UNIVERSITY OF Southampton

# Energy Harvesting Using Flexible Piezoelectric Materials

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# Presentation Outline

1. Introduction
2. Current energy harvesting research in our research group
3. Prototypes and demonstration
4. Applications and market surveys

# Funding

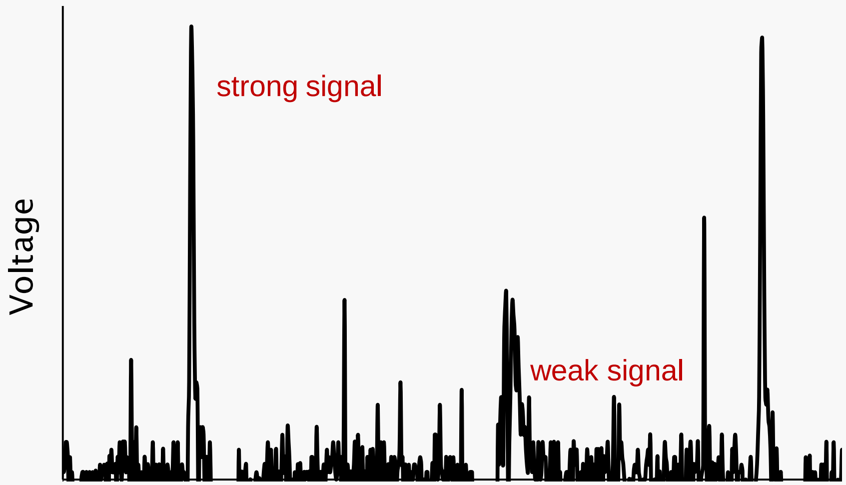
1. EPSRC SPHERE IRC Grant - a Sensor Platform for Healthcare in a Residential Environment www.irc-sphere.ac.uk

2. Prof. Steve Beeby's EPSRC Fellowship Grant

# Piezoelectric sensing and energy harvesting

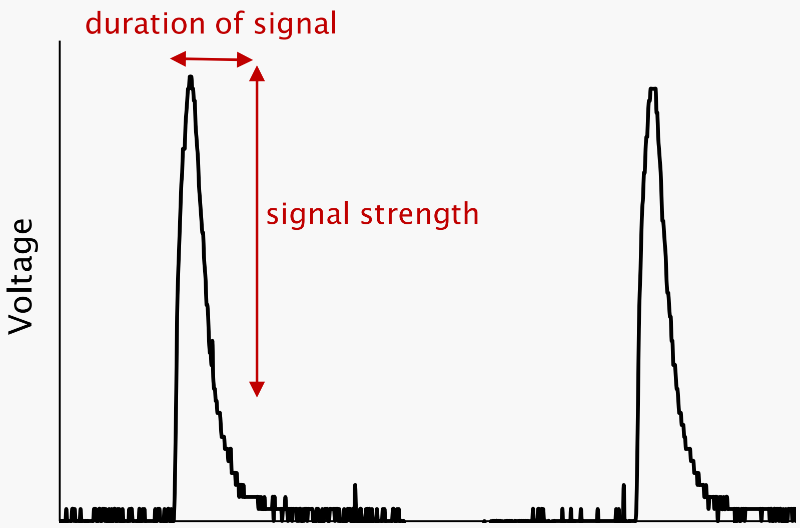
- Principle: convert mechanical energy into electrical energy

Sensor




- Signal to Noise Ratio = $v_s\ /\ \sigma$

Energy Harvester



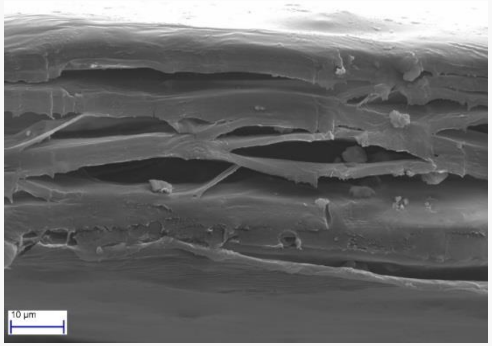

- Signal strength and duration
  - Energy = $\left|\int_{t1}^{t2} V(t) \cdot I(t)dt\right|$

# Materials:
## (Piezoelectric polymer composite, Ferroelectret)

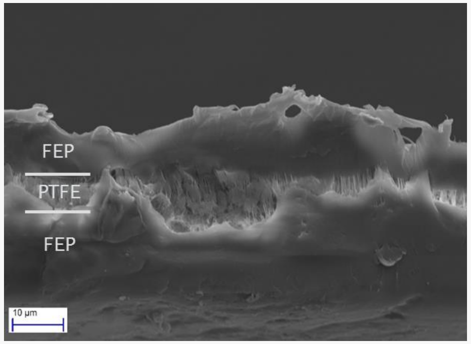
Piezoelectric polymer composite

PZT-polymer insole

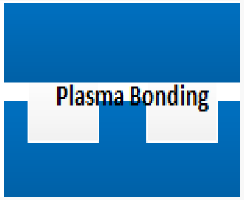
Ferroelectret



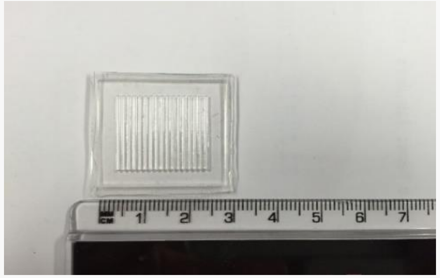

PP ferroelectret

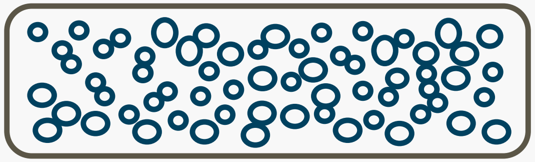



PTFE ferroelectret

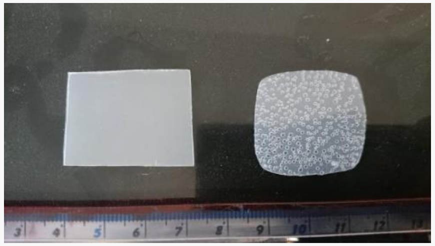




PDMS ferroelectret foam

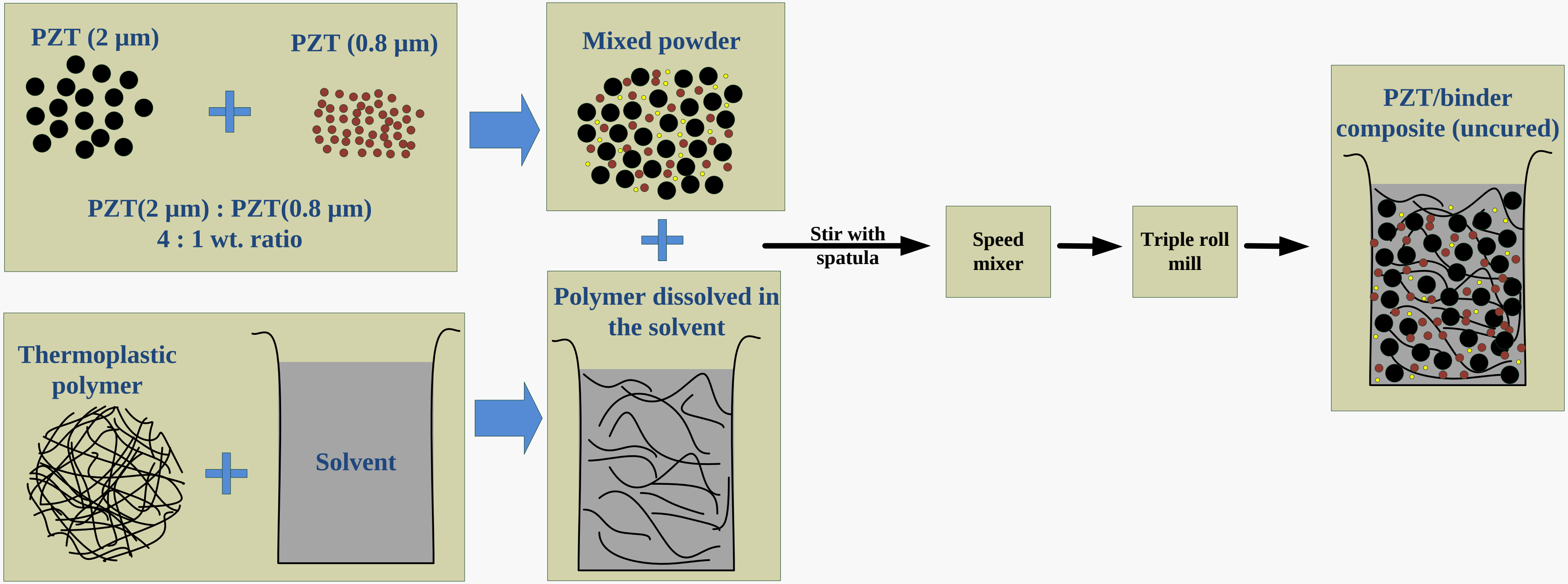




LDPE ferroelectret foam

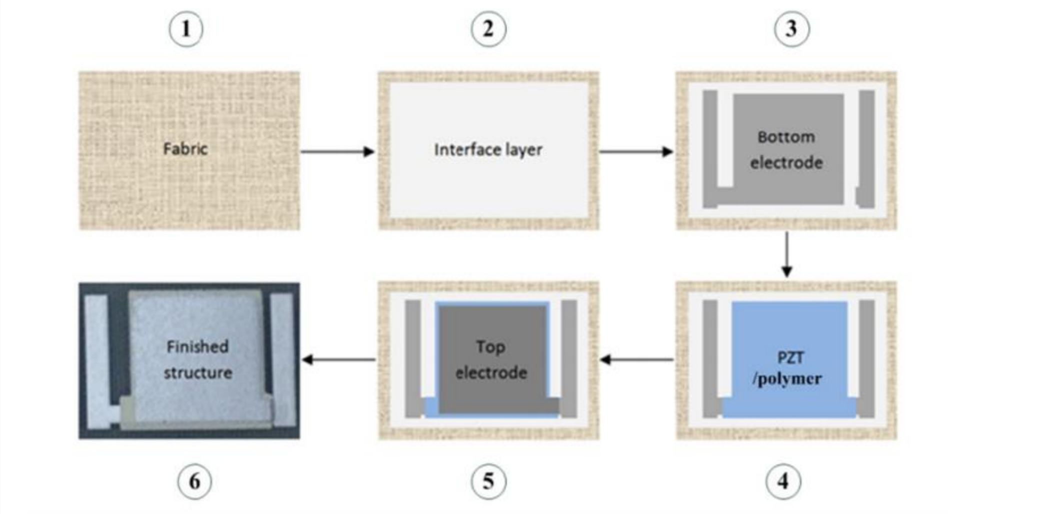


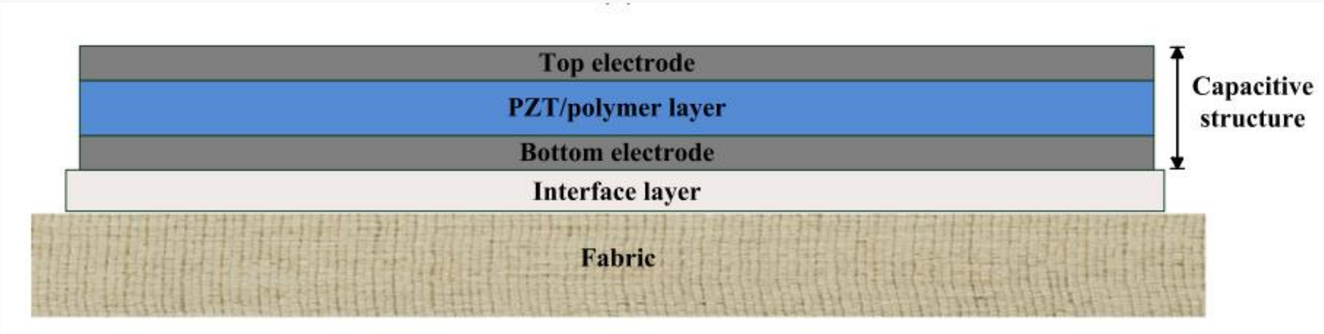
# PZT polymer composite




- The PZT-polymer film was a screen-printed piezoelectric composite
- Two sizes of PZT particles were used 2 and 0.8µm, mixed with weight ratio of 4:1.
- Thermoplastic polymer was dissolved in a solvent producing the binder phase of the composite.
- The PZT mixture and binder were blended together with a weight ratio of 2.51:1 with the aid of spatula, speed mixer and triple roll mill.

# Screen-printing the device



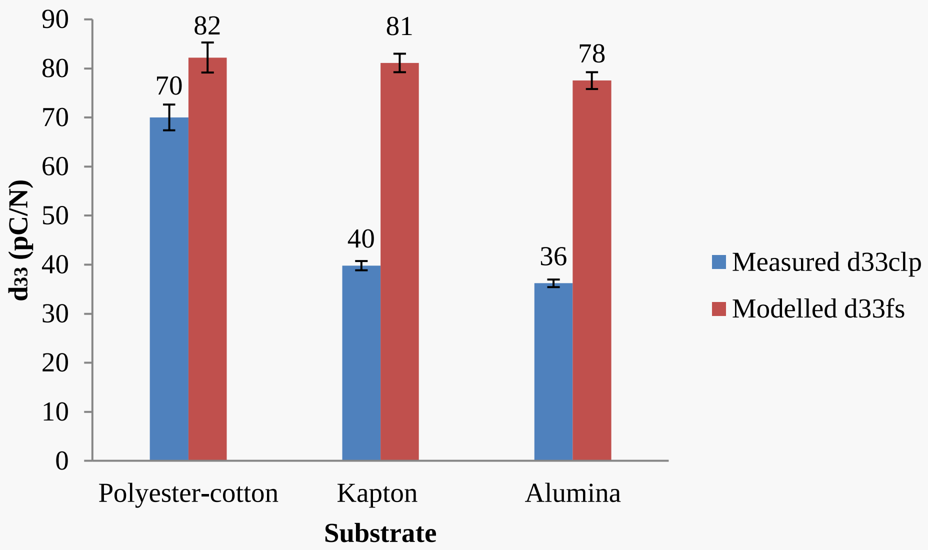

- A UV-cured interface layer was required to be printed for Polyester-cotton woven fabric substrate to treat the surface roughness.
- A silver-polymer layer was used as bottom and top electrode to extract the charge during d33 measurements.

# The $d_{33}$ measurement

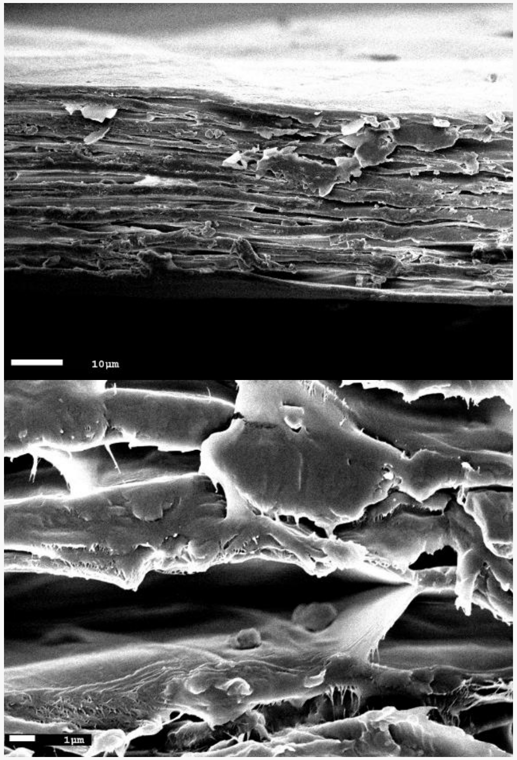
- The screen-printed PZT-polymer films showed a $d_{33}$ measurements of 70, 40 and 36 for the devices printed on Polyester-cotton, Kapton and Alumina, respectively.
- This difference in the $d_{33}$ measurements was due to the variations of the clamping effect among the substrates.
- The free-standing (without a substrate) $d_{33}$ value without a substrate was estimated using the following equation

$$d_{33fs} = \frac{d_{33clp}}{\left[1 - 2.v_p.\left(\frac{\left(\frac{v_p}{Y_p}\right) - \left(\frac{v_s}{Y_s}\right)}{\frac{1}{Y_p} - \frac{v_p}{Y_p}}\right)\right]}$$

- The results showed an average free-standing d33 value of the PZT-film of 80 pC/N

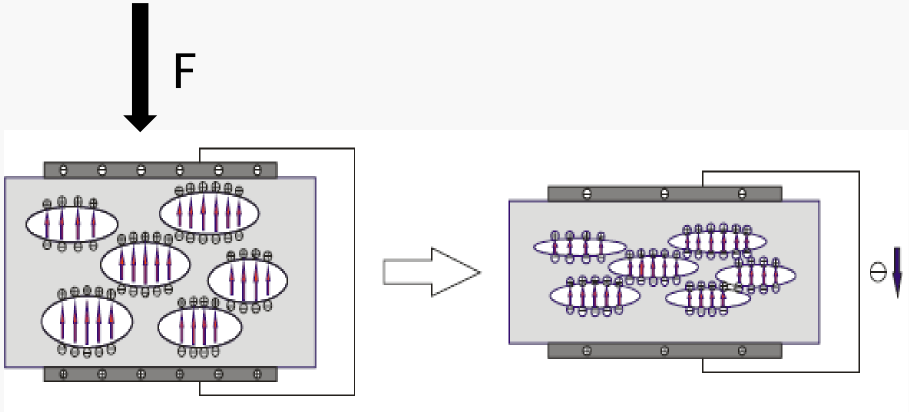


# How Ferroelectret Generates Energy

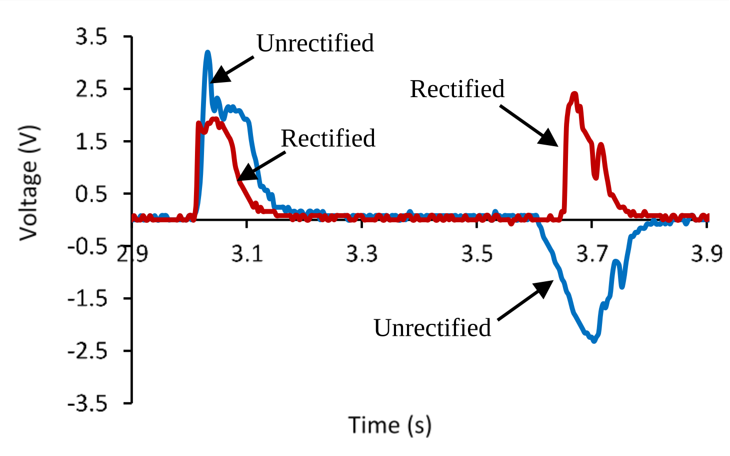


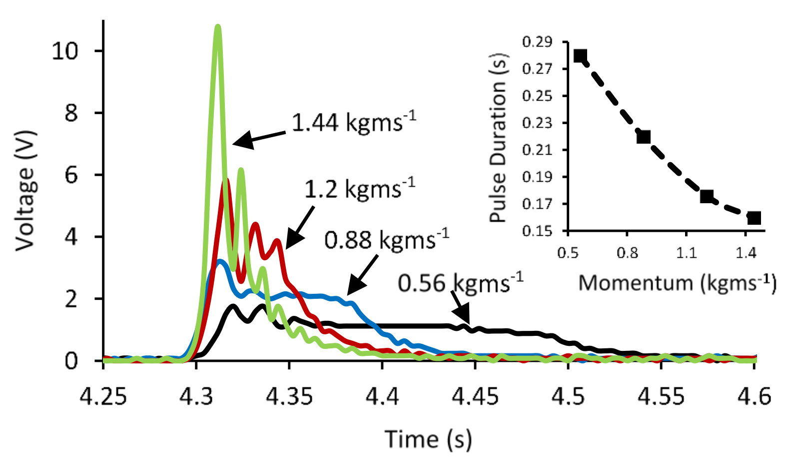
Polypropylene (PP) Ferroelectret (Emfit Ltd)

Inflation and charging processes



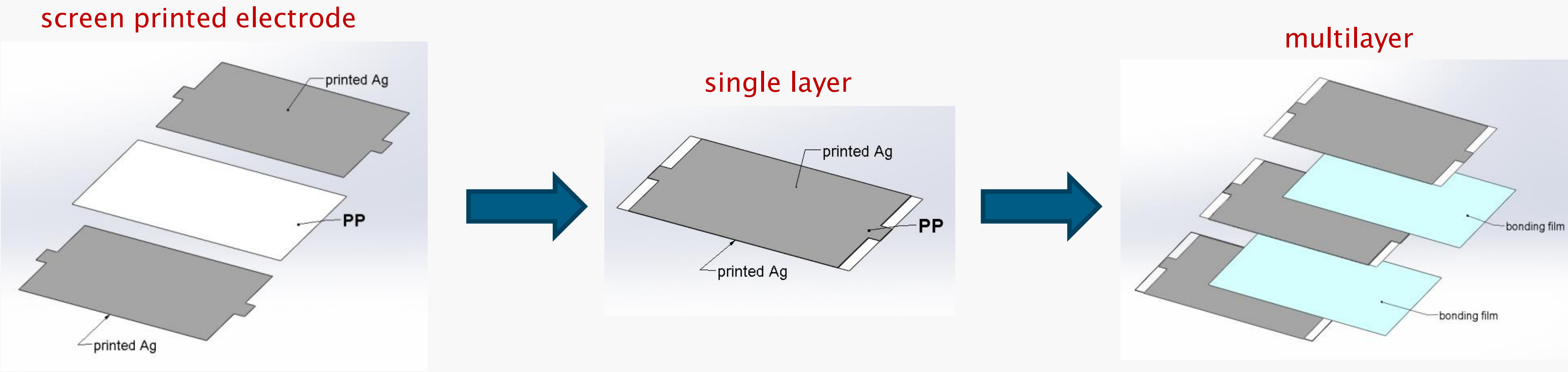

*** $d_{33}$ in the range of 200 to 300 pC/N**

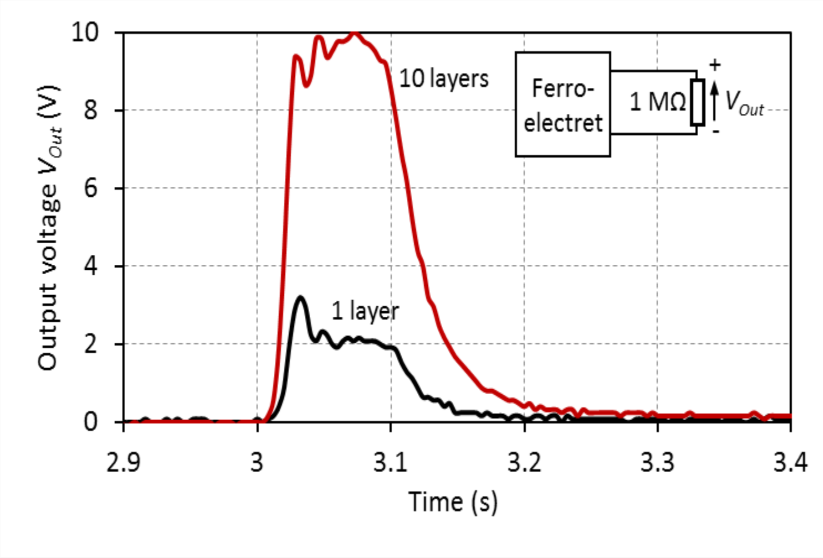


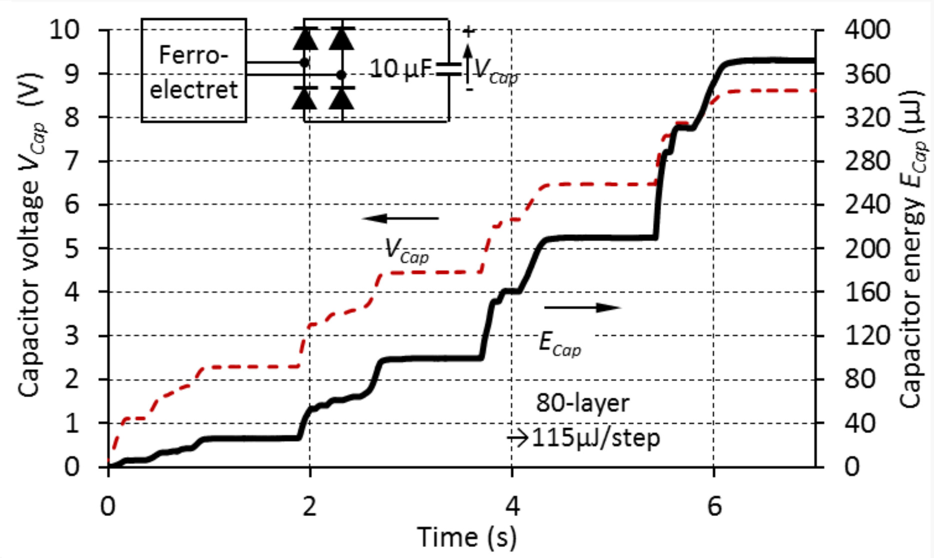




a 70μm thick PP ferroelectret can generate 1~2 μJ of energy per 800N of compressive force

# Multilayer Ferroelectret



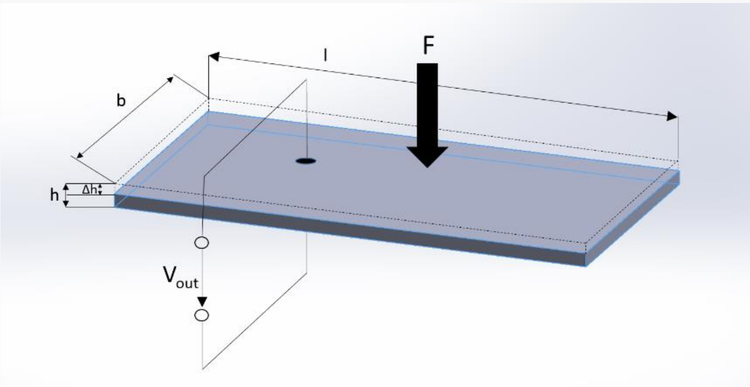

Latest result: more than 100µJ of energy generated per footstep from a 50-layer (total thickness 5mm). And more than 200µJ from a 100-layer.

- This energy is sufficient to power a sensor to transmit data wirelessly!

Z. Luo, D. Zhu, J. Shi, S. Beeby, C. Zhang, P. Proynov, and B. Stark, "Energy harvesting study on single and multilayer ferroelectret foams under compressive force", IEEE Trans. Dielectr. Electr. Insul., Vol. 22, No. 3, pp. 1360-1368, 2015.

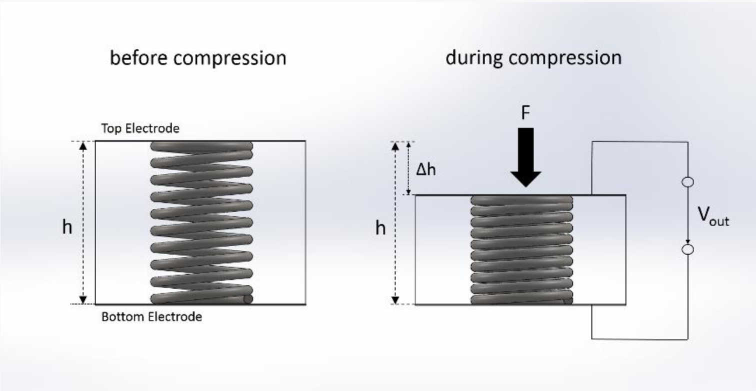
# Model of Ferroelectret for Energy Harvesting Application (capacitor + spring-mass-damper)

capacitor model




+

spring-mass-damper model

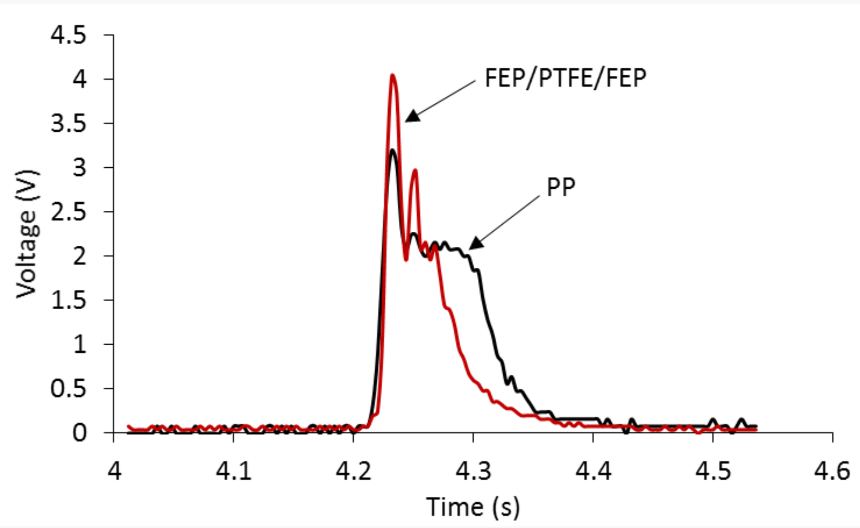


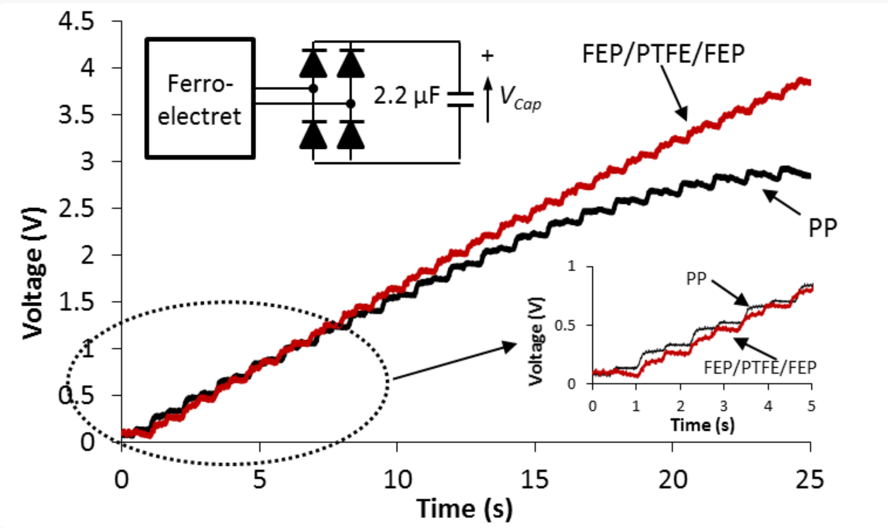

$$V_{out} = \frac{Fd_{33}}{C}$$

$$V_{out} = \frac{Fd_{33}(h-\Delta h)}{\varepsilon_{33} bl}$$

$$V_{out} = \frac{A}{Y}$$

$$t = \frac{F\Delta h \times Y^2}{\left(\frac{1}{R} + C\right) A^2}$$

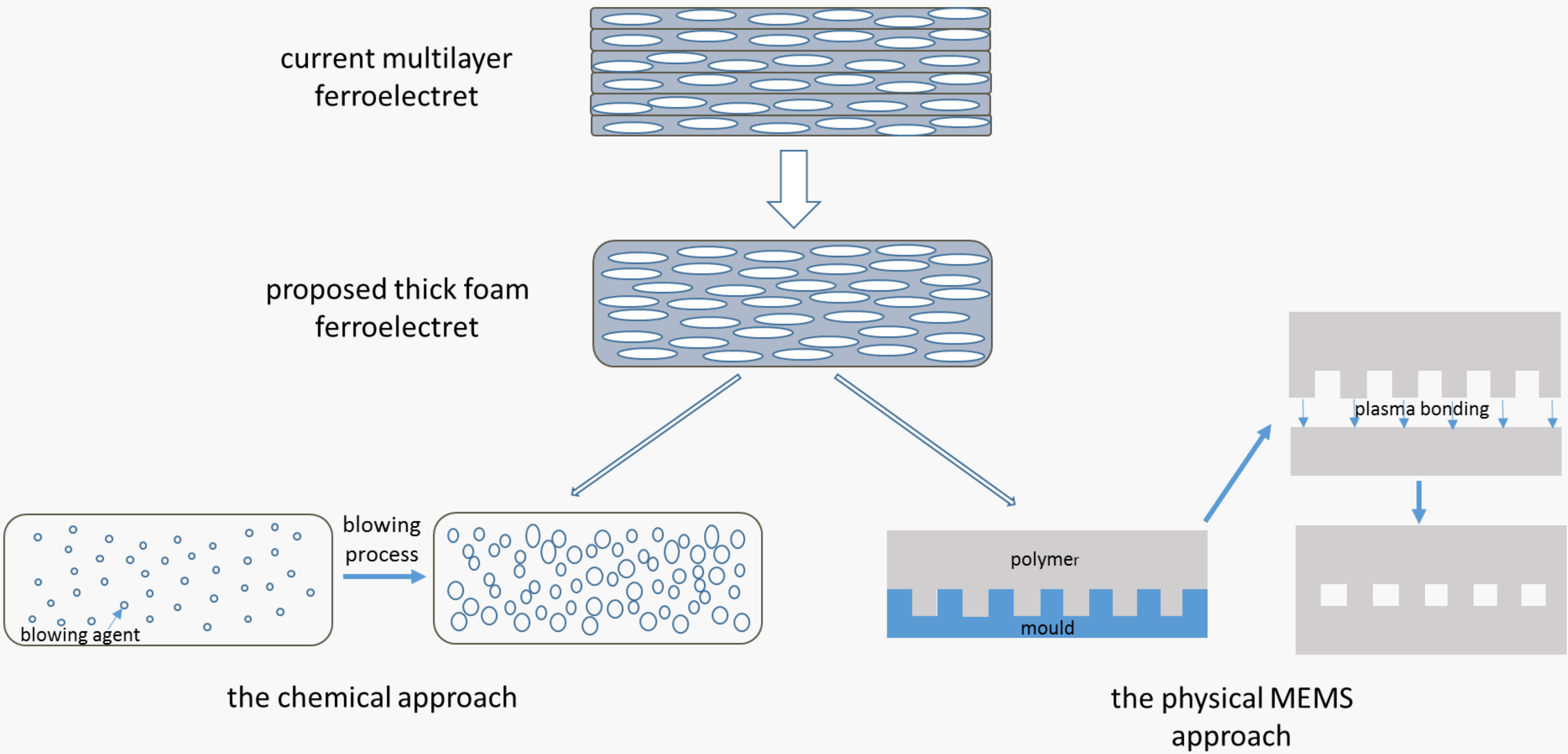


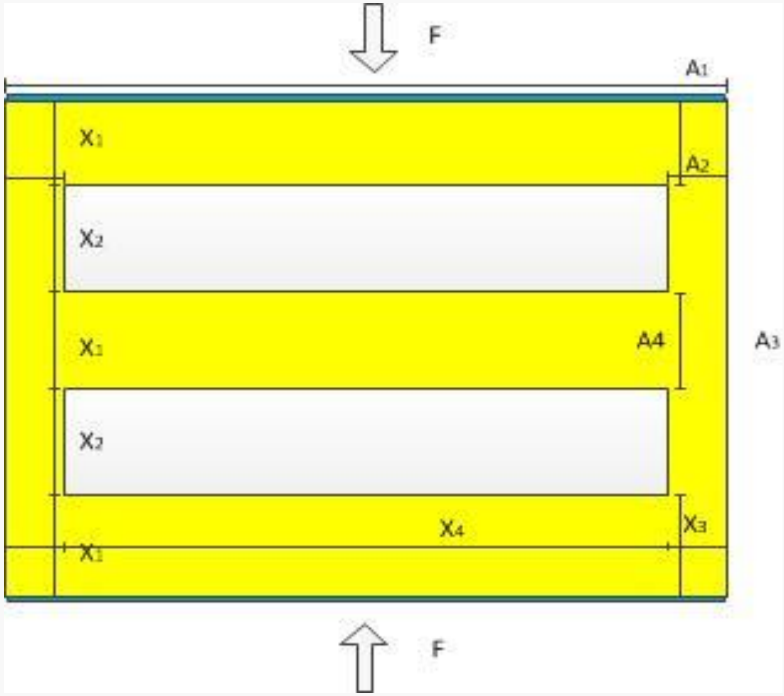



[1]Z. Luo, D. Zhu, S. Beeby. “An electromechanical model of ferroelectret for energy harvesting application”. Smart Materials and Structures.

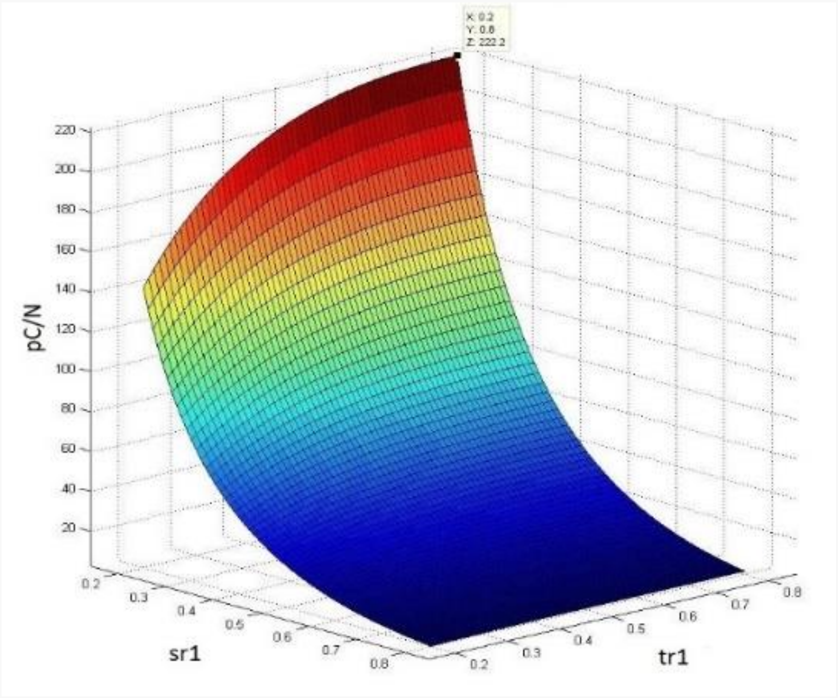
# Novel Ferroelectret Materials



# PDMS Ferroelectret Foam (Simulation)



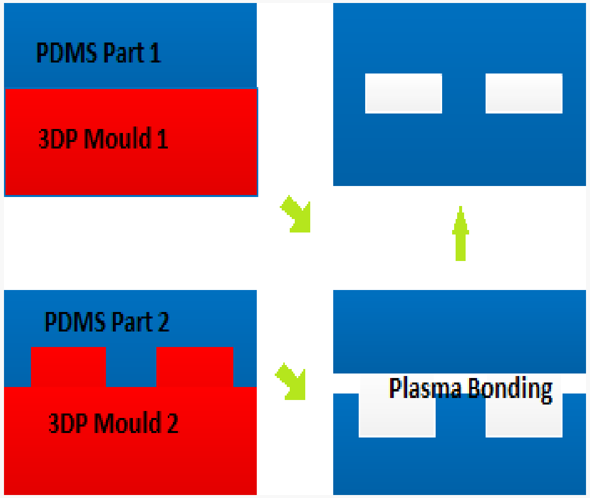

A model for the piezoelectricity of a charge-implanted composite microstructure




Analytical rectangle model results varying with the size of voids

- The PDMS ferroelectret foam works the same as other polymer ferroelectrets, but the dimension of its voids is designed and controlled.
- Simulation tools are used to optimize the structural dimension for maximum $d_{33}$.

# PDMS Ferroelectret Foam (Fabrication)




Schematic of fabrication processes

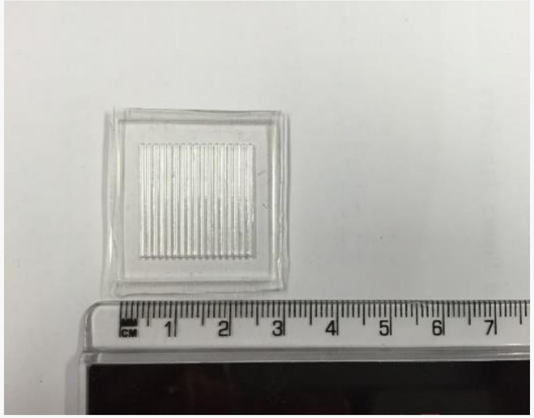
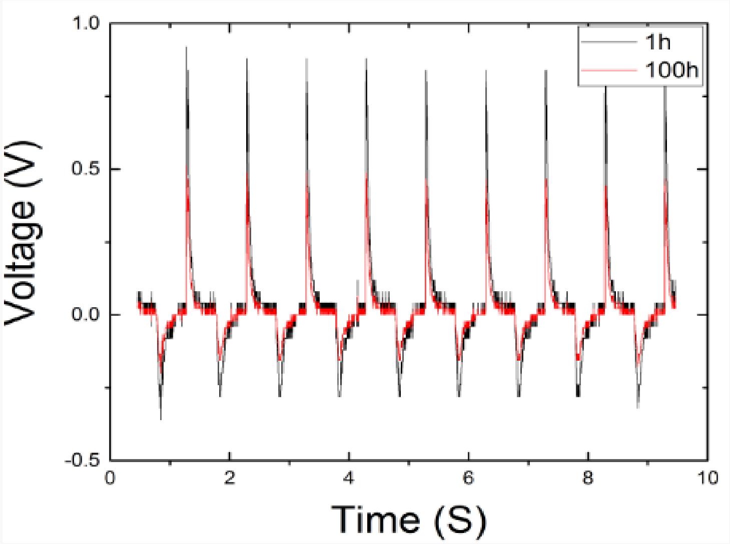


Image of PDMS ferroelectret foam

* $d_{33}$ about 120 pC/N



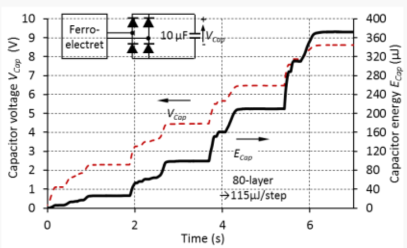

Measured voltage output under 800N compressive forces with 1 Hz force frequency, 800N and 21MΩ loading resistance

# Power Output Demonstration
# (Multilayer PP ferroelectret)

# Energy Harvesting Insole Application Concept

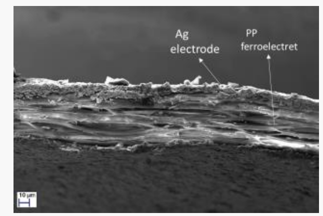
Personal Self-Monitoring

Professional Medical Monitoring

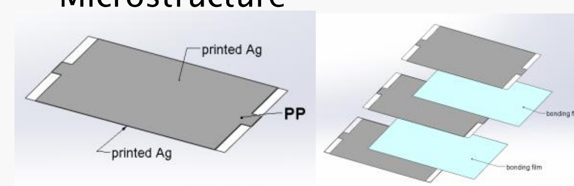



Energy harvested from insole from footstep


Self-Powered Monitoring using Energy Harvesting Insole




Microstructure

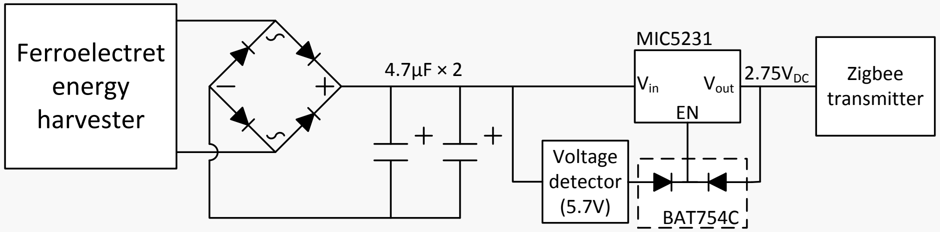



Multilayer design

* We have developed two energy harvesting insole prototypes for this application

# Energy Harvesting Insole Powering Wireless Transmission
## (Prototype No.1 using multilayer ferroelectret)

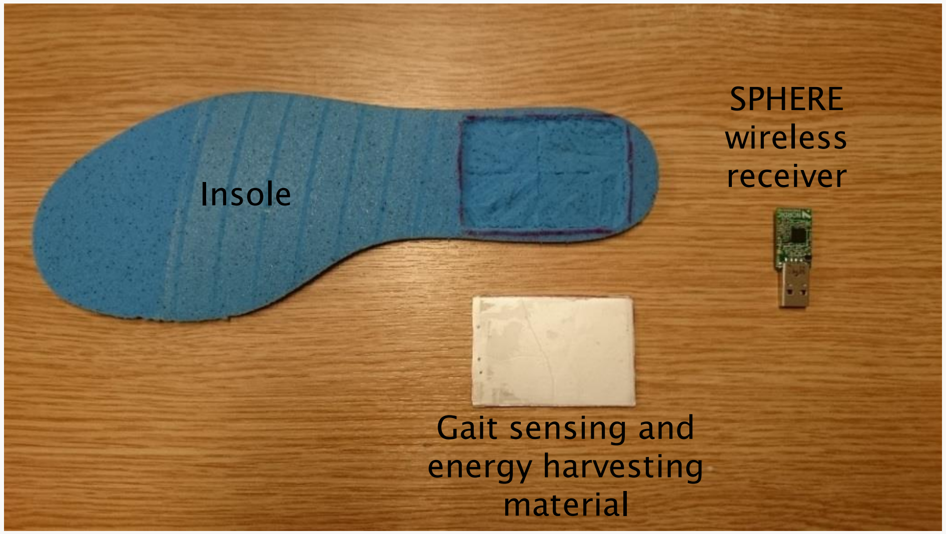
1st ferroelectret insole prototype




- Using Commercial Zigbee transmitter, for every 2 to 3 footsteps, the transmitter gains sufficient energy from the insole and is able to send 1 byte (8-bit) of wireless data to its receiver, which is 6 to 8 meters away from the source.

- The start-up and transmission of the chipset is solely powered by the ferroelectret insole - completely battery-free!

# Energy Harvesting Insole Powering Wireless Transmission
(Prototype No.2 using multilayer PP ferroelectret)



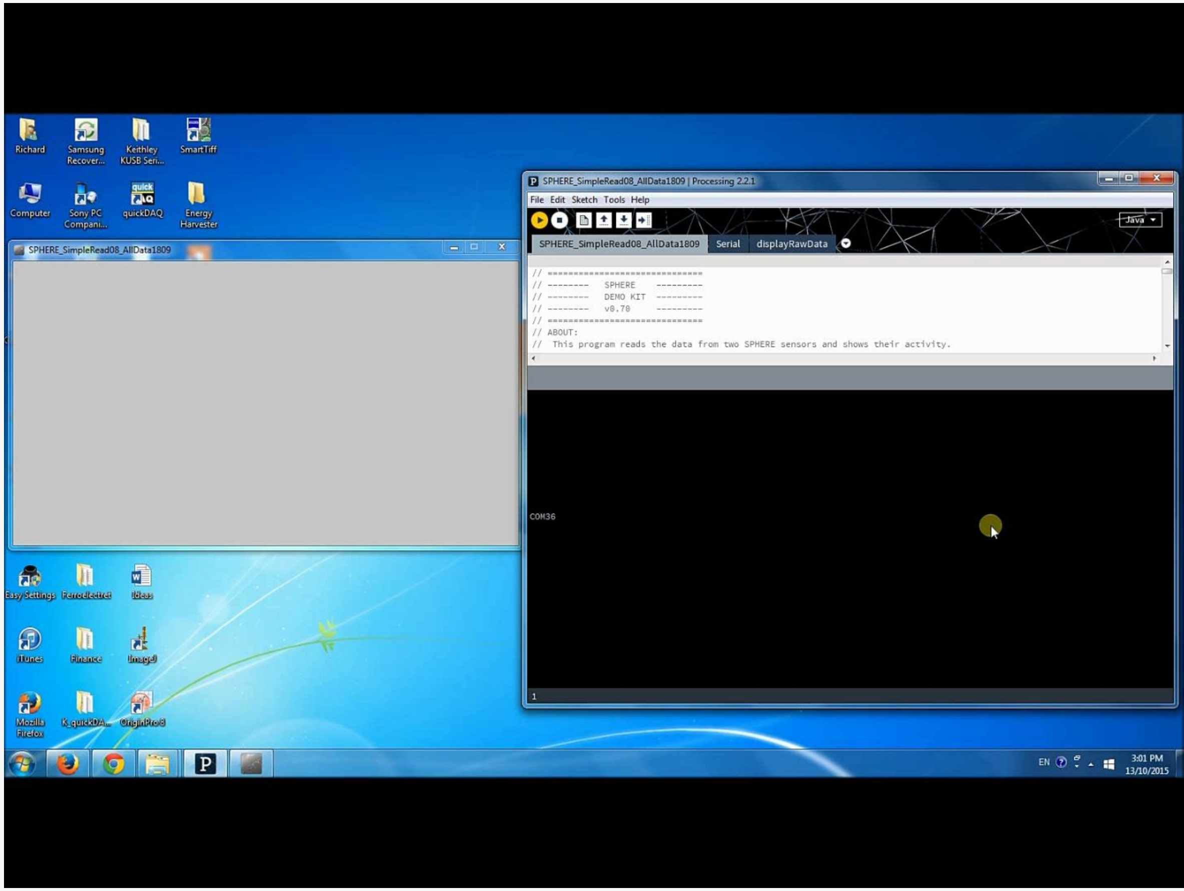

- Using the SPHERE Wearable Transmitter developed in this project, for every single footstep, the transmitter gains sufficient energy from the insole and is able to send 3 to 4 packages of 32-byte wireless data to its receiver.

- A battery is needed to supply the background power (22μW) for this transmitter. The energy harvester extend the battery life for more than 17 times.

# Gait data transmitting wirelessly to the receiver on laptop (Prototype No. 2)

- applications: e.g. indoor localization, identification and sensing

wireless data



# What next ?

- We are looking at the applications

1. Insole sensor
2. Wearable identification
3. Indoor tracking

……

# Insole sensor currently in use

**Pressure plates**

- Solid (Novel, Zebris, Rsscan, Tekscan, Nitta,..)
- Flexible (Novel, Tekscan)

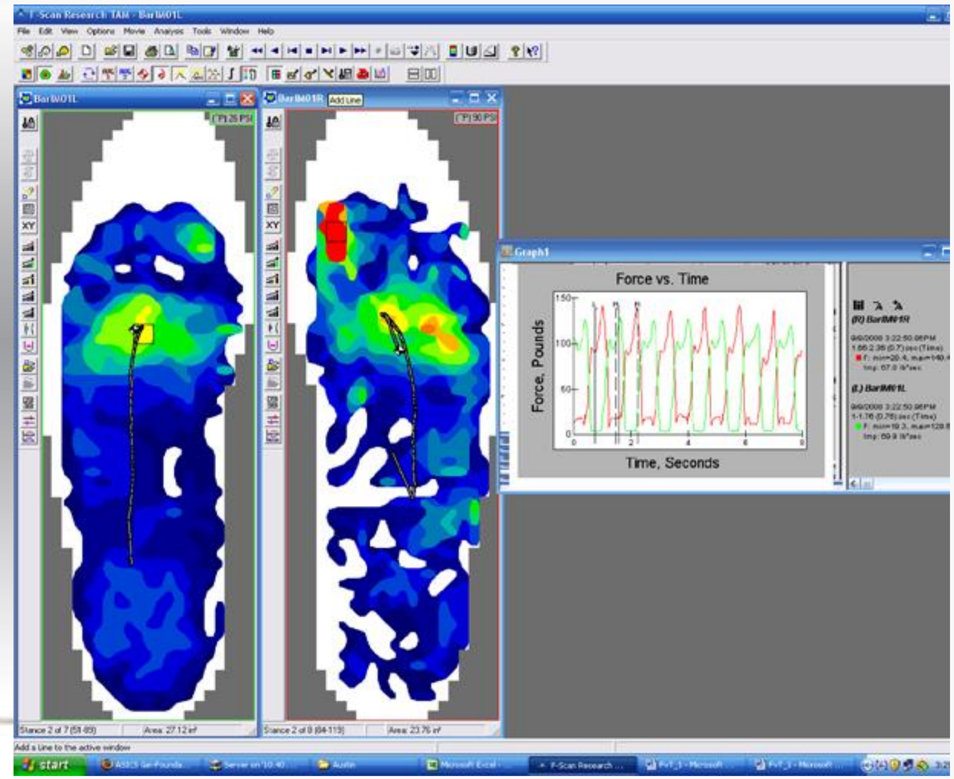
**Pressure insoles**

- Novel, Tekscan

**Technologies**

- Resistive
- Capacitive
- Gyroscope

# F-Scan @ Southampton Hospital



# Objectives

(Current project with medical professionals at Southampton General Hospital)

- ✓ Market surveys from clinicians, clinical researchers, biomechanics researchers, sports researchers, trainers and general public.

- ✓ Develop a 'smart' insole

**Sense Your Sole**

**Survey**

We want to develop new technology to measure foot pressures. At the start of this project, we find it crucial to be informed by stakeholders like you, and target our research right.
We therefore thank you for taking part in our survey. The data will be used anonymously in a research grant proposal and are no scientific study as such.

***What is your position?*** (E.g. clinician, physiotherapist, trainer, biomechanist...)

...

***What is your main use of plantar pressure measurements?***

...

***How long have you been using plantar pressure measurement technology?***

...

***Which system(s) are you currently using?***

*plate(s): ...*

*insole(s): ...*



***What do you like/dislike about your current system?***

# Positive replies from:

**Biomechanists (n=13)**

Liverpool John Moores University, UK
Ghent University, Belgium
University of Antwerp, Belgium
Shinshu University, Japan
Sports University Köln, Germany
University Hospital Ghent, Belgium
Amsterdam University, The Netherlands
Korea National Sport University, Korea
Thomas More University College, Belgium
Technical University Chemnitz, Germany
University of Calgary, Canada
University of Göteborg, Sweden
University of Goiás, Brazil

**Clinicians (n=16)**

Southampton General Hospital

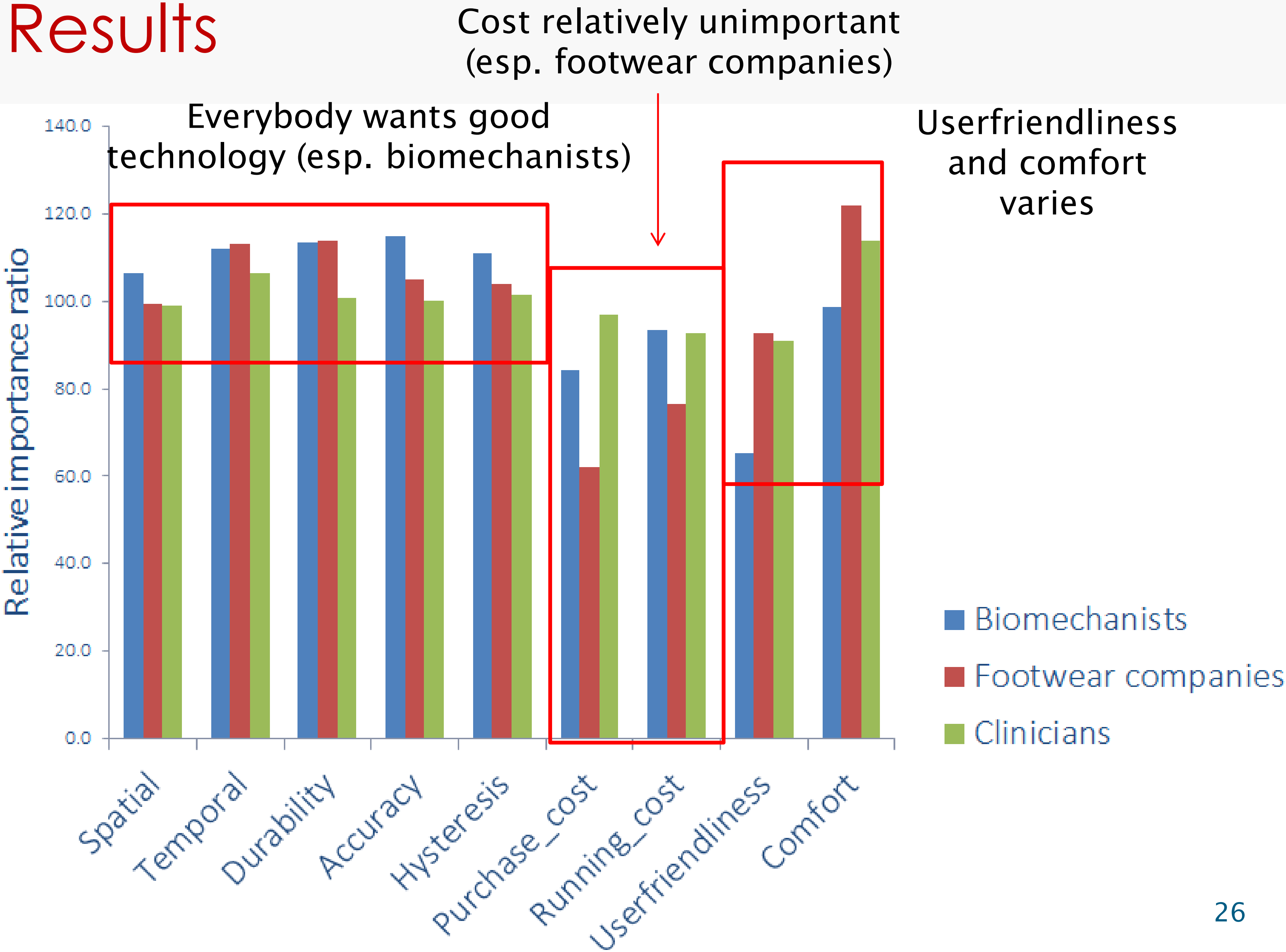
**Footwear companies (n=9)**

Adidas
Brooks
Decathlon
Fitflop
New Balance
Saucony
Salomon
Reebok
Vibram

**Trainers (n=2)**

Vivobarefoot
GB Paralympics Swimming Team

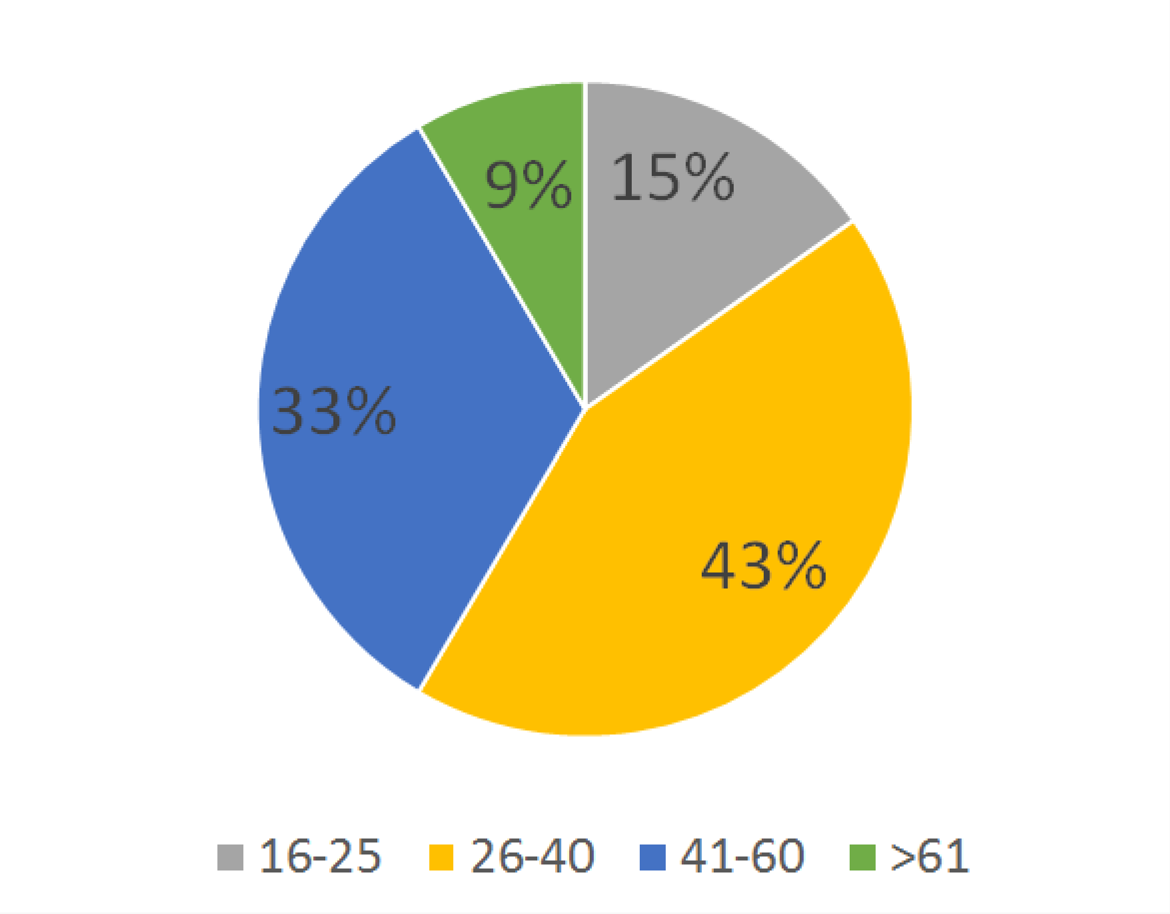
# Results



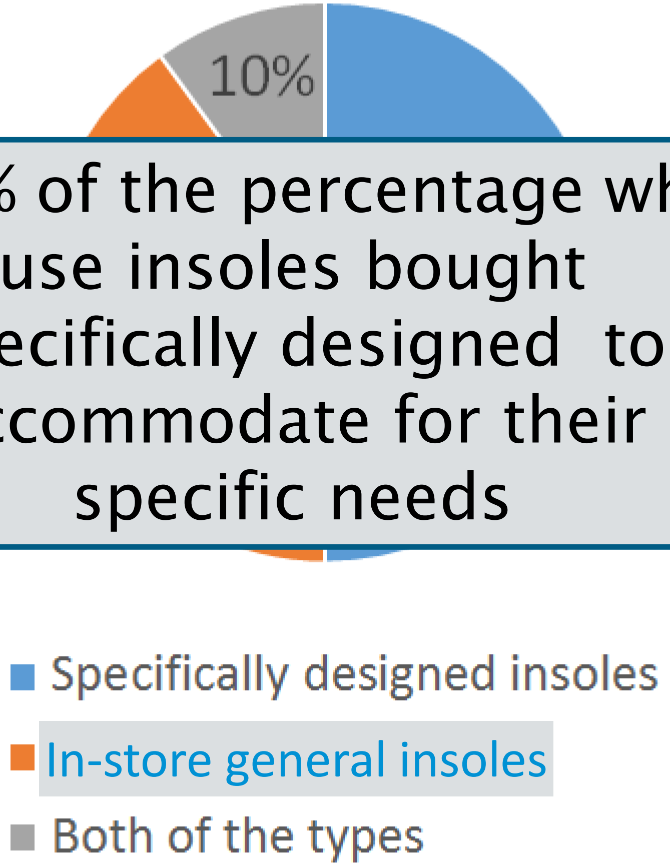
Cost relatively unimportant (esp. footwear companies)
Everybody wants good technology (esp. biomechanists)
Userfriendliness and comfort varies
Relative importance ratio
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
Spatial
Temporal
Durability
Accuracy
Hysteresis
Purchase_cost
Running_cost
Userfriendliness
Comfort
Biomechanists
Footwear companies
Clinicians

# General public view. Third Survey.

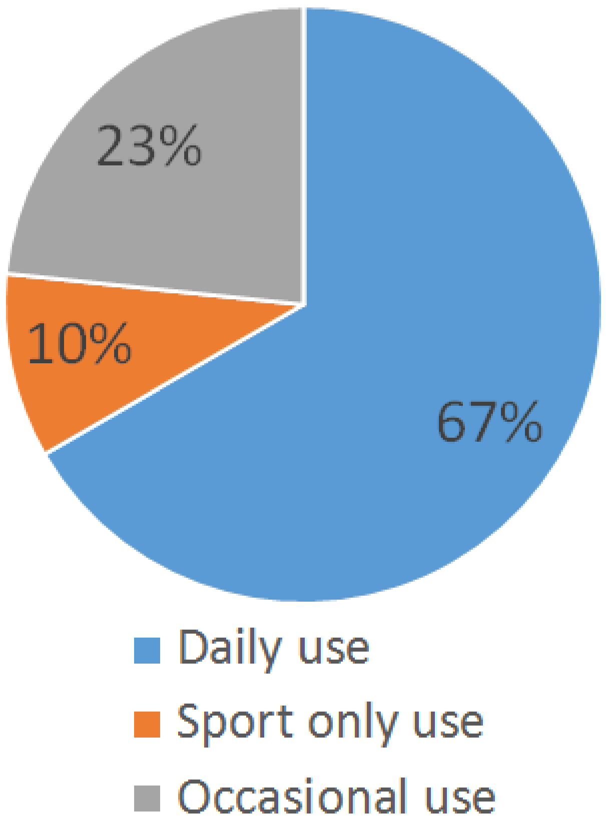
- 118 respondents of age groups below:



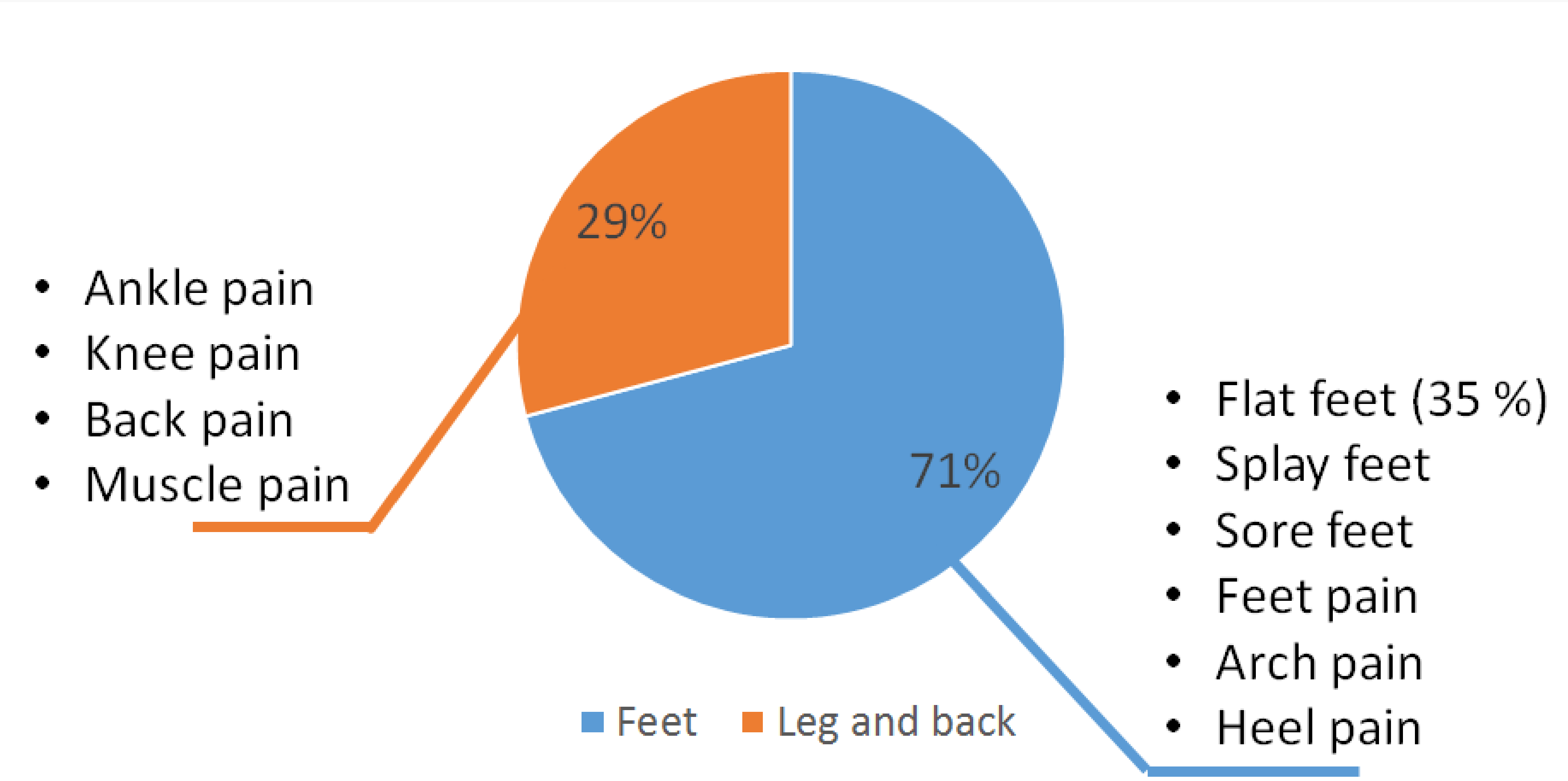
# Use of insoles (25%)




>60% of the percentage who use insoles bought specifically designed to accommodate for their specific needs



# Problems being solved by use of insoles



# In Summary…

- Insoles are being worn by 25% of respondents surveyed;

%.

- Those who benefit from gait analysis and specially designed insoles comprise up to 20%.

# Conclusions

1. An energy harvesting insole has been developed. The energy generated from this insole is sufficient to power the wireless transmission of a sensor chipset.

2. Two prototypes are developed to demonstrate the wireless data transmission powered by the energy harvesting insole.

# Future Work

1. Further improve the design to improve the energy conversion efficiency

2. Collaborate with institute/industry to develop applications in sensing and energy harvesting, e.g. medical and IoT.

# Thank You

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