SHORT TERM SCIENTIFIC MISSION (STSM)
SCIENTIFIC REPORT

This report is submitted for approval by the STSM applicant to the STSM coordinator

Action number: CA17107
STSM title: Characterization of piezoelectric responses of electrospun polymer fibers for smart textiles application
STSM start and end date: 01/03/2019 to 31/03/2019
Grantee name: Piotr Szewczyk

PURPOSE OF THE STSM:

The purpose of this STSM was to investigate piezoelectric properties of electrospun Poly(vinylidene fluoride)(PVDF) and odd-numbered Polyamide 11(PA11, Nylon-11) fibers, learn AFM based characterization techniques and establish long lasting cooperation between Cambridge and AGH universities.

The main research goal was to introduce a novel one-step process of obtaining highly piezoelectric material without chemical, mechanical, electrical or thermal post-treatment necessary in standard polymer piezoelectrics. Moreover, it is necessary to understand the mechanisms ruling this phenomenon and to pinpoint the main factors in electrospinning process that can influence the overall performance of the obtained fibers as the relation between voltage and its polarity on piezoelectric output is still not entirely understood. In the future piezoelectric fibers could bring new solutions for energy harvesting in textiles as electrospun fibers can be intertwined between regular yarns or even replace them creating smart fabrics.

DESCRIPTION OF WORK CARRIED OUT DURING THE STSMS

Extensive literature research on the topic of electrospun piezoelectric fibers was carried out at the beginning of the STSM. After literature research infrastructure at the Home institution was used to prepare samples for measurements at Host Institution.
Solutions for electrospinning were prepared as follows:

PVDF (M_w= 275000 g mol^{-1}, Sigma Aldrich, UK) granules were dissolved in a solution with 1:1 ratio of dimethylacetamide (DMAc, analytical standard, Avantor, Poland) and acetone (analytical standard, Avantor, Poland) to produce a polymer solution with a concentration of 24 wt. %. The solution was stirred for 4h at a speed of 700 rpm with a hot plate set to 50°C. Nylon-11 (M_w= 201.31 g mol^{-1}, Sigma Aldrich, UK) granules were dissolved in formic acid (95% pure, Sigma Aldrich, UK) to produce a polymer solution with a concentration of 12 wt. %. The solution was stirred for 2h at speed of 1100 rpm with a hot plate set to 45°C.

Electrospinning was carried out with electrospinning apparatus EC–DIG with climate upgrade system (IME Technologies, The Netherlands). During electrospinning temperature and humidity of the chamber were constant at 25°C and 60% respectively. The fibers were deposited directly on Silicon wafers coated with a 10nm sputter coated Au layer. Parameters of electrospinning are shown in Table 1.

Table 1 Electrospinning parameters of PVDF and Nylon-11 fibers.

Sample	Voltage[kV]	Polarity	Distance to collector [cm]	Flow rate [$\mu l h^{-1}$]
PVDF	15	+	18	1.5
PVDF	15	-	18	1.5

Nylon-11	20	+	12	6
Nylon-11	22	+	12	6

In total 2 samples for each corresponding set of parameters were prepared giving a total of 8 electrospun samples used for this investigation. The AFM and PFM measurements were carried out using Multi mode 8 (Bruker, USA) with conductive Pt/Cr coated silicon tips (spring constant 3 Nm^{-1}). Firstly, the topography of the samples was measured using the tapping mode. Secondly, the piezoresponse of the fibers was confirmed by PFM with an internal lock-in amplifier.

DESCRIPTION OF THE MAIN RESULTS OBTAINED

Parameters chosen for PVDF and Nylon-11 electrospinning were found to be satisfactory and fiber networks on Au coated Silicon substrates were obtained successfully.
Showed in Fig 1. are topography measurement results. PVDF sample Fig.1a, b) diameters were 3.32 ± 0.08 and 3.13 ± 0.09 for PVDF15kV+ and PVDF15kV- respectively showing that voltage polarity does not affect the morphology of the fibers in a significant manner which is in line with literature.[1]

Nylon-11 samples Fig. 1 c, d) diameters were found to be 3.48 ± 0.12 and 1.32 ± 0.02 for Nylon11 obtained at 20kV+ and 22kV+ respectively. These results show that there is a relation between voltage polarity and a fiber diameter of obtained Nylon-11 fibers.

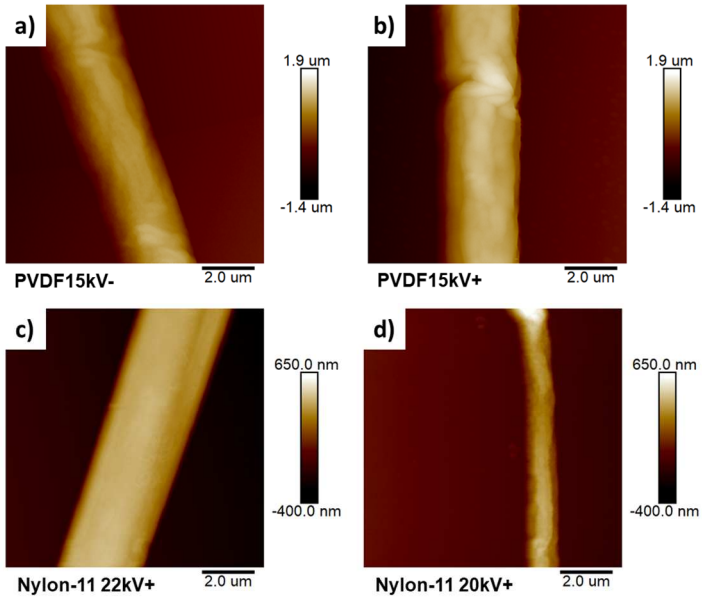

Fig 1. Topography measurements of a,b) PVDF and c,d) Nylon-11 samples.

In Fig 2. The PFM results are presented. PVDF samples Fig.2 a, b) were both found piezoelectric with 1.27mV and 0.58mV for PVDF15kV+ and PVDF15kV- respectively. PVDF electrospun at negative voltage polarity gave more than 2 times higher piezoelectric response.
Both Nylon-11 samples showed Fig. 2 c, d) were found to be piezoelectric with a small difference between fibers obtained at 20 and 22kV being 0.78mV and 0.72mV respectively confirming that electrospun Nylon-11 fibers are piezoelectric as previously found in the literature for bulk material.[2]

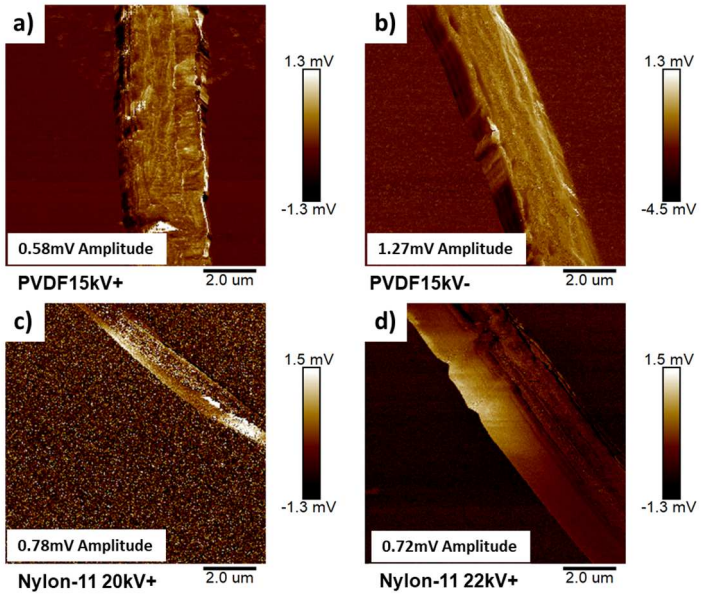

Fig 2. Piezoelectric measurements of a,b) PVDF and c,d) Nylon-11 samples.

Obtained results bring great promise for future research and possible application of electrospun piezoelectric mats in smart textiles. Electrospinning was found to be a suitable technique for the production of piezoelectric fibers in one step production method for both polymers.

References:

(1) Busolo, T.; Ura, D. P.; Kim, S. K.; Marzec, M. M.; Bernasik, A.; Stachewicz, U.; Kar-Narayan, S. Surface Potential Tailoring of PMMA Fibers by Electrospinning for Enhanced Triboelectric Performance. *Nano Energy* 2018.

(2) Wu, G.; Yano, O.; Soen, T. Dielectric and Piezoelectric Properties of Nylon 9 and Nylon 11. *Polym. J.* 1986, *18*, 51.

FUTURE COLLABORATIONS (if applicable)

This research will be continued with help from Host institution as the results proved promising and the scope of this research will be expanded. Results obtained during this STSM will be published in two scientific papers.