Quantum Tunneling Nanocomposite Textile Soft Structure Sensor and Actuators

Investigators: Prabir K. Patra (Leader), Paul D. Calvert, Steven B. Warner, Yong K. Kim and Chi Hau Chen

Graduate Students: Amit Sawhney and Animesh Agrawal

ABSTRACT

We started printing of poly(3,4-ethylenedioxythiophene) PEDOT/PSS (shown in figure 1) solution onto soft structured matrices like nylon fabric. Solutions are of varying concentrations (0.1% and 1.0% aqueous dispersions) based on two different grades of PEDOT. The solution consists of PEDOT/PSS and 10% ethylene glycol. Ethylene glycol was used to inhibit clogging of nozzles.

We printed 500 layers and cured the printed samples at the temperature of 90ºC for 6hrs to 24hrs. Curing process helped evaporating the ethylene glycol and conductivity was increased by two orders of magnitude. This rise in conductivity may be because of the alignment of the molecules in the printed layer with the temperature. We measured the conductivity of the cured sample. We are conducting strain test to observe the change in conductivity with respect to stretch. This will lead us to assess the material behavior as strain sensors on the textile fabrics. As a part of our ongoing effort we also printed electroless silver onto nylon 6 and obtained selective conductivity in the printed region. Initial TEM measurement on the silver printed sample shows good adhesion of silver and single fiber of the nylon fabric giving us a hope for improved electron tunneling.

GOAL STATEMENT

The objective of this research is to begin with molecular scale investigation and understanding in designing textile based soft switch sensors and actuators with novel electromechanical and electrochemical properties. The main goal of this proposal is to gain fundamental scientific insight of electron tunneling principle of the sensors and actuators that respond to force, temperature and volatile organic compounds. The specific goals are to:

- Understand the ability of quantum tunneling composite (QTC) to transfer conducting behaviors to textile substrates on touching, twisting and stretching (i.e. the effect of force and temperature).
- Understand and elucidate the mechanism by which QTC performs in detecting volatile organic compounds or its vapor (chemical sensing) at a very low level.
- Investigate QTC actuation function from the molecular scale.

The principles thus established will be used to create fabrics and integrate them into truly wearable-instrumented garments and to design next generation complex-structured smart materials.

INTRODUCTION

Quantum tunneling composites (QTC) comprise conducting particles in a polymer matrix, where resistance changes as a result of changes in particle-particle near contacts when the composite is pressed, stretched or twisted. Quantum mechanical electron tunneling occurs as a result of overlapping wave functions between conducting particles that are not in physical contact [1,2]. The dependence of tunneling current upon conductor particle separation is exponential; therefore, an enormous resistance range can be controlled by relatively small changes in separation. Nano sized granular particles will be much more effective in covering a wider range of resistance. It is worth mentioning that these granular QTC have conducting properties comparable to the conductor and do not sacrifice the conducting properties from the bulk QTC [3]. Combining these systems with conducting polymers rather than insulators will provide much closer control of the resistance changes. We propose to exploit some novel electromechanochemical phenomena by using of π electron conjugated conducting polymers with QTCs in the presence of a suitable ionic reservoir to achieve improved sensing and actuation behaviors. Design of granular QTC embedded textile fabrics, with careful and controlled dispersion of QTC particles in conducting polymers (CP) in a ionic atmosphere, may well be the turning point for vast improvement of sensing and actuation with soft and flexible structure. Such structures can also be tailored to micro fiber forms since they offer quicker electrochemical response than films. QTCs with some amazing qualities being ultra touch sensitive and conductive in a series of quantum leaps can lead to advances in sensing and actuation principles in textile based soft switch development. Compared to organic transistors, QTCs have the advantage of simplicity, printability and processability [4]. Two major current issues can demonstrate the capability of QTC sensors. One is the sensing of explosives. A wide range of sensor systems have been developed, especially for mine detection, but the best sensor remains the dog's nose and best synthetic sensors are only about 1/10 as good. We do not yet know in detail how the nose works, but it does have arrays of sensing cells each of which bind and respond to groups of molecules. Much of the sensitivity seems to come from the use of large arrays of similar sensors rather than a single device and from the ability of the dog to track across a trail so that different time points are compared. Textiles with a large number of integrated sensors open the way to totally new strategies for chemical detection. Using changes in resistance as the signal generation the change in resistivity is brought by through change in QTC concentrations or though it's conformational change. Conductivity changes will thus be induced by polymer/QTC distribution changes [5,6]. Chemical vapors that are either electron donors or electron acceptors have a dramatic effect on conductivity The second major problem is that of health monitoring. Large structures such as buildings, bridges and composite aircraft are vulnerable to small cracks, which are difficult to detect, but might become critical. There is a desire to implant or attach sensor arrays, which would provide a signal if some mechanical signature of the system changes, the equivalent of pain in the human body. The best current answer is to embed fiber Bragg gratings into concrete or composites but these require complex and disruptive optical hook ups. Embeddable textile mechanical sensing systems would be an answer to this problem.

EXPERIMENTAL MATERIALS AND METHODS

1) **<u>PEDOT/PSS solution</u>**: purchase from sigma-aldrich

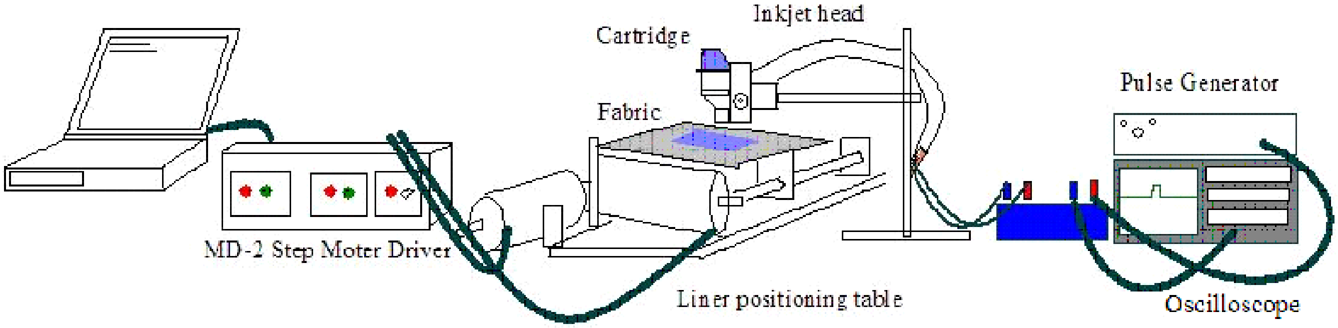
a) Poly(styrenesulfonate) / poly(2,3-dihydrothieno(3,4-b)-1,4-dioxin), 1.3 wt % dispersion in water Poly(3,4-oxyethyleneoxythiophene) / poly(styrene sulfonate), Poly(styrenesulfonate) / poly(2,3-dihydrothieno[3,4-b]-1,4-dioxin), PEDOT/PSS

b) Poly(styrenesulfonate) / poly(2,3-dihydrothieno(3,4-b)-1,4-dioxin), dispersion 2.8 wt.% in water electronic grade Poly(3,4-oxyethyleneoxythiophene) / poly(styrene sulfonate), Poly(styrenesulfonate) / poly(2,3-dihydrothieno[3,4-b]-1,4-dioxin), PEDOT/PSS

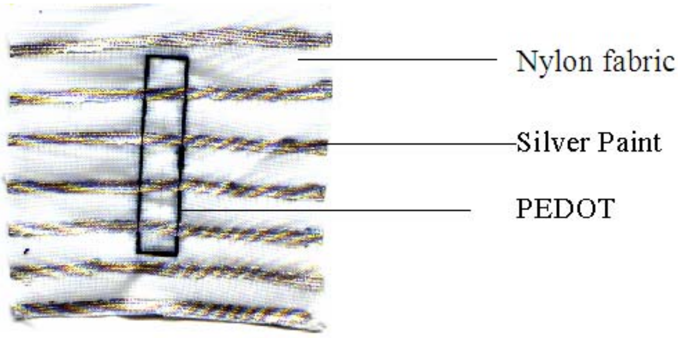
2) **Ethylene glycol:** purchase from Sigma-Aldrich.

3) Nylon and AgNO3

Setup:



We designed an inkjet printing set up, which consists of inkjet cartridge head connected to an oscilloscope and a pulse generator, it is based on pyroelectric principle, tiny resister present in the cartridge heats the polymer to form a drop. Single-line patterns were written on the fabric by a linear motion of the inkjet print-head attached to a computer-controlled X-Y liner positioning table.



Above is a sample of printed fabric, which was subjected to cured at 100C for 12Hrs and silver line is used for measuring the conductivity between the two points.

RESULTS AND DISCUSSION

Results and discussion:

In conjunction with our project M03-MD14 we have started our investigation on selective conductivity on polymer fabric on a patterned sections and our initial results are given below.

1) Concentration: 1% PEDOT/PSS(a) water solution containing 10% ethylene glycol
   Cured at 90ºC for 10hrs
   Resistance: 4MΩ / cm
2) Concentration: 1% PEDOT/PSS(b) water solution containing 10% ethylene glycol
   Cured at 90ºC for 10hrs
   Resistance: 0.5 to 1Ω / cm

The difference in conductivity of the samples arises from the presence of PSS in PEDOT/PSS solution; PSS act as primary impurities, which can improve the conductivity of PEDOT/PSS film.

We are also trying to quantify the proper condition for printing and curing by changing the concentration, curing condition (time, temperature and dry/wet curing).

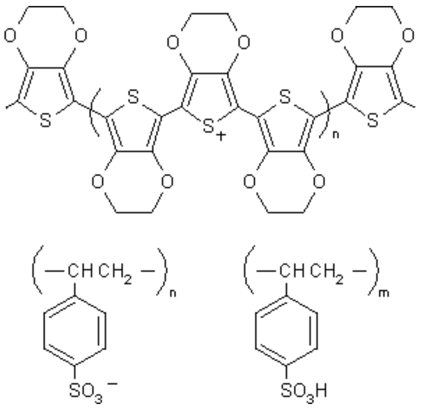


Figure 1.Chemical structure of PEDOT/PSS

CONCLUSIONS AND FUTURE CONSIDERATIONS

PRELIMINARY CONCLUSIONS

Printing of PEDOT on nylon fabric gave rise to selective conductivity in the patterned region and the value increased on curing the sample. Eletroless deposition of silver on nylon showed promise with improved conductivity.

FUTURE CONSIDERATION

Sensing and Actuation

Fabrics coated with thin layers of CP/QTC will posses unique properties of strain, temperature and chemical sensing and also will show electromechanical actuation. The time-dependent resistance of the composites will be subjected to strain cycles under different environments in the form of coatings on fibers and films and as freestanding fibers. We will also follow development of electrical potentials within the system during stress.

In order to predict the dependence of resistance on strain and time we will develop a model relating to the current flow into the polymer by quantum tunneling composite granules to the electrical potential size effect of QTCs in electron tunneling. The same test will be performed in case of conducting polymers with out using QTC granules and quantitative efficiency of QTC in electromechanical actuation will be assessed.

Electrochemical impedance of CP and QTC/CP will be measured to predict the frequency response of the polymer and additional contributions arising out of QTCs. Electrochemical actuation mechanism will be established when the conducting polymer molecules are attached to the QTCs to form efficient π -π stacking through electron tunneling. A molecular simulation will be developed to understand the expanded and contracted state of QTC-based nanocomposites.

Chemical Sensing

Chemical sensing in this system will arise primarily from adsorption at the particle-polymer interface, which will occur rapidly in the thin film. We will functionally modify the QTCs by attaching nitroamines and nitrosamines to achieve chemical compatibility with DNT, TNT and other volatiles. Changes in resistance and potential will again be monitored during exposure to active compounds. The dispersions of QTC within the conducting polymers (CP) will be studied using small and wide angle x-ray. The nanoscopic structural pattern of QTC in CP will be assessed using TEM. The Active surface area of the QTCs will be determined using a BET surface area analyzer. The surface morphology of the QTC/CP matrix will be studied using SEM. An important part of both efforts will be to develop strategies to handle simultaneous information streams from many sensors on a piece of textile in order to enhance sensitivity and to get directional and time dependent information. The goal will be to develop a biomimetic sensing strategy. We have hired two more graduate students (Senthil K. Krupaswamy and Somya Iyenger) to work along these lines.

OUTSIDE CONTACTS

We have established contacts with ICI. In our meeting with them we made short presentation based on our preliminary work. They have shown interest in our work. Ricardo Bermudez, President of Sensing Systems, Inc has expressed interest in this research. For sources of conducting nanopowders we will work with Superior Micropowder of Albuquerque NM. In the composite health monitoring area we will work with Adherent Technology, also of Albuquerque, to interest NASA in a prototype system. On the chemical sensing, we will talk with colleagues at Sandia National Laboratories in relation to sensing of explosives. Contacts with Sandia National Laboratory were established when one of the PIs (PDC) was working there.

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3. www.peratech.co.uk/www.dur.ac.uk/physics

4. H. E. Katz, A. J. Lovinger, X. M. Hong, A.J.J Dodabalapur, B-C.Wang and K. Raghavachari, " Design of Organic Transistors Semiconductors for Logic elements, Displays, and Sensors" in Organic Field effect Transistors, F. Denis and B. Zhenans, eds., Seattle. Society for Optical Engineering, (2001), pp 20-30

5. J.W. Gardner, T.C. Pearce, S. Friel, P.N. Barthlet and N. Blair Sensors and Actuators(B) 240, 18-19, (1994)

6. R.Stella, G. Serra, D. DeRossi, J.N. Barisci and C.G. Wallace, Sensors and Actuators, 63, 1 (2000)