THE FIBER SOCIETY

Advancing Scientific Knowledge
Pertaining to Fibers and Fibrous Materials

The Fiber Society 2012 Fall Meeting and Technical Conference

in partnership with

Polymer Fibres 2012

present

Rediscovering Fibers in the 21st Century

November 7–9, 2012

Conference Chairs

Stephen Eichhorn, University of Exeter
Cheryl Gomes, QinetiQ North America, Inc.
Gregory Rutledge, Massachusetts Institute of Technology

Venue

Boston Convention and Exhibition Center
Boston, Massachusetts, USA

Program

Tuesday, November 6

1:00 PM–5:00 PM	Governing Council Meeting, Room 160C
5:00 PM–6:00 PM	Early-Bird Registration and Reception, Room 102A

6:00 **Reception (Room 104B)**

6:30–10:00 **Banquet and Awards Ceremony**
Ms. Shevy Rockcastle, KVA Kennedy & Violich Architecture
Going Soft: Textiles and Resilient Architecture

Friday, November 9

8:00 Continental Breakfast (Room 102A)

9:00	**Keynote Speaker: Dr. John F. Rabolt, University of Delaware, USA** ***Preparation and Characterization of Multilayer Polymer Nanofibers by Multiaxial Electrospinning*** **(Room 104A)**

9:40	***Break (Room 102A)***

	Room 104A	**Room 104C**
	Session: Nanofibers ***Michael Jaffe, Chair***	**Session: Sensors and Electrical Properties** ***Phillip Gibson, Chair***
10:00	*A Historical Perspective on Nanofibers: Can We Make It More Relevant?* H. Young Chung, Et Esus	*Base Fiber Technologies for Smart Textiles* R. Hufenus, D. Hegemann, S. Gaan, F.A. Reifler, and L.J. Scherer, Empa
10:20	*Electrospun Nanofibers Functionalized with Cyclodextrins and Their Potential Applications* Tamer Uyar, Asli Celebioglu, Fatma Kayaci, Zeynep Aytac, and Yelda Ertas, Bilkent University	*Functional Fibers for Integrated Sensing and Actuation* Ton Peijs[1,2], Oliver Picot[1], Mian Dai[2], Nanayaa-Hughes Brittain[1], Emiliano Bilotti[1], and Cees Bastiaansen[1,2], [1]Queen Mary University of London, [2]Eindhoven University
10:40	*Spinning Functional PLA Nanofibers for Controlled Release, Protein Capture, and Sensing* Margaret Frey[1], Dapeng Li[1,2], Chunhui Xiang[1,3], and Ebru Buyuktanir[4,5], [1]Cornell University, [2]University of Massachusetts at Dartmouth, [3]Iowa State University, [4]Kent State University, [5]Stark State University	*Mechanical and Electrical Properties of Polyamide 66 Nanocomposites Reinforced with Buckminster Fullerene C60* Reyhan Keskin[2], Ikilem Gocek[1], Guralp Ozkoc[3], Koray Yilmaz[2], and Yunus Kamac[2], [1]İstanbul Technical University, [2]Pamukkale University, [3]Kocaeli University
11:00	*Electrospinning of Reactive Mesogens* Ton Peijs[1,2], Jian Yao[1], and Kees Bastiaansen[1,2], [1]Queen Mary University of London, [2]Eindhoven University	*Production of Polymer Filament-Shaped Piezoelectric Sensors for E-Textiles Applications* H. Carvalho[4], R.S. Martins[1], R. Gonçalves[2], J.G. Rocha[3], J.M. Nóbrega[1], S. Lanceros-Mendez[2,5], [1]Institute for Polymers and Composites, [2]Centro/Departamento de Física, [3]Dep. Industrial Electronics, [4]University of Minho, [5]International Iberian Nanotechnology Laboratory
11:20	*Characterization of Compressive Properties of Electrospun Mats* Looh Tchuin Choong and Gregory Rutledge, MIT	*Chemical Resistance of Poly(3,4-ethylenedioxythiophene) on Textiles* Christopher DeFranco, Qinguo Fan, and Jinlin Cai, University of Massachusetts at Dartmouth

11:40	*Fabrication of Composite Polyallylamine-Nanodiamond Fibers* Marjorie Kiechel, Ioannis Neitzel, Vadym Mochalin, Yury Gogotsi, and Caroline Schauer, Drexel University	*Tunable Force Sensor Based on Flexible Polymeric Optical Fibres* Marek Krehel[1,2], René Rossi[1], Gian-Luca Bona[1,2], and Lukas Scherer[1], [1]Empa, [2] ETH Zurich

12:00	**Close of Conference: Room 104A**

****

Poster Presentations

Session Chair: ***Stephen Michielsen***
Room 102A

Zachary Dilworth	*3D Volume Representation of Nanowebs*
Carole Winterhalter	*Comparison of Evaporative Resistance of Carbon-Based Chemical Protective Undergarments*
Yusuf Ulcay	*Preparation and Characterization of Poly(ethylene terephthalate)/Nanoclay Nanocomposites Fibers*
Larissa Buttaro	*Phase Separation to Create Hydrophilic Yet Nonwater Soluble PLA/PLA-b-PEG Fibers via Electrospinning*
Meryem Pehlivaner	*The Effects of Solvents on the Morphology and Conductivity in PEDOT:PSS / PVA Nanofibers*
Laura Toth	*Chitosan Fiber Scaffolds for Craniofacial Bone Tissue Engineering*
Fuan He	*Preparation and Characterization of Organosilicate-Reinforced Electrospun Membrane*
Eliza Allen	*Incorporation and Performance of Molecular Polyoxometalates in Cellulose Substrates*
Zhang Jiang	*Nanoconfinement-Induced Enhancement of Thermal Energy Transport Efficiency in Electrospun Polymer Nanofibers*
Yunfei Han	*Reactivity of Methyl Parathion Degradation with Immobilized Zinc Oxide Nanoparticles*
Helder Carvalho	*Surface Electromyography Using Textile-Based Electrodes*
Seyed Ravandi	*Physical Properties of PLGA Nanofiber Yarn with Potential Application Surgical Suture*
Kaiyan Qiu	*Biodegradable Polymer Nanocomposites Using Polyvinyl Alcohol and Nanomaterials*
Yunshen Cai	*Real-Time Control for Electrospun Nanofiber: Experimental Investigation of Electrospinning Physics*

Production of Polymer Filament-Shaped Piezoelectric Sensors for E-Textiles Applications

R.S. Martins[1], R. Gonçalves[2], J.G. Rocha[3], J.M. Nóbrega[1], H. Carvalho[4], S. Lanceros-Mendez[2, 5]
[1]IPC/I3N-Institute for Polymers and Composites; [2]Centro/Departamento de Física; [3]Dep. Industrial Electronics; [4]Centre for Textile Science and Technology, University of Minho; [5]INL-International Iberian Nanotechnology Laboratory, Portugal
helder@det.uminho.pt

INTRODUCTION

This work aims at the development of piezoelectric materials for flexible sensors produced with various geometries, at low cost and high production rates, adequate for the industrial scale. In particular the filament form, appropriate for integration into textiles, is described, but other geometries, such as tape, are also being studied. The filaments are produced by co-extrusion of multiple layers with piezoelectric and electrically conductive polymer composites.

In the last years, many researchers and also some industrial enterprises have put large effort studying the integration of systems and devices into textile products [1,2]. This integration normally requires separate industrial processes for the textile and the device. Preferably, functional fibres providing a more significant part or even the complete solution for a given application should be used. In this work, the production and testing of filaments working as mechanical sensors is presented.

PIEZOELECTRIC POLYMERS AND THEIR APPLICATION IN TEXTILES

Poly(vinylidene fluoride) (PVDF) is a polymer that has been extensively studied due to its piezoelectric properties. These properties depend on the degree of crystallinity, structure and orientation of the polymer crystalline fraction, which, in turn, depends on the processing conditions [3]. The piezoelectric properties of the polymer can be useful in applications such as sensor and actuator devices.

PVDF presents at least 4 crystalline phases. The non-polar α-phase is obtained by crystallization from the melt [3]. The β-phase is the most interesting form the point of view of the electroactive activity, and results optimally from stretching α-PVDF at 80ºC using a stretch ratio (R) between 3 and 5 [4,5]. The molecular chains are thus aligned. Further, a poling process is carried out through the application of a strong electrical field to the PVDF layer [6]. After poling, the polymer has an optimal piezoelectric response. This means that an electrical potential will be produced upon mechanical excitation of the polymer, or a mechanical action is produced in the polymer when it is subjected to an electric field. To measure this electrical potential (or to apply voltage to the polymer), electrodes making up equipotential surfaces have to be provided, at which the voltage produced by the polymer (applied to the polymer) can be connected to adequate signal conditioning (drive equipment).

PVDF-based sensors are available on the market in the form of films. In this case, a thin PVDF layer is deposited with electrode layers on both sides, normally by metallization or sputtering. Some research work has targeted the development of PVDF sensors in filament/cable form. The filament-shaped piezoelectric sensor for textile applications should be arranged in a coaxial manner, as shown in figure 1.

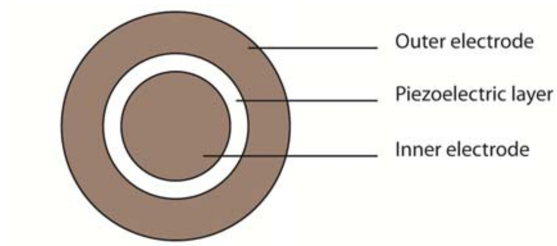

Figure 1: Layer arrangement for piezoelectric filament

Several authors have studied different aspects related to the production of such filaments. Vatansever *et a*l [7] reported on the production of simple PVDF monofilaments which are stretched and poled inline by an electric field produced between two parallel plates. Walter *et a*l [8] have extensively studied the phase transitions in extruded PVDF monofilaments and produced a piezoelectric composite based on monofilaments. Mazurek *et a*l [9] described the production of concentric piezoelectric cables by co-extrusion and sequential processing.

The use of conductive polymer composites for creation of the electrodes has been studied in previous work [10]. PVDF filament has been co-extruded with a Polyproplylene/Carbon Black conductive inner core and a PVDF outer layer, and it has been shown that the electroactive phase content is not affected by the conductive inner core, depending only on the processing temperature and stretch ratio, as previously found for single filaments. Similar work has been described by Lund and Hagström in [11].

DEVELOPMENT AND TEST

In this work, two and three-layer filaments incorporating electrically conductive layers as electrodes and a piezoelectric layer, in a coaxial arrangement, are produced using conventional polymer extrusion equipment. The process is presented in figure 2

Figure 2: Schematic view of the production process

The conductive layers are produced using a commercial PP/carbon black composite polymer (Pre-Elec Premix 1396). In the case of two-layered filaments, the outer electrode is achieved by painting the filament with conductive silver ink. Poling is accomplished by applying high voltage (in the order of 10 kV) directly connected between the inner and the outer electrodes. Variable periods of time and poling temperatures were studied in order to optimize the piezoelectric response.

The filaments are then connected to a charge amplifier and the signals are acquired with a data acquisition board and a computational application developed in Labview. Piezoelectric activity is tested by applying mechanical action, either using a vibration generator to produce cyclic bending deformation, or using a universal testing machine to deform the filament in an extensional manner.

RESULTS

To achieve stable production conditions for both 2 and 3-layered filaments, the experimental conditions have to be optimized for the specific equipment and materials used in order to optimize the α-to-β phase transition. β-phase content larger than 70% were obtained in the PVDF layer. Piezoelectric activity has been shown and depends on the processing and poling conditions. Figure 3 shows a signal acquired by applying traction stress with a universal testing machine (1mm extension of a 10 cm long filament at a frequency of about 1 Hz).

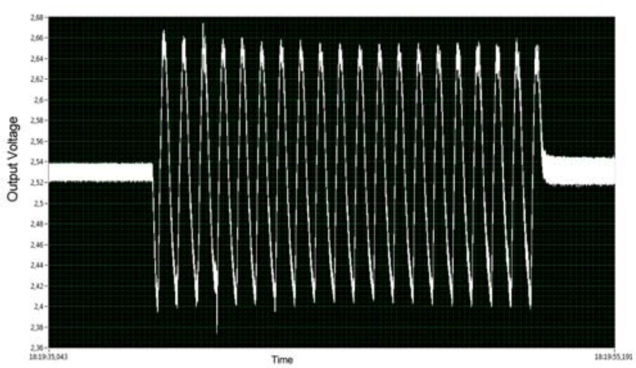

Figure 3: Output at the charge amplifier (amplitude about 250mV)

CONCLUSIONS

Multilayered all-polymer filaments that exhibit piezoelectric behavior have been produced through an industrial scalable methodology based on co-extrusion.

ACKNOWLEDGMENTS

The authors thank the Portuguese Foundation for Science and Technology (FCT) for financial support under PDTC (PTDC/CTM/108801/2008)

REFERENCES

1. D. Meoli, T. May-Plumlee, Interactive electronic textile development- A review of technologies, *Journal of Textile and Apparel, Technology and Management*, Vol.2, Issue 2,(2002).
2. J. Edmison, M. Jones, Z. Nakad, and T. Martin, Using piezoelectric materials for wearable electronic textiles, Sixth International Symposium on Wearable Computing, ISWC 2002, pp 41–48, (2002).
3. J. Lovinger, Developments in crystalline polymers, Elsevier Applied science, London (1982).
4. J. Gomes, J. Serrado Nunes, V. Sencadas and S. Lanceros-Mendez, Smart Materials and Structures, 19 (6) (2010) 065010.
5. V. Sencadas, R. G. Jr. and S. Lanceros-Mendez, Journal of Macromolecular Science, Part B: Physics 48 (2009), p. 514.
6. Dickens B, Balizer E, DeReggi AS, Roth SC. Hysteresis measurements of remanent polarization and coercive field in polymers. J Appl Phys 1992;72:4258.
7. D.Vatansever, R. L. Hadimani . T. Shah, E. Siores, Piezoelectric Mono·Filament Extrusion for Green Energy Applications from Textiles, International Congress of Innovative Textiles, ICONTEX2011, Istanbul, (2011).
8. S. Walter, W. Steinmann, J. Schütte, G. Seide, T. Gries, G. Roth, P. Wierach and M. Sinapius, “Characterisation of piezoelectric PVDF monofilaments,” Materials Technology: Advanced Performance Materials, vol. 26, no. 3, (2011) pp. 140–145.
9. B. Mazurek, S. Różecki, D. Kowalczyk, T. Janiczek, Influence of piezoelectric cable processing steps on PVDF beta phase content, Journal of Electrostatics, Volumes 51-52, Elsevier B.V. pp 180-185 (2001).
10. A. Ferreira, P. Costa, H. Carvalho, J.M. Nóbrega, V. Sencadas, S. Lanceros-Mendez, Extrusion of poly(vinylidene fluoride) filaments: effect of the processing conditions and conductive inner core on the electroactive phase content and mechanical properties, Journal of Polymer Research, Springer, Netherlands, Doi: 10.1007/s10965-011-9570-1 (2011).
11. A. Lund, B. Hagström, Melt Spinning of b-Phase Poly(vinylidene fluoride) Yarns With and Without a Conductive Core, Journal of Applied Polymer Science,Vol. 120, 1080–1089 (2011).