Printed Soft Structured Piezoresistive Strain Sensor

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ABSTRACT

In this communication, we present a novel approach for the fabrication of soft structured polymeric strain sensors composed of, woven cotton as a base matrix, and a conducing poly (3, 4 – ethylenedioxythiophene) - poly (4-styrenesulfonate) (PEDOT/PSS). A suspension of 1.3 wt % of PEDOT-PSS was inkjet printed on the mercerized cotton fabrics. The resistance drops as more ink is deposited by the means of overlapping of printed layers. For determining the effect of substrate geometry on sensing properties, different fabric weaves such as plain, twill and sateen and different fabric orientation of 0°, 45° and 90° were used. Sensitivity was determined in the form of gauge factor, defined as the quotient of change in electrical resistance to that of strain of the sensory material. The gauge factor of the printed materials is negative and ranges from 5-10 depending on the types of the substrate. The gauge factor did not change with fabric orientation but varied significantly with the types of fabric. The Negative gauge factor means increase in resistance with strain and decrease in resistance with relaxation. Our material has gauge factor higher than that of the metals and other available conductive polymer based piezoresistive sensors.

***Keywords*:** inkjet printing, softstructure, piezoresistive, gauge factor

1 INTRODUCTION

Controlled micro-nozzle printing of molecules, which leads to well defined structure has recently attracted considerable interest because of the versatile applications of the process in nanostructuring, mimicking biological systems and fabrication of micro/nano electronics. Examples include solder for micro-nano electronics soldering, lubricants for micro-mechanical parts, UV curable resin for manufacturing of entire micro-optical parts, such as wave guides, micro lenses and arrays. [1] Electronic textiles or e-textiles are a new emerging field of research that brings together specialists in information technology, Microsystems, materials and textiles [1]. A large number of studies have focused on the inkjet printing [2-7] of organic molecules, metal nanoparticles, carbon nano material dispersions to form unique structures with piezoresistive sensing and actuation behavior. However, there are only few reports on the preparation of flexible piezoresistive strain sensors with defined and comparable gage factors using drop on demand thermal inkjet printing. Inkjet printing is considered to be one of the key technologies in the field of defined polymer deposition particularly in relation to the manufacturing of soft matrix based sensors, polymeric light emitting diodes displays and other polymer electronics [1].

In this communication we presents, a novel approach for the fabrication of textile materials based polymeric strain sensors composed of, cotton matrix, and a conducing polymer PEDOT/PSS.

Resistance of conducting lead was found to follow a downward trend once the number of print cycles increased. The reason for the particular trend was attaining more uniform and thick conductive line of polymer with increase number of printed layers.

2 EXPERIMENTAL

We employed the inkjet printing technique to form well connected conducting leads of polymeric lines on cotton woven fabric. The suspension of 1.3 wt% of poly (3, 4 – ethylenedioxythiophene) - poly (4-styrenesulfonate) (PEDOT-PSS), was printed onto the mercerized cotton fabric. The printed lines were about 5 cm long and less than 1 mm wide. Since the printing formulation, on evaporation, leads to its spreading on the substrate, thus the woven fabric was mounted on a heating plate so as to avoid the spreading of the ink. This technique allows the individual droplets to fuse but hinders the formation of large droplets and thus prevents smearing of the printed solution.

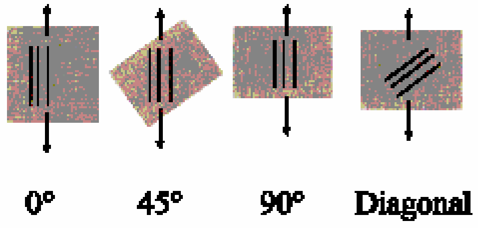

Fig 1 Sample Preparation

3 RESULTS AND DISCUSSION

3.1 Gauge factor for different samples

Three trials of each sample were carried out in order to calculate the gauge factor value. The chart below shows the mean value of the gauge factor with respect to fabric types and the printing angle. Calculation for gauge factor was carried out when sample reaches to its stable condition means change in the gauge factor value become constant with the number of cyclic loading. The cycle number was different for different sample.

Table 1 Gauge Factor value for different sample

Fabric	Angle	Gauge Factor (Mean Value)
Twill	0	11.90
	45	10.42
	90	11.50
	Diagonal	9.50
Plain	0	10.50
	45	10.66
	90	11.61
	Diagonal	13.50
Sateen	0	11.37
	45	10.22
	90	9.20
	Diagonal	7.50

3.2 Reproducibility:

Four samples of the same specification printed on the 6 different fabrics. The samples were tested under the same conditions for the reproducibility test. Following are the gauge factor values and the corresponding standard deviation values. Cotton plain 45 degree and the cotton plain 90 degree printed samples show the large variation (S.D.) as compared to four other samples. The possible reason for this behavior would be the open structure of plain weave as compared to densely packed twill and sateen fabric. That would be responsible for the variation in the gauge factor value. The open structure causes the instability in variation while performing the strain testing. The amount of polymer trapped inside the fabric weave is dependant on the fabric structure. Twill and sateen fabrics have more thickness as compared to plain fabrics.

Table 2 within sample variation in gauge factor value

	Twill		Sateen		Plain	
Sample	0	45	0	45	45	90
1	12.0	9.5	11.9	9.7	9.5	10.2
2	11.4	10.6	11.8	9.4	11.8	10.7
3	12.3	10.8	10.6	11.3	12.2	13.2
4	11.9	10.8	11.2	10.5	11.5	11.2
S.D.	0.37	0.6	0.6	0.8	1.2	1.31
Mean	11.9	10.4	11.3	10.2	11.2	11.3
C.V.	3.1	5.9	5.2	8.3	10.6	11.6

3.3 Repeatability:

Four randomly selected samples were subjected to cyclic loading for four conjugated days for 100 cyclic loading. The variation that occurred in the gauge factor value was recorded. The gauge factor value increased each day but became constant after few days. We also observed the after each day of testing the part (a) of the graph (as shown in fig 7) was nullified means as soon as the load was applied to sample it started responding; whereas in the initial testing it took time to reach the equilibrium condition. The variation that occurred with time was more in the case of cotton plain 90 degree printed fabric as compared to others. The reason would be the same as mentioned above for the high variation in cotton plain fabrics.

Table 3 variation in gauge factor value with repetition

	Twill	Plain	Sateen	
Repeat	0	90	0	45
1	12.00	10.20	11.20	11.30
2	14.40	12.30	11.80	12.90
3	14.70	13.20	12.50	13.80
4	15.30	14.10	13.20	13.90
S.D.	1.44	1.67	0.87	1.20
Mean	14.10	12.45	12.18	12.97
C.V.	10.21	13.42	7.11	9.25

Repeatability can also be expressed by overlapping the sensors responses. Figures 7, 8 and 9 show the overlapped curve of cyclic loading for three different pairs of samples. All graphs show the approximately the same gauge factor values and follow the same path.

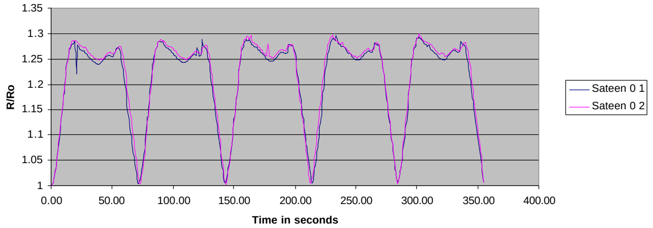

Figure 2 cyclic strain curve for five cycles of Sateen fabric

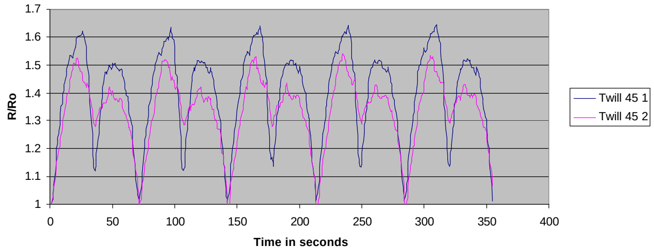

Figure 3 cyclic strain curve for five cycles of Twill fabric

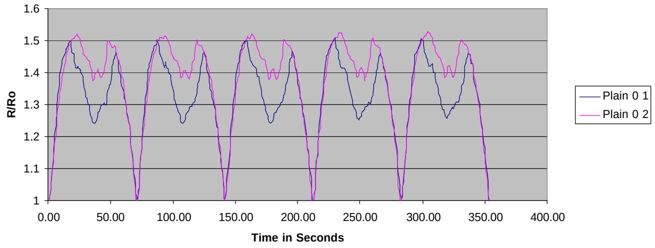

Figure 4 cyclic strain curve for five cycles of Plain fabric

3.4 Microscopic Analysis

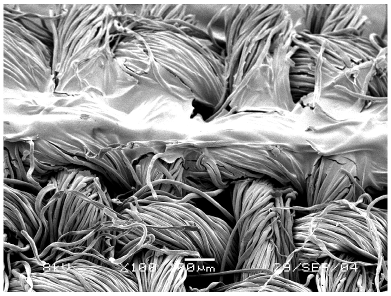

Figure 5 SEM image of printed sample before stretching

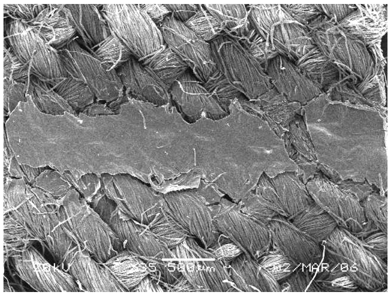

Figure 6 SEM image of printed sample ample after stretching

SEM images taken before and after stretching show cracks formation during cyclic strain testing. The crack formation is responsible for increment in the resistance value. The same behavior was observed in all the samples that were subjected to cyclic loading.

The fig 7 shows the change in resistance during cyclic loading for the first 28 cycles. To study the explanation, the resultant graph is divided into three parts,

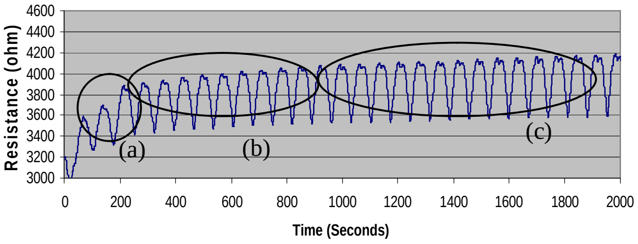

Figure 7 1cyclic loading

Part (a) is the response of the sensor at the initial loading cycles. It shows the rapid increment in resistance which last for 3-5 cycles depend on the sample. The change in resistance is due the formation of cracks on the surface layers. As the cracks generate the resistance value increases suddenly from few hundred ohms to kilo ohms. Visible cracks can be seen in SEM analysis.

After a sudden increment in resistance as shown in part (a) the response of the sensor becomes decrease in resistance with loading and increase in resistance with unloading. However, the graph shows the increment in resistance at the initial point (0% strain) and at the final point (5% strain) of every cycle as the number of cycles is increased.

As the surface layer break down during initial loading, the absorbed conductive polymer comes into play. During the preparation of the sample, a large amount of polymer is absorbed by the fabric, which settles down in the empty space present between the yarns and fibers. The complex geometry of fabric does not allow the absorbed polymer to come out during the testing; thus the entrapped polymer helps to form the conductive path for sensing. The length of part (b) for different sample varies from 10 to 50 cyclic loading depending upon the number of printing layers.

In part (c) the response of the sensor becomes constant this means the change in resistance with loading and relaxing becomes uniform. This consistency was observed in up to 400 numbers of cyclic loading.

3.5 Sensing Mechanism

Let us assume that we have a sensing element (metal or conductive polymer) in the form of cylindrical shape. When a load is applied across the two ends, its length increases and diameter decreases with the loading, resultantly conductivity decreases due to the increment of the surface area. This behavior was observed in various metal based sensors.

But in the case of the fabric or a single yarn based sensor, where the substrate was not in the form of a solid structure observations were much different. Yarn has a different geometry than the metal sheets or polymeric sheets. Let's assume that in the yarn, each fiber has a coating of conductive material to make a yarn conductive. When the yarn is in a relaxed condition, the total contact surface area of fibers to fibers is not the same as the sum of the total fibers surface area, because the presence of air gaps between the fibers prohibits the direct contact between the fibers. That empty space causes less net conductivity of fabric as compared to the sum of the conductivity of the total fibers. When a load is applied across to the yarn, it will stretch in a vertical direction (in the direction of loading) and try to compress in a lateral direction due the pressure applied by twist present in the yarn. So the net contact surface area increases. That's why the conductivity of fabric increases with the applied load. Whereas in the case of the other solid substrate based sensor conductivity decreases with the load. [8]

4 CONCLUSIONS

The gauge factor of the printed materials is negative and ranges from 5-10 depending on the types of the substrate. The gauge factor did not change with fabric orientation but varied significantly with the types of fabric. The Negative gauge factor means increase in resistance with strain and decrease in resistance with relaxation. Our material has gauge factor higher than that of the metals and other available conductive polymer based piezoresistive sensors with gauge factor ranging from 1-5. [9-11]

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