SMART MATERIALS FOR ENERGY REGENERATION

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CONTENT

University of Bolton

- ✓Aims and objectives
- ✓Polymer based piezoelectric filament production
- ✓Characterisation (Statimat, DSC, FTIR, NMR, SEM)
- ✓Impact test (Instron Dynatup 9200) and the test results
- ✓Possible Woven Structures
- ✓Hybrid piezoelectric-photovoltaic (HPP) film and fibre production process
- ✓ Characterisation (4 probe *J-V*, SEM, AFM)
- ✓ Conclusions

Aims of the research work

To generate piezoelectric filaments via a continuous process that is;

- ✓ lead free,
- ✓ flexible,
- ✓ light weight,
- ✓ less expensive to produce
- ✓ easy to use.

To develop a hybrid structure, combining piezoelectric technology with photovoltaic technology, that enables to convert;

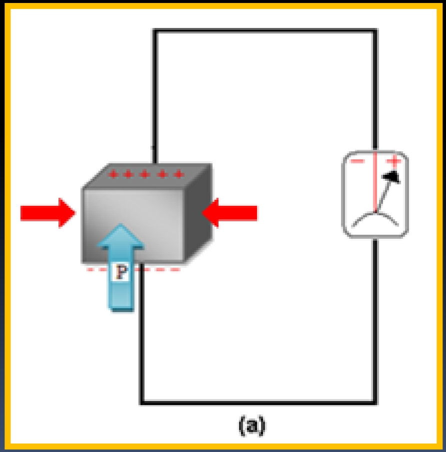
- ✓ mechanical energy (in the form of impact or vibration) to electrical energy
- ✓ photon/solar energy to electrical energy

Introduction to Piezoelectricity

Piezoelectricity is the ability of some materials to transform mechanical stress into electrical charge and vice versa.

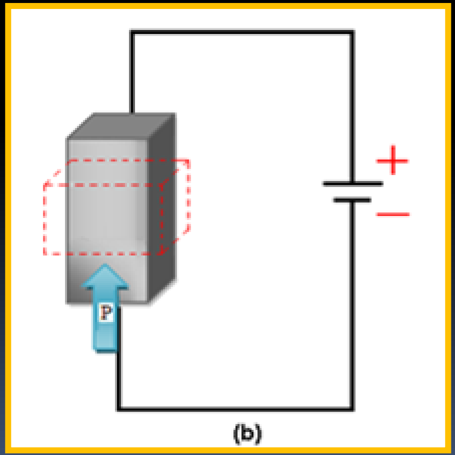
- ✓ The notion came from Charles Coloumb in 1817.
- ✓ Direct piezoelectric effect was first demonstrated and defined by Pierre and Jacques Curie brothers in 1880.
- ✓ Converse piezoelectric effect was first mentioned by Lippmann in 1881.
- ✓ Name of ”piezoelectric” was given by Hankel in 1881.

Direct Piezoelectric Effect



- ✓ also known as generator effect or
- ✓ sensor effect.

Converse Piezoelectric Effect



- ✓ also known as motor effect or
- ✓ actuator effect.

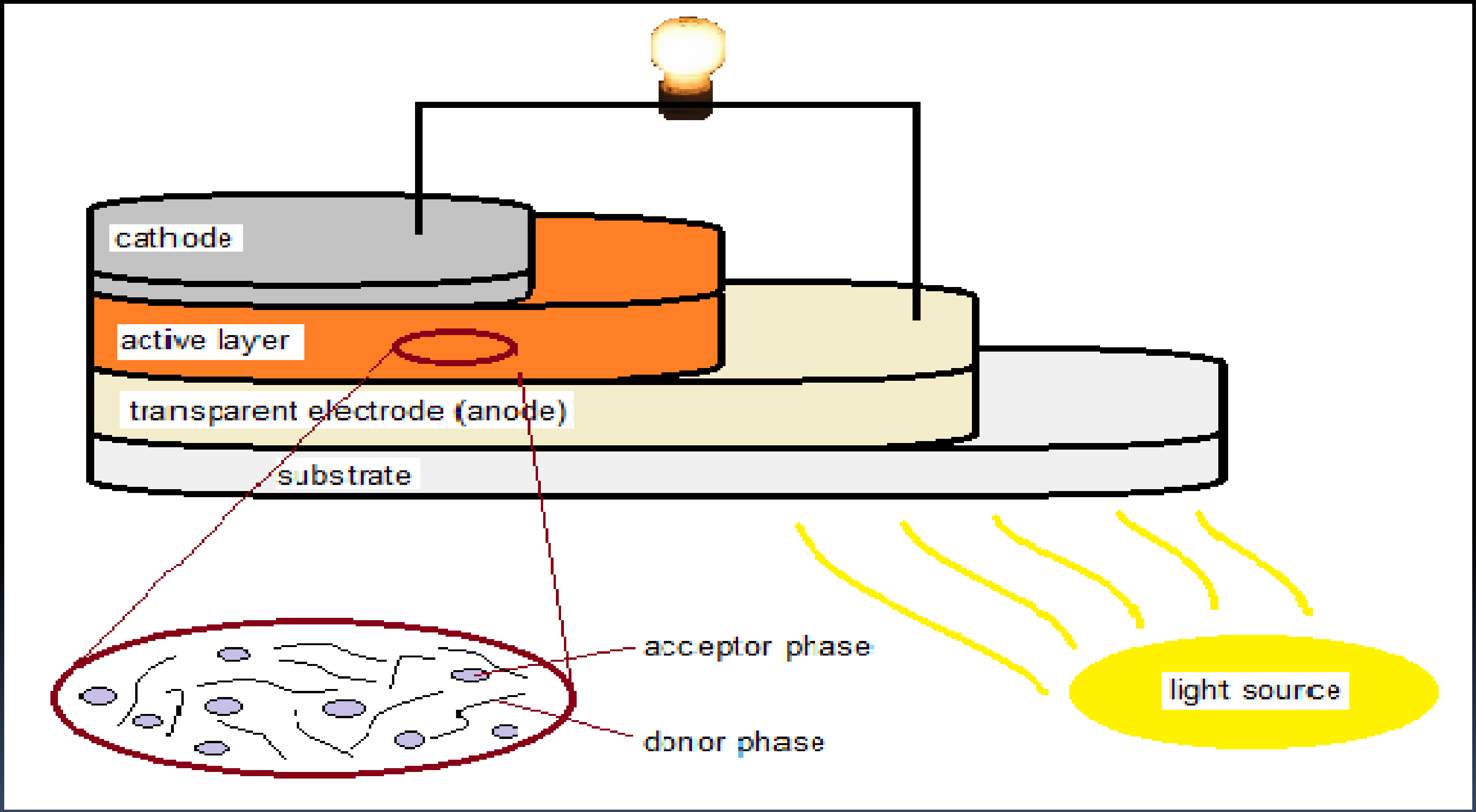
Why flexible piezoelectric fibre?

- Existing piezoelectric fibres are;
  - ✓ lead-zirconate titanate (PZT) based,
  - ✓ rigid,
  - ✓ brittle

- Existing flexible piezoelectric structures are;
  - ✓ polyvinylidene fluoride (PVDF) based,
  - ✓ commercially available only in film form

- None of these commercial piezoelectric materials are suitable to be used in flexible textile structures.

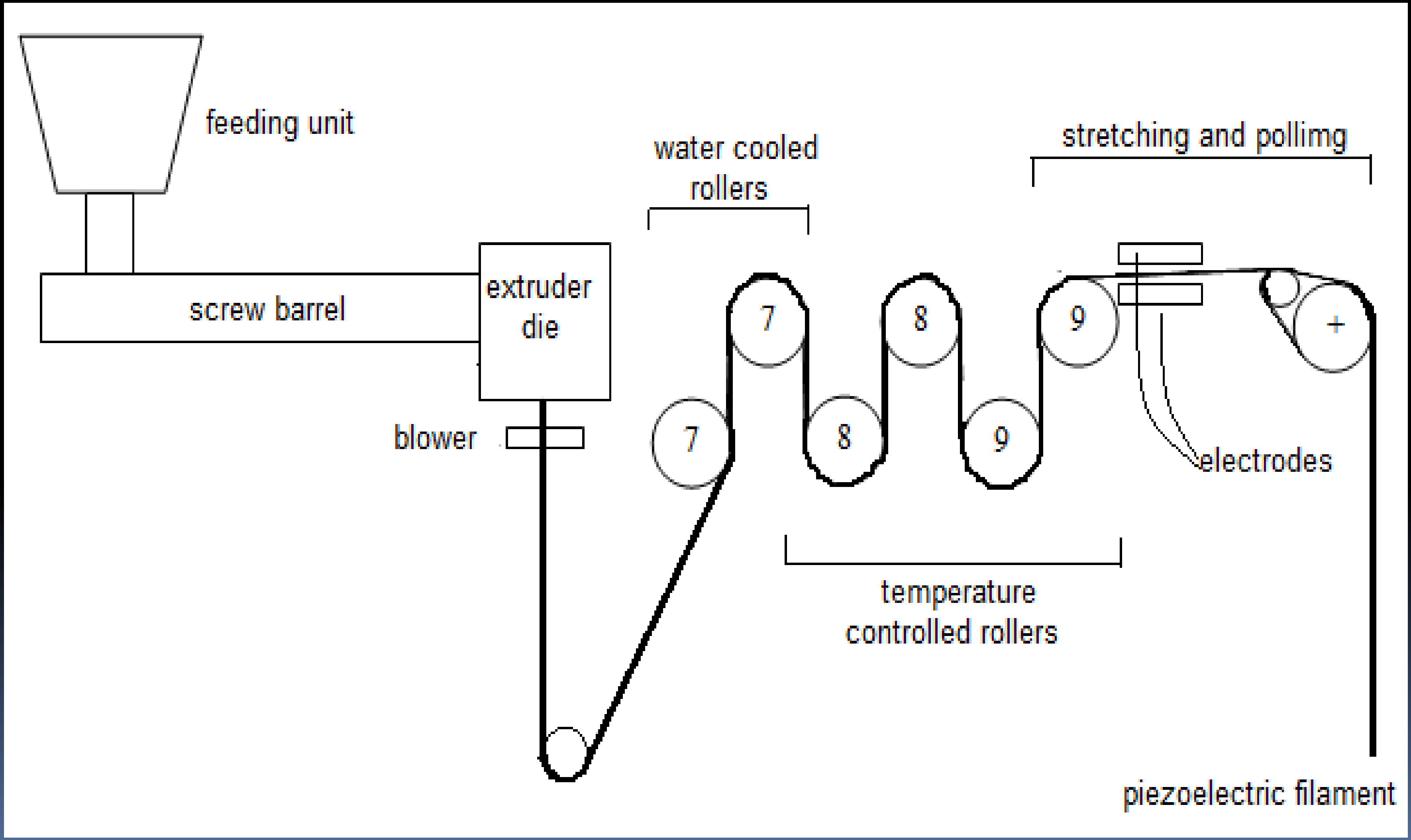
Introduction to Organic Photovoltaic (OPV) Technology



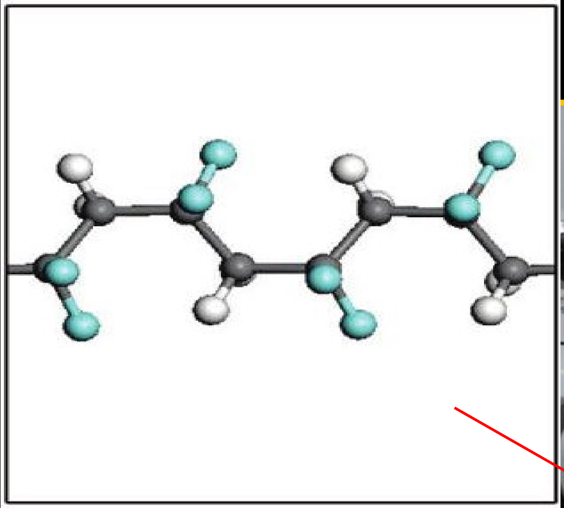
Basic operational principles for a polymer solar cell

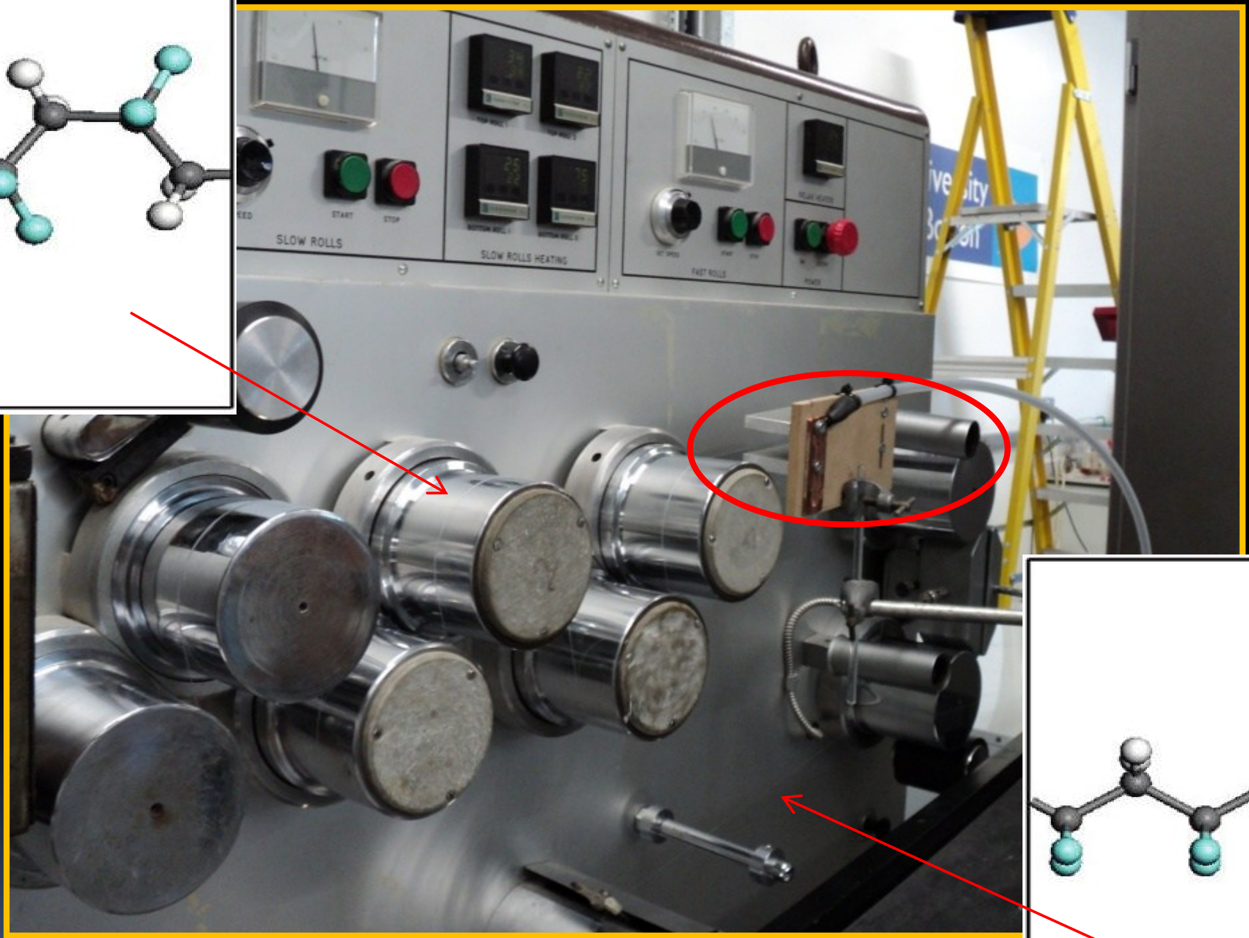
- Coupling of the photons
- Photon absorption by active layer, η_{abs}
- Electron-hole pair creation (excited state) and diffusion, η_{diff}
- Charge separation, η_{tc}
- Charge transportation within the respective polymer to the respective electrodes, η_{tr}
- Charge collection, η_{cc}

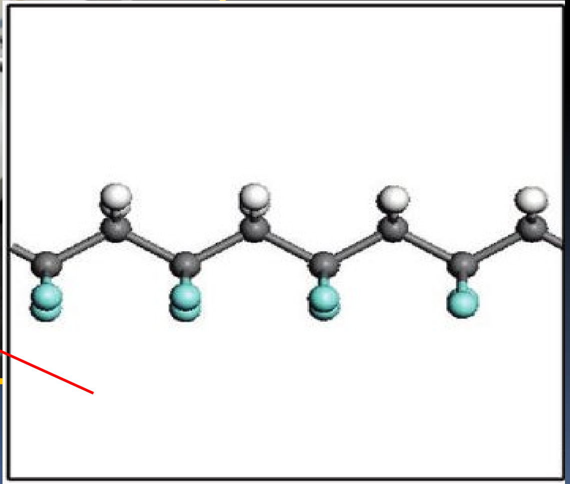
Schematic of a melt extruder piezoelectric filament extrusion process



Piezoelectric Filament Production





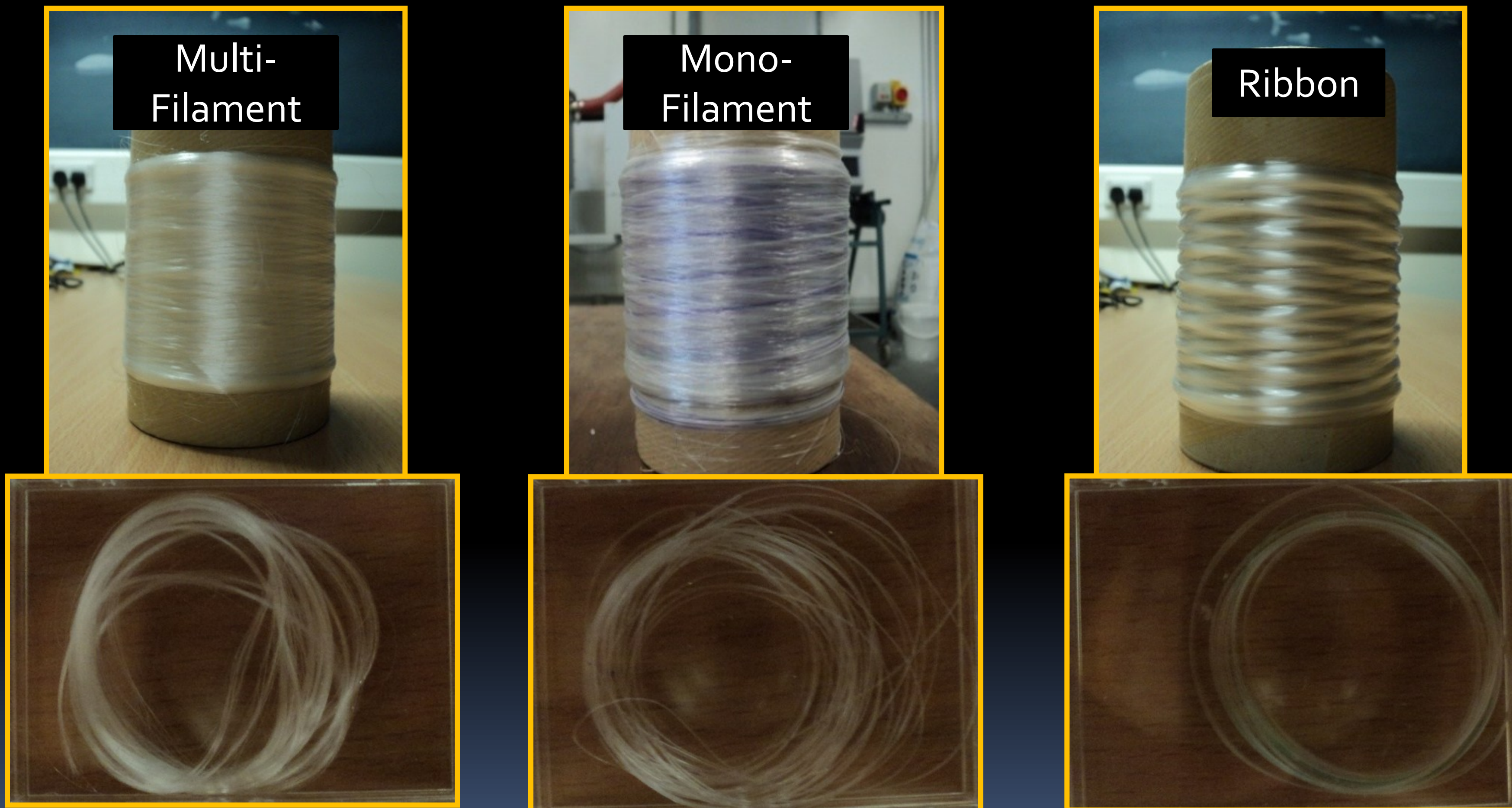


* R. L. Hadimani, D. Vatansever, and E. Siores, “Piezoelectric Polymer Element and Production Method and Apparatus Therefor,” U.K. Patent GB1015399.7

What polymers we have used so far?

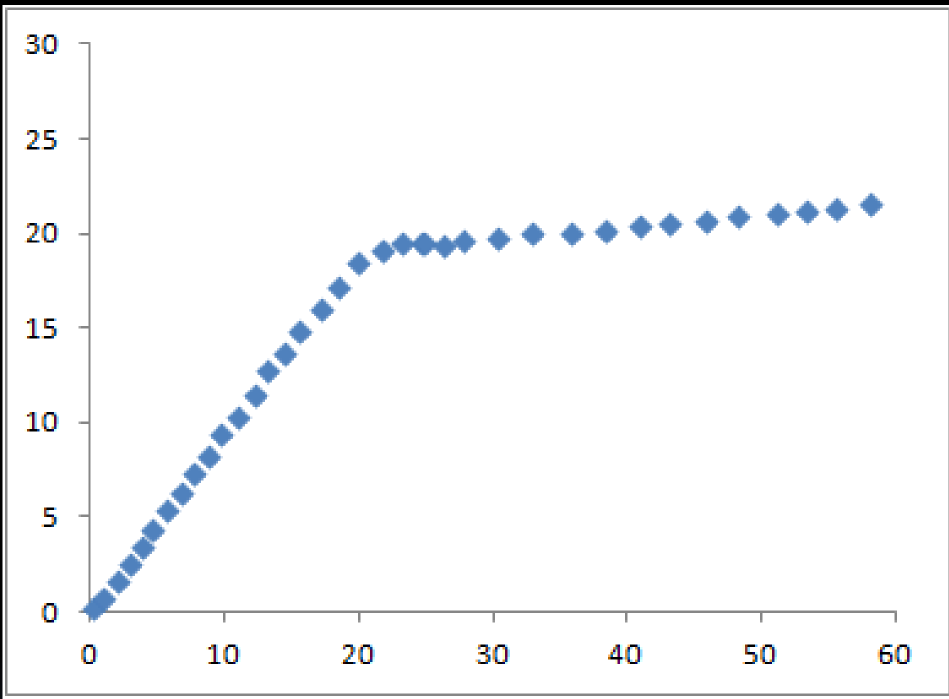
- Poly(vinylidene fluoride) – PVDF
  - homopolymer
  - copolymer
- Polypropylene – PP
- Polyamide 11 – PA 11

Piezoelectric Filaments Produced via a continuous process

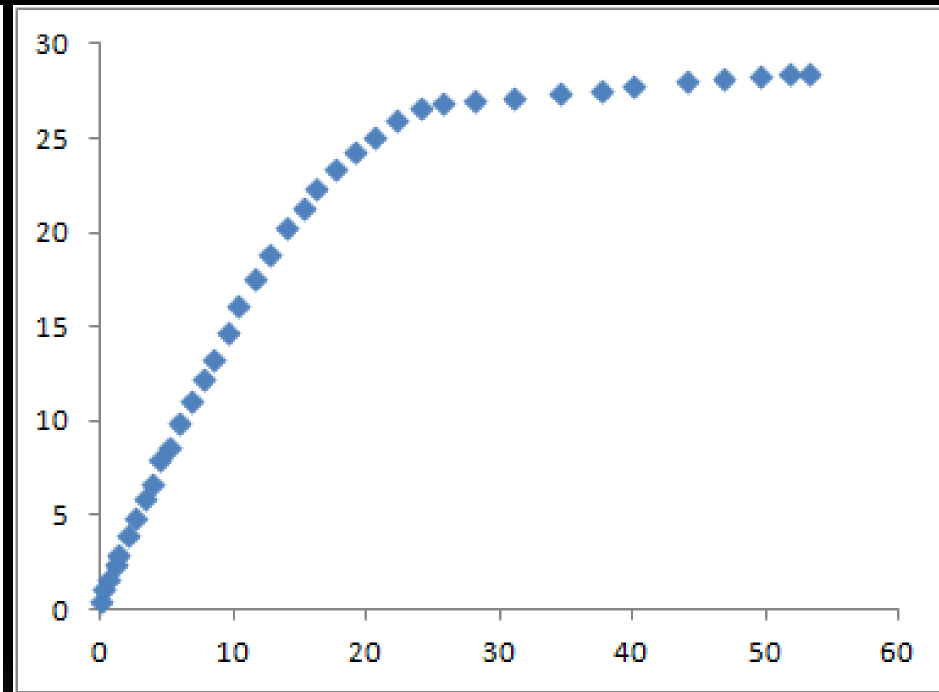


- ✓ Resulted piezoelectric PVDF filaments are very flexible and easy to process and integrate into textiles

Tensile stress vs strain curves for unpoled and poled PVDF fibres

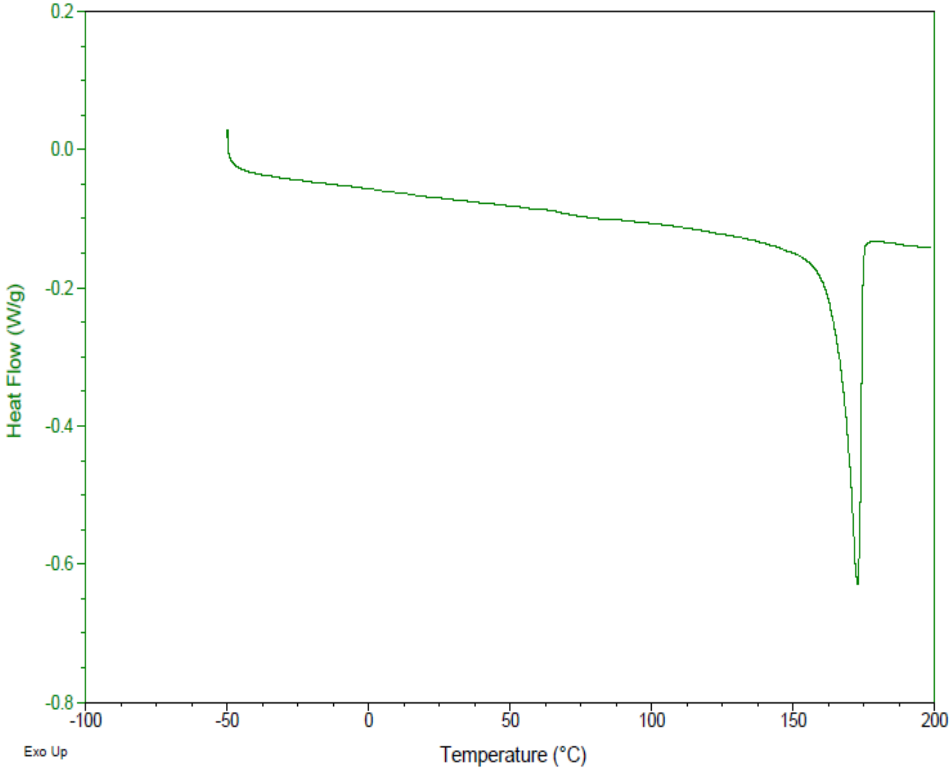


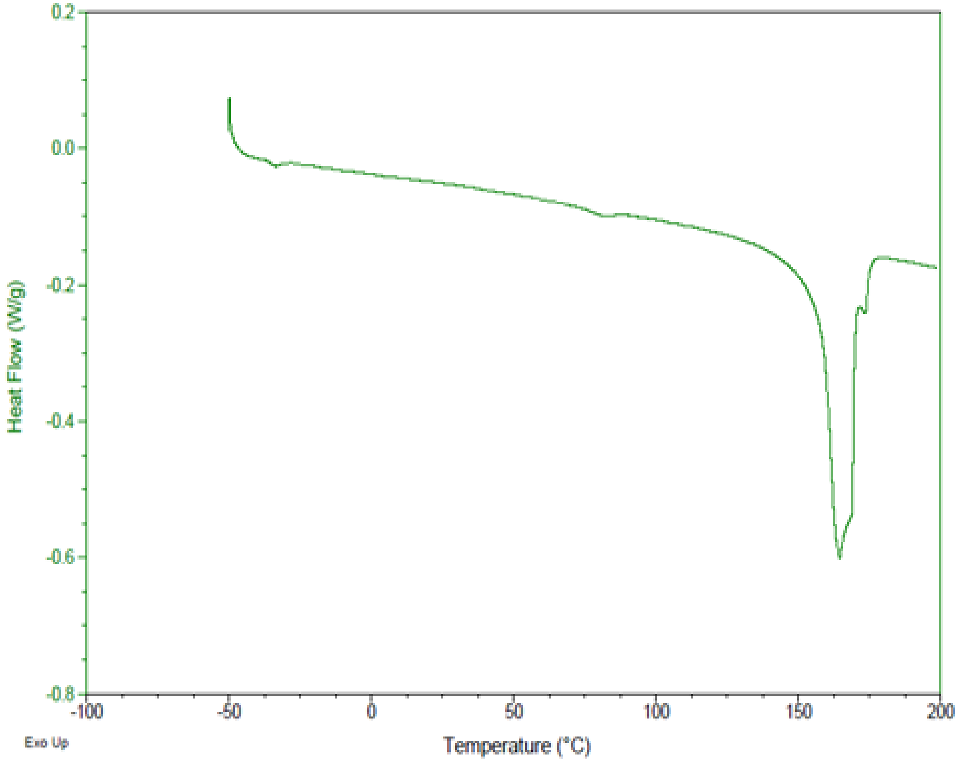
Stress (cN/tex) vs strain (%) curve of unpolled PVDF fibres



Stress (cN/tex) vs strain (%) curve of polled PVDF fibres

DSC results of PVDF fibres

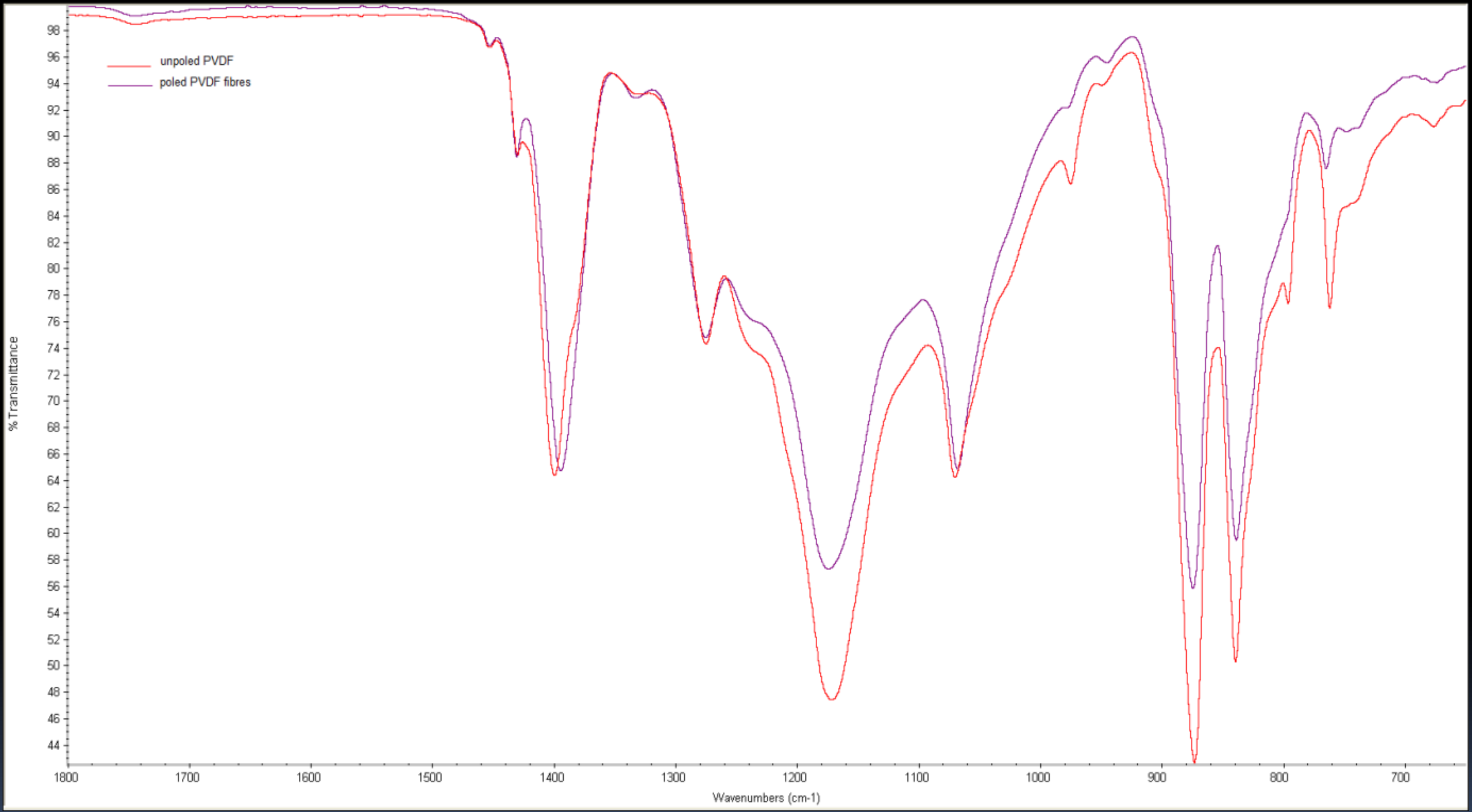




DSC thermogram of unpoled PVDF at a 5°C/min heating rate

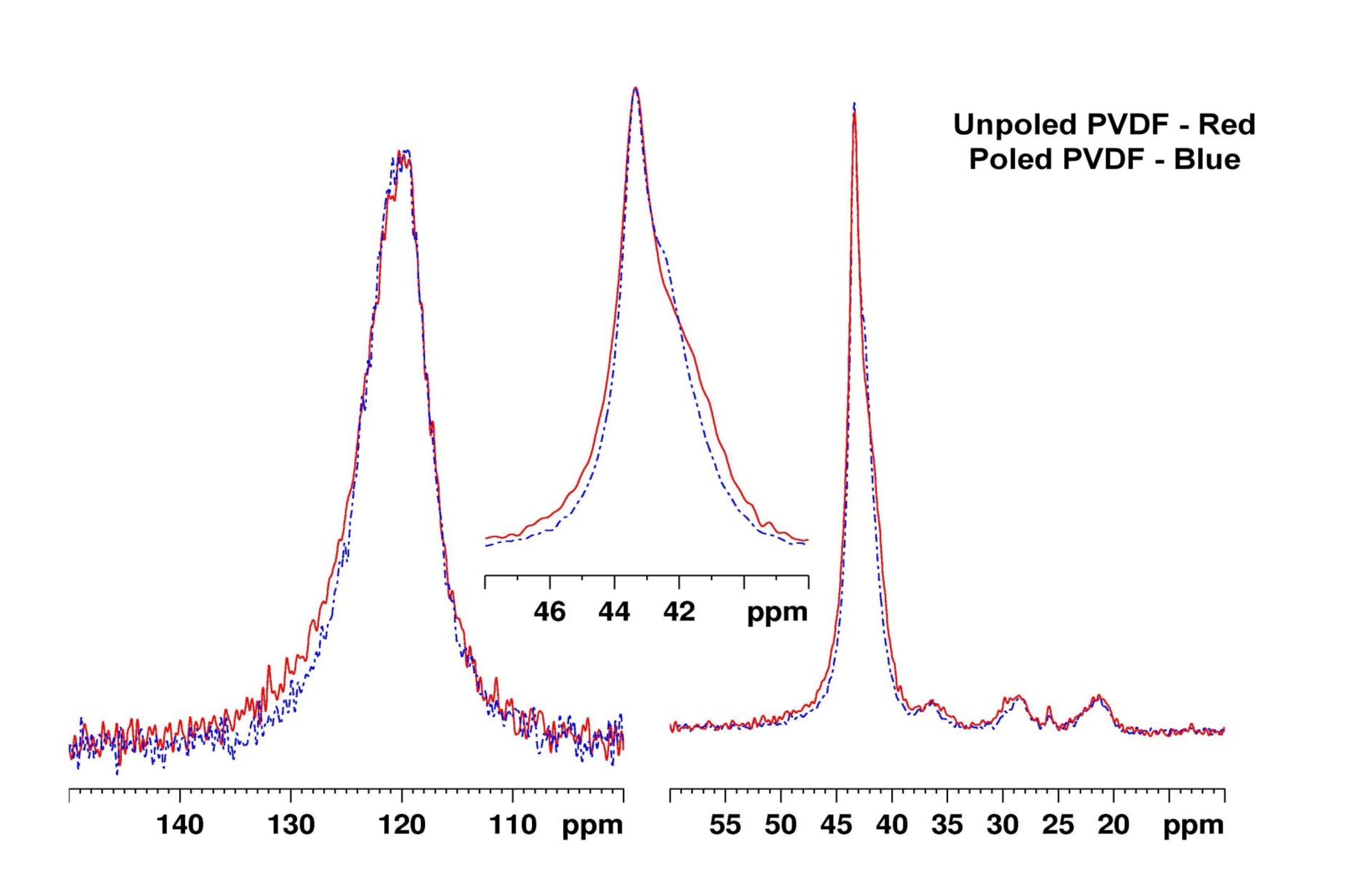
DSC thermogram of poled PVDF fibre at a 5°C/min heating rate

FTIR results of PBDF fibre



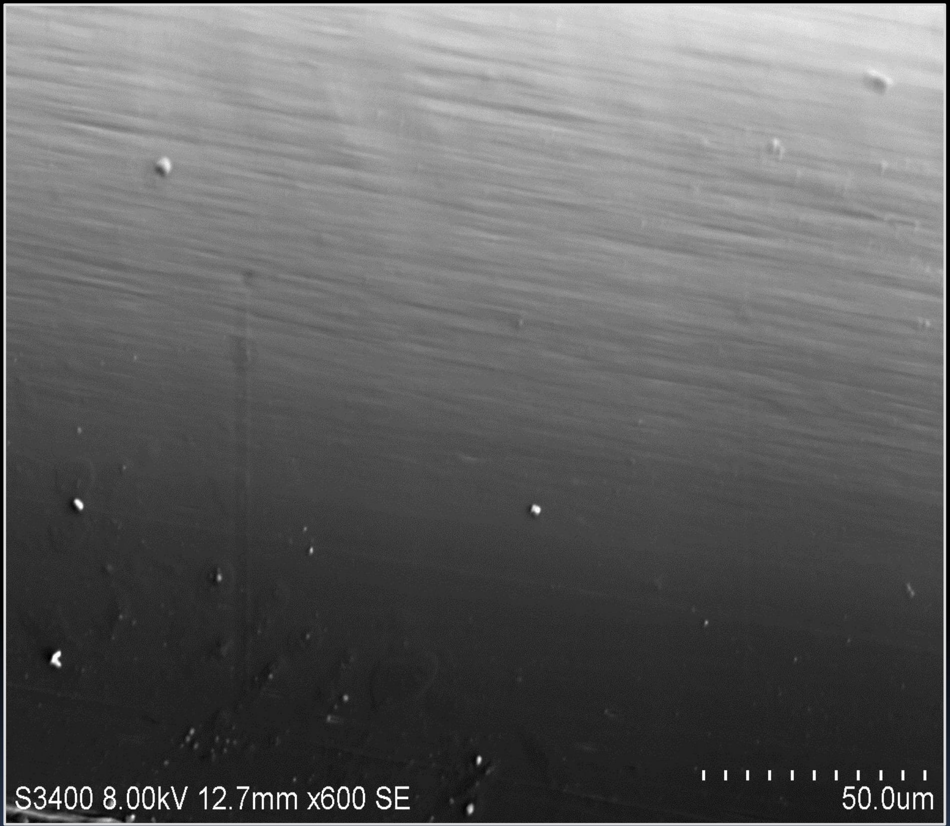
FTIR measurement of unpoled PVDF fibre (red) and poled PVDF fibre (blue) for a shorter wavelength (600 – 1800 cm^{-1})

NMR results of PVDF fibres

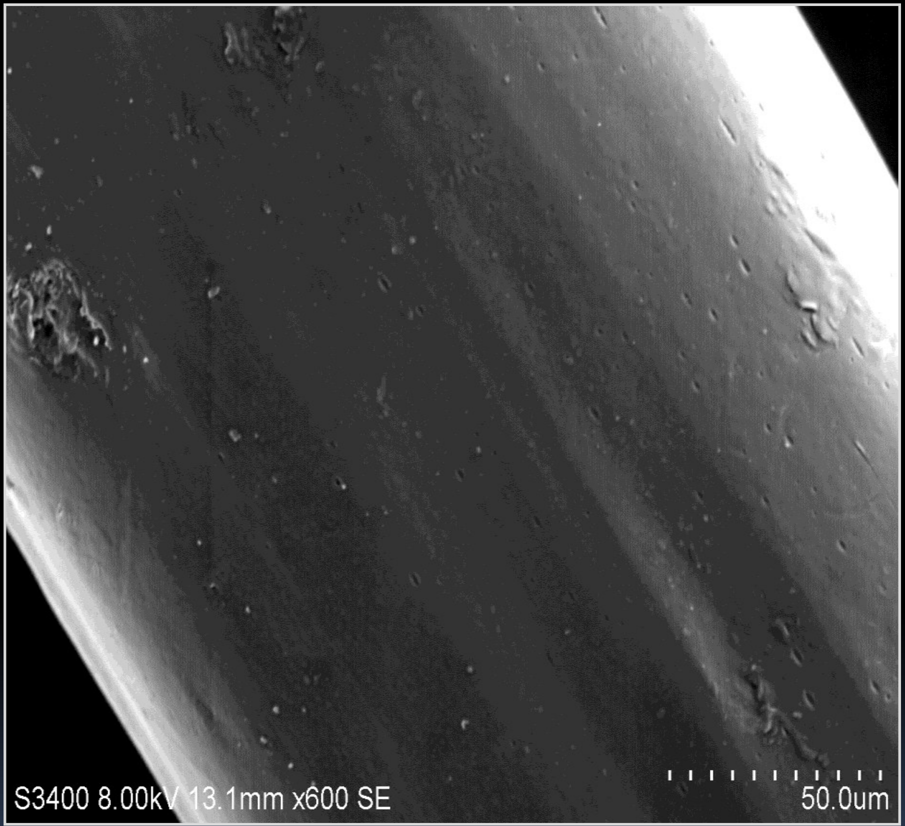


Solid-state ^{13}C-NMR profiles of both poled (blue) and unpoled (red) PVDF ribbon fibres.

SEM Images for unpoled and poled PVDF fibres

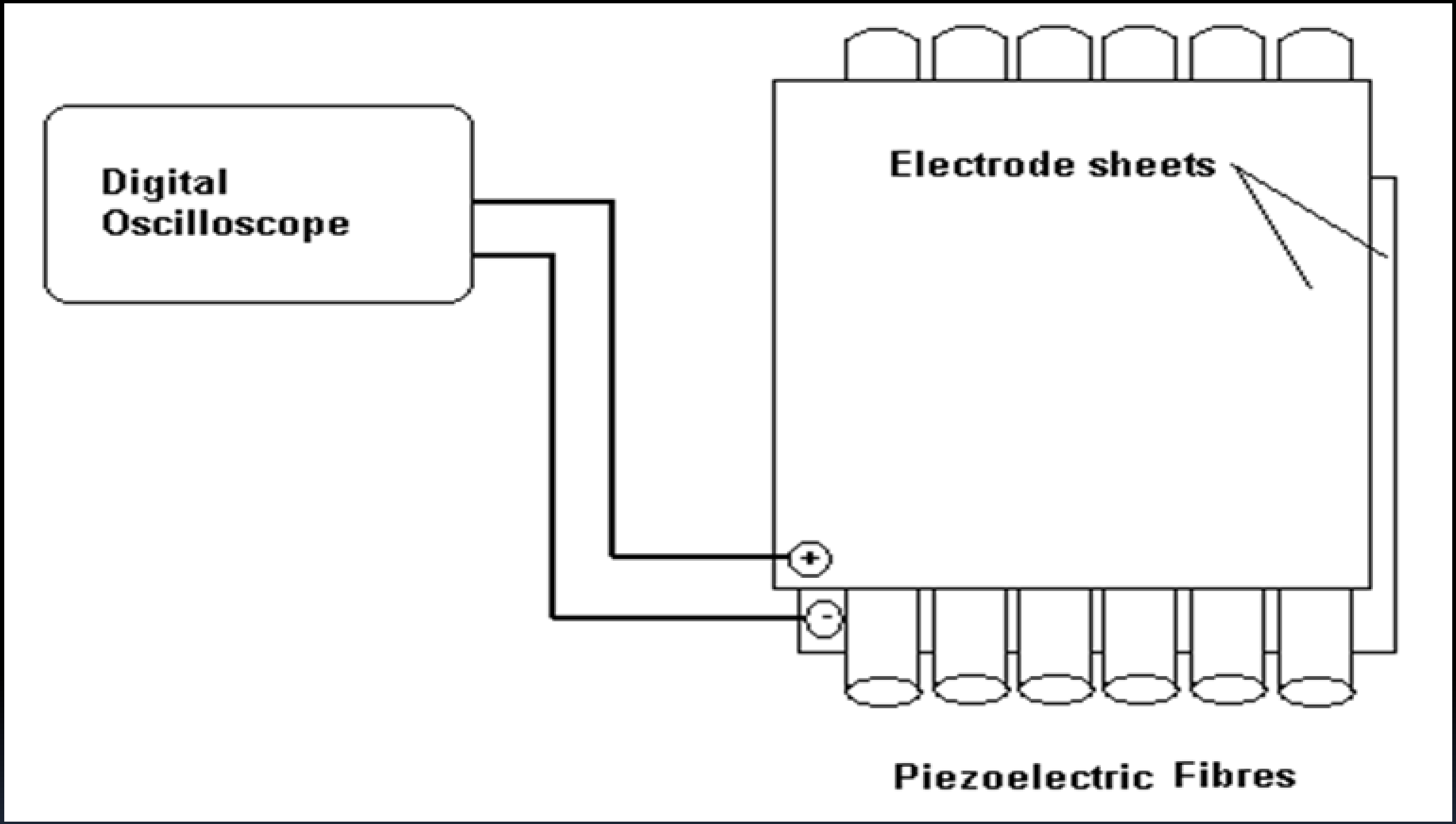


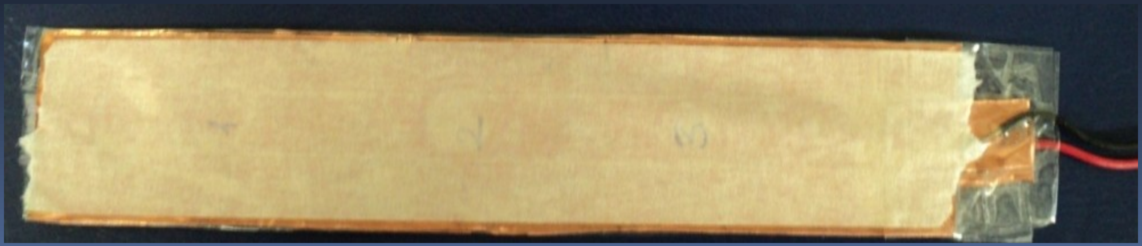
SEM Image of unpoled PVDF fibre



SEM Image of poled PVDF fibre

Preparation of test specimens





Instron Dynatup 9200 Impact Test Equipment

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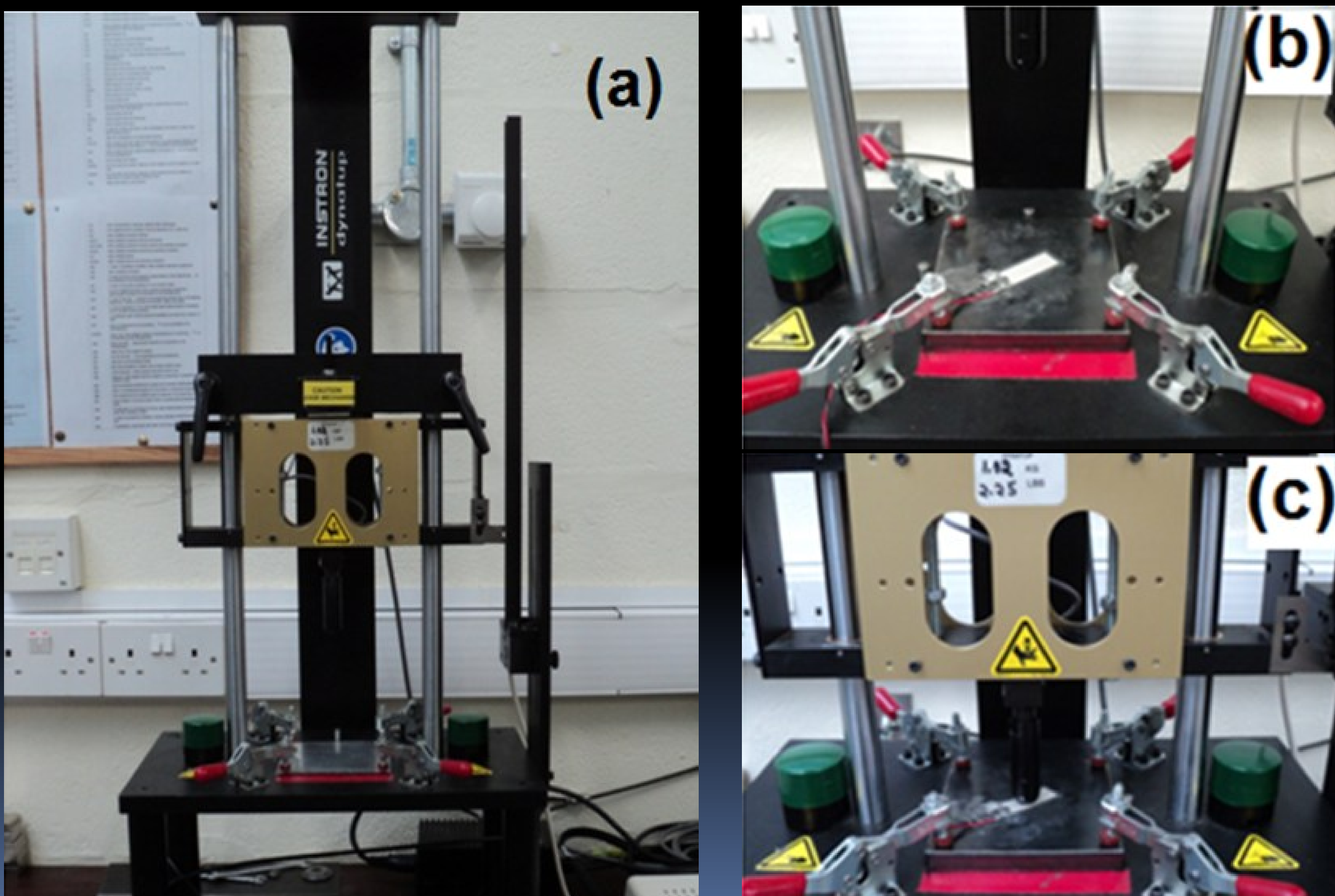
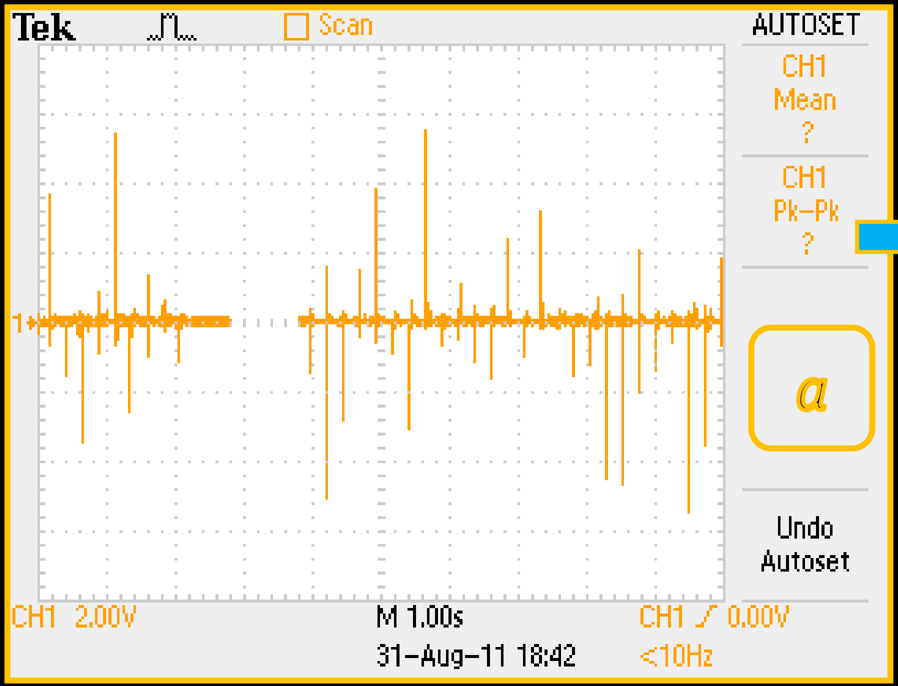
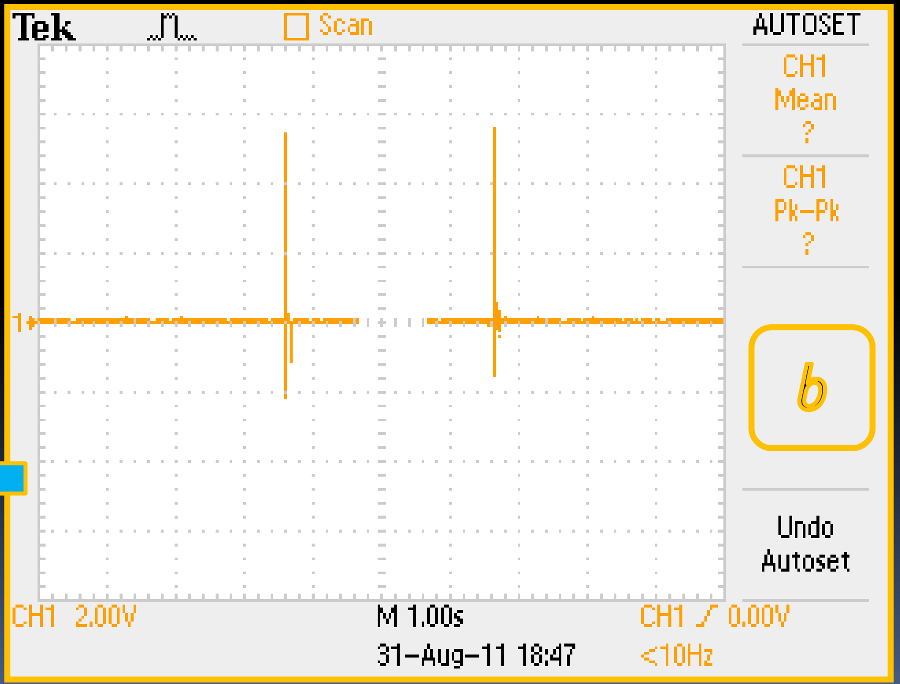


Impact Results



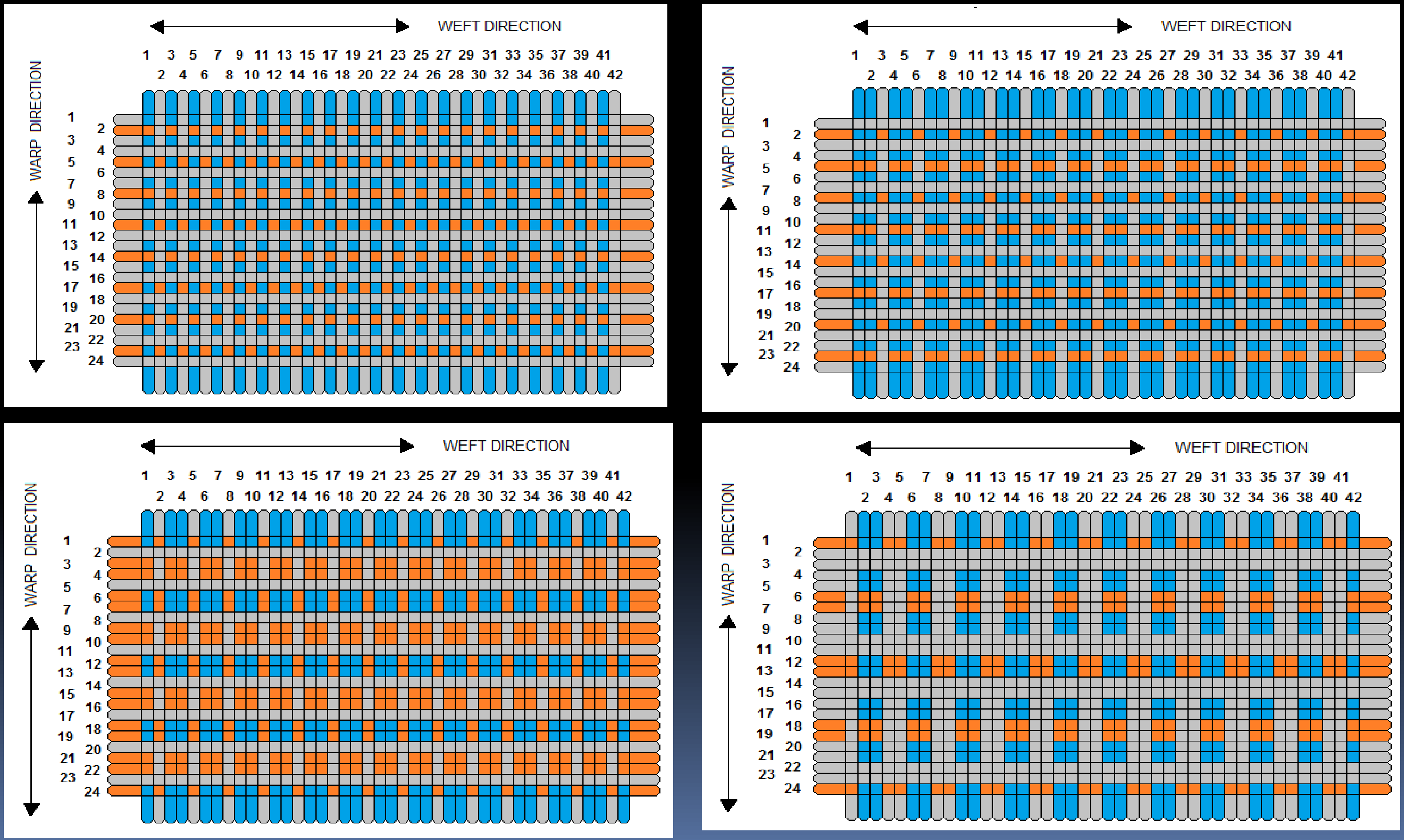
- An increase in the voltage generation was observed with an increase in the applied force .



- A peak voltage of 5.5V was observed and this peak voltage was reproducible when the same impact was applied.

Possible Woven Structures

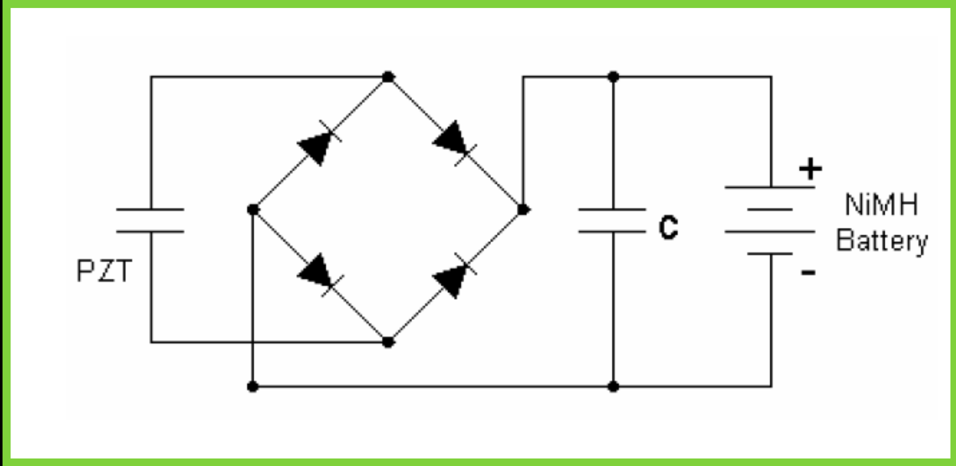
piezoelectric thread, conductive thread, non-conductive thread

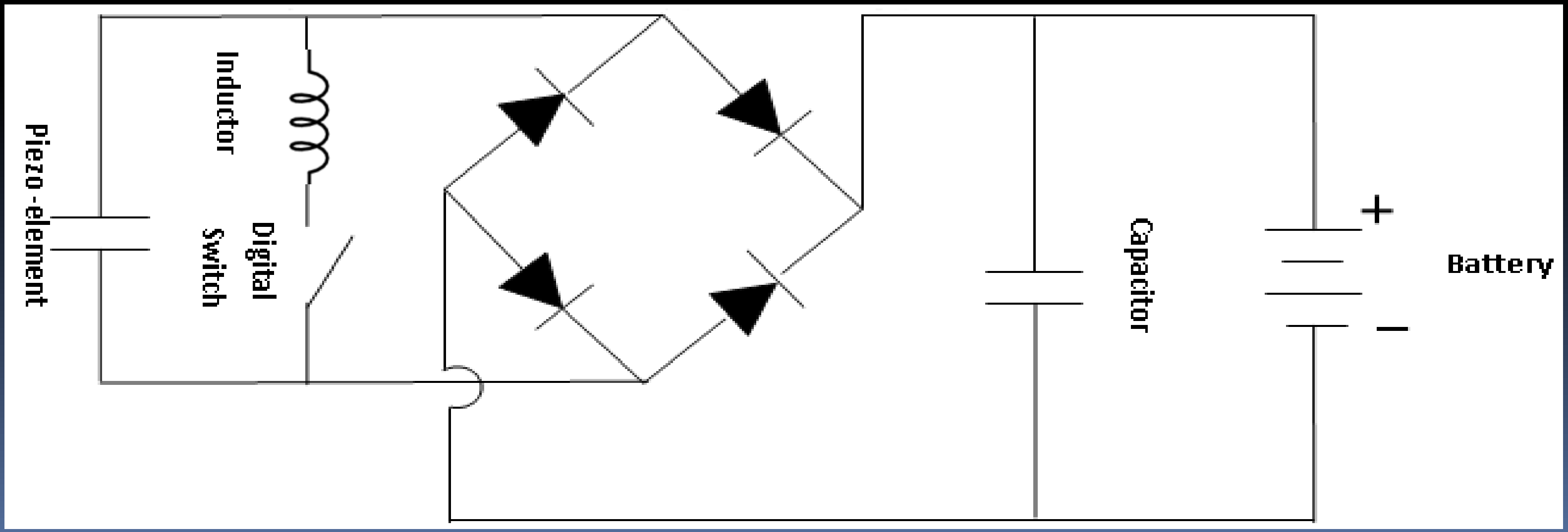


Electronic Circuitry

Voltage generated by the piezoelectric material will be fluctuating with random frequency. This signal needs to be converted to a standard DC voltage.

This is done using a full wave rectifier and a capacitor. By using complex circuits we can improve the conversion efficiency.





Why hybrid piezoelectric photovoltaic (HPP) films and fibres?

- Piezoelectric materials can convert mechanical energy to electrical energy; but if there is no mechanical stimuli…?
- Photovoltaic materials can convert sun light to electrical energy; but if there is no sun light…?
- HPP technology offers almost undisturbed energy generation by combining these two smart technologies into a single structure.

Production Process of Films

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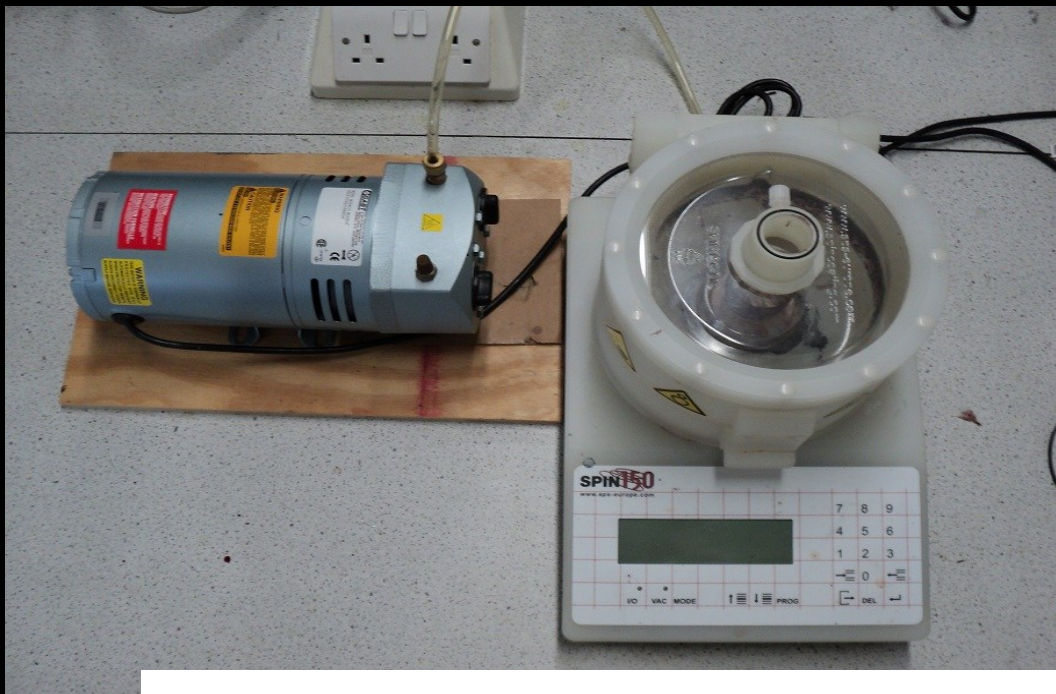
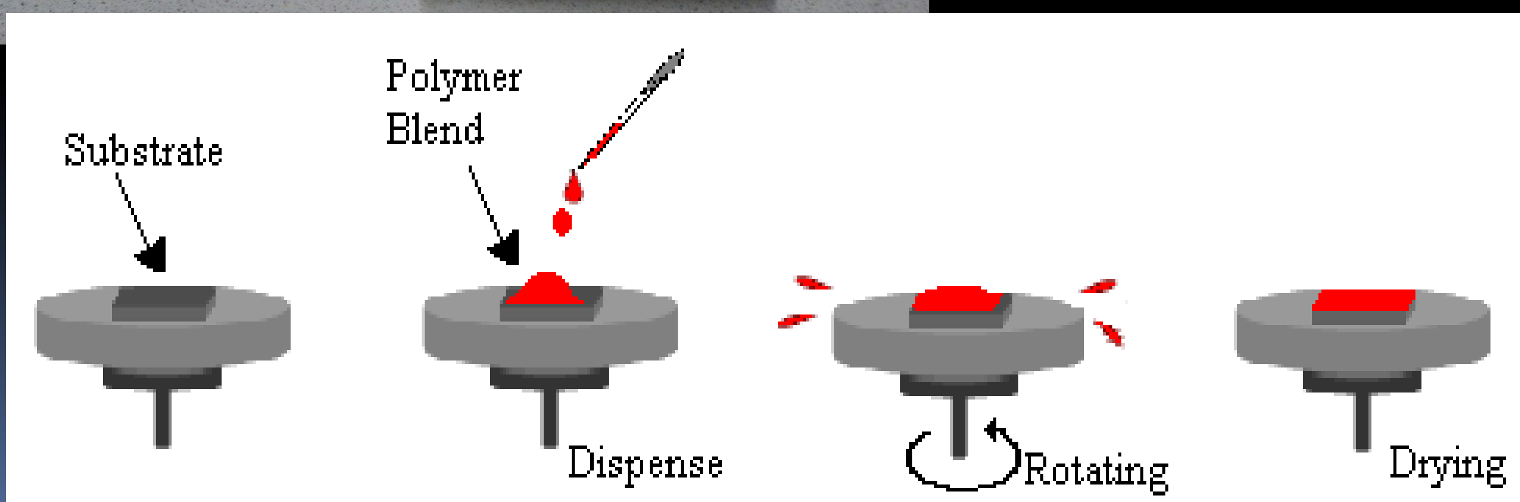
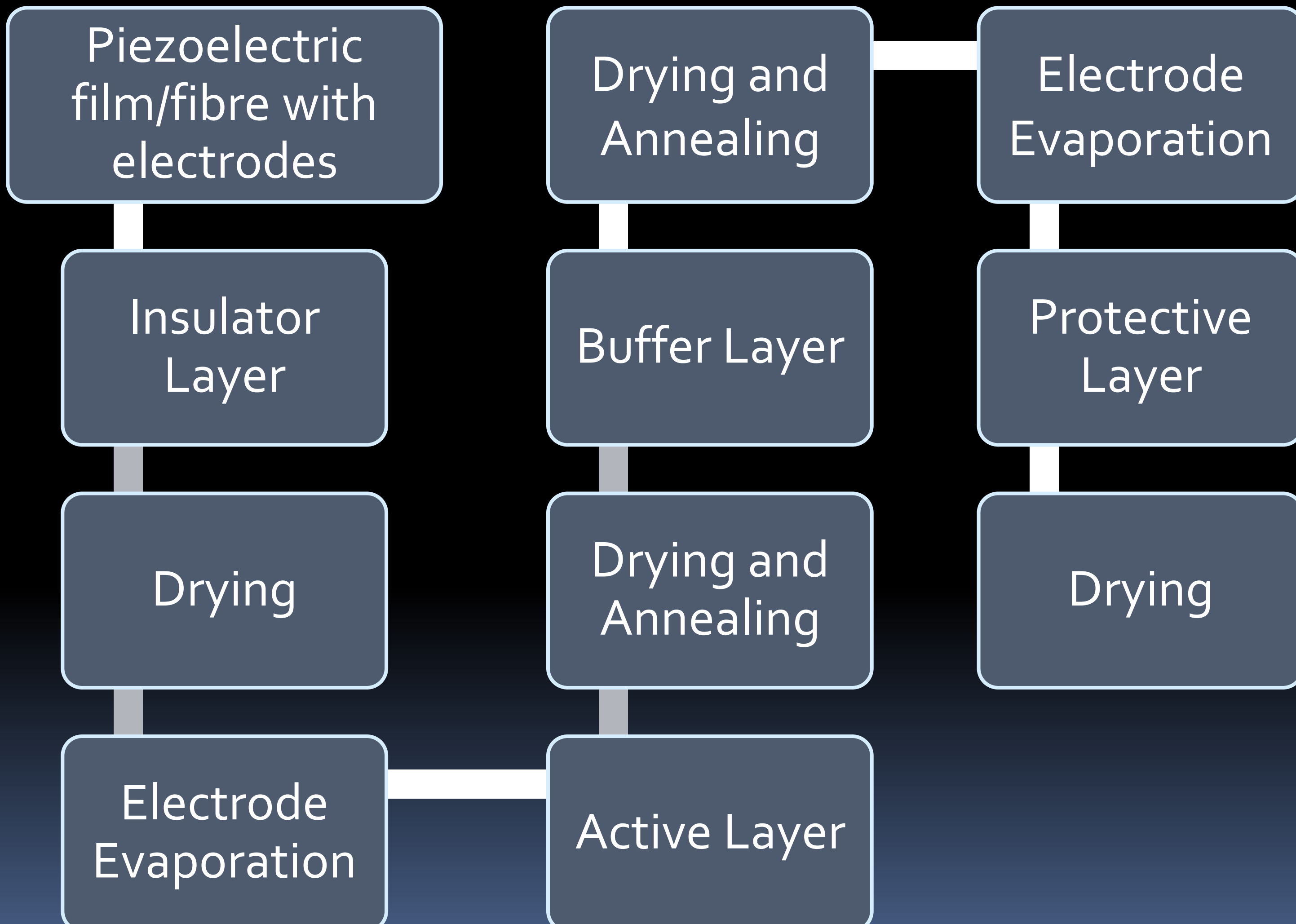


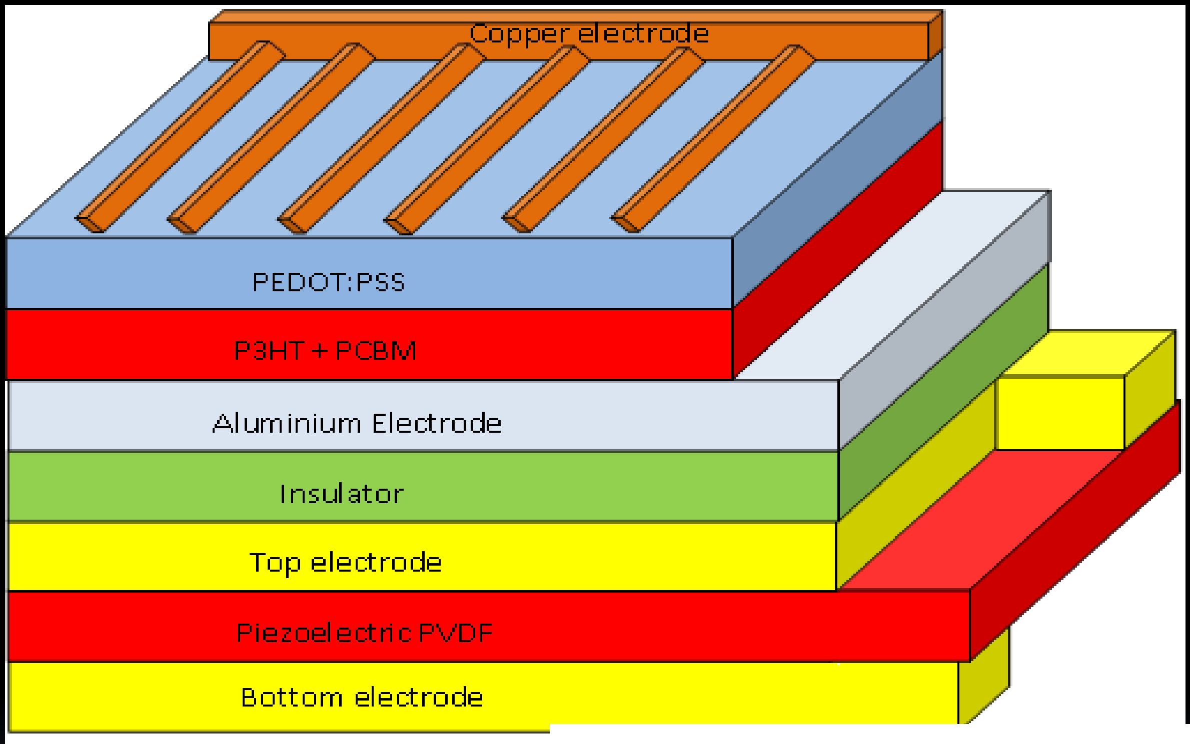
- Piezoelectric substrate
- Electrode
- P3HT:PCBM
- PEDOT:PSS
- Electrode
- Protective layer

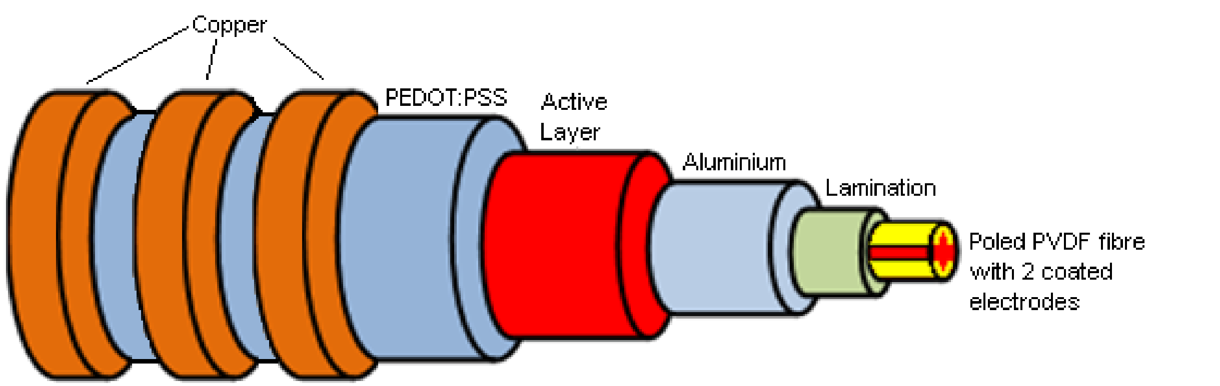


Production Process of Hybrid Film & Fibre



HPP Materials Produced at IMRI





HPP Materials Produced at IMRI

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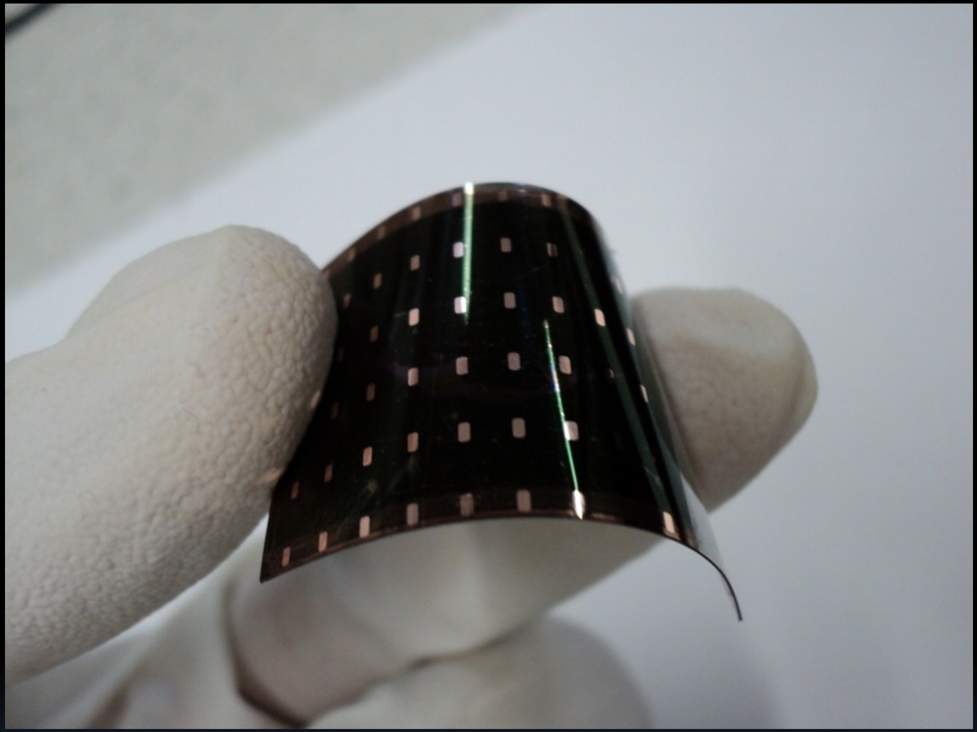
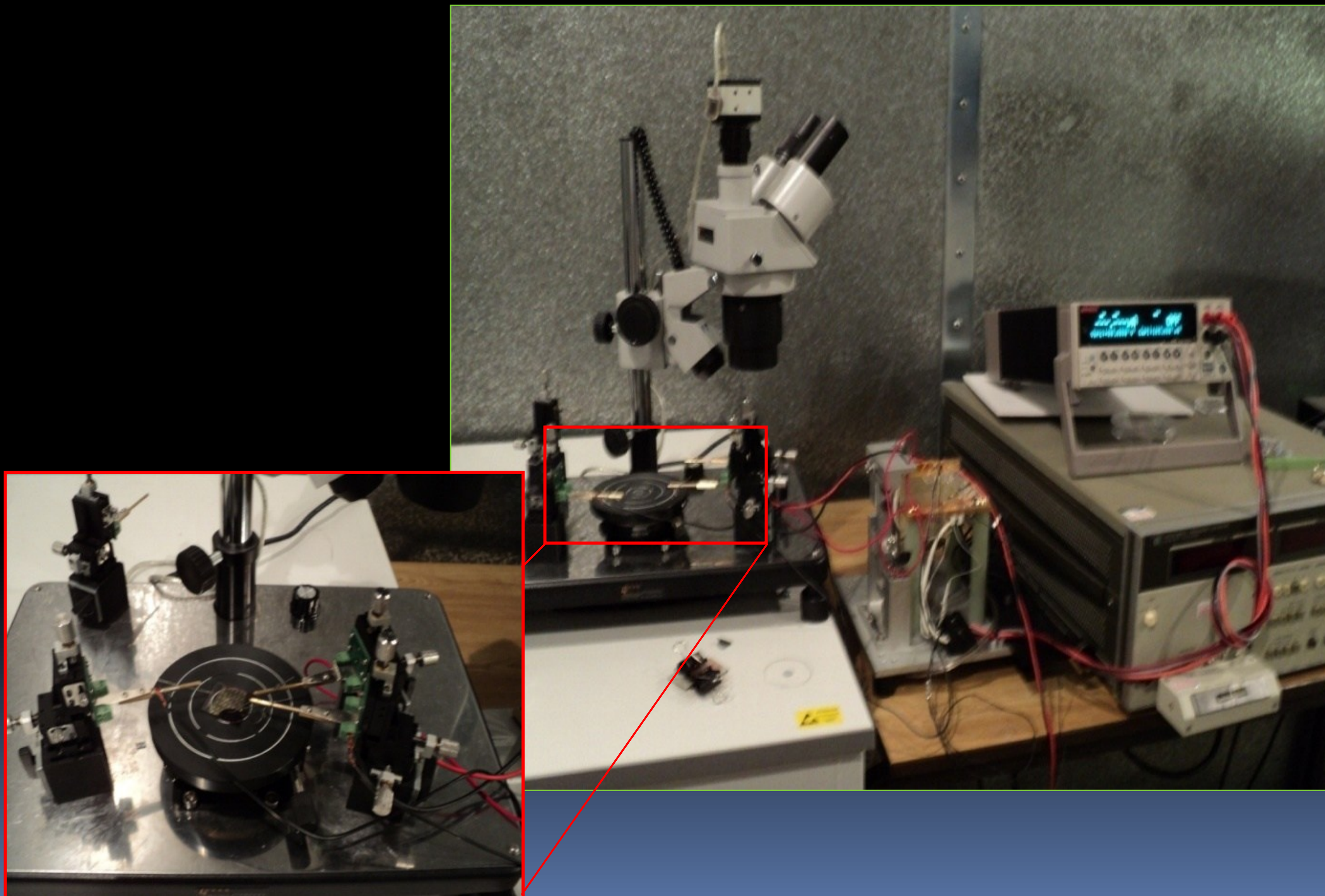
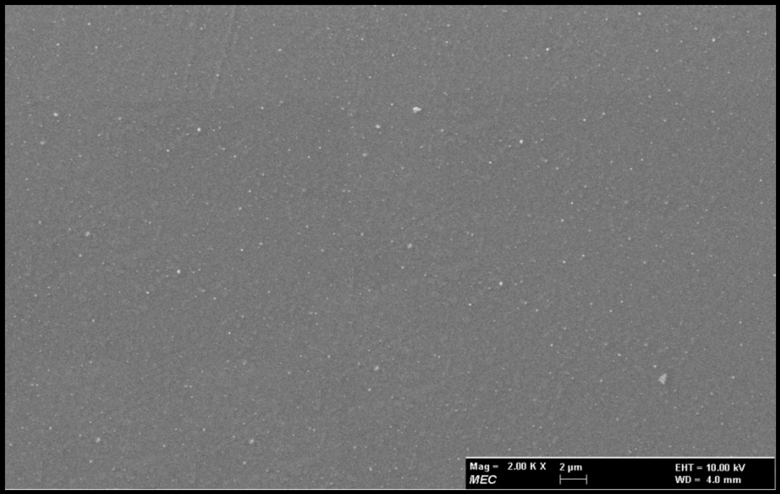


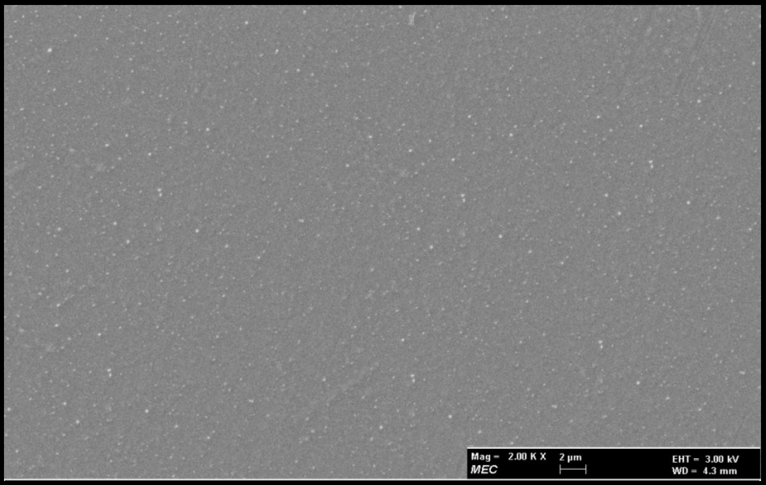
Power Conversion Efficiency Measurement



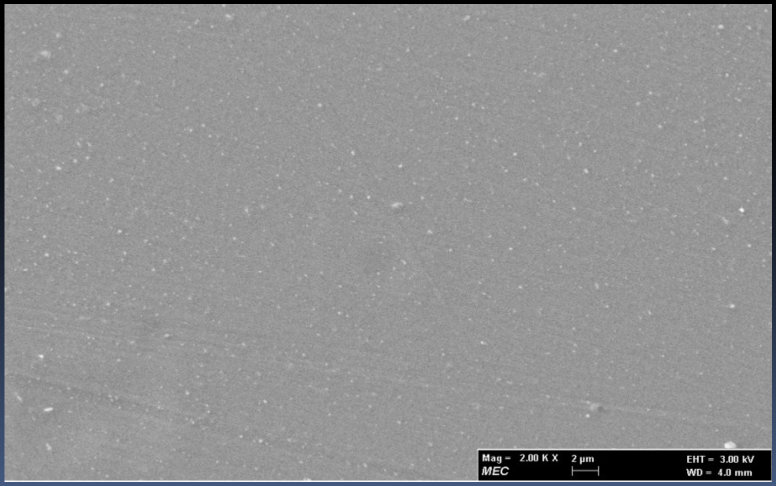
Microstructural Analysis (SEM)



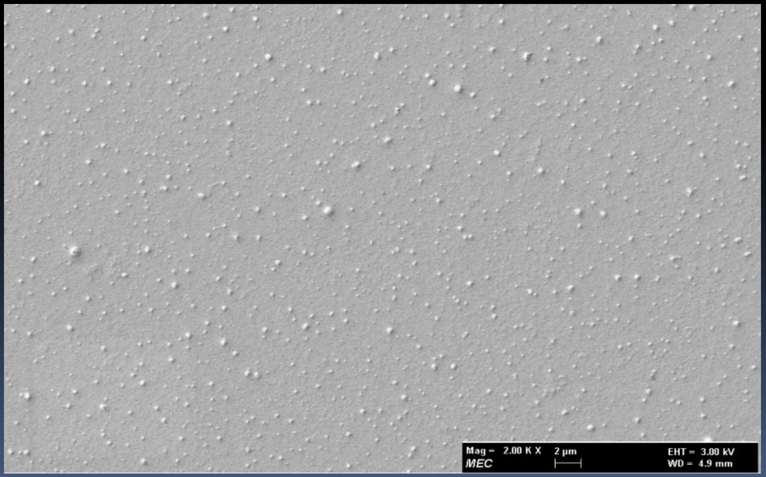
Aluminium Evaporated



Al Evaporated+Active layer coated

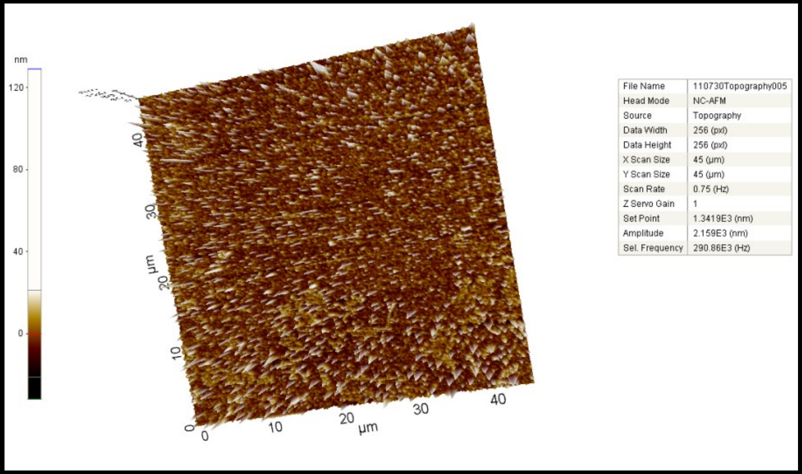


Al Evaporated+Active layer +Annealed

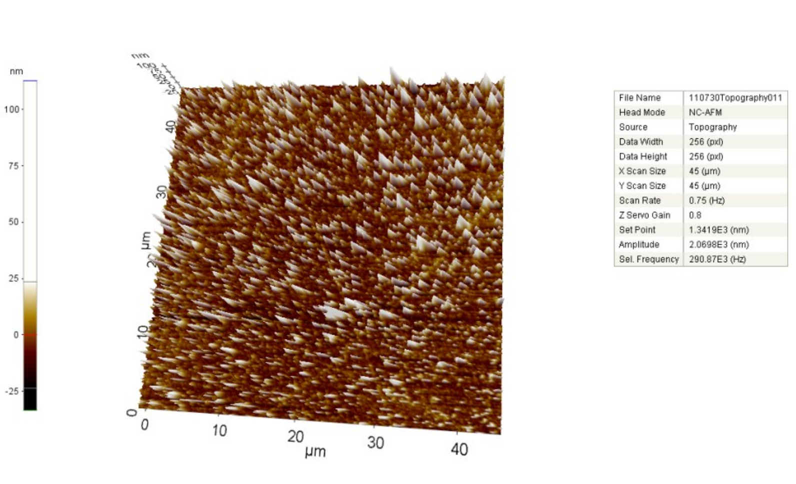


Al+Active layer +Annealed+electrodes evaporated

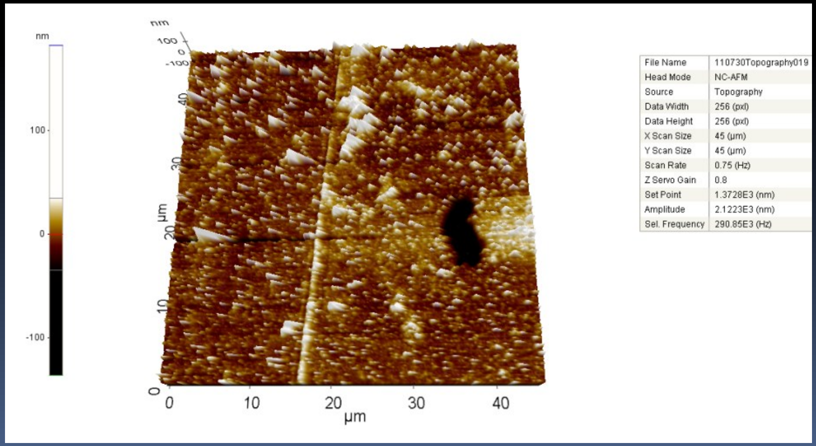
Microstructural Analysis (AFM)



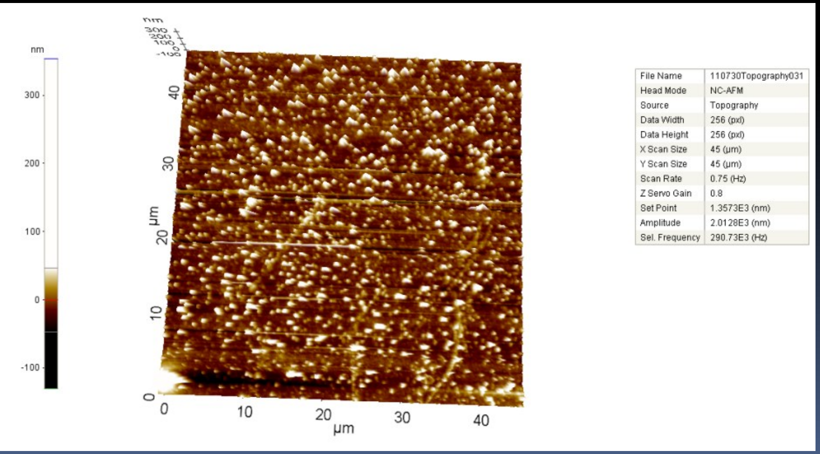
Aluminium Evaporated



Al Evaporated+Active layer coated



Al Evaporated+Active layer +Annealed



Al+Active layer +Annealed+electrodes evaporated

Conclusions

- ✓ For the first time a flexible piezoelectric filament has been successfully produced via a continuous process by applying a high stretching ratio, heat and high voltage, simultaneously.
- ✓ The impact test results proved that resulting produced filaments were piezoelectric and flexible enough to be used into textile structures.
- ✓ For the first time flexible HPP film and fibre have been successfully produced and tested.
- ✓ Additionally, a rectifying circuit consisting of 4 diodes and a capacitor can be used to rectify the fluctuating voltage of various frequencies to a constant DC voltage.
- ✓ The constant voltage generated and rectified can then be either stored in an electrical storage device such as batteries and super capacitors or can be utilised on-line directly.