



The Hong Kong Polytechnic University

# **World Textile Conference 2016, Mumbai**

## **New Paradigm for Textile Materials: From Practicality to Intelligence**

**Prof Jinlian Hu**  
**Editorial Board Member of Fibers**  
**Guest Editor: Smart Textiles**

**16-17 2016**  
**Mumbai, India**

**Institute of Textiles and Clothing**

*Shape Memory Textile Center*



# Contents

- Introduction to Institute of Textiles and Clothing, the Hong Kong Polytechnic University
- ATC-14 an Invitation
- A Paradigm Shift to Sensitive Textile Materials
- Drivers to the Paradigm Shift
- Sensitive Textile Materials and their applications
- What is next: Challenges and opportunities
- Conclusions and further references

**The Hong Kong Polytechnic University**

**Institute of Textiles and Clothing (ITC)**

## **ITC's Mission**

**International Center of Excellence  
in Fashion and Textiles Education &  
Research**

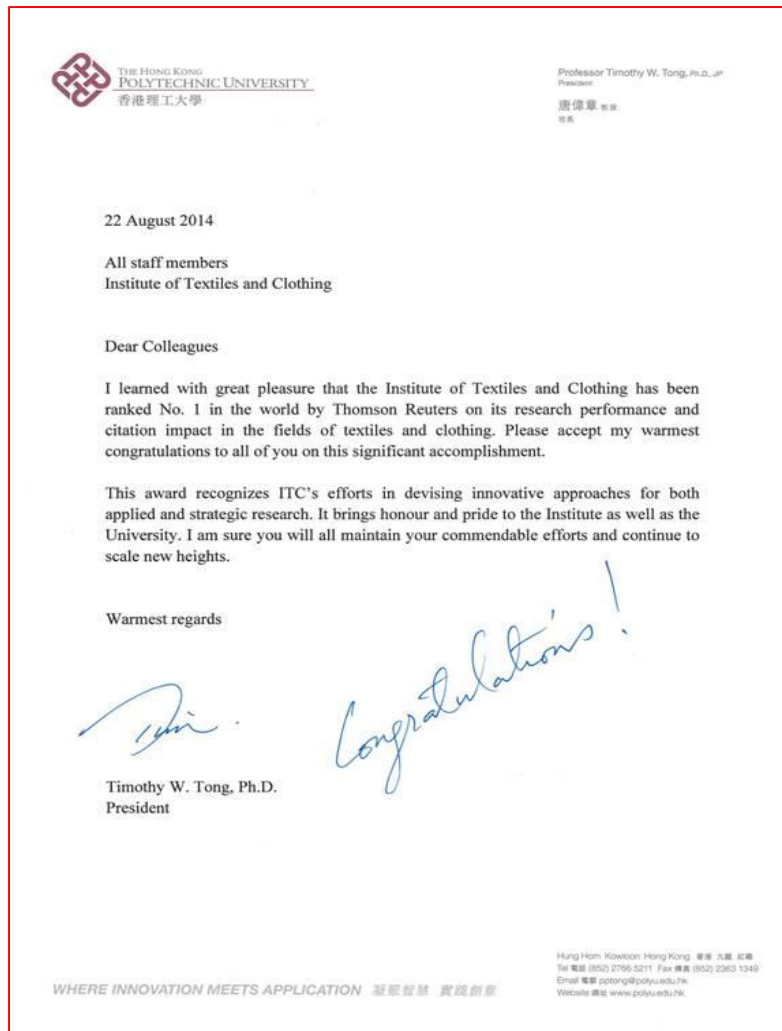
# **Trinity Structure**

## **Three Major Disciplines**



**We have very attractive teaching and research programs in  
fashion design, business and technology**

# Track Record



- **Outstanding in Publications: ITC ranked No. 1** in SCI among the world top universities with textiles and clothing
- **Strong industry support: >100 industry sponsors** for the past projects

*Science, Prog. In Polym. Sci. ;  
NPG Asia Materials; PNAS;  
Nano Lett; JACS; Agnew  
Chem; Adv. Mater.; Adv.  
Funct. Mater.; Small ;*

- **Competitive in large scale of external research projects from GRF, HKRTA and ITF. In 2013/14, 27 external peer-reviewed research projects with a total value of around HK\$45.3m**

*JMCA*

# Hong Kong PhD Fellowship Scheme

- <http://www.ugc.edu.hk/eng/rgc/hkphd/hkphd.htm>, University Grants Council, Hong Kong
- <http://www.polyu.edu.hk/ro/hkphd-fellowship/en/>, The Hong Kong Polytechnic University
- <http://www.itc.polyu.edu.hk/en/home/>, ITC, PolyU
- [www.baidu.com](http://www.baidu.com) and HKPF@ugc.edu.hk
- Initial Application Deadline, Normally 1 December , >HKD20K per month studentship

[www.polyu.edu.hk/itc/atc14](http://www.polyu.edu.hk/itc/atc14)

**Disruptive Innovations for Textiles and the Supply Chain**

**14<sup>th</sup> Asian Textile conference**

27-30 June 2017 Hong Kong

# Important dates

|                                  |                             |
|----------------------------------|-----------------------------|
| Abstract Submission Deadline     | : Monday, October 3, 2016   |
| Abstract Acceptance Notification | : Friday, December 2, 2016  |
| Full Manuscript Deadline         | : Monday, December 26, 2016 |
| Early Registration and Payment   | : Friday, February 3, 2017  |
| Conference Dates                 | : <b>27-30 June 2017</b>    |



# Call for papers

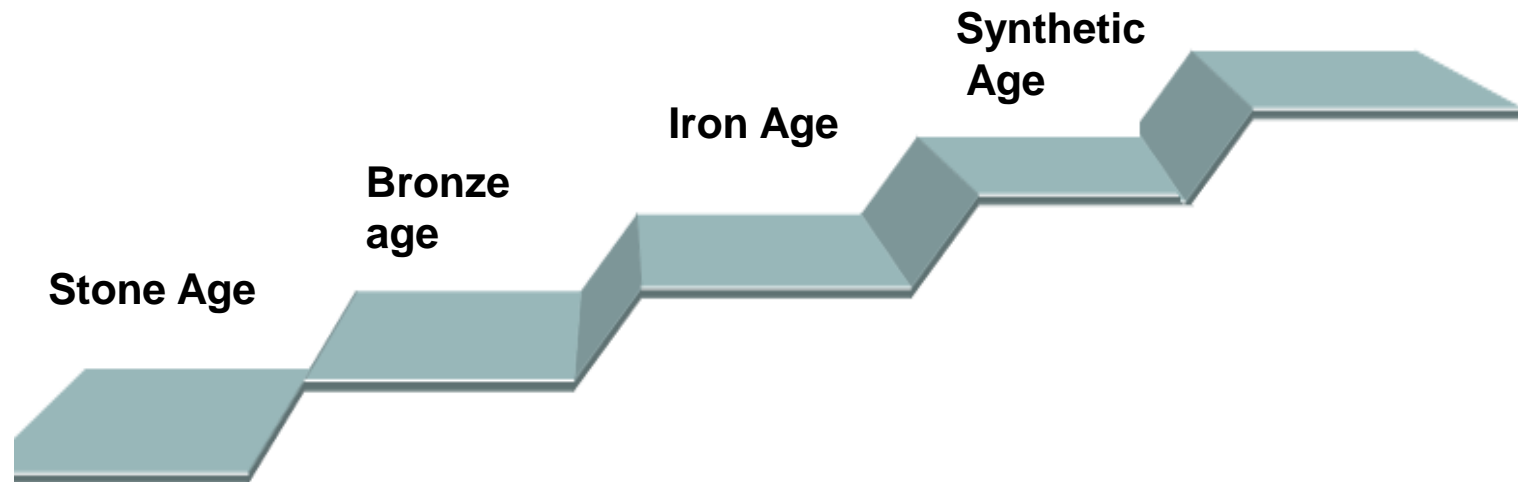
- New, advanced and smart materials for textiles
- Functional, smart and high performance textiles
- Green processing technologies for textiles
- Automation (robotics) in clothing, textiles and testing equipment
- Sustainable fashion supply chain
- Quality, management and branding of textiles and fashion
- Digital technologies for textiles and fashion
- Textiles for emerging technologies: energy, environment, automation, electronics,..
- Fashion design and technologies
- Opportunities in disruptive era for textiles and fashion

# **A Paradigm Shift to Sensitive Textile Materials**

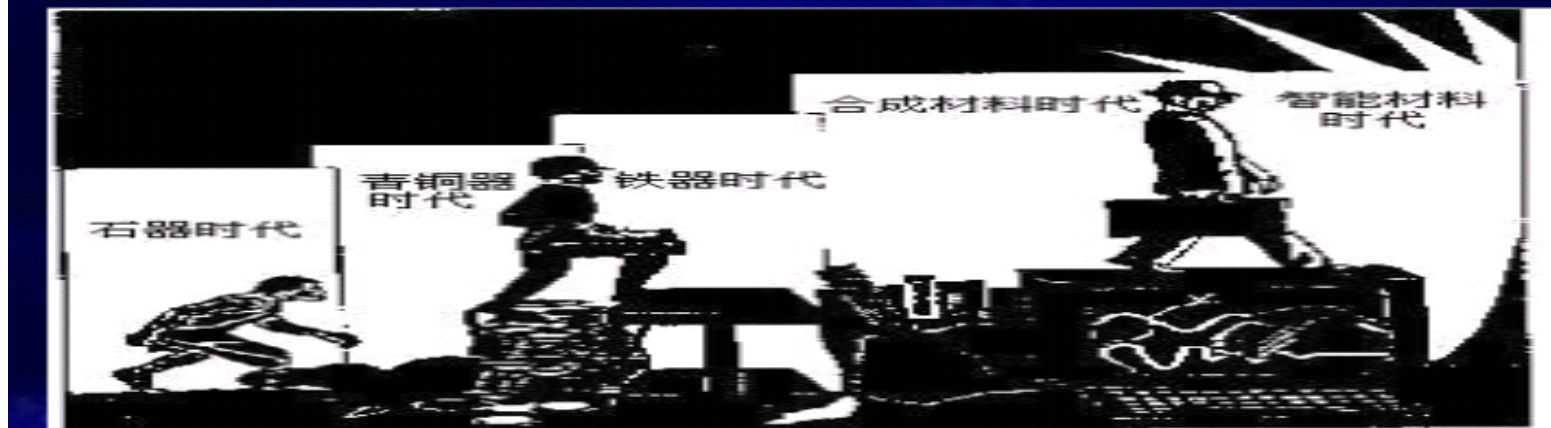
# The history of our human civilization is a history of Materials

It undergoes different ages

Smart material Age

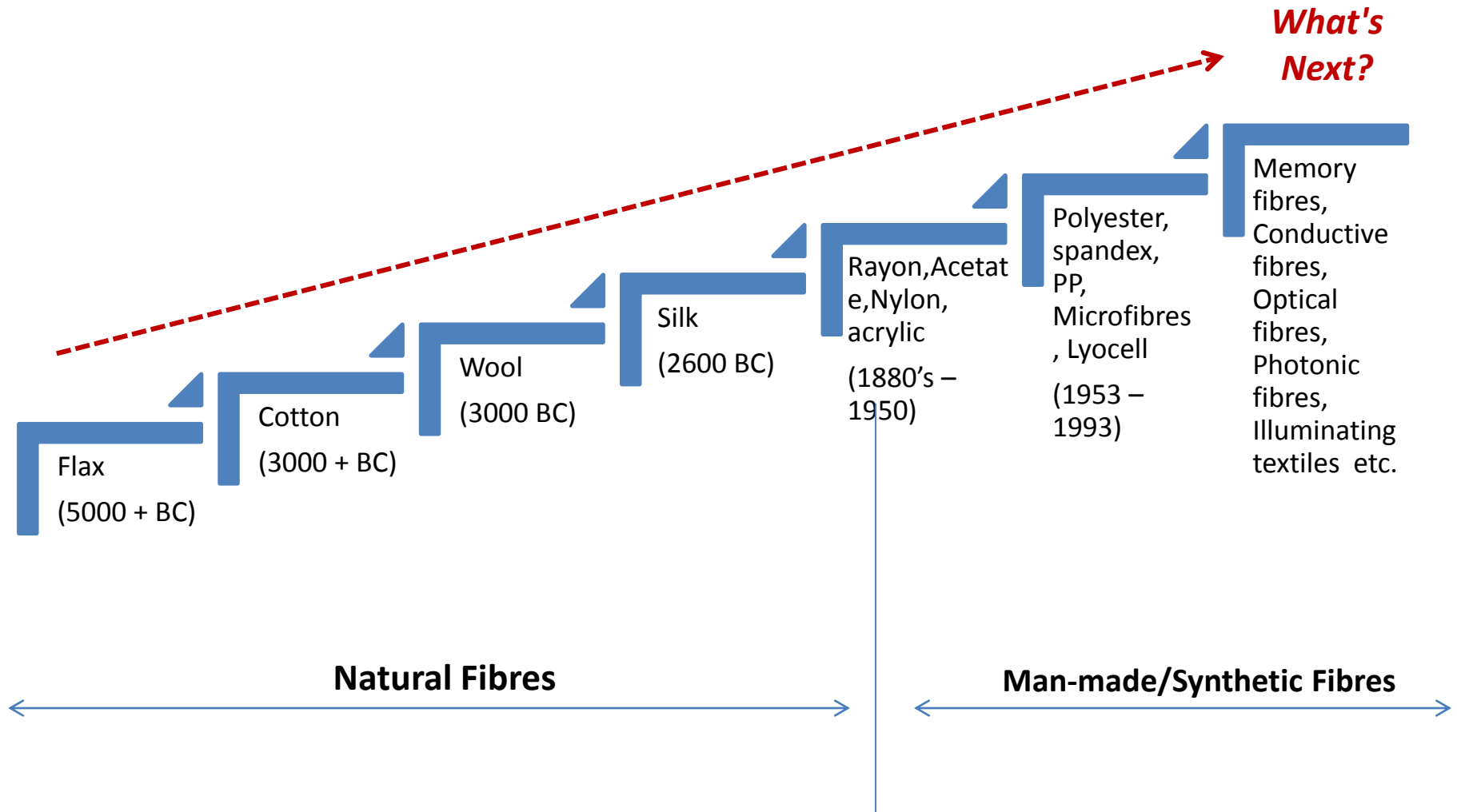


材料的发展和应用历史:



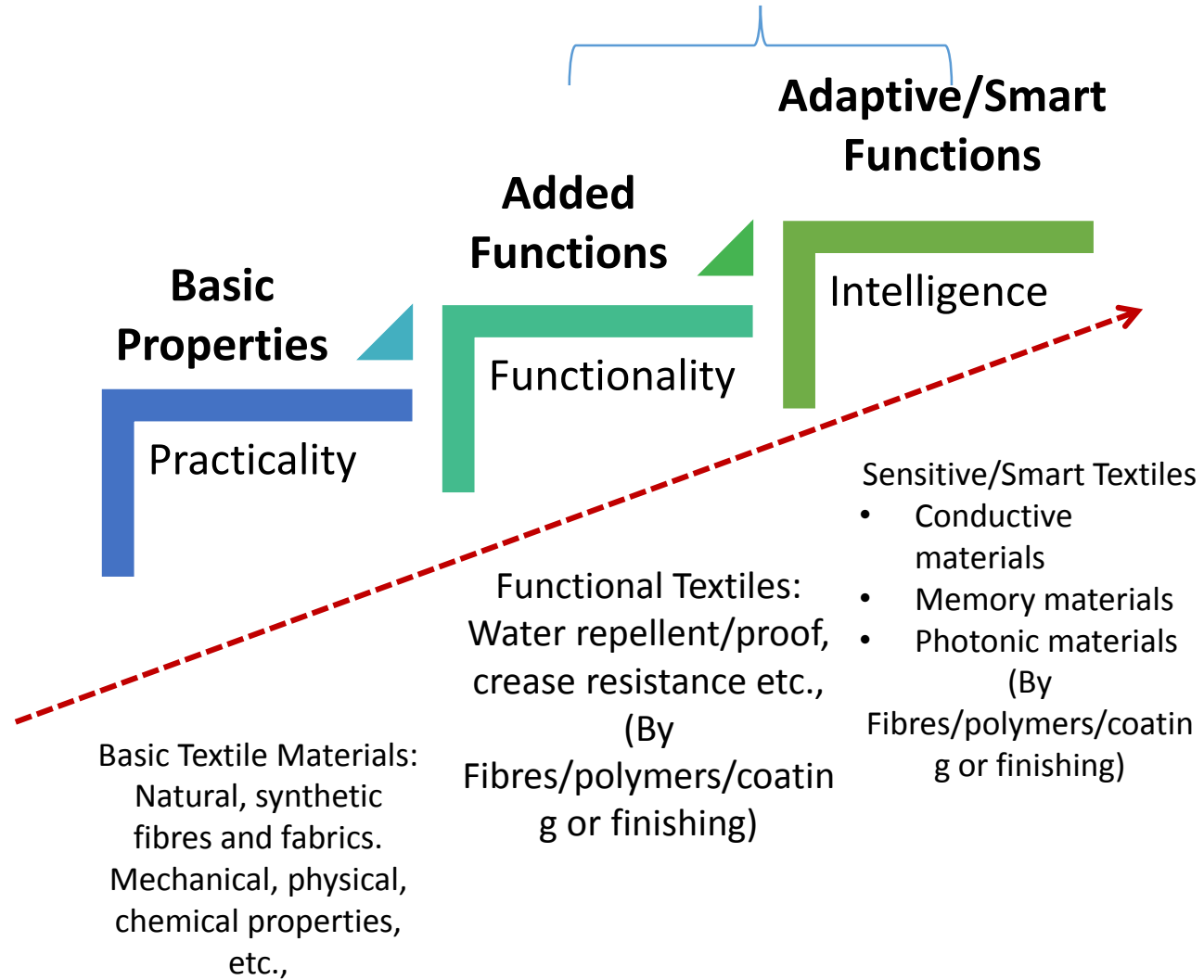
# Basic Textile Materials - History

## *Fibres + Yarns + Fabrics*



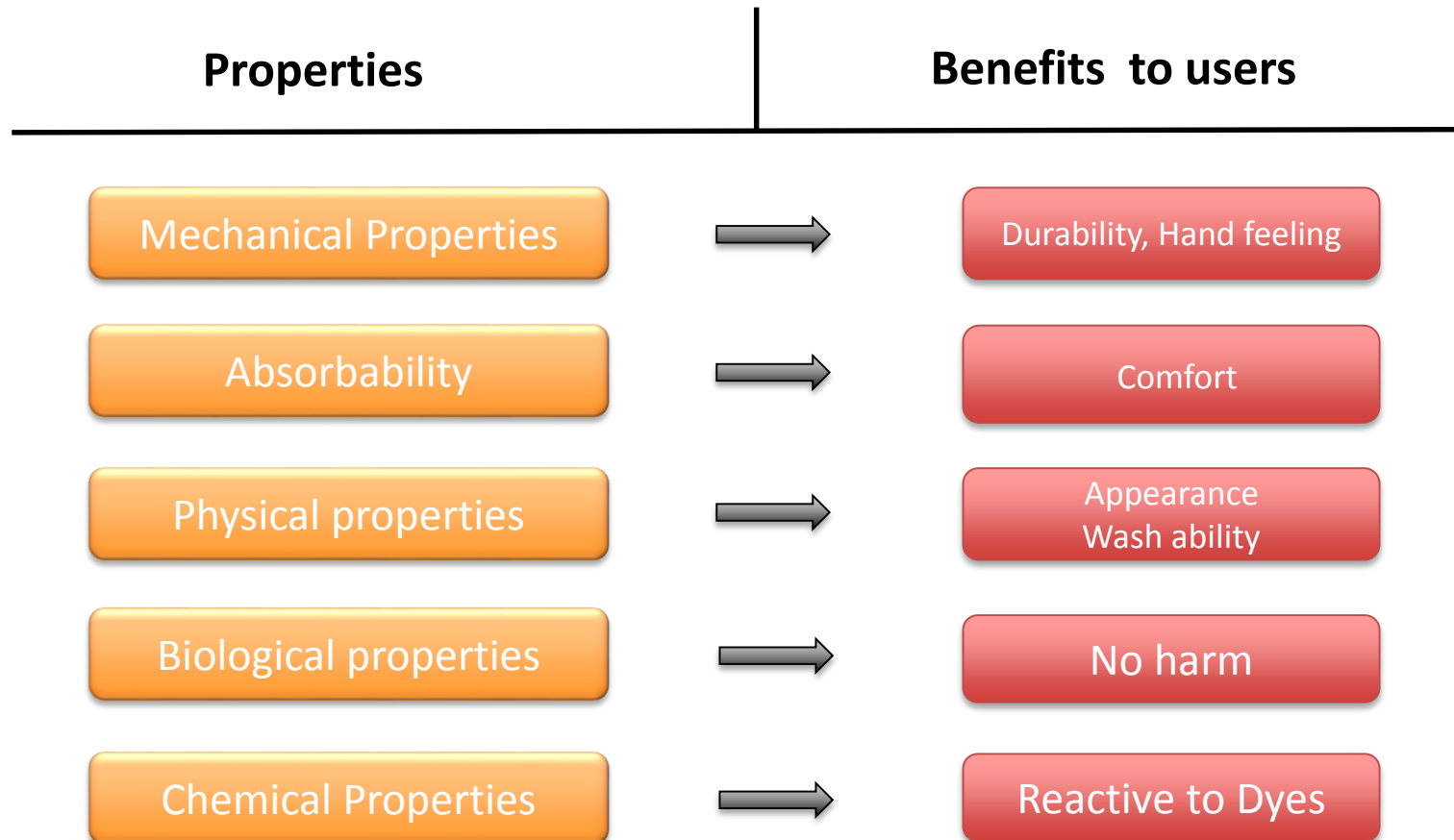
# A Paradigm Shift

## From Practicality to **Sensitivity**



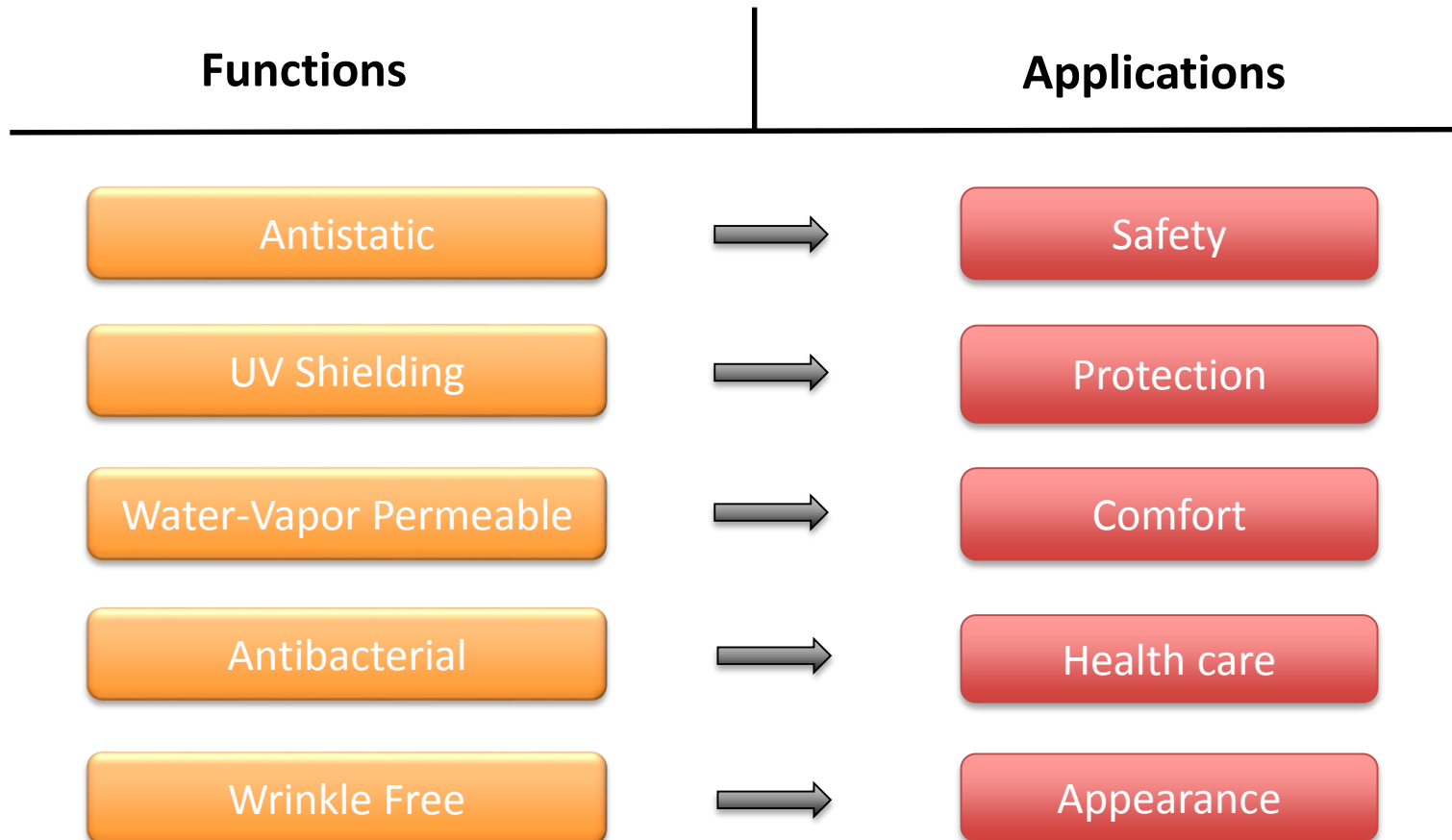
# Textile Materials with Practicality

Common and conventional textile materials have basic properties meeting the universal requirements



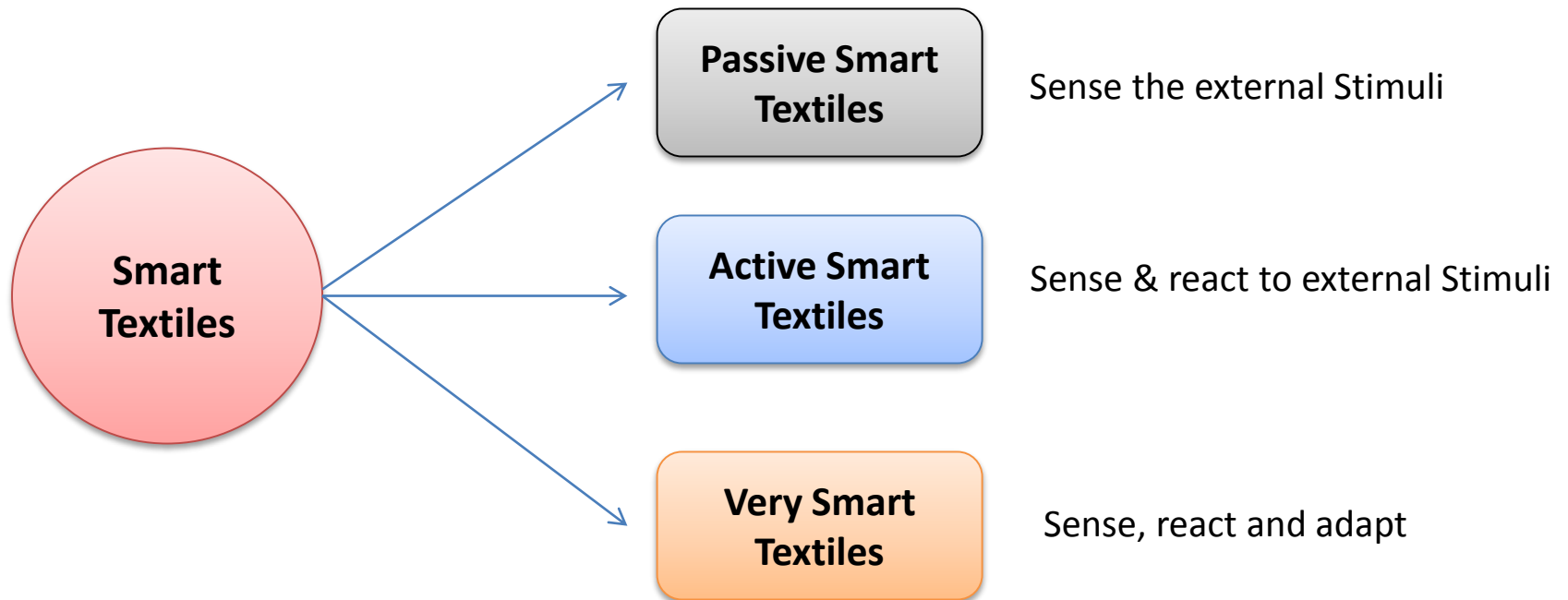
# Functional Textile Materials

Functional textiles refer to those with improved functionalities, which could add extra value to common textile for advanced applications



# Smart textiles

Materials and structures that can sense, react to environmental conditions or stimuli such as Mechanical, thermal, chemical, electrical, magnetic or other sources.





# Trends of Textiles

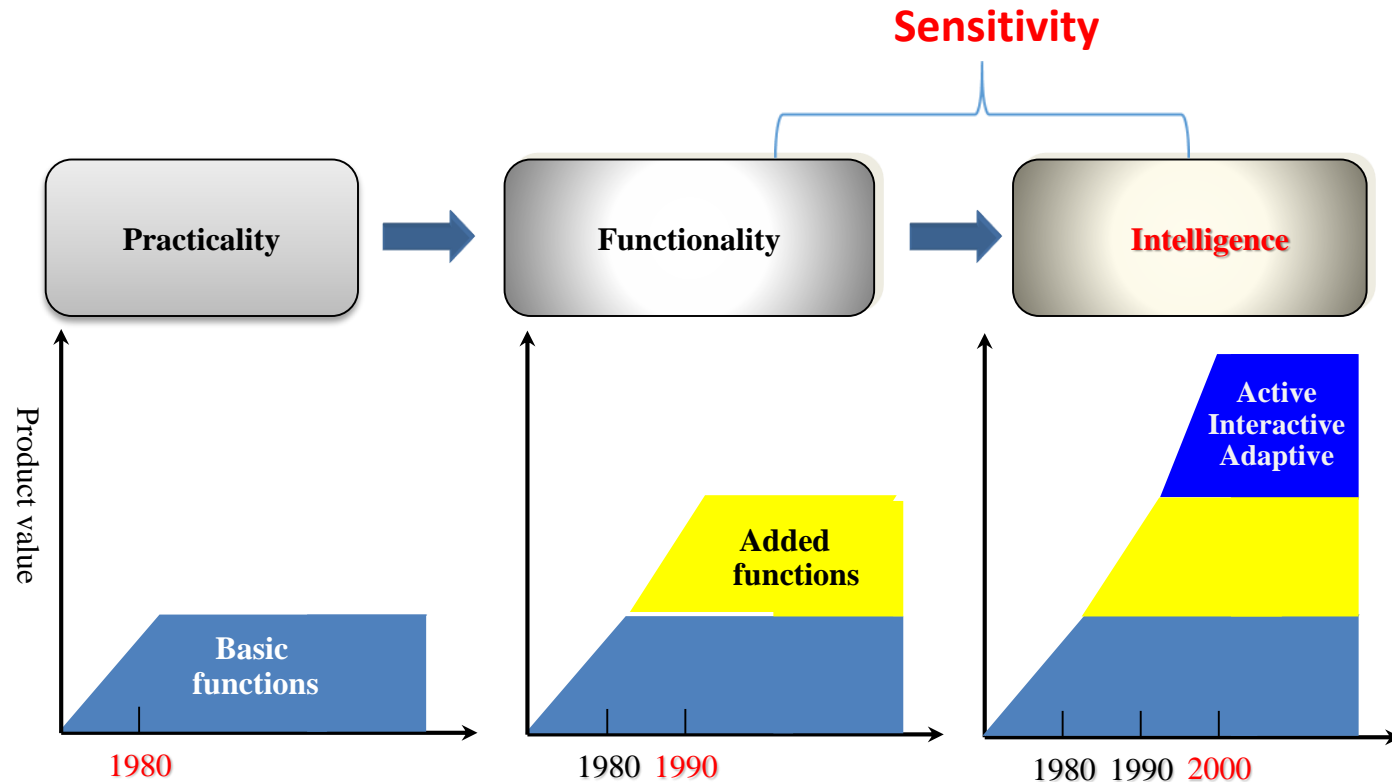
## Paradigm:

- An example serving as a model or pattern
- An outstandingly clear or typical example or archetype
- A philosophical or theoretical framework of any kind

**Practicality:** Adapted or designed for actual use

The quality of being effective, useful, or suitable for a particular purpose or situation

**Sensitivity:** The capacity or ability to respond to changes in the environment or physical stimuli.



# Functional & smart textiles

## Functional

## Smart

### Heat transfer

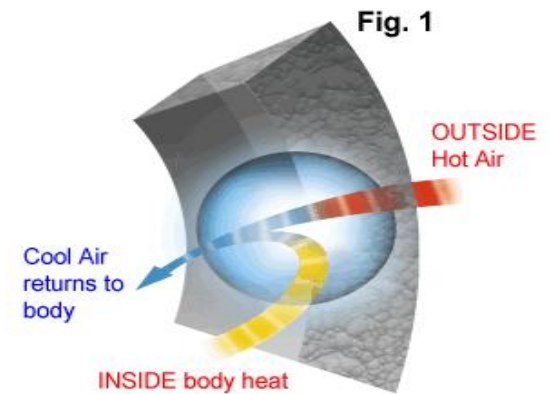
Thermal insulation



*Smart Make functions*

- *Active*
- *Interactive*
- *Adaptive*
- *responsive*

Thermal regulation



### Conductivity

Anti-static

Sensor

# Optical Materials → Functional or Smart?

## Functional

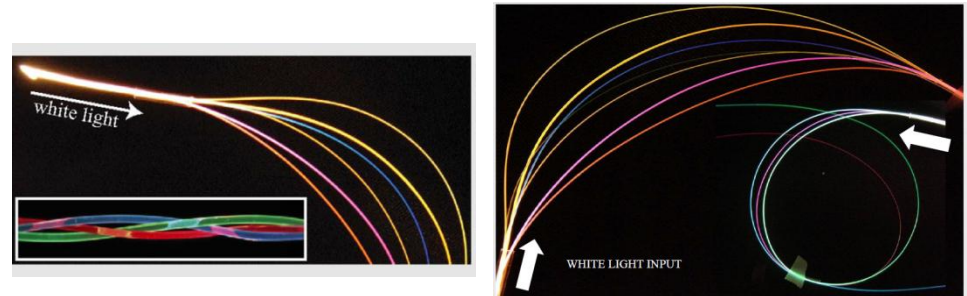
### Light Illumination



Optical fibres (POFs)

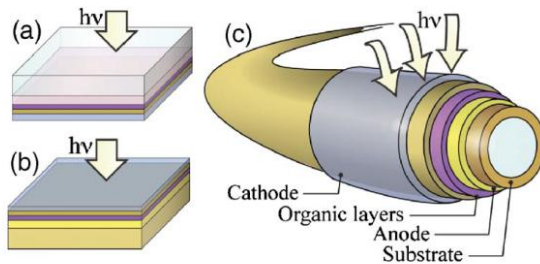
## Smart

### Light Manipulation



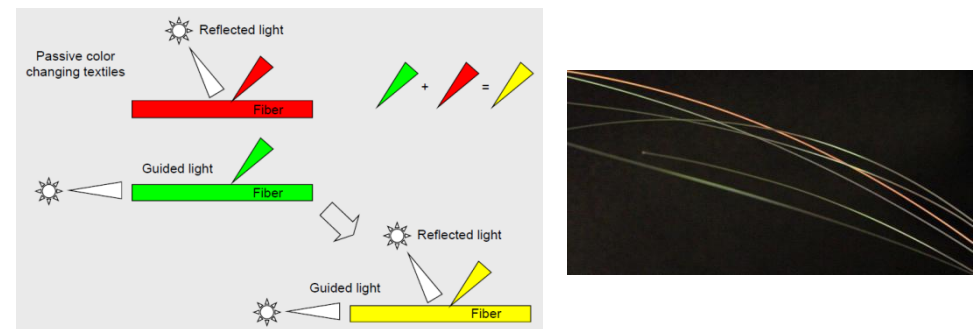
Colour Changing Photonic Band Gap Fibres

### Energy Harvesting



Photovoltaics

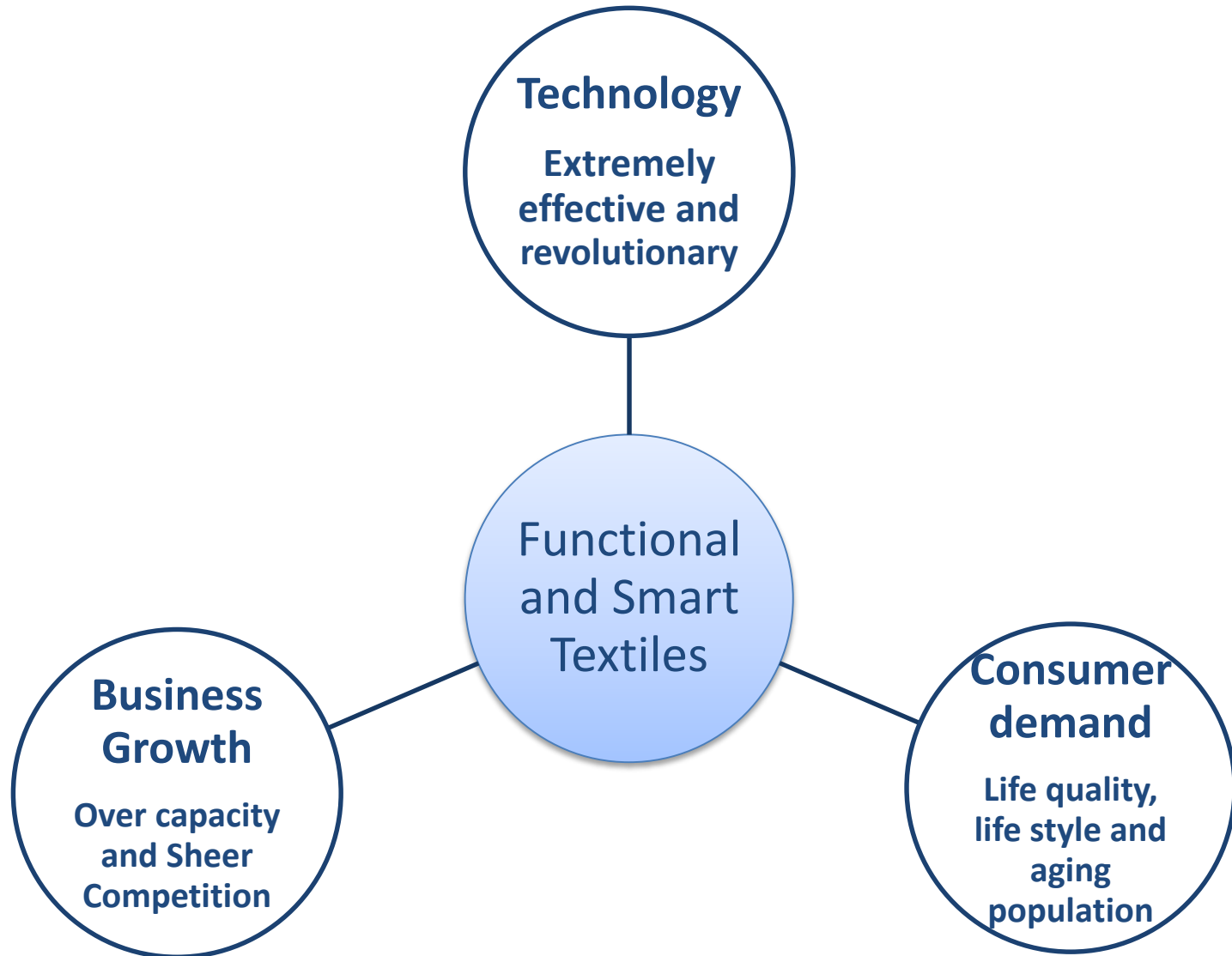
### Camouflage Function



Hollow Core Photonic Band Gap Fibres

# **Drivers to the paradigm Shift Sensitive Textile Materials**

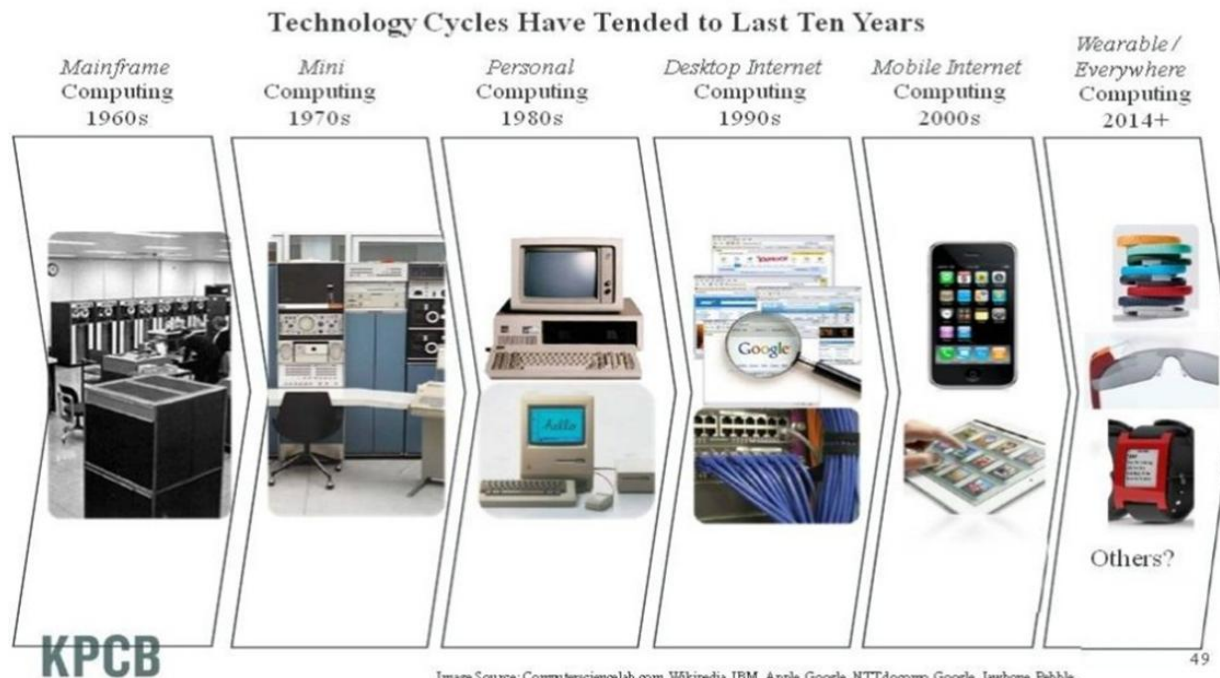
# Drivers for Sensitive Textile Materials



# The development of computer

Mainframe computer → Mini computer → PC → desktop Internet → mobile internet  
→ **wearable /everywhere product**

智能手机和平板电脑生态圈尚且年轻，可穿戴设备已在迅猛增长

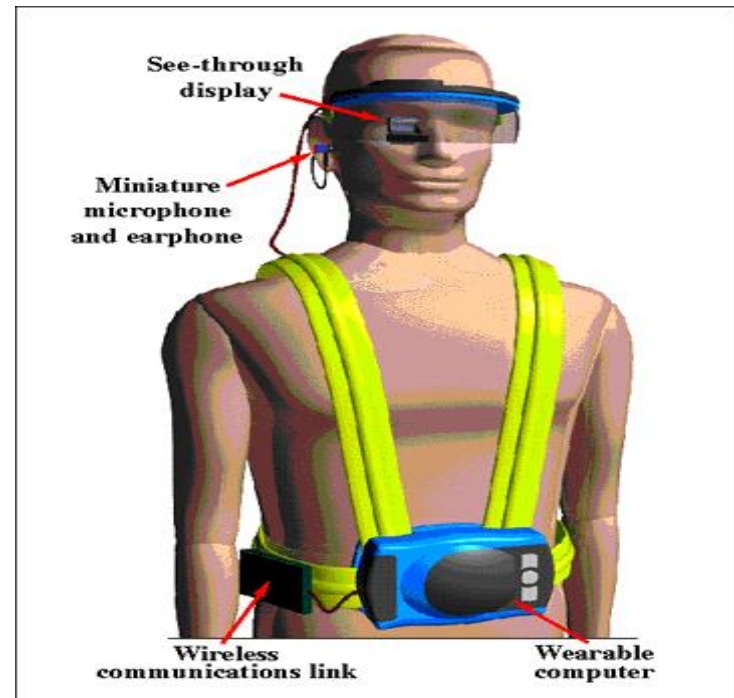


# Computing/Wearable electronics

Electronics



Wearable computer



*A convenient and smart life style*



# Fast Growth--- Forecasts on wearable electronics

## Traditional wearable electronics

Small size; Good properties

Rigid; Heavy;  
Environments contaminated  
Large batteries



## Wearable electronics

Small size, active devices,  
wireless and non-invasive,  
user friendly

Working with high energy  
not integrated into clothing



## E-textiles

Portable, washable,  
stretchable, comfort,  
wireless, foldable,  
durable, invisible,  
integral energy  
harvesting



past 2015 2024

\$  
3-5B

\$  
30B

\$  
94B



# Evolution of wearable electronics

Original



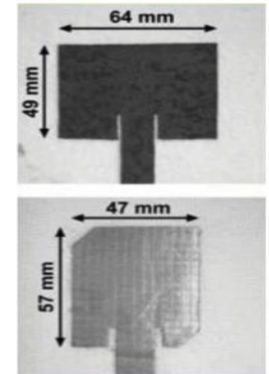
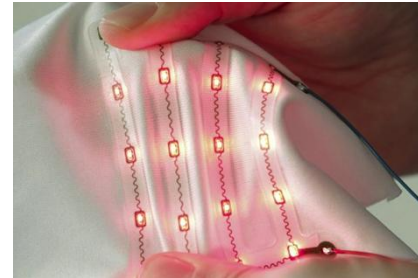
Yesterday



Today



Tomorrow



All textile antenna

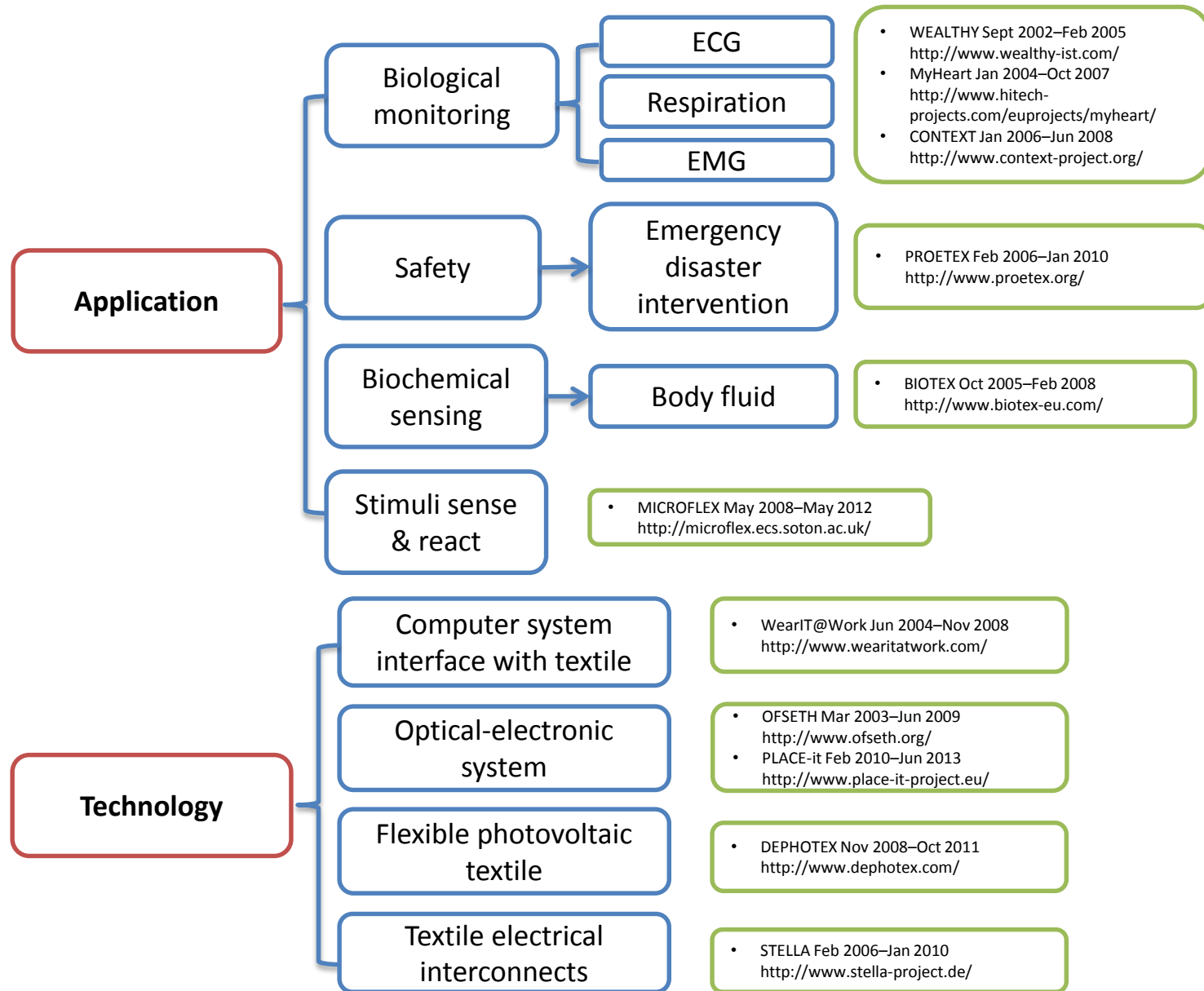
Electronics

Textile-adapted

Textile-integrated

Fully Textile-based

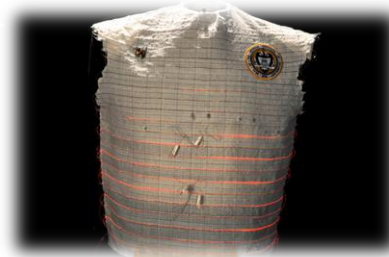
# Smart textile project in Europe



1



Healthcare



Military

3



Fashion

Key  
markets

Safety and security

4



Sports and fitness

5



Entertainment

6



- 1 Life vest-detect the sudden cardiac arrest(SCA)
- 2 Wearable Motherboard developed by Georgia Tech University
- 3 Blushing dress-Philips, show wearers emotional states
- 4 Mino, a baby monitor tracks baby's temperature, breathing, activity and sleep
- 5 Nymi bracelet is equipped with a sensor
- Pic.6 Joanna Berzowska co-founded with MIT vet Maggie Orth, musical jacket

# Multi-component Systems



General components of  
E-textile system



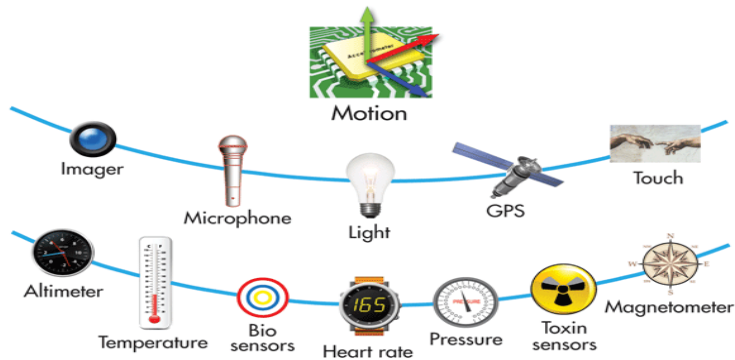
Interface

Communication

Energy supply

Data  
management

Integrated  
circuits



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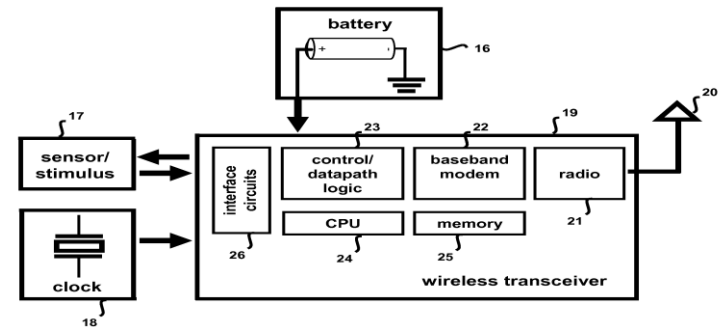
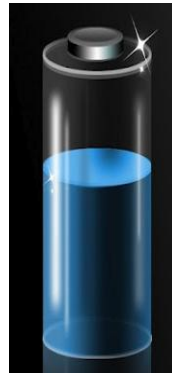
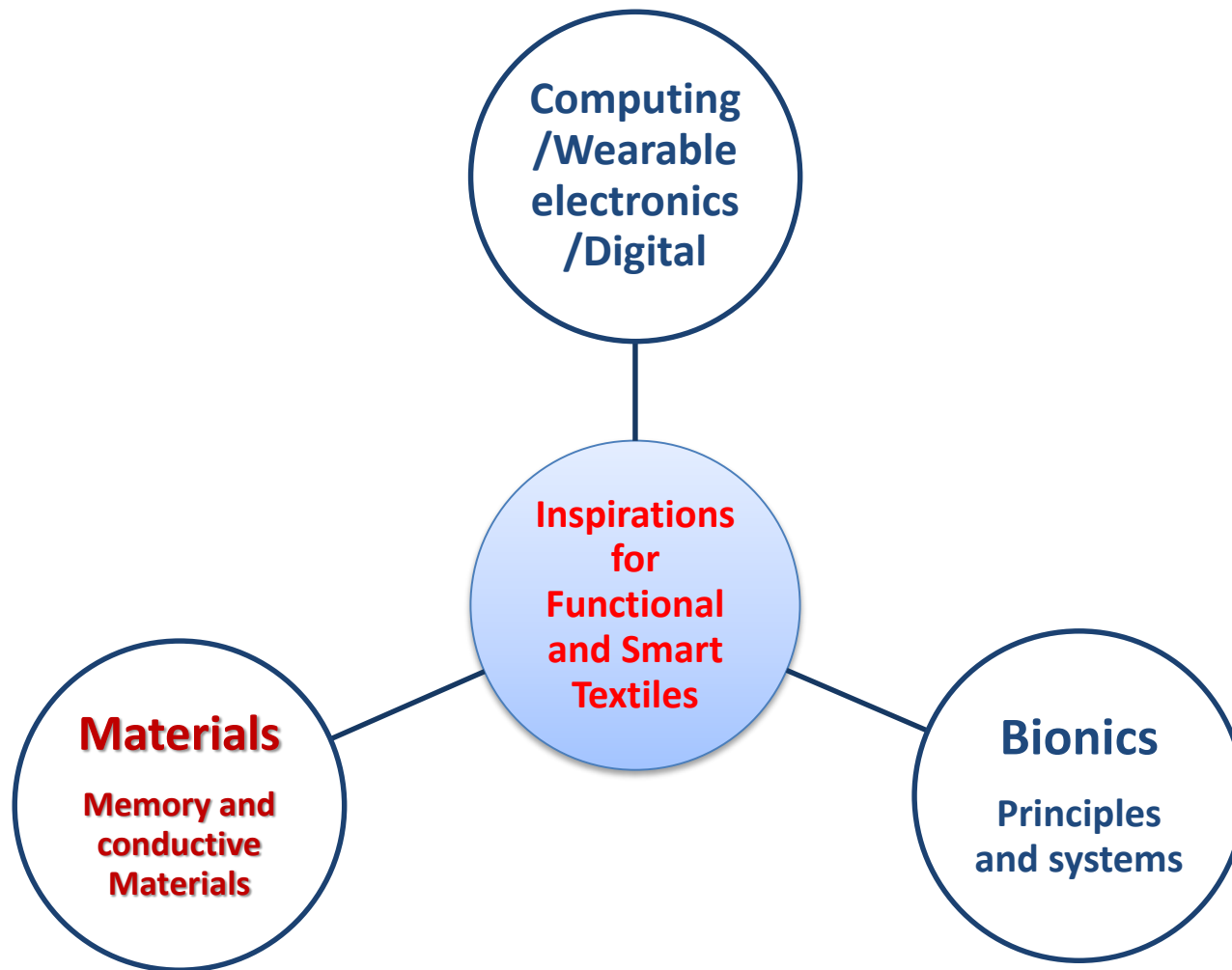


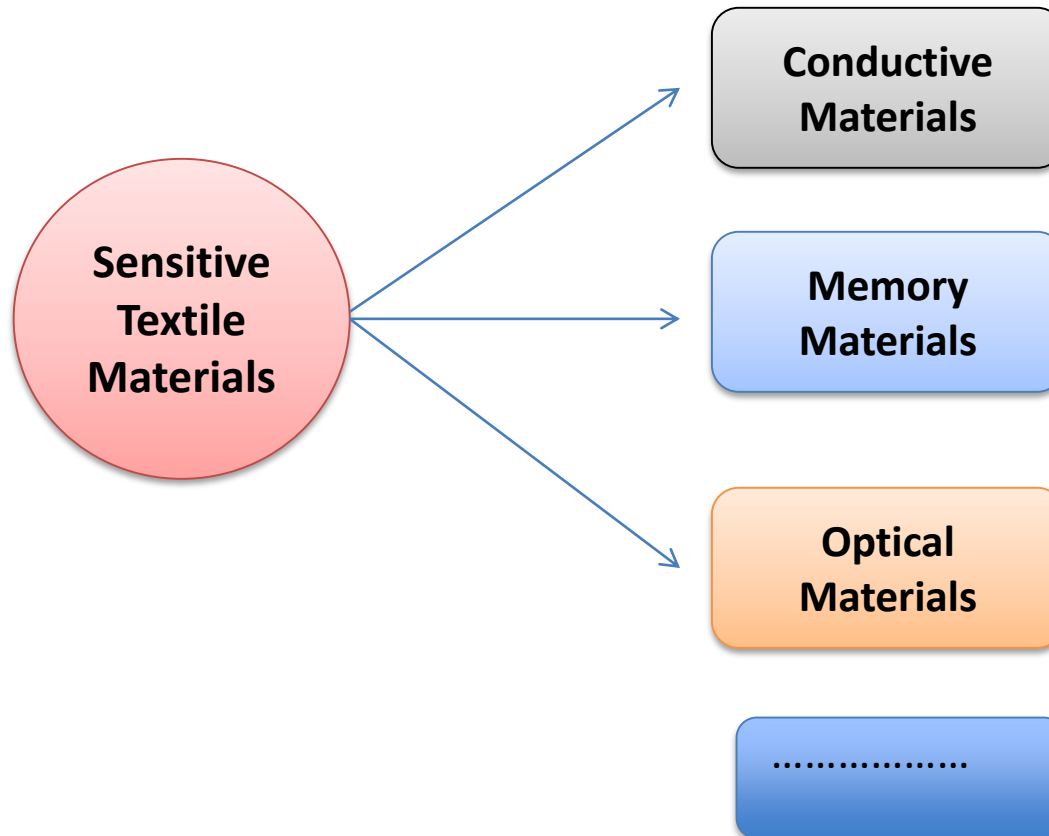
FIGURE 5

# How to Get Sensitive Textile Materials



# Sensitive Textile Materials

Sensitive textile materials refer to those which can transport and sense environmental conditions or stimuli such as Mechanical, thermal, optical, electrical, chemical, electrical, magnetic or other sources.



# **Conductive Materials**

# Conductive Raw Materials

## Conductive polymer

Intrinsic  
conductive  
polymer

- Polypyrrole (PPY)
- Polyaniline (PANI)
- Polythiophene (PT)
- Poly(3,4-ethylenedioxythiophene (PEDOT)

Conductive  
composites

- ✧ Conjugated polymers can be made to conduct electricity through doping
- ✧ Poor processability: mainly by dispersion
- ✧ Conductivity: metallic or semiconductor

## Metal-based

- Ag
- Cu
- Au
- Ni

- Nanowire
- Nanoparticle

- ✧ Very high conductivities
- ✧ The roughness, haze, and stability issues have hindered their emergence in industry

## Carbon-based

- Carbon nanotube (CNT)
- Graphene
- Carbon black

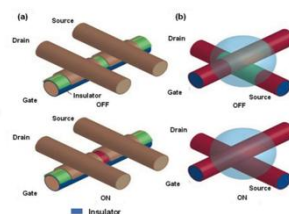
- ✧ High electrical conductivity
- ✧ Superior mechanical properties
- ✧ CNTs and graphene: most intensively explored
- ✧ Great potential in wearable electronics



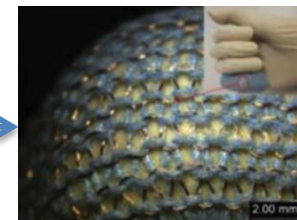
# Fiber/Fabric-based electrical system

## Basic electronic circuit components

Fiber transistors



Electrical connector



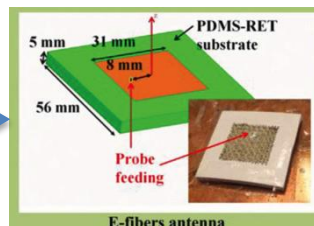
Knitted connector

Sensor

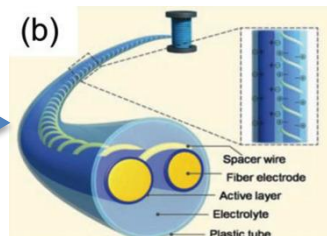
- Strain sensor
- Pressure sensor
- Chemical sensor
- Optical sensor
- Humidity sensor



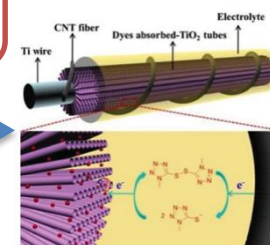
Antenna



Energy storage

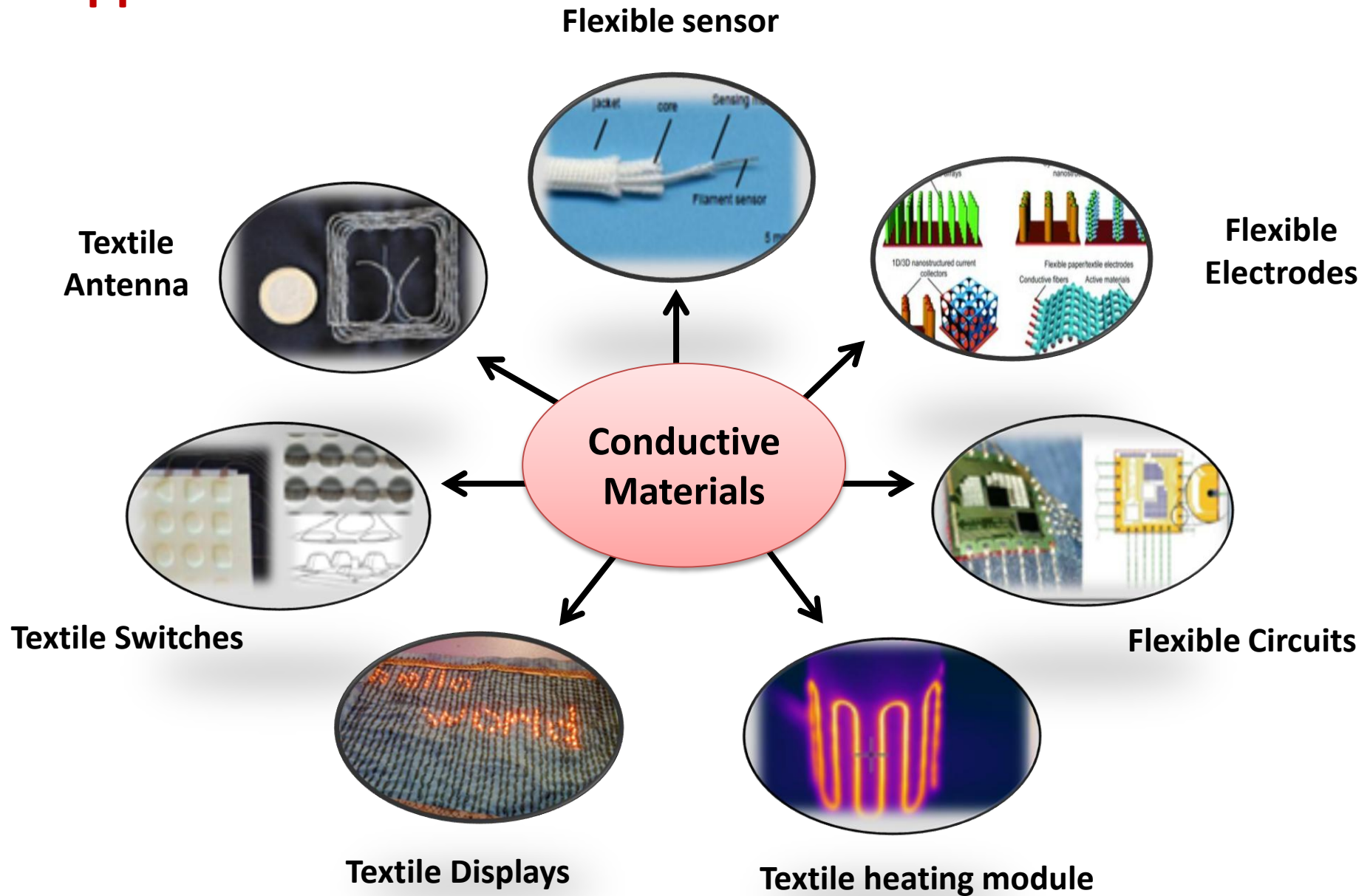


Energy convertor

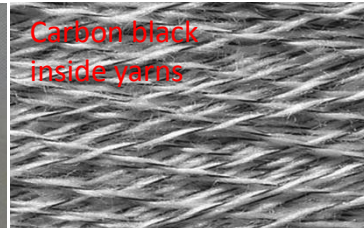
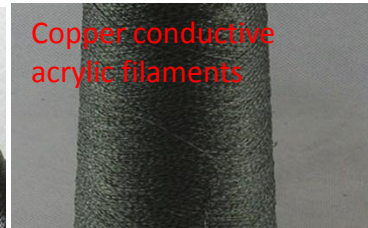
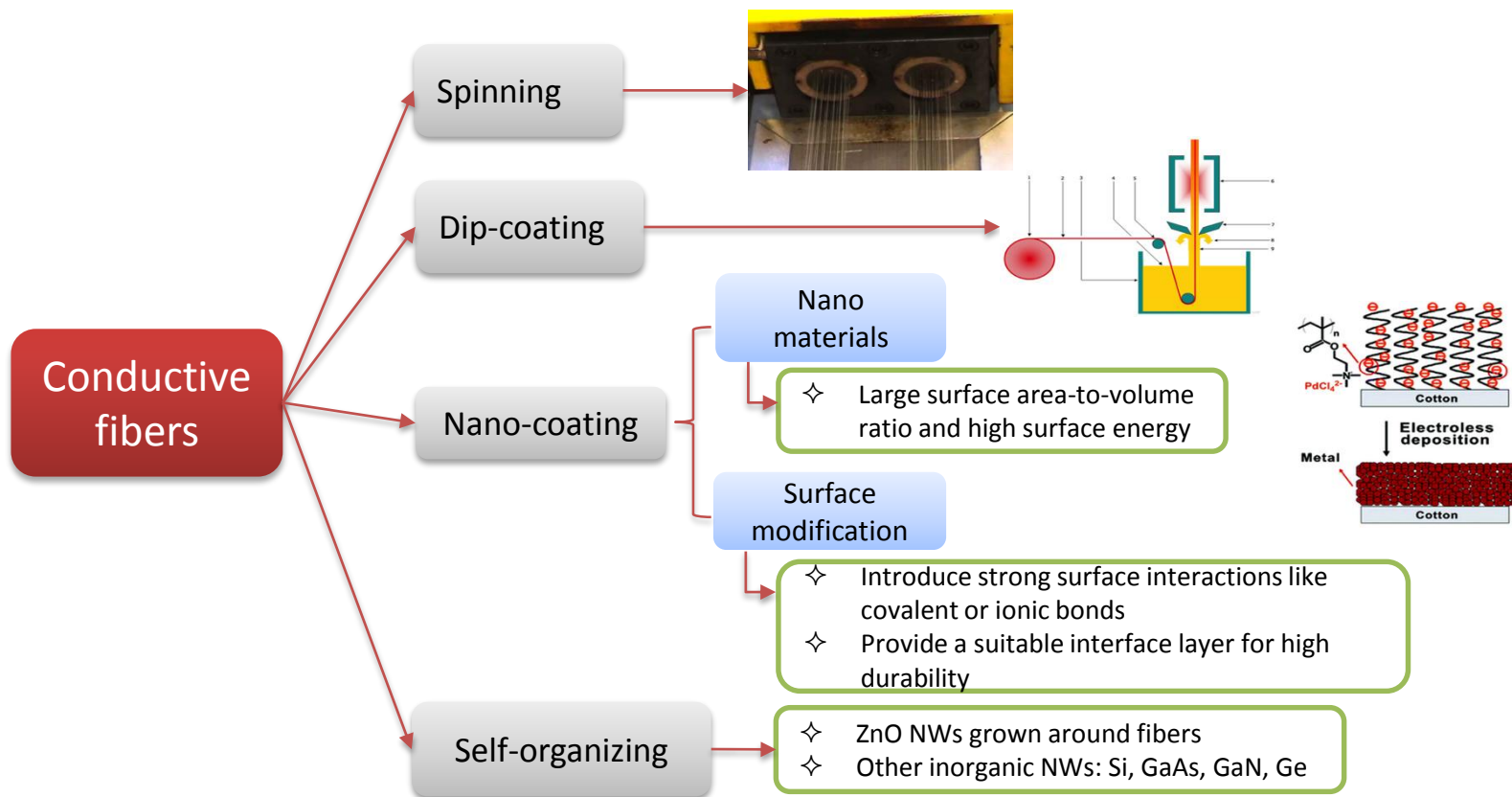


Power system

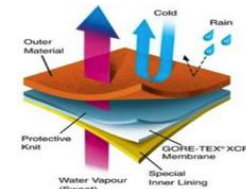
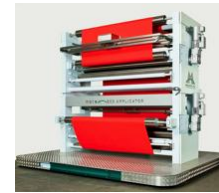
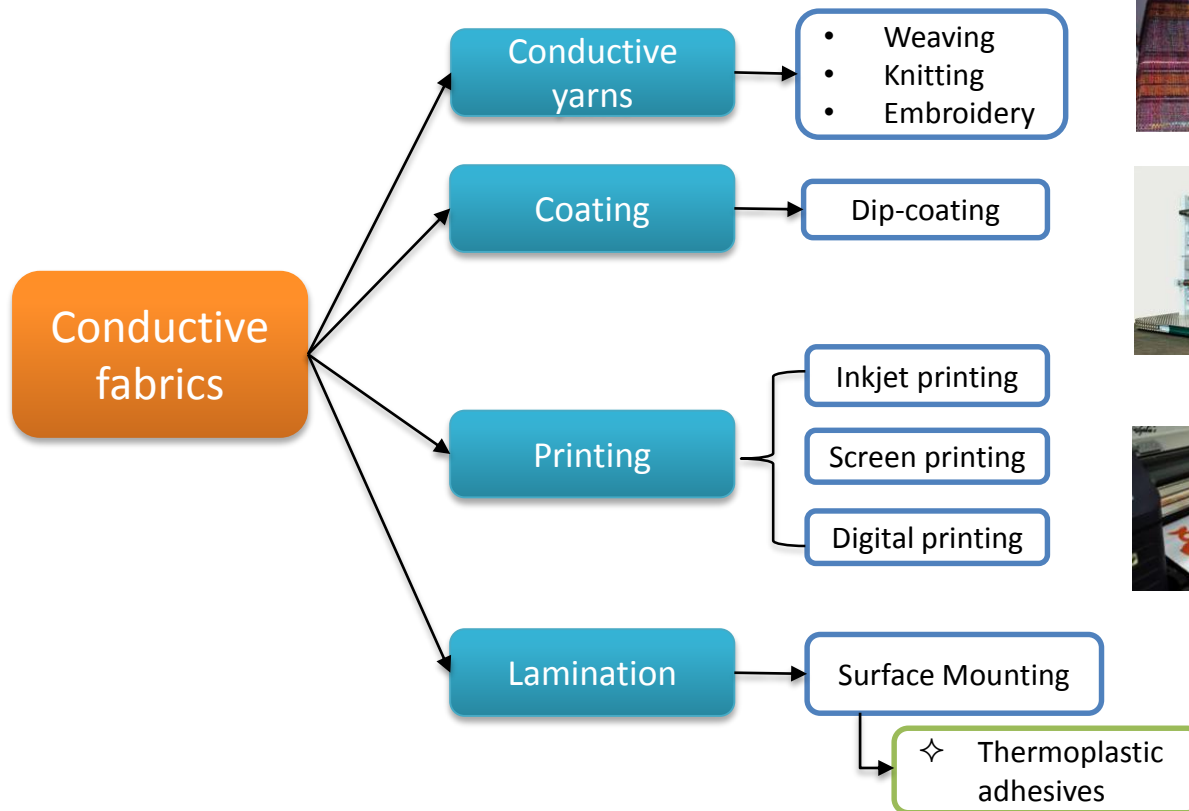
# Applications



# Conductive fibers

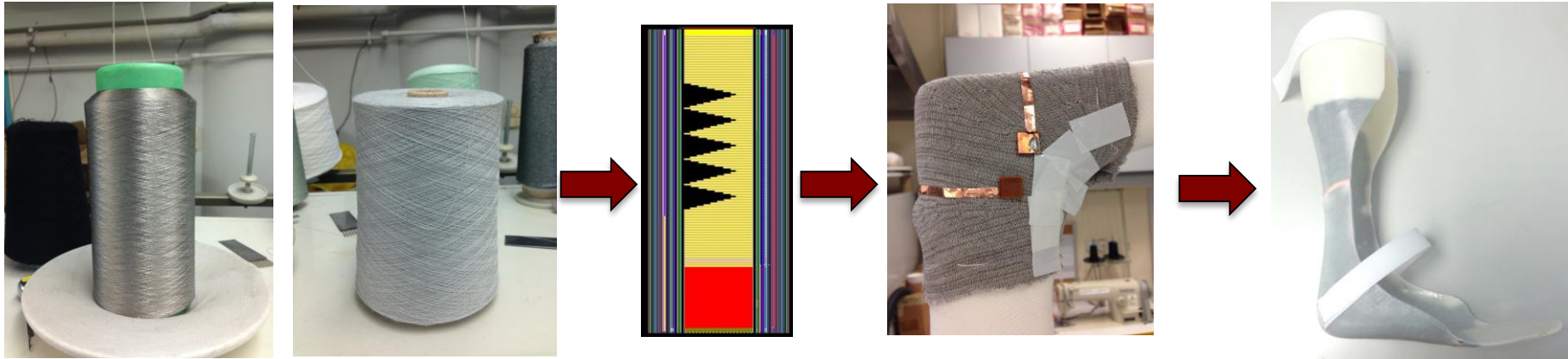


# Conductive fabrics



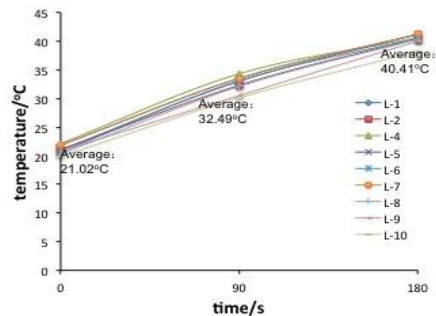


# Three-dimensional direction heating fabric used into the AFO device

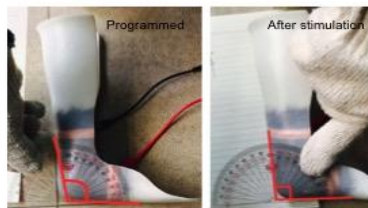
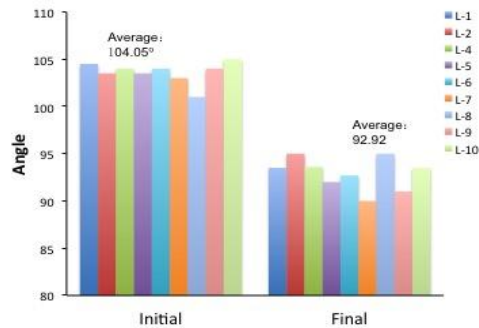


Evaluation of properties of AFO devices

Left foot



Average rate of temperature vs time

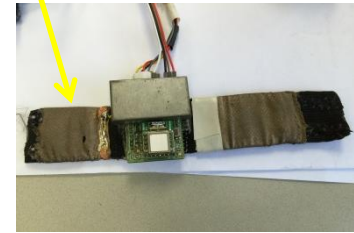
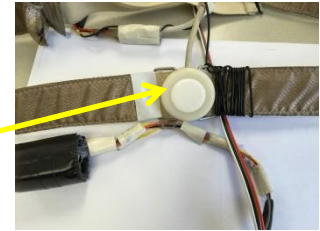
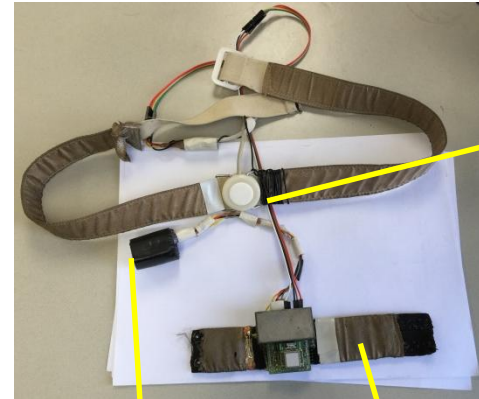
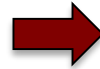


Average angle change before and after stimulation

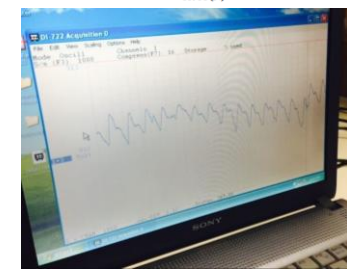
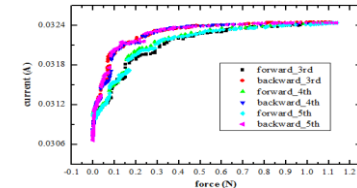
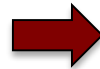
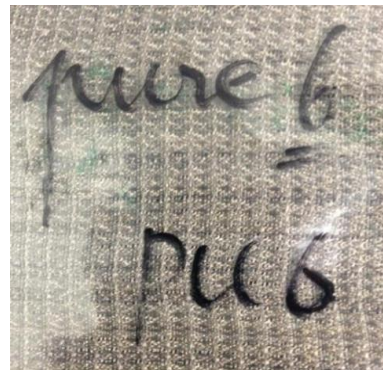
- Avoid hot spot problems resulting from the short-circuiting
- Uniform heating generates in three-dimensional direction even the fabrics are under the curved shape
- Heating process is time efficient
- Production process in a low cost and easy method

# Conductive fabric for vital signs detection

Sensor for detecting ECG and respiration signals

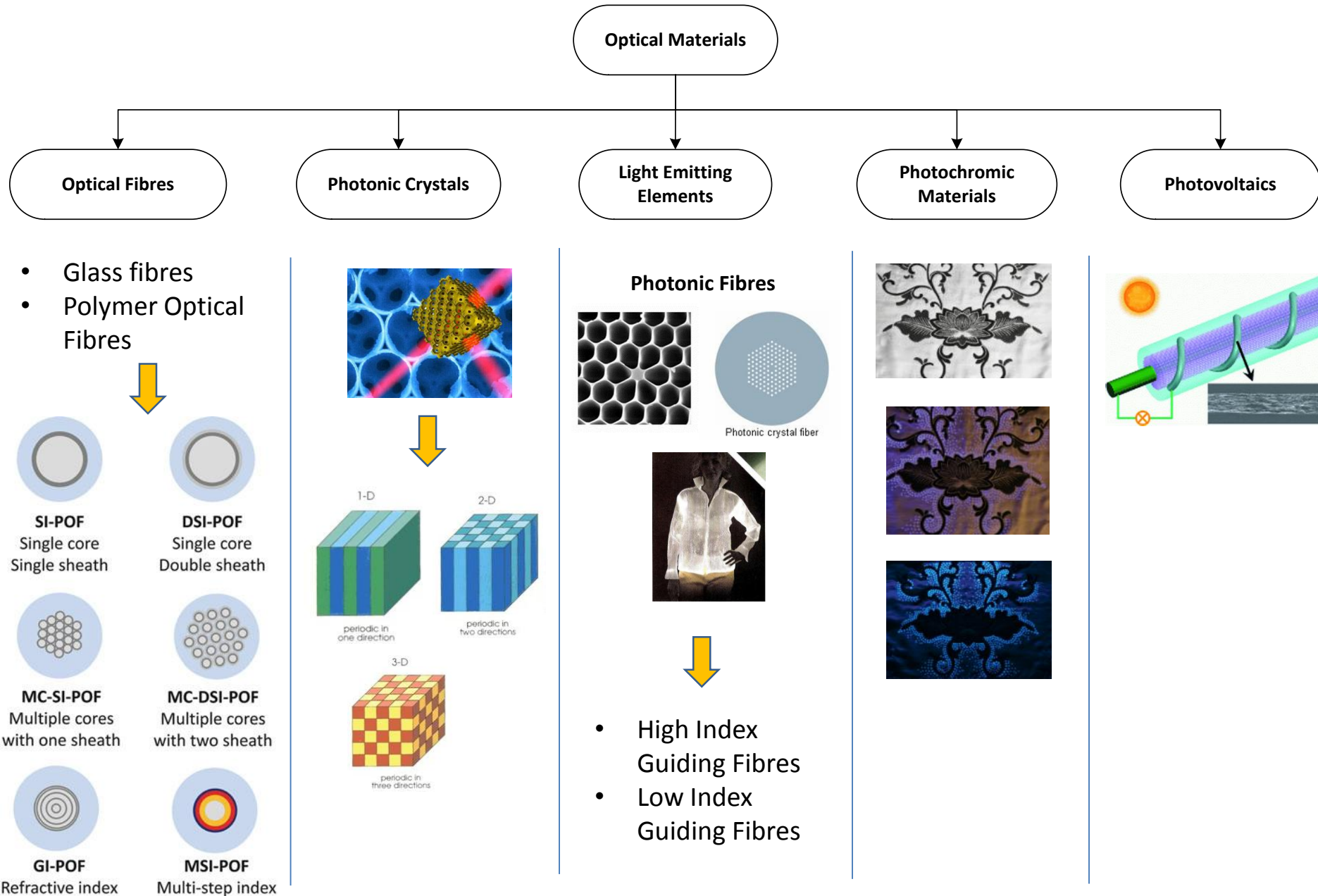


Sensor for detecting pulse rate (and blood pressure in the future)



# Optical Materials

# Classifications of Optical Materials



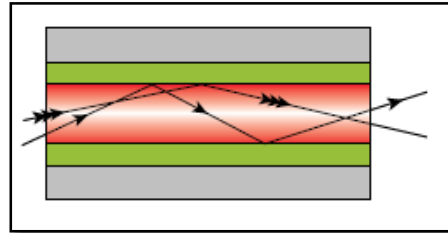


# Functions of Optical Materials

## Safety

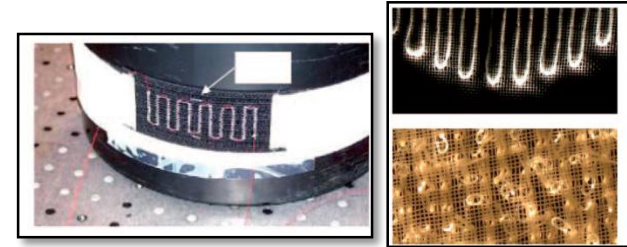


## Signal Transmission



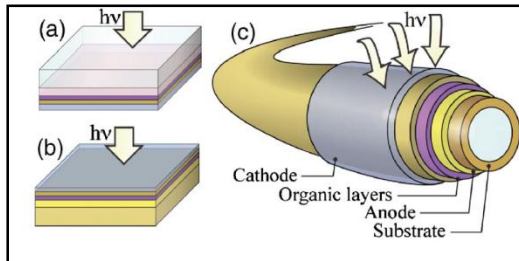
Glass / Plastic Optical Fibres

## Sensing



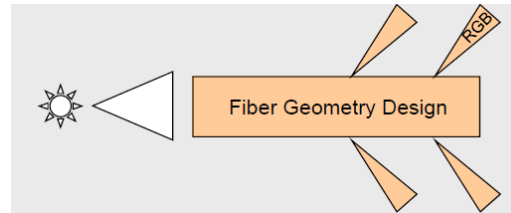
Glass / Plastic Optical Fibres

## Power Generation



Photovoltaics

## Illumination

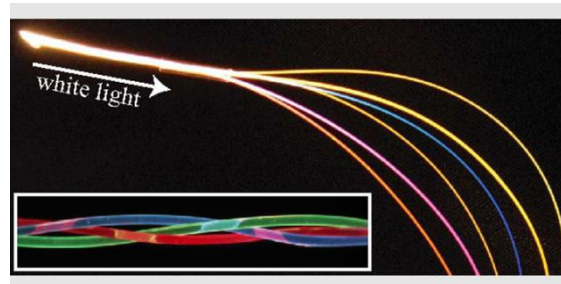
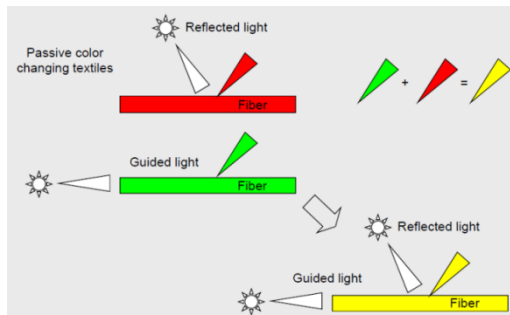


Colour Tunable Photonic  
Fibres

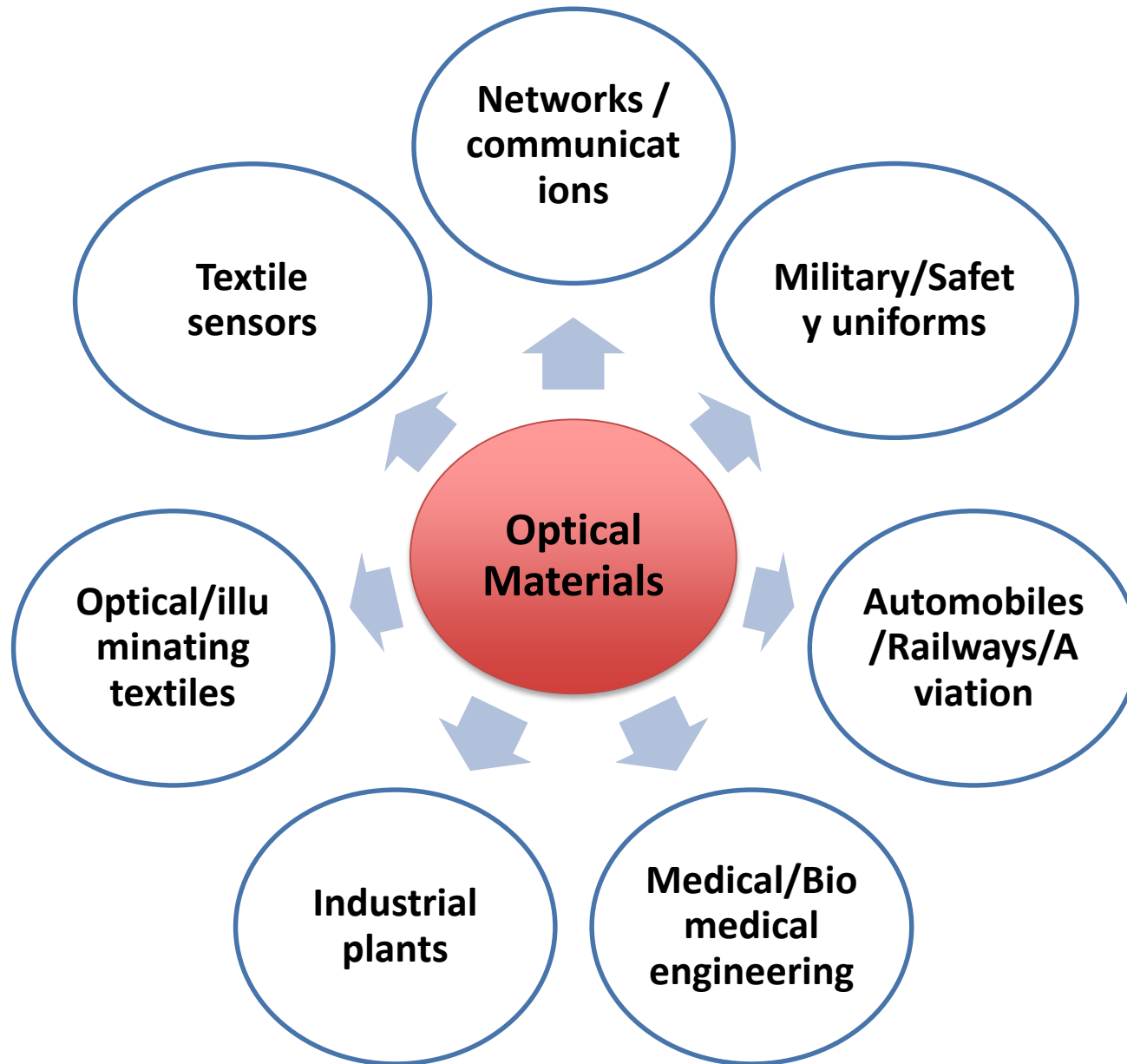
## Adaptability



## Structural Colours



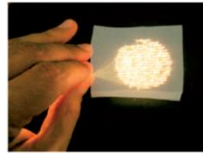
# Applications of Optical Materials



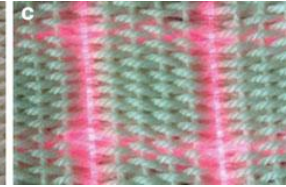
# Applications of Optical Materials



**Communication &  
Military Applications**



**Light Therapy: Biomedical  
Applications**



**Textile Sensors  
(Strain/Temperature/Humidity/Pressure sensors)**



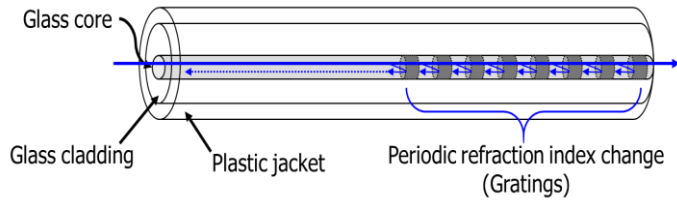
**Decoration/Display Applications**



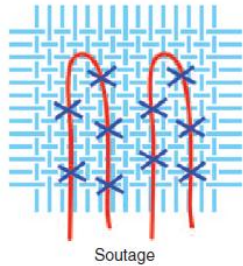
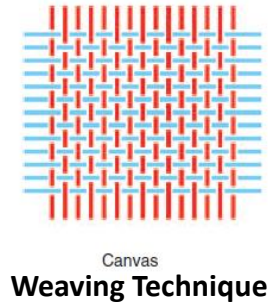
**Fashion Related Applications**

# Technologies for Optical Materials

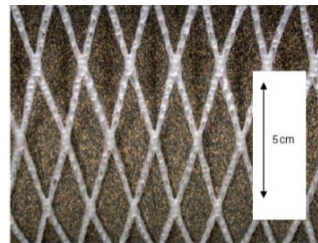
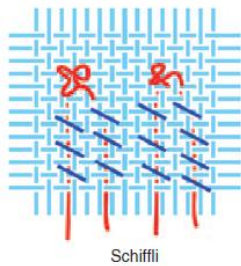
## Optical Fibres



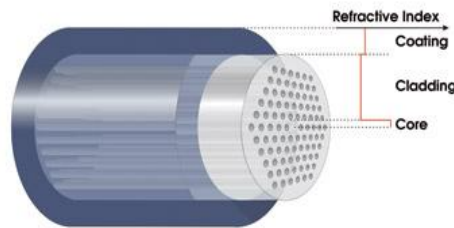
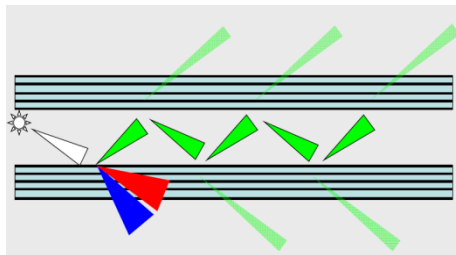
Fibre Grating



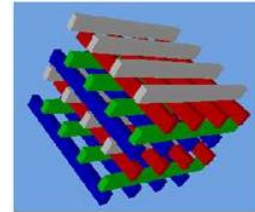
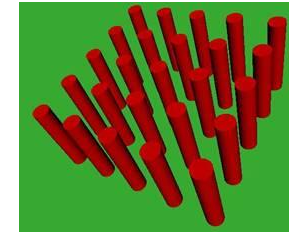
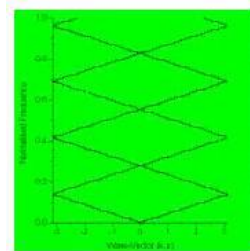
Embroidery Technique



## Photonic Fibres



## Photonic Crystals



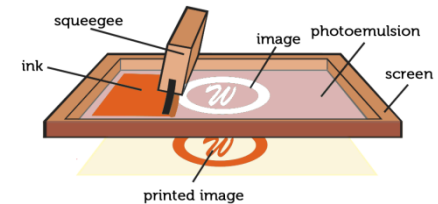
1D Band Structures 2D Band Structures 3D Band Structures

Arrangement of dielectric arrays in different dimensions for localization of lights (optical fibres, nanoscopic lasers, ultraviolet pigment, radio frequency antennas, reflectors, light emitting diodes, and photonic integrative circuits).

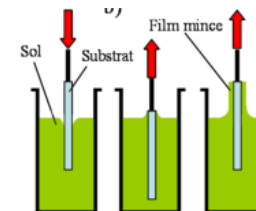
## Photochromic Materials



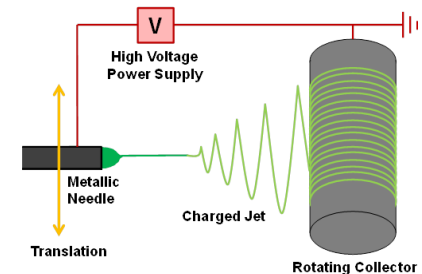
Exhaust Dyeing of Fibres/Fabrics



Screen Printing



Sol-Gel coating

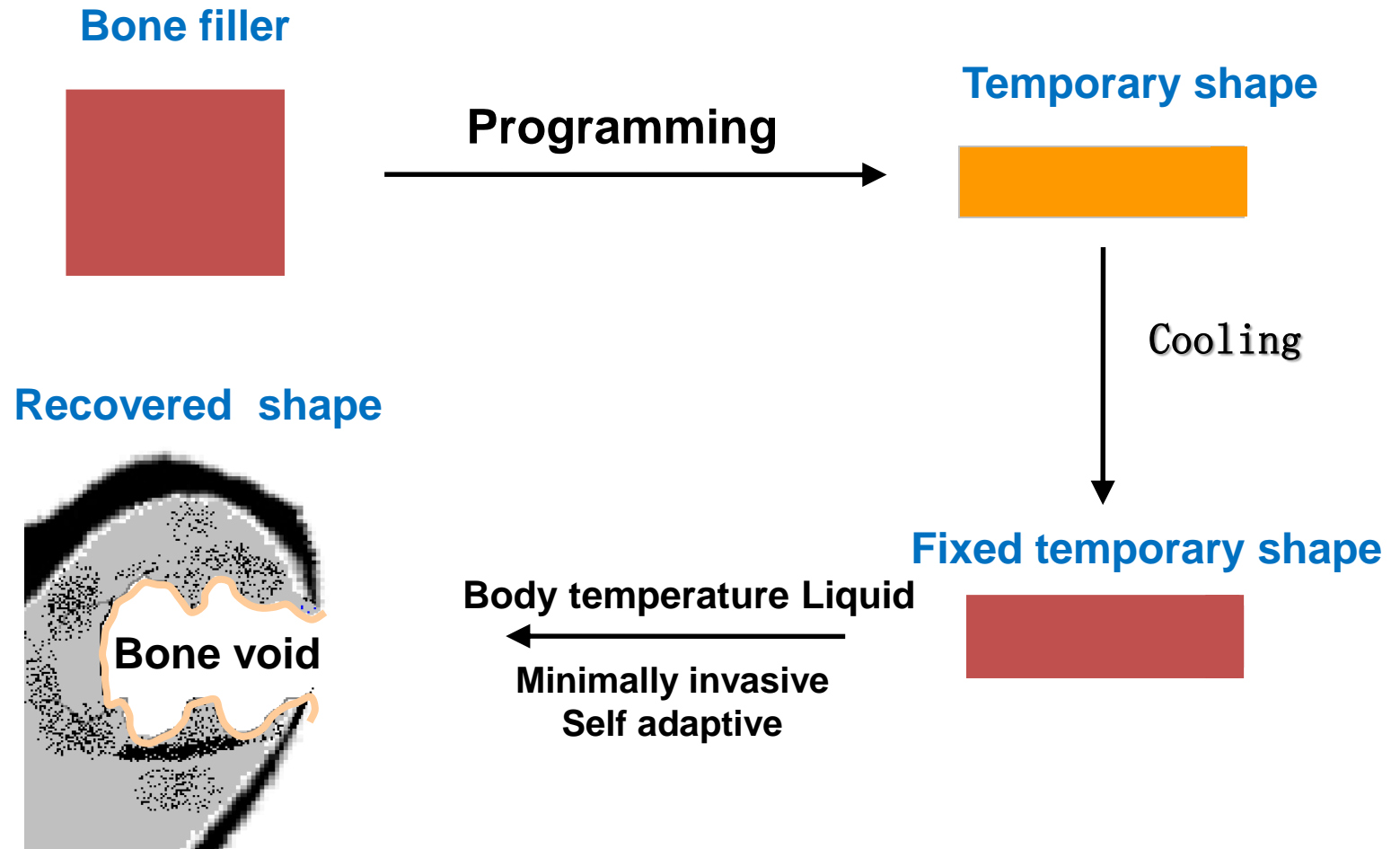


Electrospinning

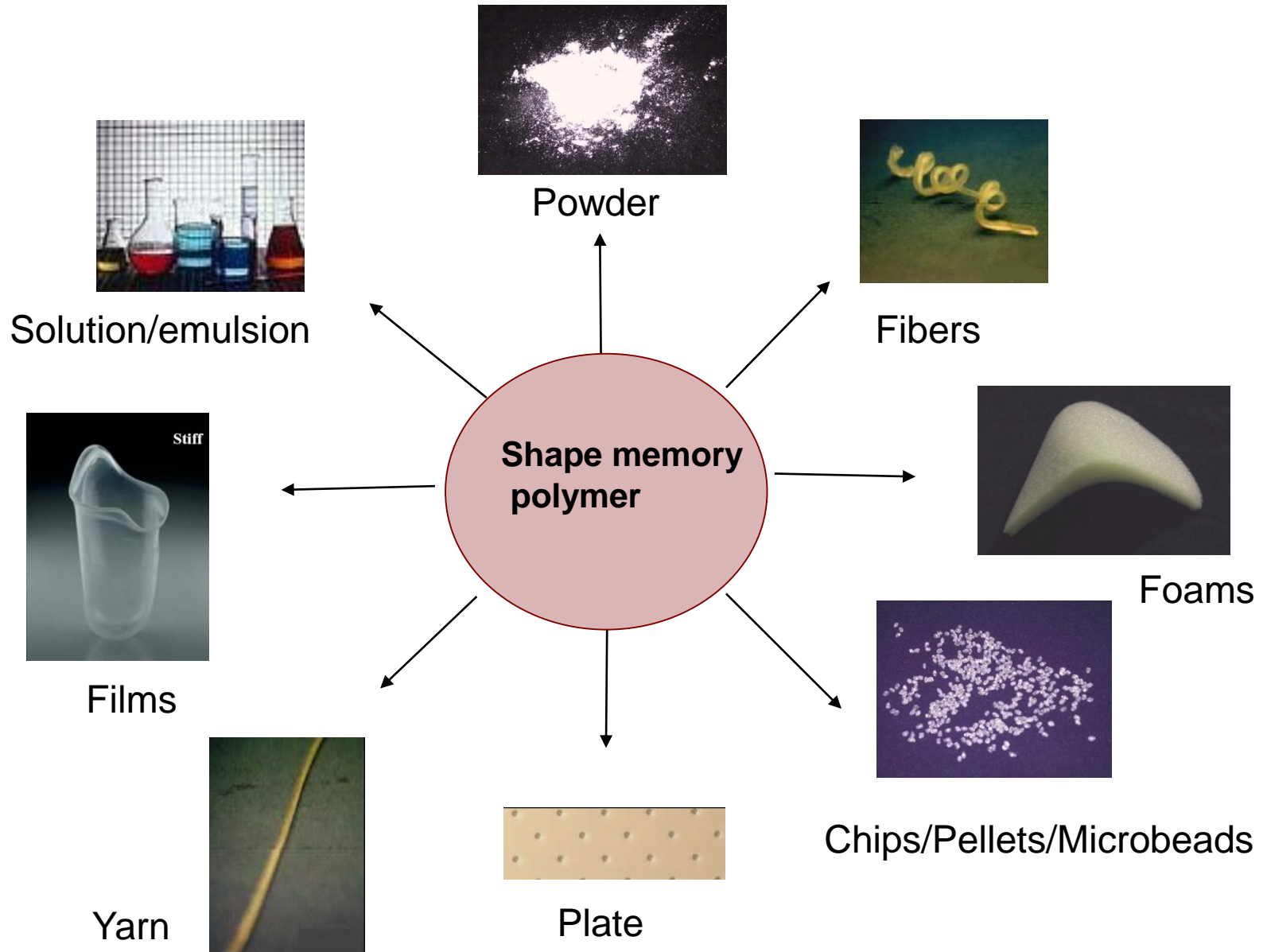
# **Memory Materials**



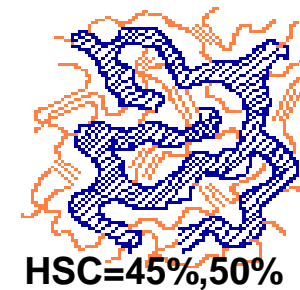
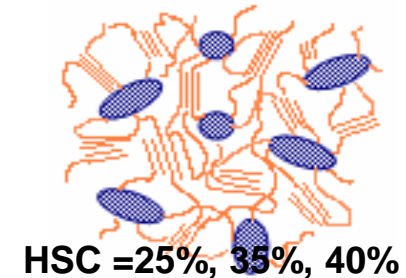
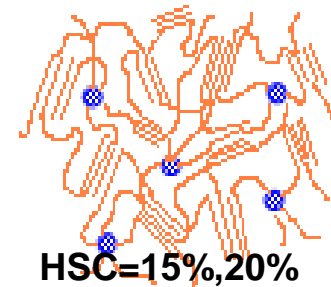
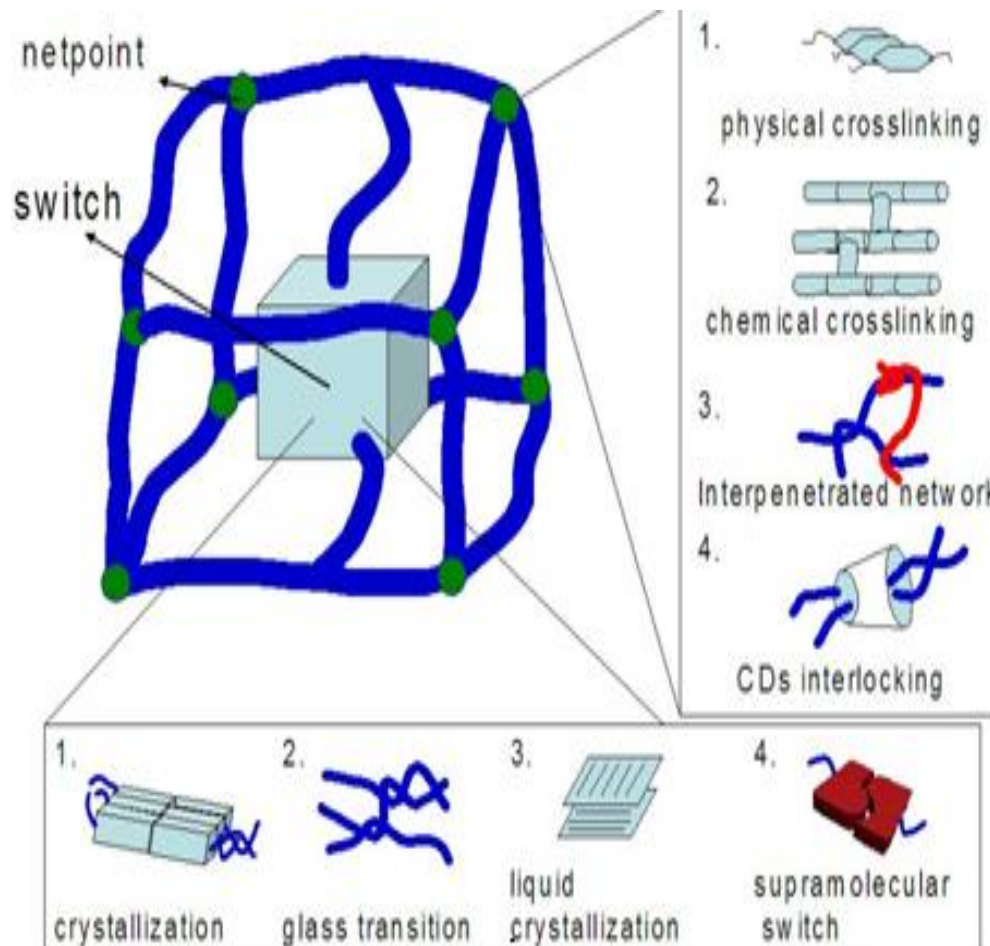
# Shape Memory Polymers



# Excellent Processability



# Flexible Design




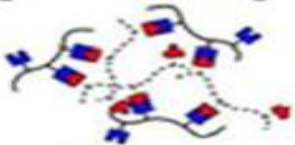

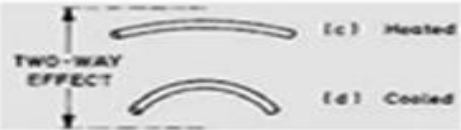






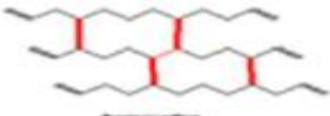





**Proposed Models of  
SMPU's Morphology**

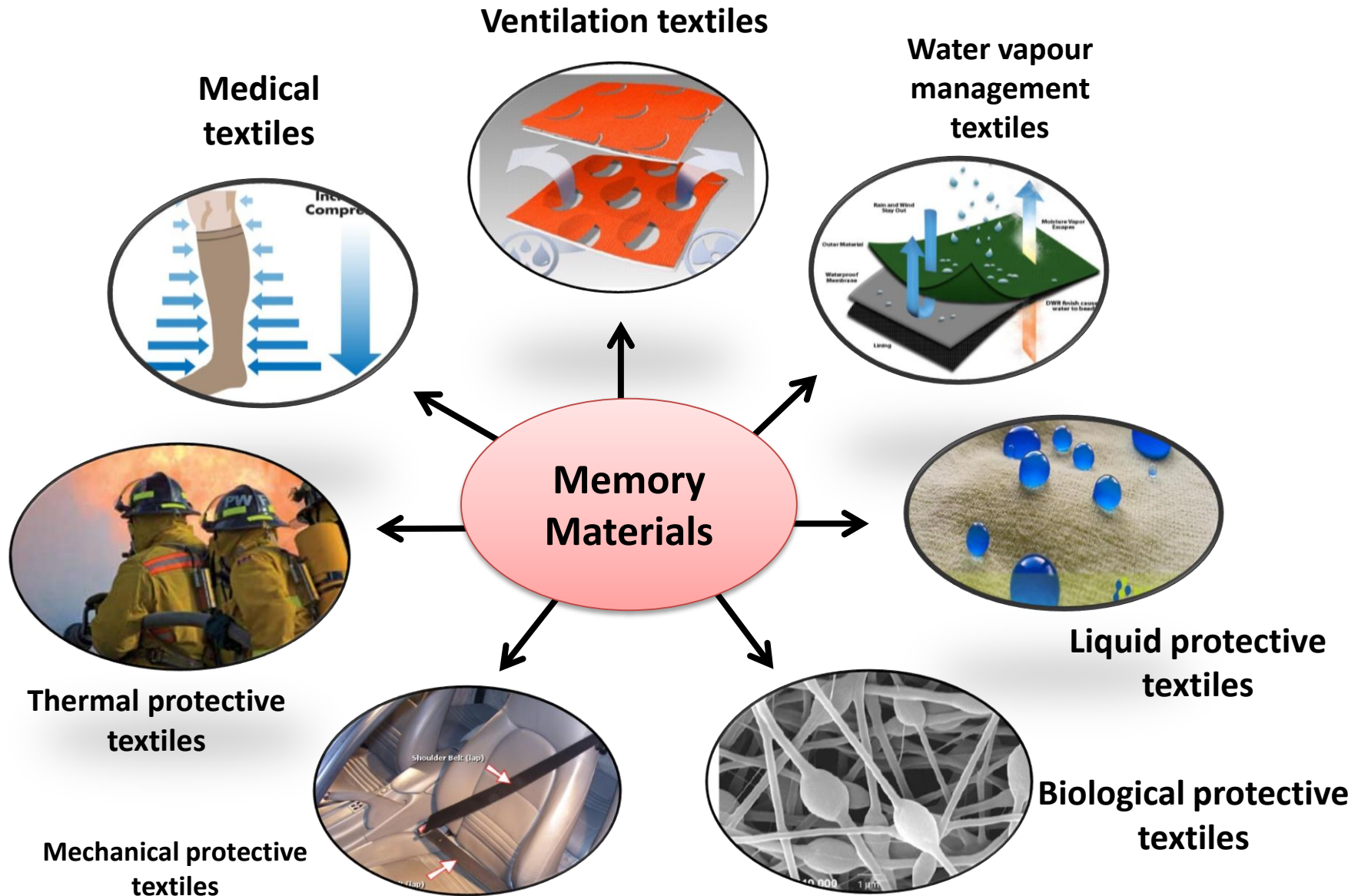
Hu, J. L. and S. J. Chen (2010). Journal of Materials Chemistry 20(17): 3346-3355.  
Ji, F. L., J. L. Hu, et al. (2007). Polymer 48(17): 5133-5145



# Wide Functionality

| Composition & structure   | Stimulus  | Shape memory function   |
|---|---|---|
| <b>Block-copolymer</b><br>           | <b>Temperature</b><br>           | <b>One way SME</b><br>           |
| <b>Supramolecular polymer</b><br>    | <b>Electricity</b><br>           | <b>Two way SME</b><br>           |
| <b>Polymer blend / composite</b><br> | <b>Magnetic</b><br>              | <b>Triple shape SME</b><br>      |
| <b>Polymer IPN/semi IPN</b><br>    | <b>Water sensitive</b><br>       | <b>Multi shape SME</b><br>     |
| <b>Crosslinked Homopolymer</b><br> | <b>Light/radiation</b><br>     | <b>Multi functionality</b><br> |
|   | <b>Oxidation-reduction</b><br> |   |

# Broad Applications of Memory Polymers to Textiles



# Widely Available in Nature

| Shape Memory Structural Constitution of Natural Protein Biopolymer Fibers |   |  |
|---|---|--|
|   | Net-Points                                  | Switches generated From hydrogen bonding in  |
| Spider silk <sup>31</sup>   | $\beta$ -sheet<br>(Alan rich)               | $\alpha$ -helix (Gly-Pro-Gly-XX) <sub>x</sub><br>Amorphous (Gly-Gly-X) <sub>y</sub>  |
| Elastin fiber <sup>29</sup>   | Cross-links (Aldehydes)<br>formed by lysine | (Val-Pro-Gly-Val-Gly) <sub>x</sub> or (Val-Gly-Gly-Val-Gly) <sub>y</sub>   |
| Wool <sup>28</sup>  | Disulfide<br>S-S                            | (Gly-X) <sub>x</sub>   |
| Collagen <sup>30</sup>  | Cross-links (Aldehydes)<br>formed by lysine | (Gly-Pro-Hyp) <sub>x</sub>   |
| Regenerated Cocoon silk <sup>27</sup>                                     | $\beta$ -sheet<br>(Alan-Gly) rich           | (Ser-Gly-Phe-Gly-Pro-Tyr-Val-Ala-Asn-Gly-Gly-Tyr-Ser-Arg-Arg-Glu-Gly-Tyr-Glu-Tyr-Ala-Trp-Ser-Ser-Glu-Ser-Asp-Phe-Glu-Thr) <sub>x</sub> |

Net-points exist in different biopolymers in the form of **physical or chemical crosslinking** while switches are formed from **collective hydrogen bonding** between C=O••••H-N in protein chains

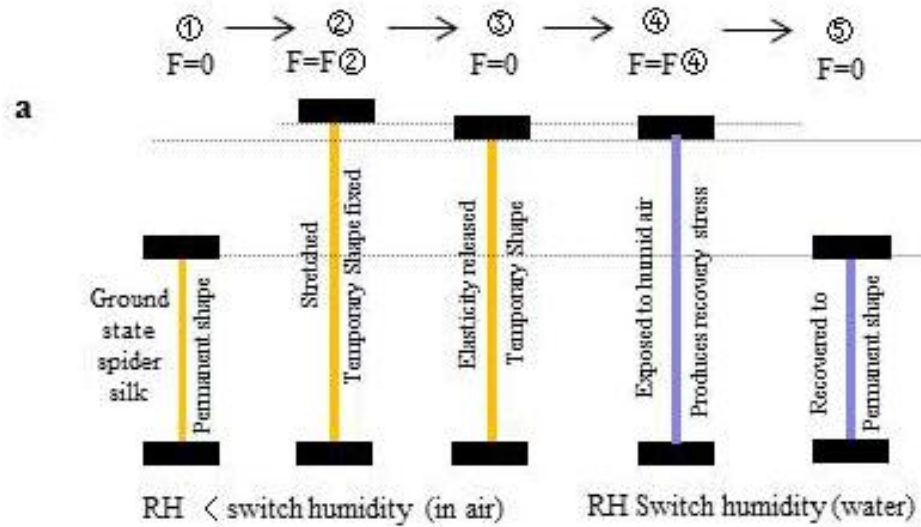
[27] Plaza, G.R., Guinea, G.V., Perez-Rigueiro, J. & Elices, M. 2006, *Journal of Polymer Science Part B-Polymer Physics*, 44 (6), pp. 994-999.

[28] Vollrath, F. & Edmonds, D.T. 1989, *Nature*, 340 (6231), pp. 305-307

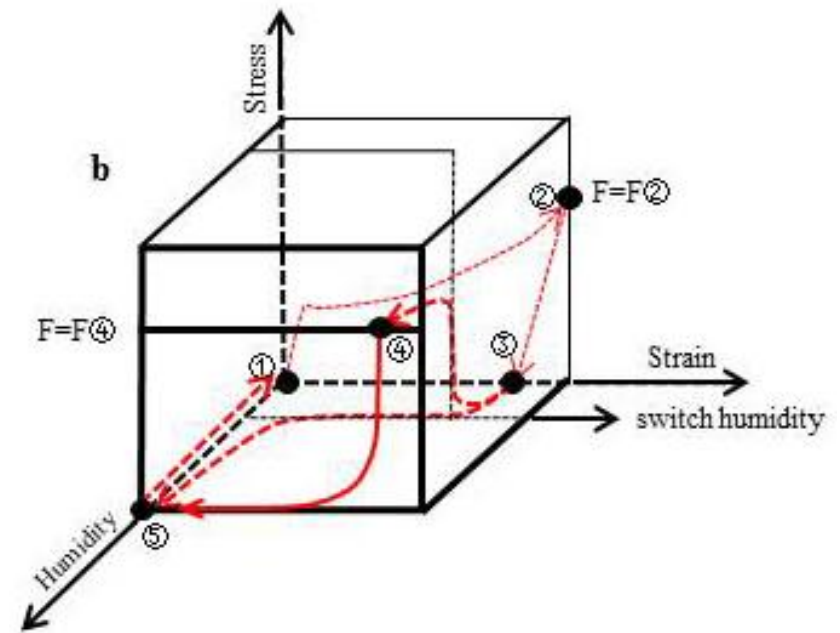
[29] Vollrath, F. & Porter, D. 2006, *Soft Matter*, 2(5), pp. 377-385

[30] Vollrath, F., Porter, D. & Holland, C. 2011, *Soft Matter*, 7(20), pp. 9595-9600

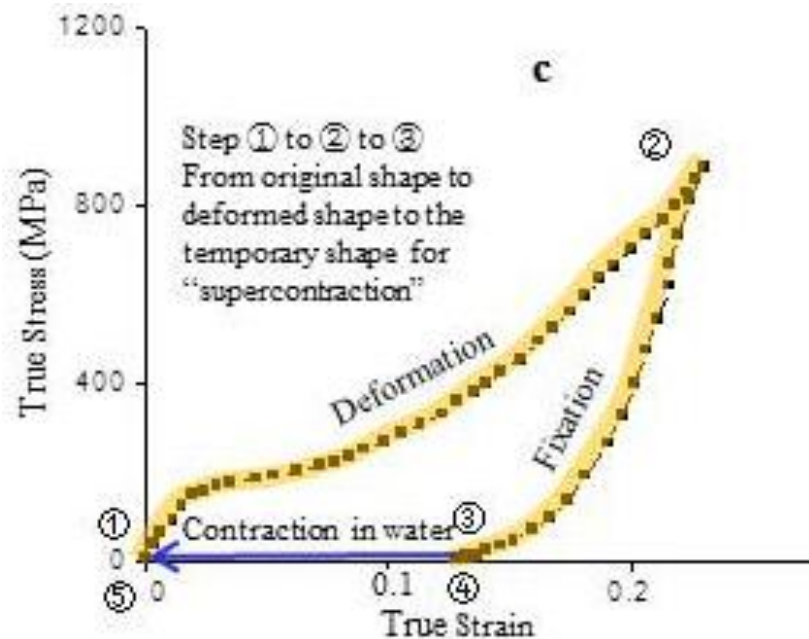
# Experimental Study of Spider Silk



**a, Shape Memory Programming of a Spider Silk.**



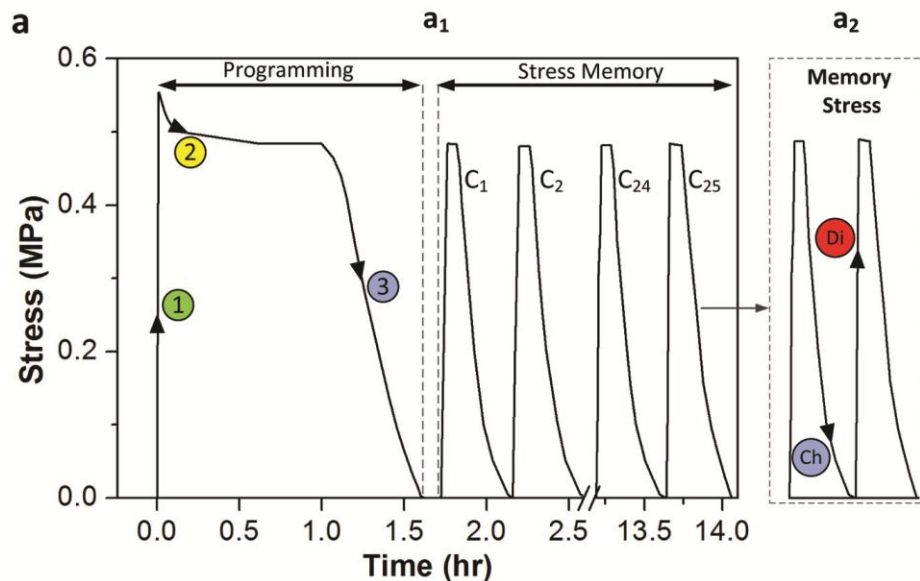
**b, General Hydro-mechanical-shape Memory Relationships.** ①, Original shape and stretching starts; recovery and drying ends. ②, Stretching ends and fixation starts. ③, Temporary Shape. ④, Wetting produces recovery stress. ⑤, Shape recovered in wetting



**c, Shape Memory Stress-strain Relationship of Spider Silk in Programming**



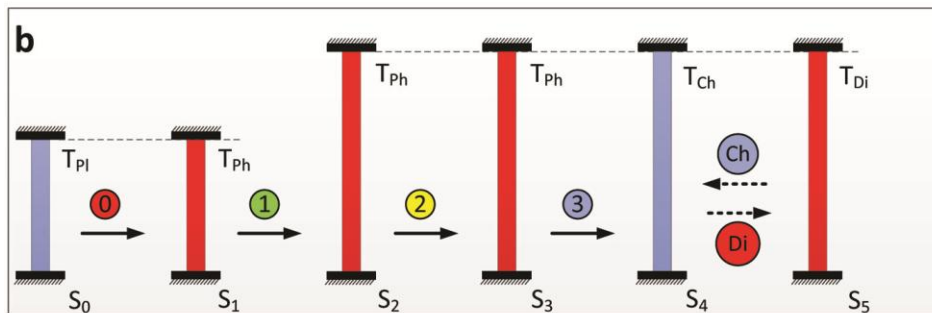
# New discovery of Memory Properties



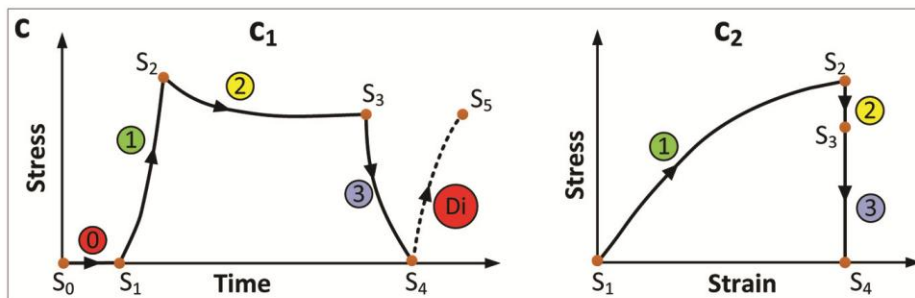
## What is Memory Stress ?

(a) Programming of stress Memory in the polymers

$T_{Di}$ : discharging temperature,  
 $T_{Ch}$ : charging temperature

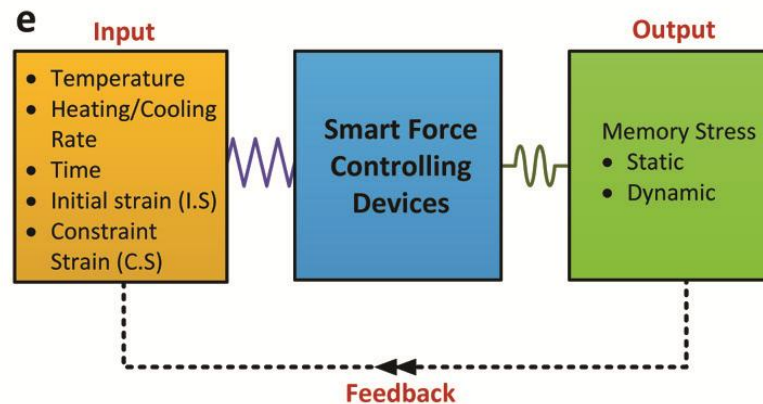
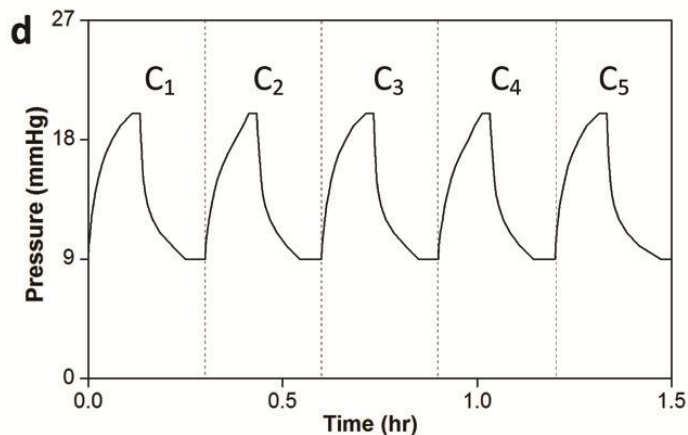
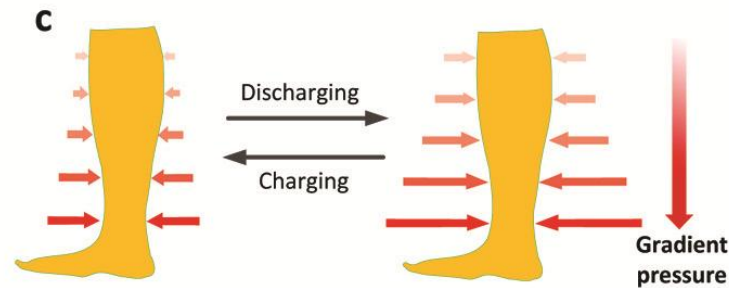
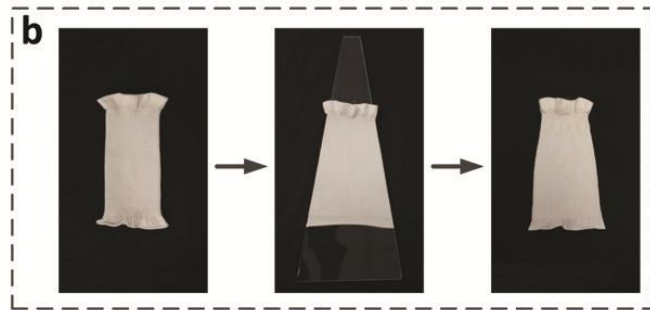
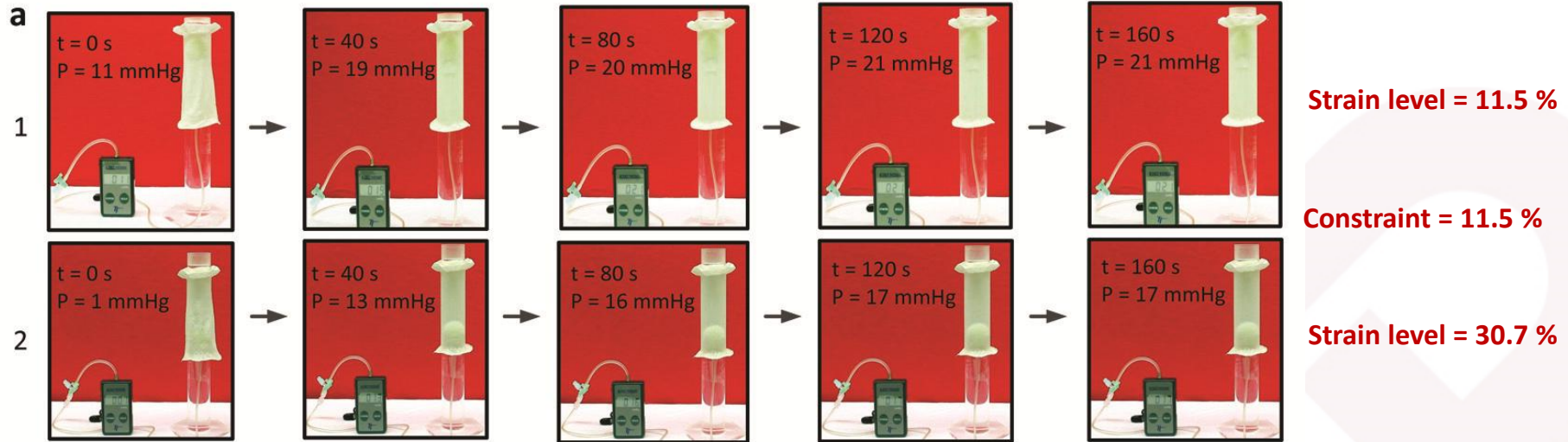


(b) Programming process of material at particular strain level

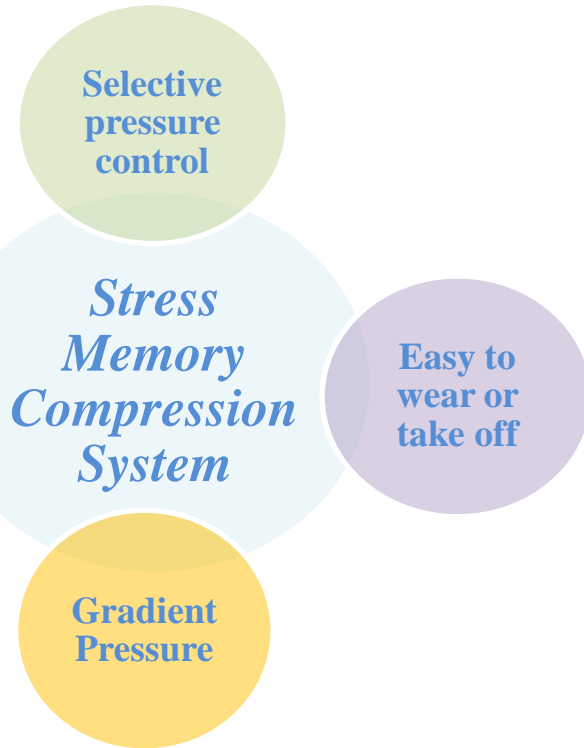


(c) Stress-strain and stress-time profiles during programming

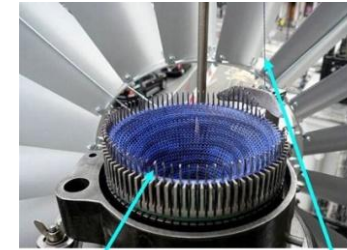
# Applications of Stress Memory to Compression Stocking ?



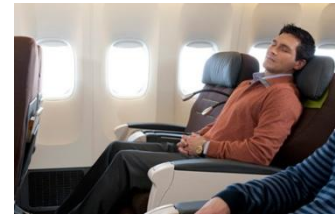
# Benefits of Memory Compression Stockings



**Low cost**



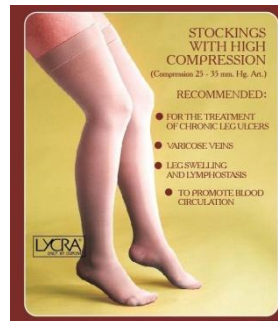
**Simple Knitting**



**Air Travel**

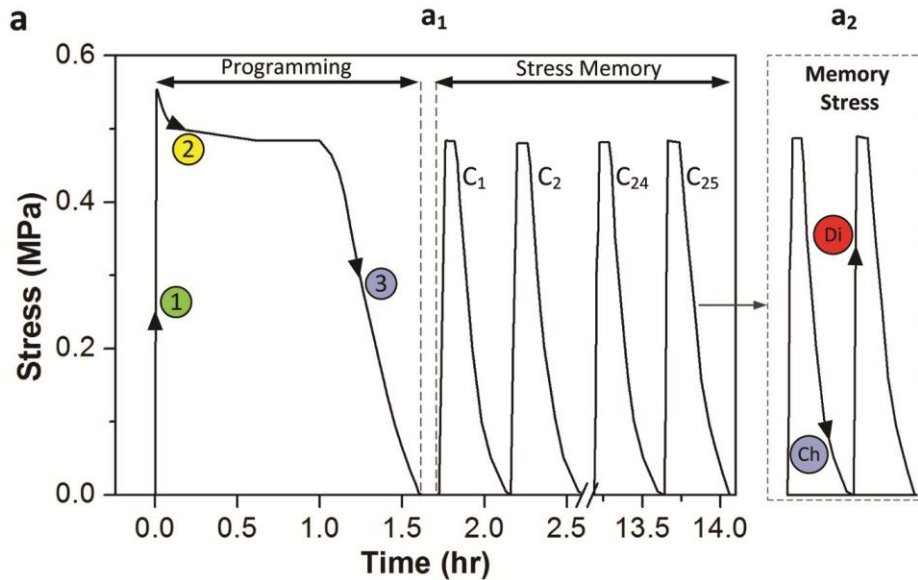


**I.C.U Patients**



- **Benefits for Older patients living in communities or home**
- **Inexpensive massage effect in rest position**
- **Simple application procedure (No nurse required)**
- **Can be offered by everyone**

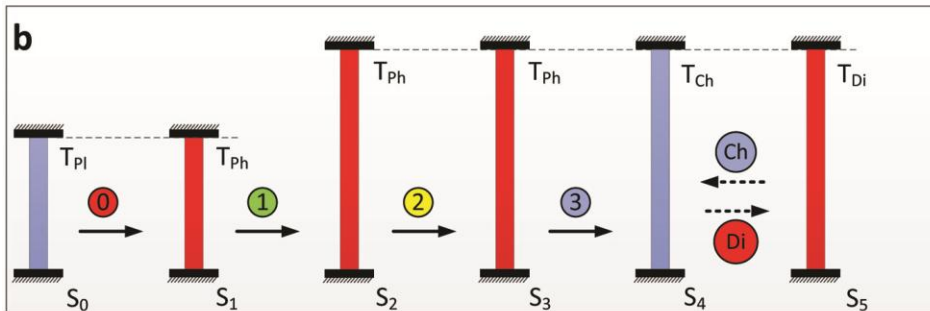
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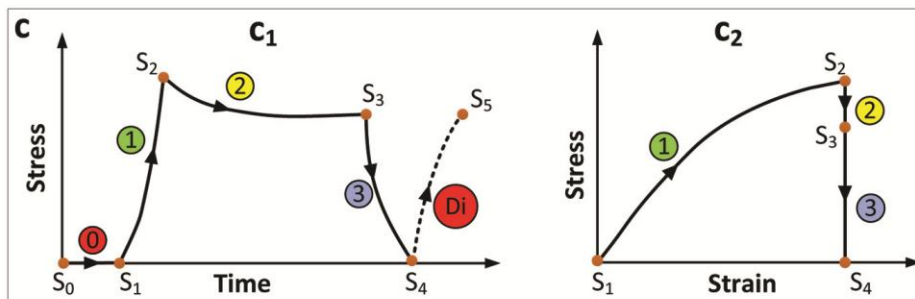
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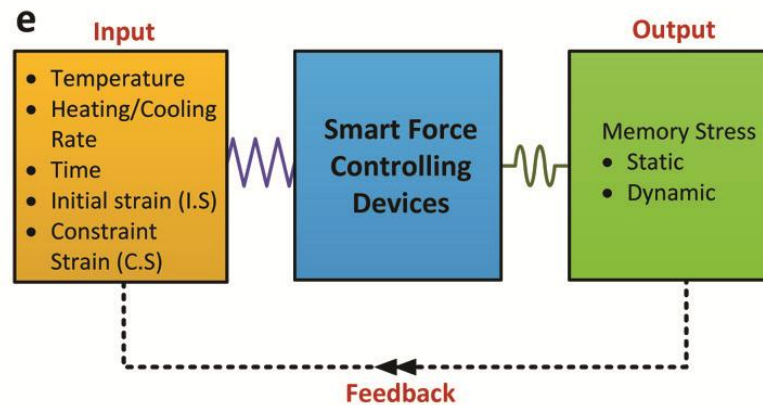
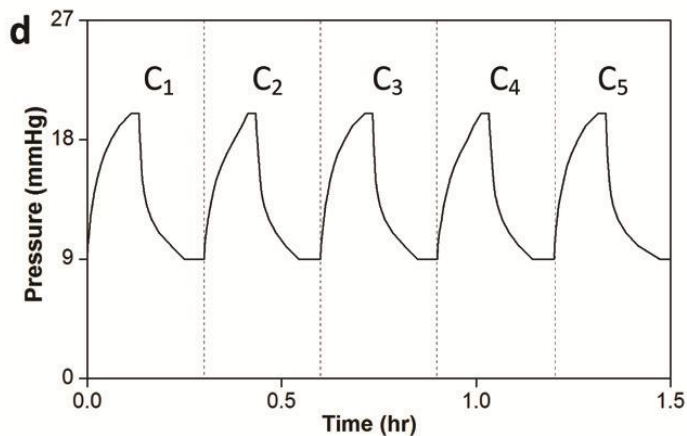
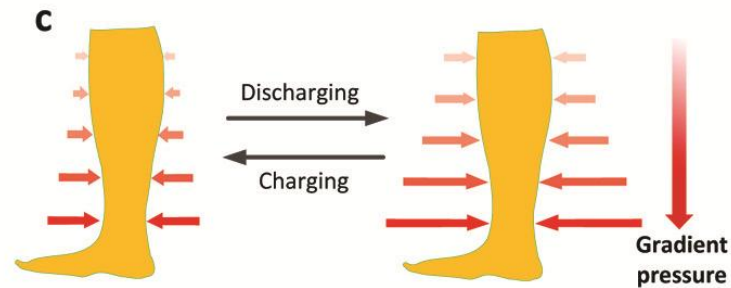
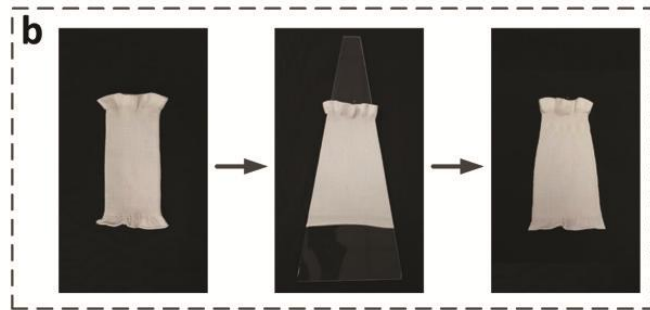
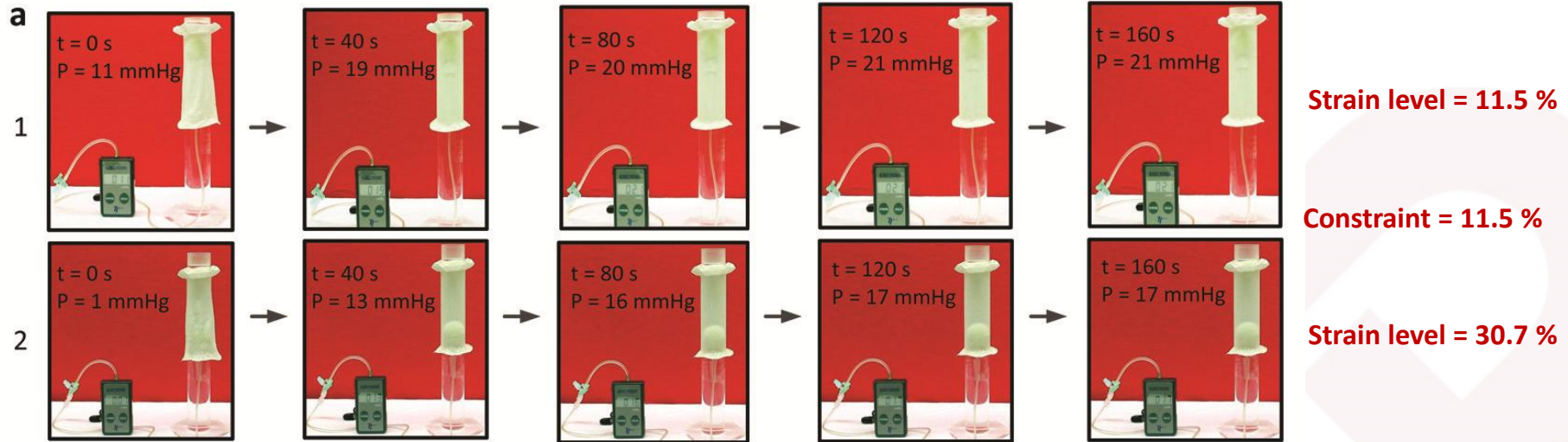
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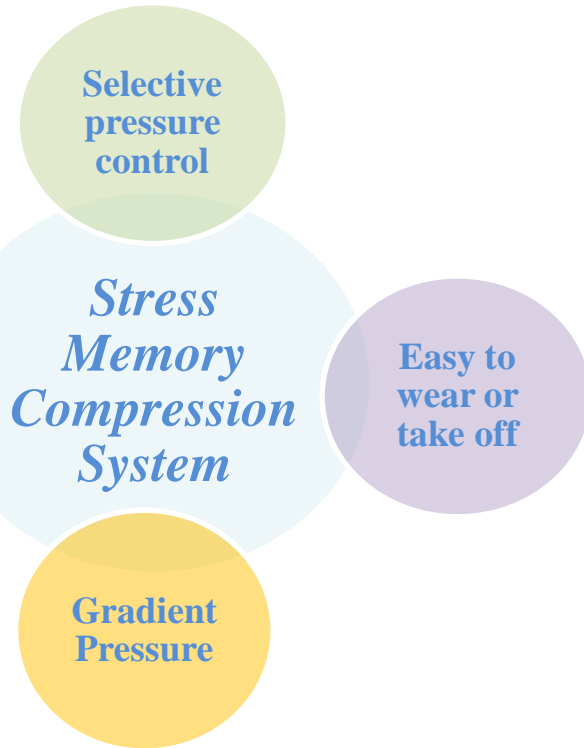
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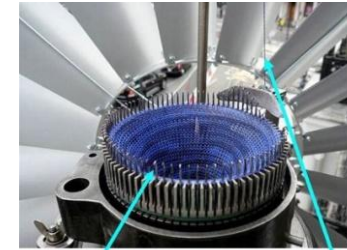
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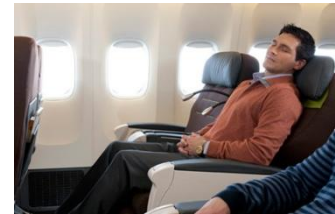
**Low cost**



Knitting needles

Yarn

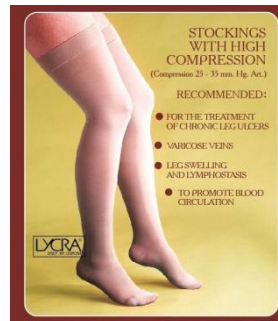
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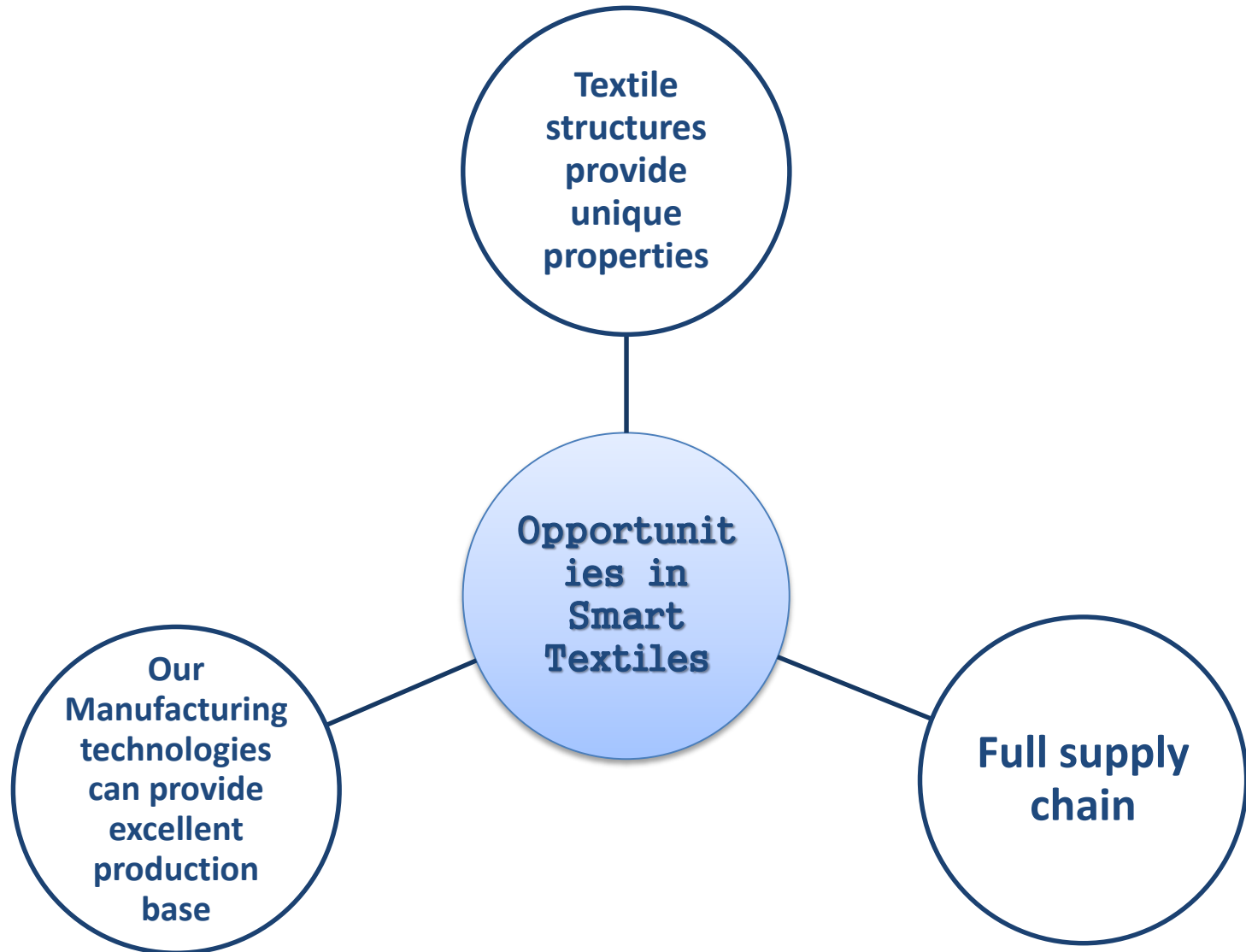
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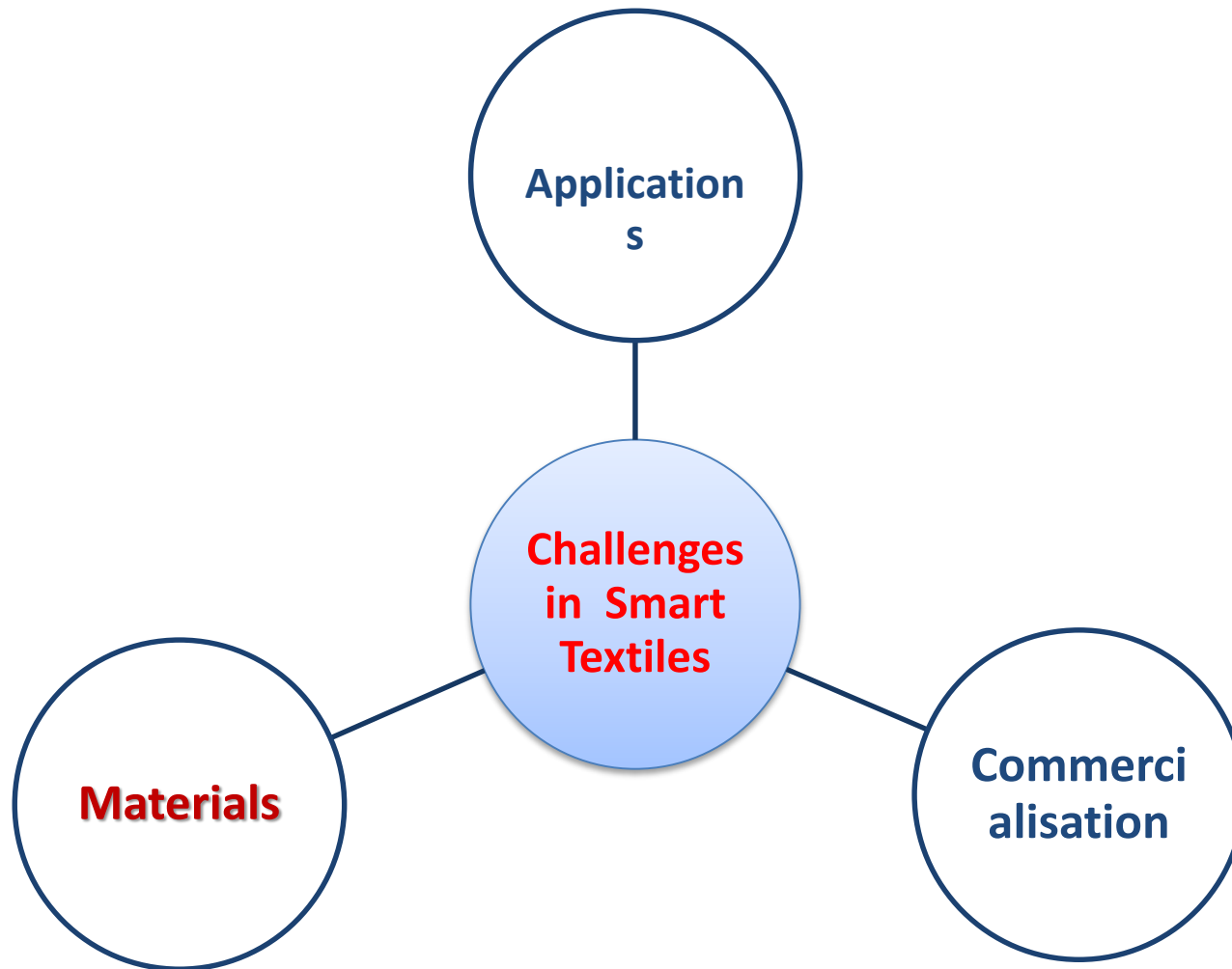
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**What is next**  
Challenges and opportunities

# For Textile Scientists and Industry

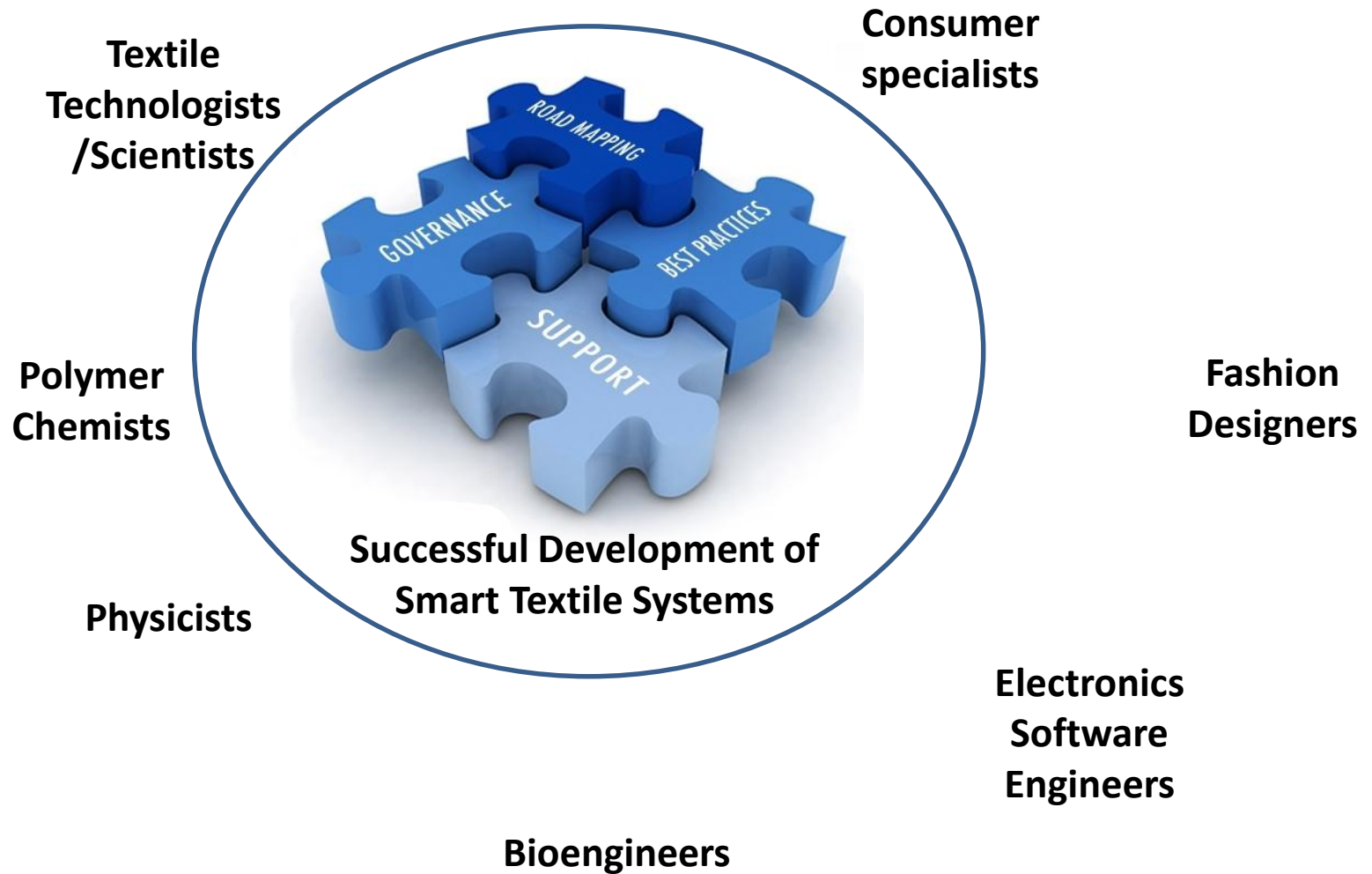


# For Textile Scientists and Industry



# R & D Areas for Sensitive Textile Materias

- Sensitive Materials for Textiles
  - Physics
  - Chemistry
  - Textile structures and properties
- Technologies
  - Micro- and nano-materials
  - Machines
  - Structures



# Summary

- The trends for textiles are from practicality, to Functional and now to smart. While functional textiles have achieved significant impacts, smart textiles has also crystal-clear trend in the coming 10 to 20 years following functional textiles
- Emerging materials for meeting and leading such trends requirements are essential for the movements of such change.
- Conductive, optical and memory polymers are the most useful and have tremendous market demands
- Sensitive materials
- A new paradigm is now formed and will have tremendous opportunities and impacts.



Xiaoming Tao  
*Editor*

# Handbook of Smart Textiles

 SpringerReference

## Contents

|   |            |
|---|------------|
| <b>Part I Smart Fibers and Fibrous Assembly Structures</b> .....  | <b>1</b>   |
| Jinlian Hu and Xiaoming Tao   |            |
| <b>1 Electric Functions of Textile Polymers</b> .....   | <b>3</b>   |
| Toshihiro Hirai and Hong Xia  |            |
| <b>2 Conducting Polymer Fibers</b> .....  | <b>31</b>  |
| Javad Foroughi, Geoffrey M. Spinks, and Gordon G. Wallace   |            |
| <b>3 Conductive Polymer Fibers for Sensor Devices</b> .....   | <b>63</b>  |
| Mutsumi Kimura  |            |
| <b>4 Optical Fibers</b> .....   | <b>79</b>  |
| Anne Schwarz-Pfeiffer, Viktorija Mecnika, Markus Beckers,<br>Thomas Gries, and Stefan Jockenhoevel        |            |
| <b>5 Polymer Optical Fiber for Smart Textiles</b> .....   | <b>109</b> |
| Wei Zeng  |            |
| <b>6 Fibers with the Tunable Structure Colors Based on the<br/>Ordered and Amorphous Structures</b> ..... | <b>127</b> |
| Wei Yuan, Chaojie Wu, Ning Zhou, and Ke-Qin Zhang   |            |
| <b>7 Photochromic Fibers and Fabrics</b> .....  | <b>155</b> |
| Marzieh Parhizkar, Yan Zhao, and Tong Lin   |            |
| <b>8 Shape Memory Fibers</b> .....  | <b>183</b> |
| Jinlian Hu and Jing Lu  |            |
| <b>9 Silk Fibers as Smart Materials Toward Medical Textiles</b> .....                                     | <b>209</b> |
| Yasushi Tamada and Katsura Kojima   |            |
| <b>10 Phase Change Fibers and Assemblies</b> .....  | <b>225</b> |
| Qinghao Meng, Guoqiang Li, and Jinlian Hu   |            |

## Special Issue “**Smart Textiles**”

Smart textiles have their foundations in different research disciplines: textile design and technology, physics, chemistry, materials science and engineering, electronics, computer science, and wearable technology. The progress of sciences and technologies necessitates interdisciplinary interaction and collaboration between basic research and innovative applications. This Special Issue, entitled Smart Textiles, calls for papers regarding the scientific study of any fibers, fiber materials, fibrous structures, and applications of smart textiles.

**Keywords:** smart textiles; hi-tech textiles; textile design and technology; fiber materials; fibrous structures; applications of smart textiles; multi-function; stimuli responsive fibers

**Guest Editor:** Prof. Dr. Jinlian Hu

**Website:** [http://www.mdpi.com/journal/fibers/special\\_issues/smart-textiles](http://www.mdpi.com/journal/fibers/special_issues/smart-textiles)

**Submission deadline:** 31 March 2016

**Contact:** [tchujl@polyu.edu.hk](mailto:tchujl@polyu.edu.hk)



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