decline in the tensile properties of the coated ones when compared with the uncoated ones. The uncoated fabric, even though is stretchable up to 716%, when coated its strain level was greatly affected. This worsening of strain level is purely because of the level of adhesiveness onto the fabric and also the additives present along with the resin. The elastomeric polymer resin that had good stretchability up to 231% provided the maximum stress up to 46.2 %. Next resin epoxy exhibits the very strong adhesive nature by 62.8% showing the stretchability level up to 157.2%.The fabric coated on single side with silicone resin has reduced performance in terms of stress strain analysis, due to its adhesion was confined to only one side with strain up 80% and stress up to 28.6%. However, the double side coated silicone resin shows better elongitivity up to 126% and stress up to 34%.

It is observed that the tensile stress, strain and elongitivity increase with increase in the number of layers for high viscous resins. However, for low viscous resins, the self-adhesive polymer resins form equal sized layers on both the sides.

4. Conclusion

Fabrics which are reversibly deformable and potency to long last be considered cheap and effective substrates for device. Polymer resin coatings for extended effectiveness over the stretchable fabric substrate for RF applications were successfully produced by doctor blade method by proper design and configuration mechanism. SEM micrographs showed the morphological analysis for the level of bonding of resins with that of substrate thereby; waterproof fabric substrates were made and investigated. The level of stretchability of the coated substrates according to ASTM standard was studied by tensile strength analysis.

The substrates with less dielectric constant and very low loss tangent are desired. The dielectric property measurements of the prepared substrates prove their effectiveness for their targeted application. i.e., RF devices.

From the comparison of all the resin coated substrates, the level of adhesiveness, elongitivity level, bonding for water resistance and the aptness of the fabrics for desired application is determined.

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