Adopting Multifunctional Material Systems

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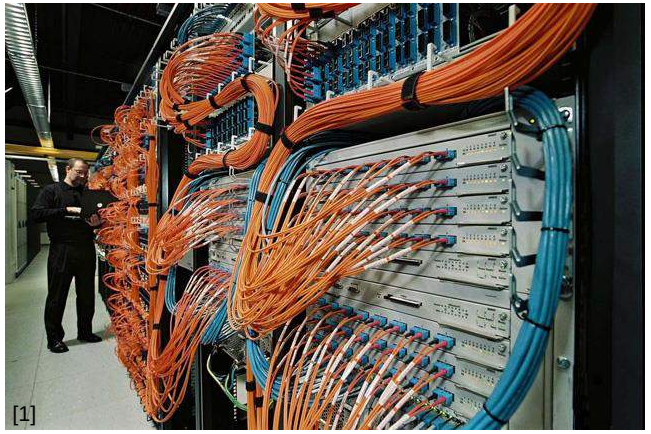
1. Introduction
2. State-of-the-art
3. Challenges
4. Methods
5. Future Work
6. Conclusions

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1 min.
7 min.
0,5 min.
1 min.
Total:
17,5min.

Introduction

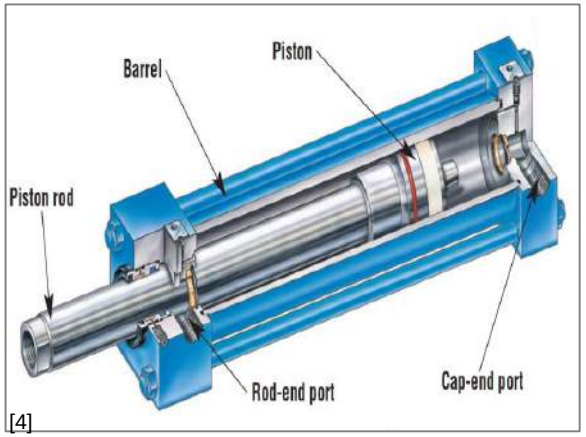
Motivation

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[1]

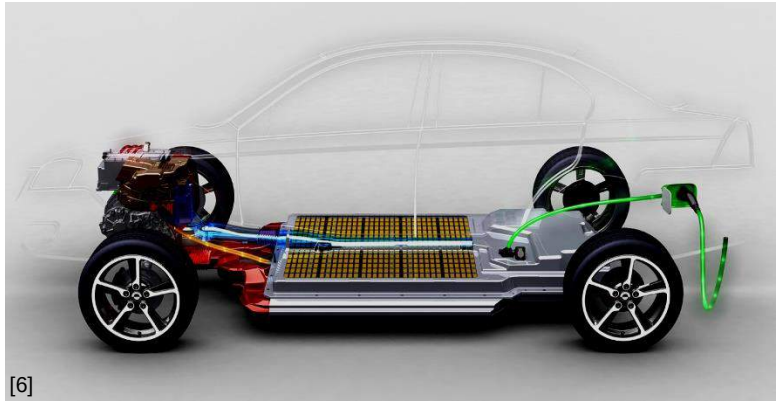

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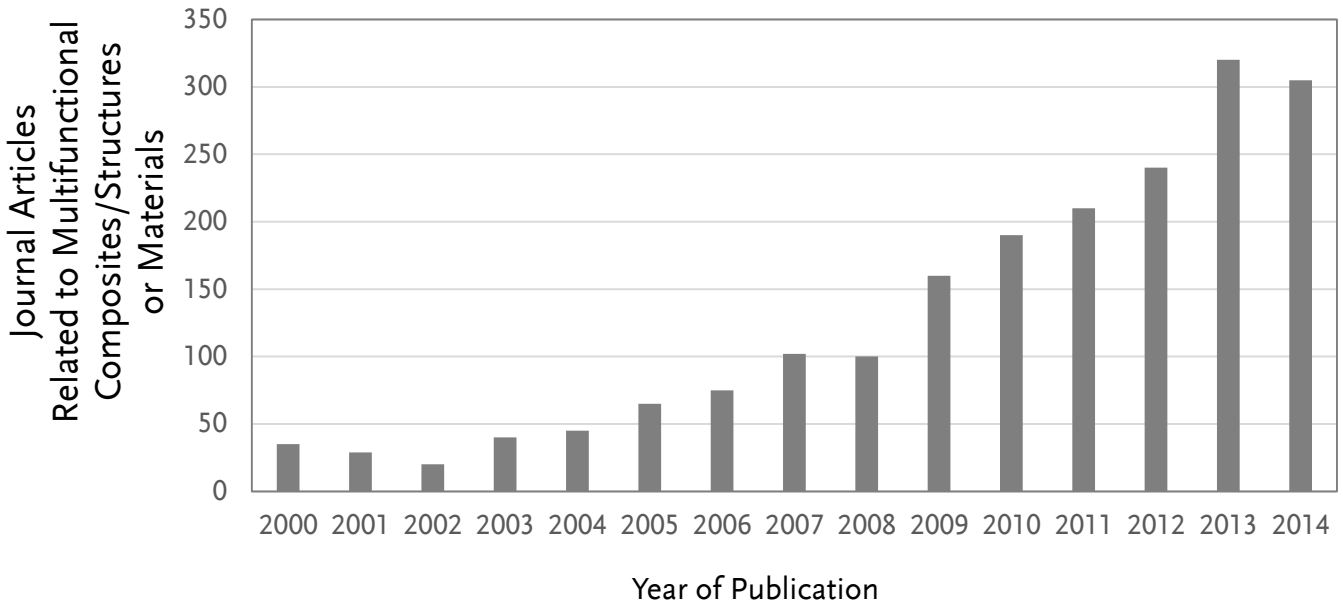

[5]


[6]


[7]

An Exponential Growth of Interest

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In March 2015, data from EngineeringVillage.com

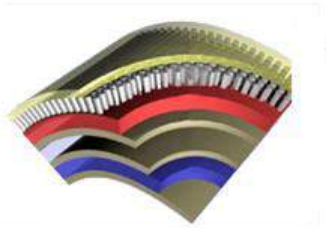
Definitions

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Multifunctional Structure (or type I)

Distinct materials, each with a different function, mounted, coated or laminated onto one another.



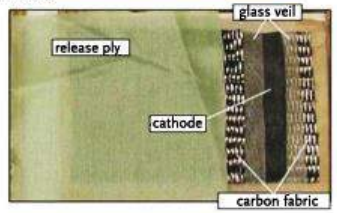


Superposition of layers of multi materials

Multifunctional Composite (or type II)

Distincit materials, embedded onto another, simultaneously taking more than one function.







Multilayered fibers

Braided multi material fibers

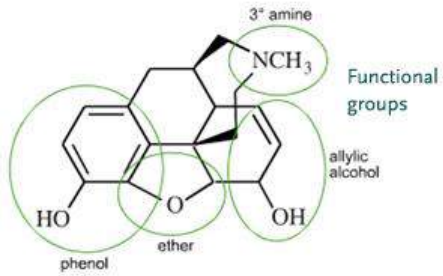


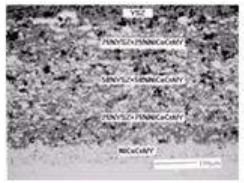
Interwoven multi material fibers

Multifunctional Material (or type III)

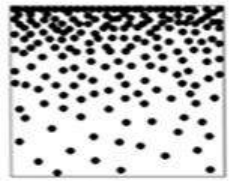
Single material: combines different functions at a molecular level.

Multi-material: Phases are highly integrated and the materials may be indistiguishable, resulting in a hybrid multifunctional material.





FGMs



Functionalized materials

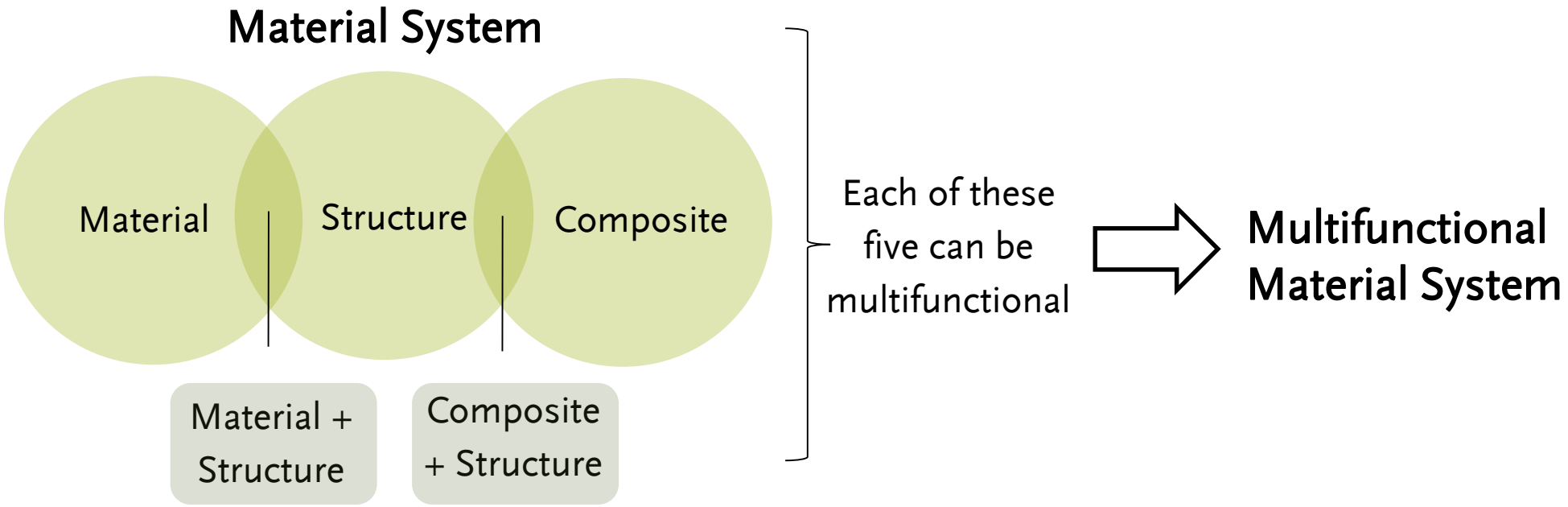
Integration increases

*[8-11]

* = adapted

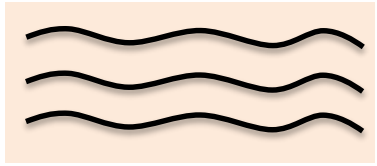
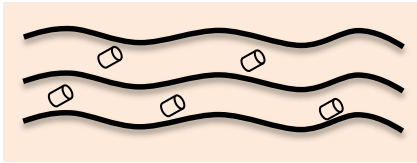
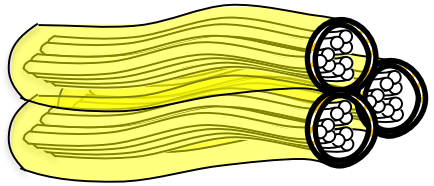
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Definitions

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Composite	Multiscale Composite	Hierarchical Composite	Molecular Composite / Hybrid Material
			
CF/Epoxy, (CF+GF)/Epoxy, reinforced concrete	(CF+CNT)/Epoxy	Many biological materials (bone, nacre, wood,...)	Organic-inorganic hybrids, FGMs
One or more fillers	Different fillers at different scale sizes	Fillers at different scale sizes hierarchically organized	Different constituents at a molecular level

System	Sensor	Actuator	Control	Processor	Power generation and Storage
Passive	●				
Sensory	●	●			
Active	●	●			
Adaptive	●	●	●		
Intelligent	●	●	●	●	
Autonomous	●	●	●	●	●

Functions

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Functions/characteristics that future multifunctional composites ought to have:

1. Autonomy
   - Self-healing/repairing;
   - Self-powered;
   - Self-monitoring/diagnostic/sensing;
   - Self-assembling;
2. Highly tailorable properties;
3. Structural;
4. Active sound/vibration damping;
5. Actuation and ability to engage in shape-changing;
6. Electrical/Thermal Isolation/Conductivity;
7. Heating and cooling;
8. Electromagnetic interference (EMI) shielding;
9. Radiation protection, including lightning strike;
10. Light emission;
11. Energy storage;
12. Environmental: environmental remediation ability, recyclability and biodegradability;
13. Bio/human-related: bio-compatibility, non-toxic, able to change sensations related to the physical senses of human and other animals;
14. Chemical reaction functions: as catalyst, selective permeation;
15. Flame retardancy;
16. Information storage/processing capabilities;
17. Being able to be selectively functional: e.g. of energy absorbing plastics;
18. Levitation and movement inducing;
19. Intelligence.

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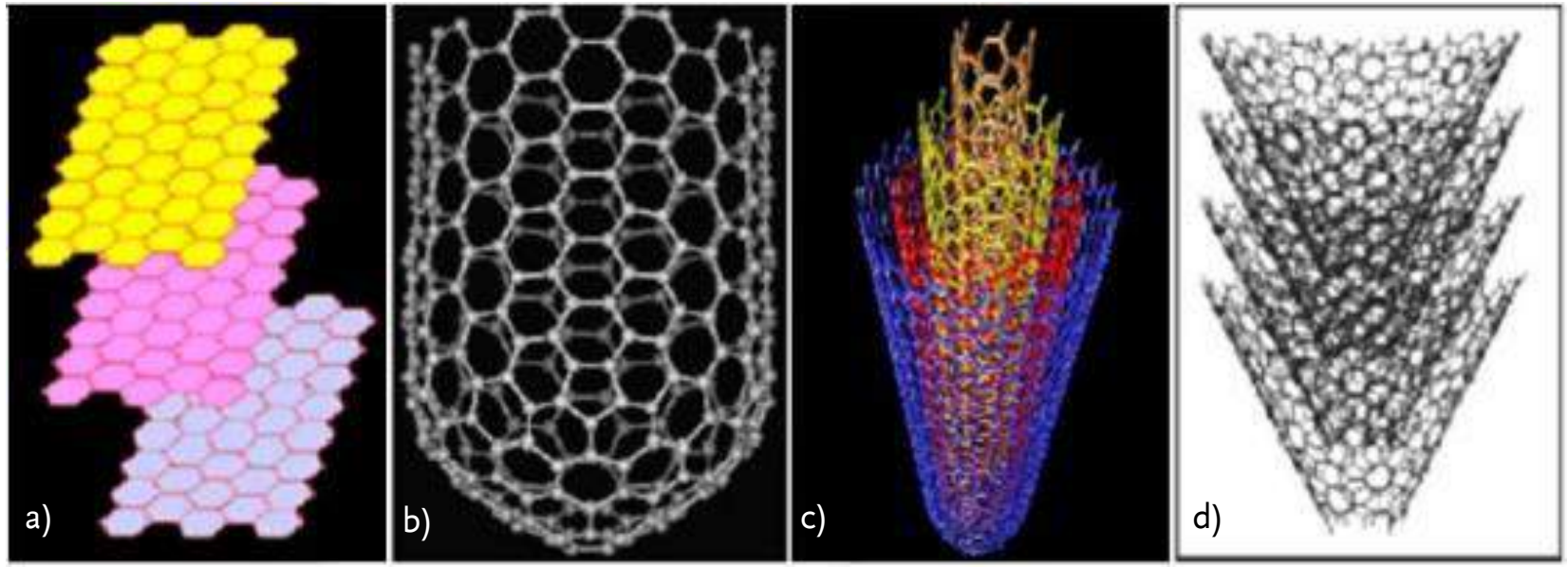
State-of-the-art

3min

Carbon Nanomaterials

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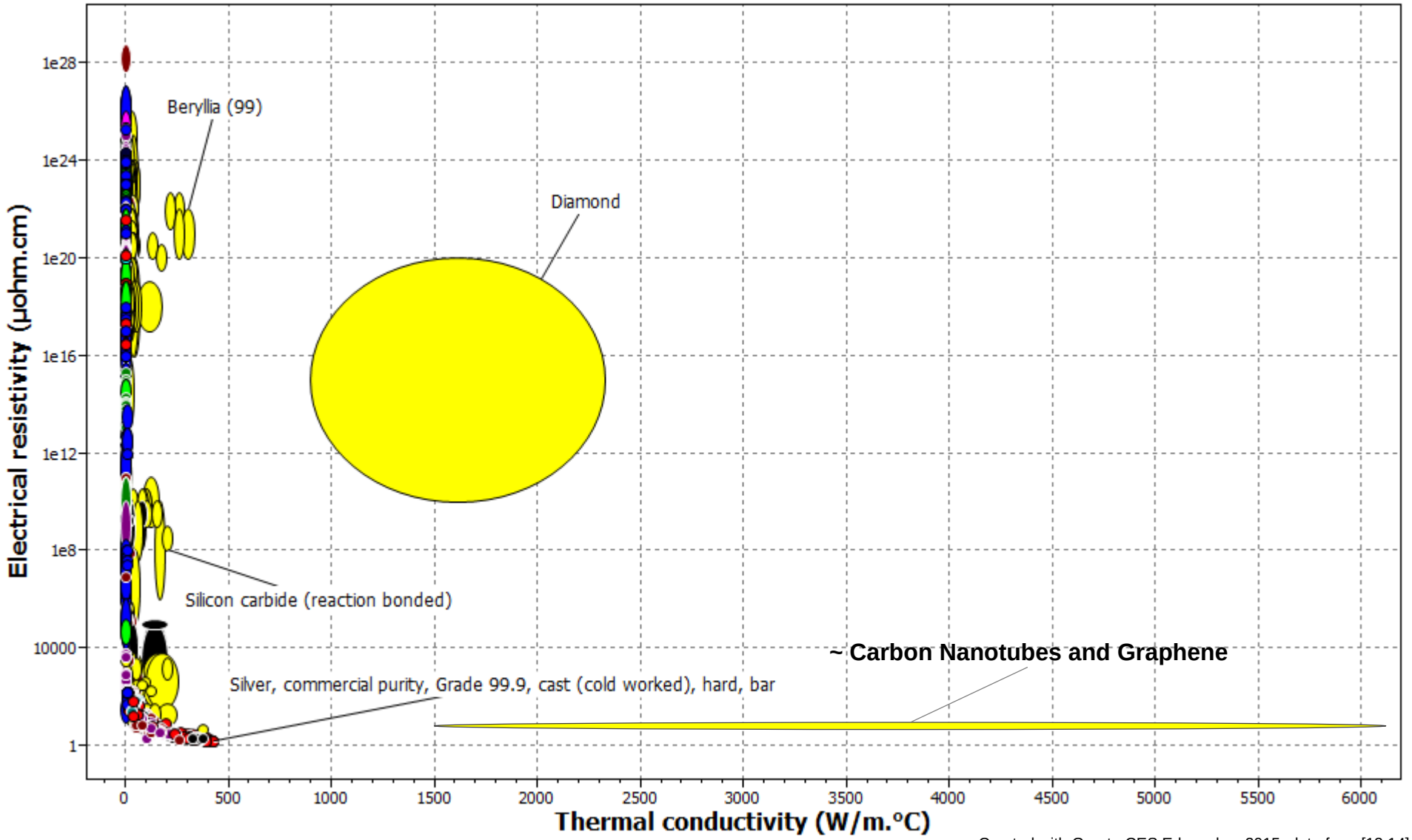


Graphene **SWCNT** **MWCNT** **CNF**

Main applications: sensing, actuation, improving several composites' properties

Carbon Nanomaterials

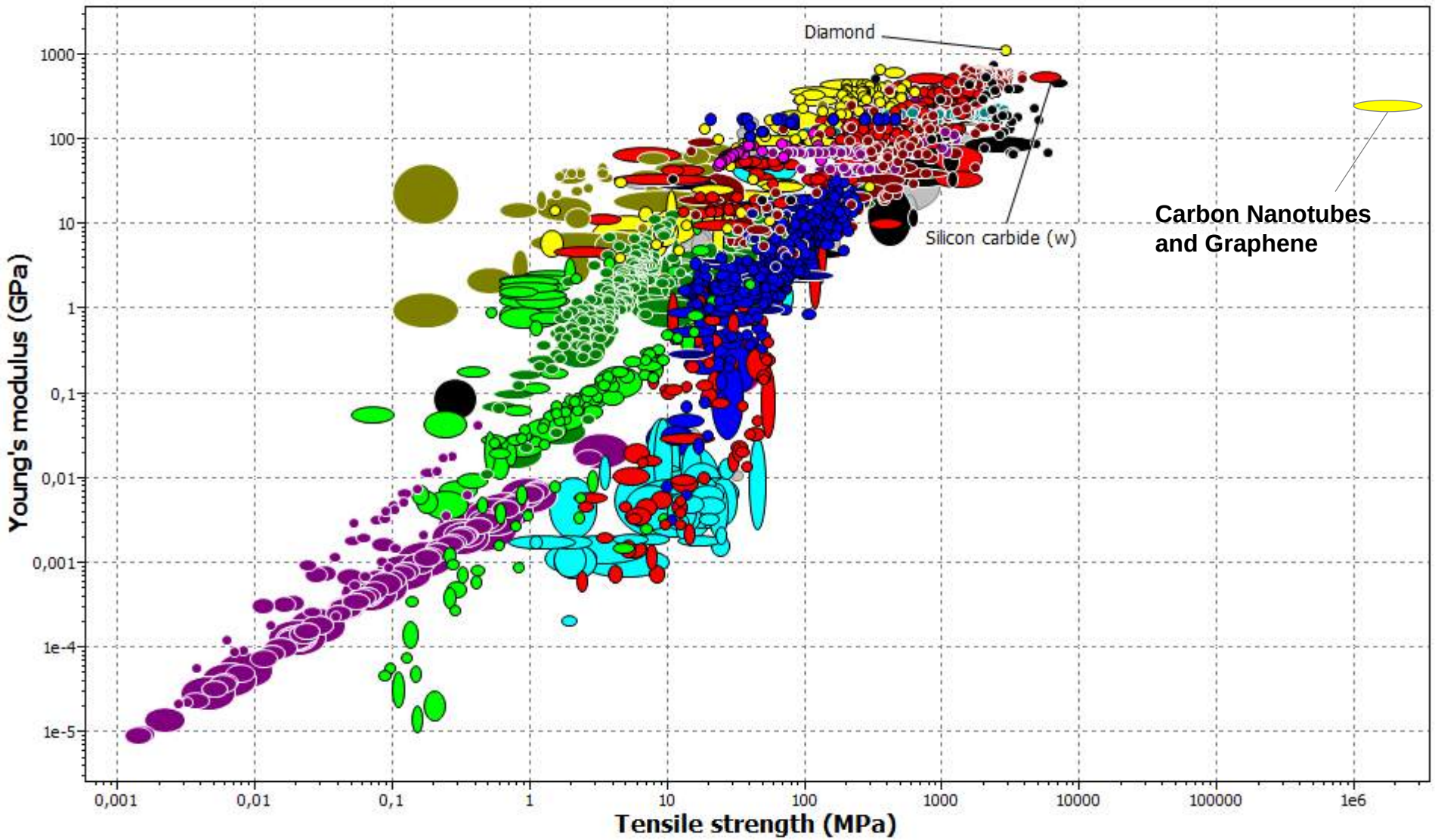
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Created with Granta CES Edupack v. 2015, data from [13,14]

Carbon Nanomaterials

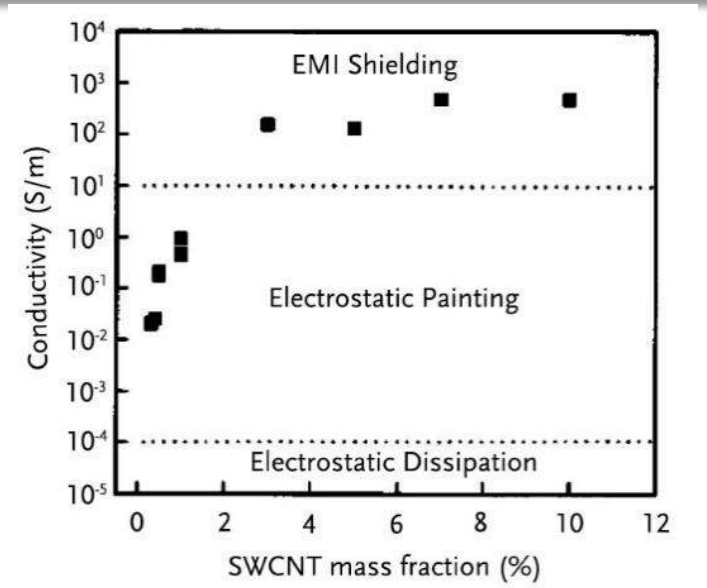
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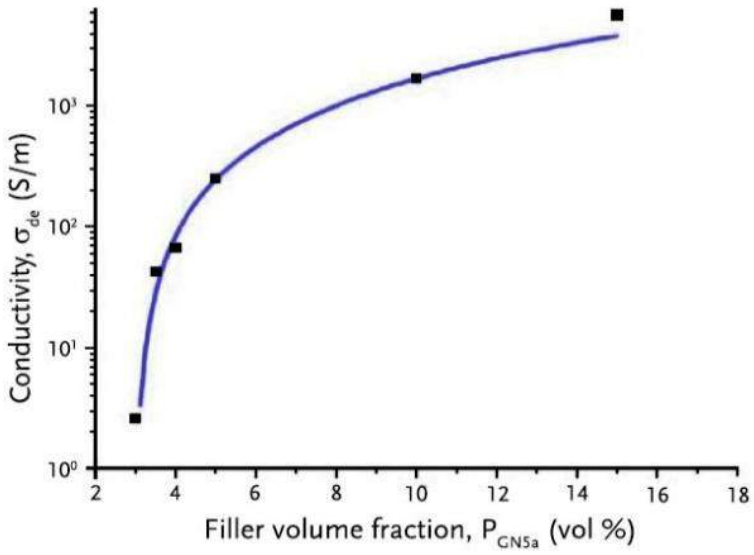
Created with Granta CES Edupack v. 2015, data from [13,14]

Carbon Nanomaterials

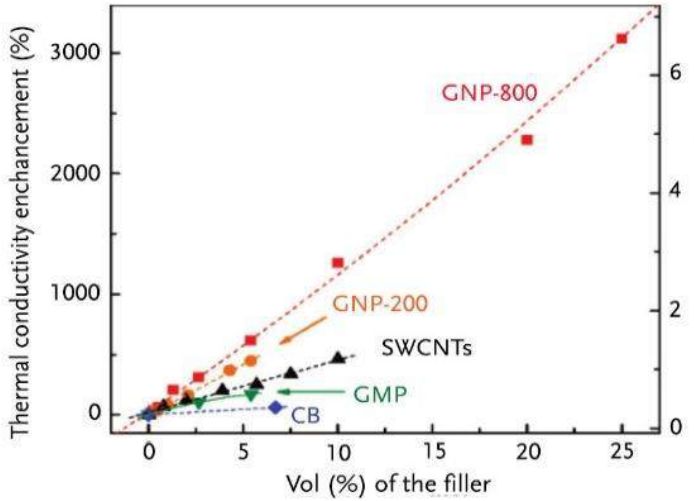
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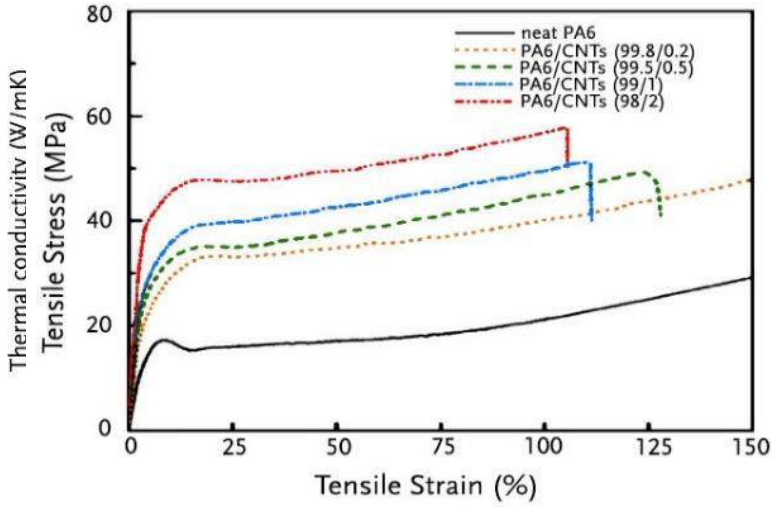
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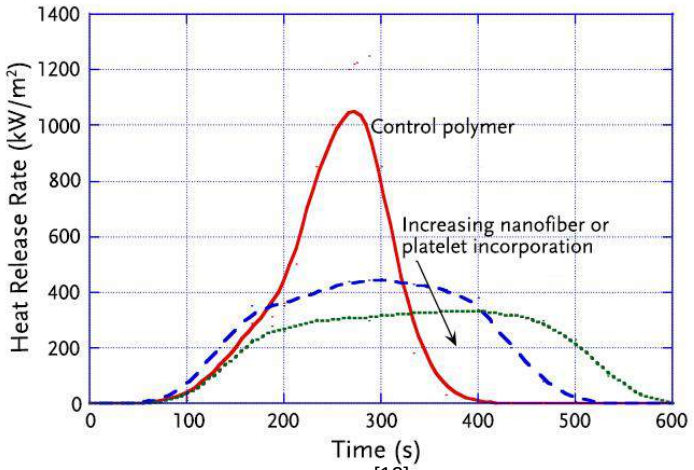
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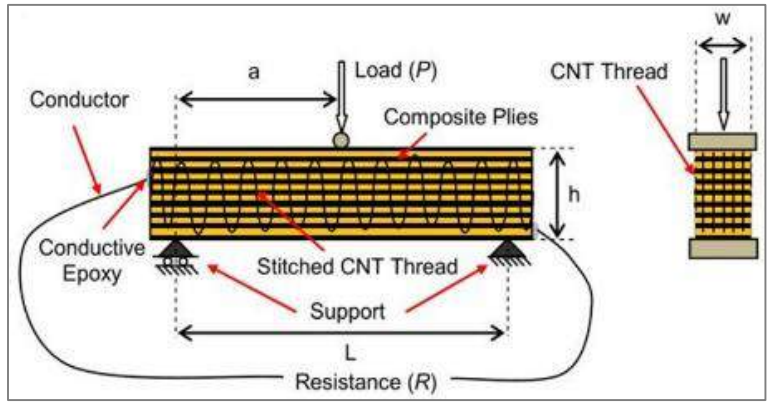
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Carbon Nanomaterials

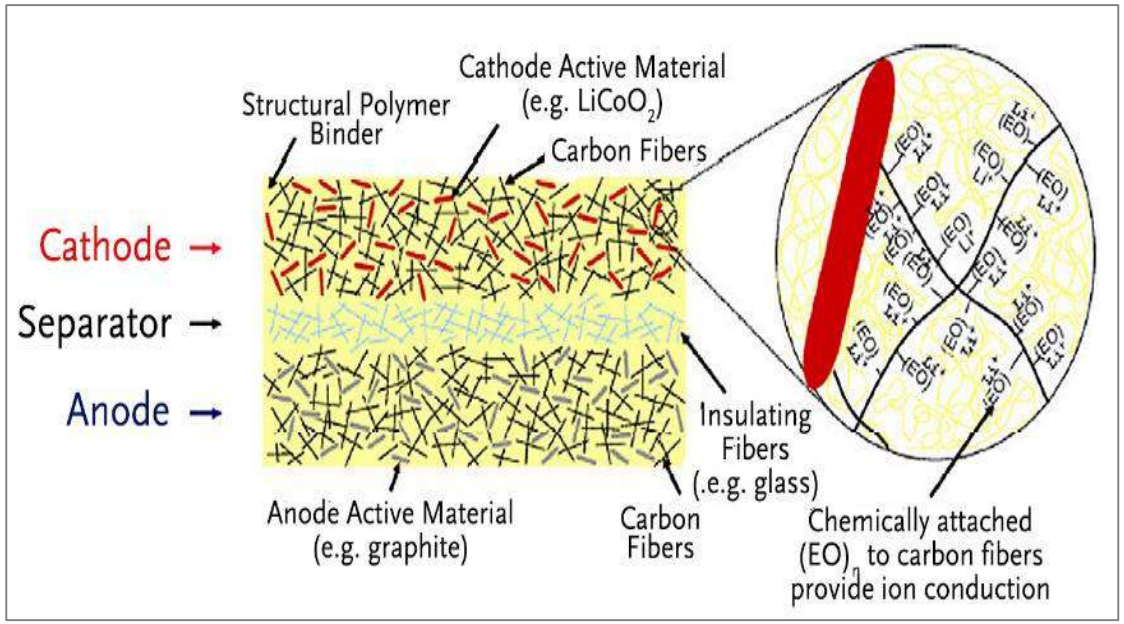
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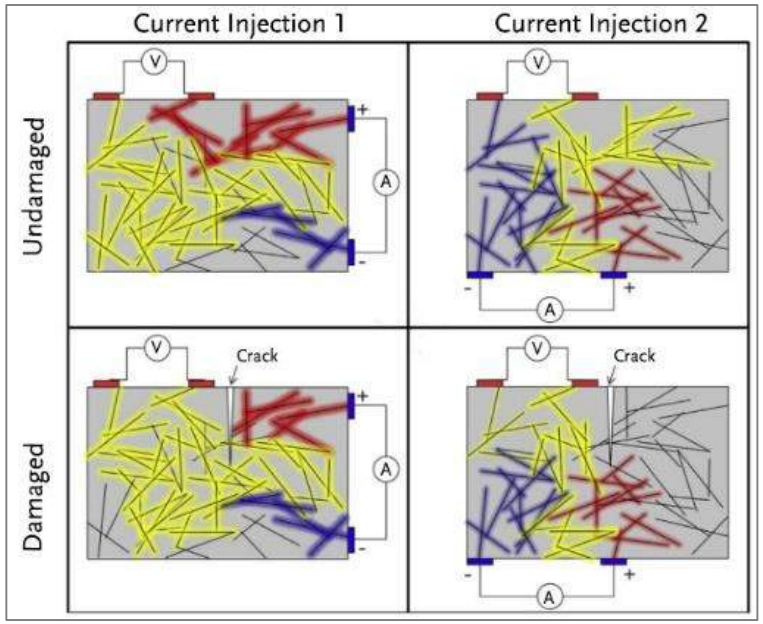
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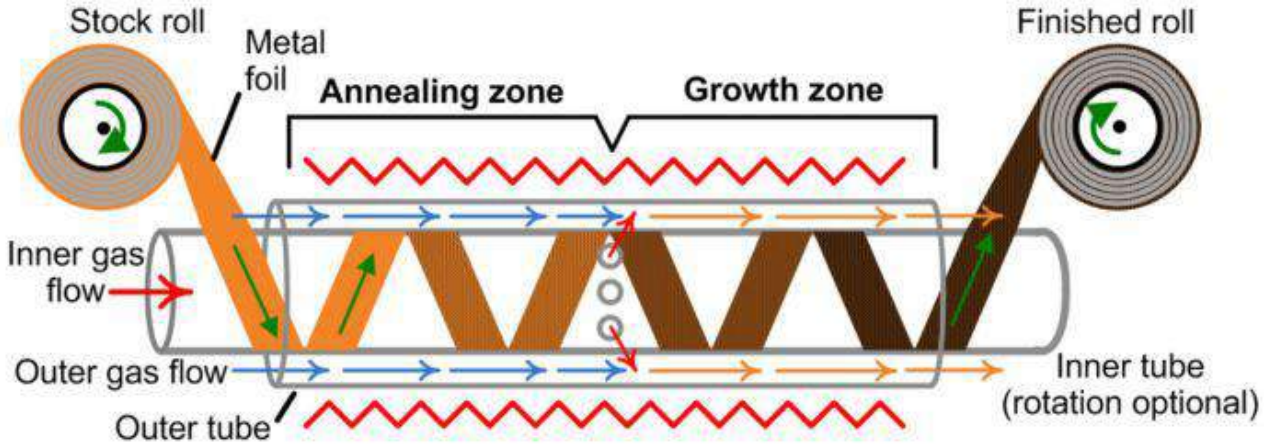
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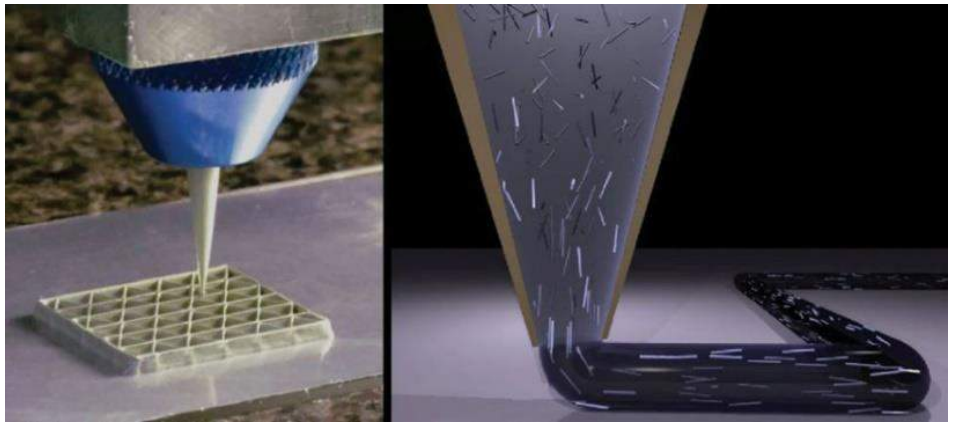
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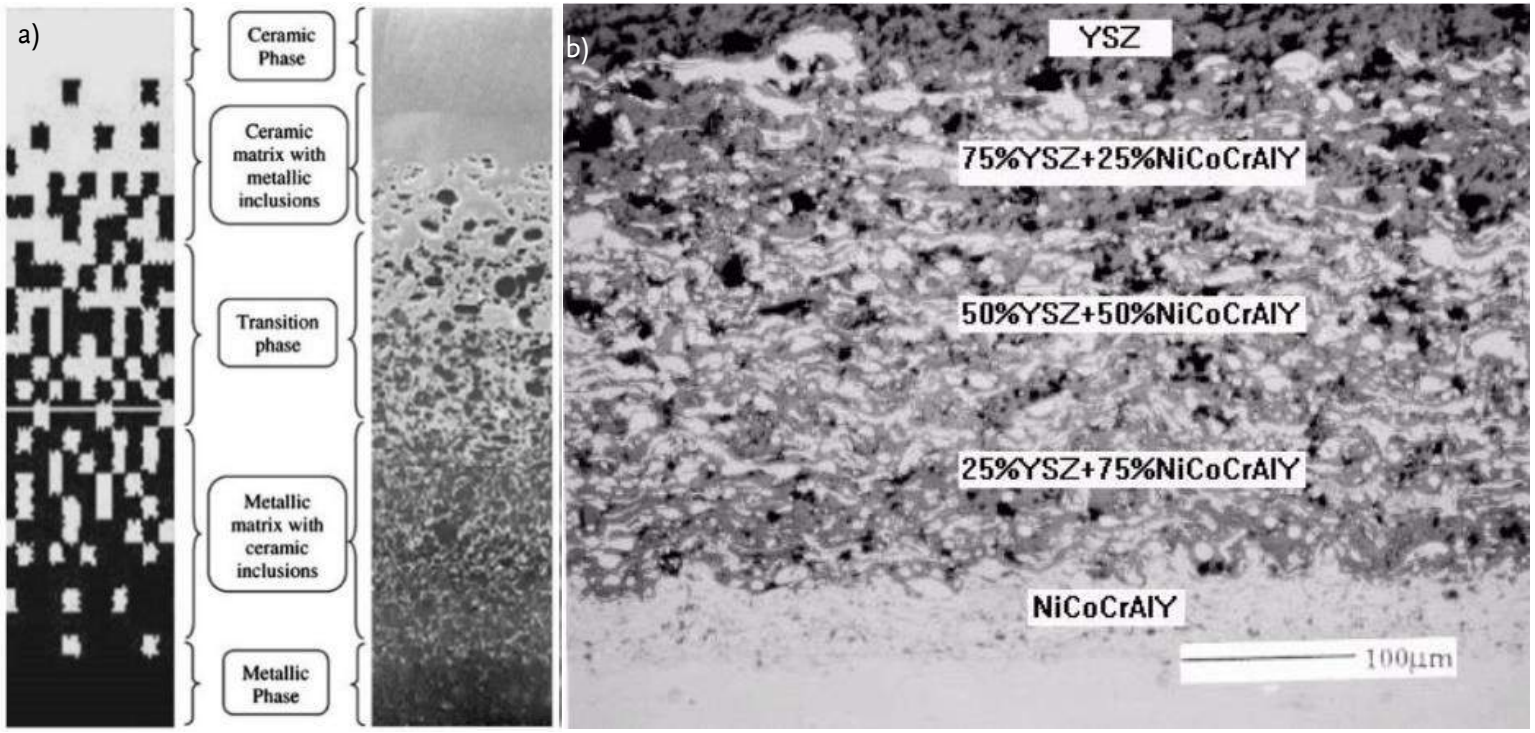
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[24]

Functionally Graded Materials

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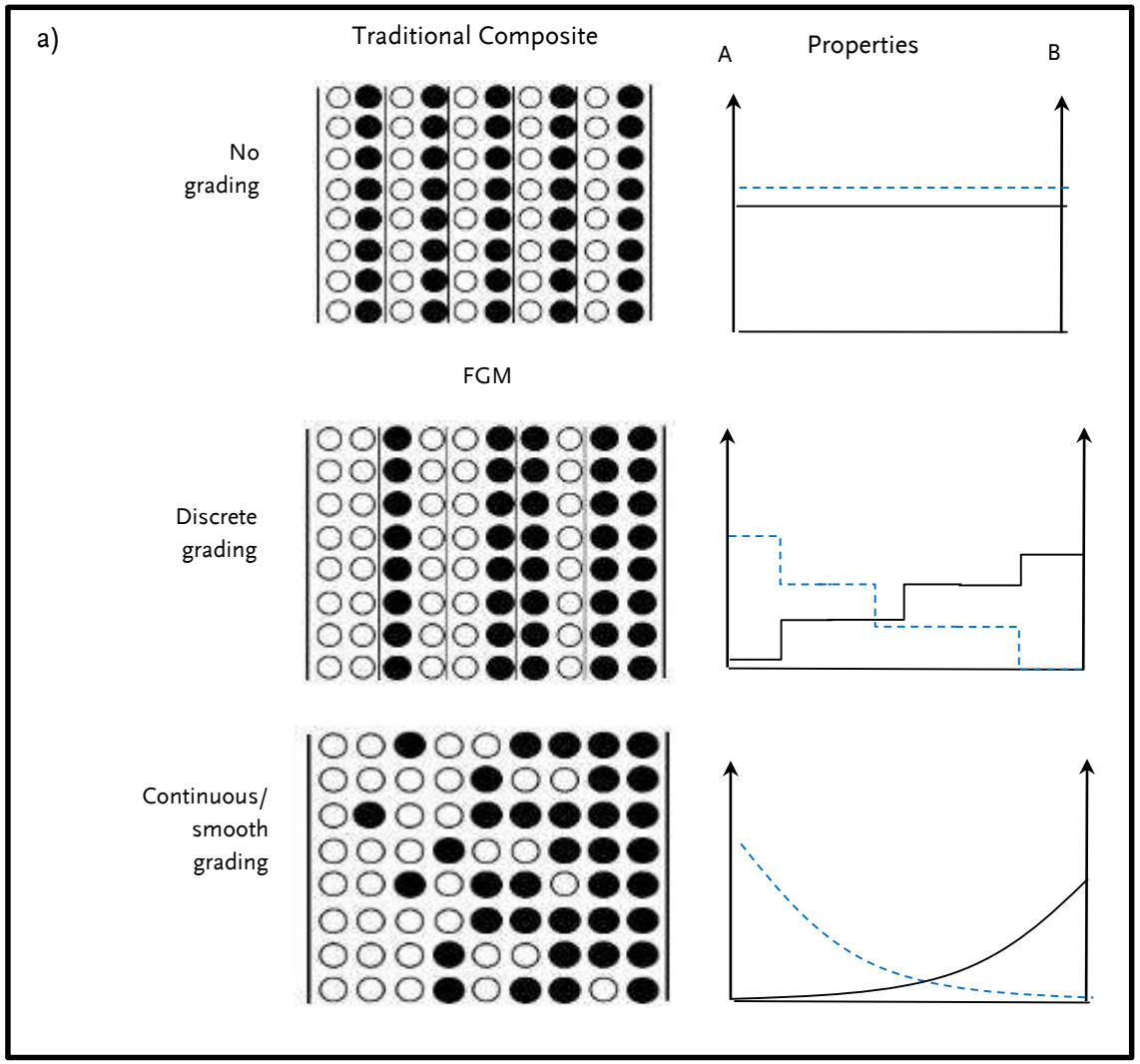


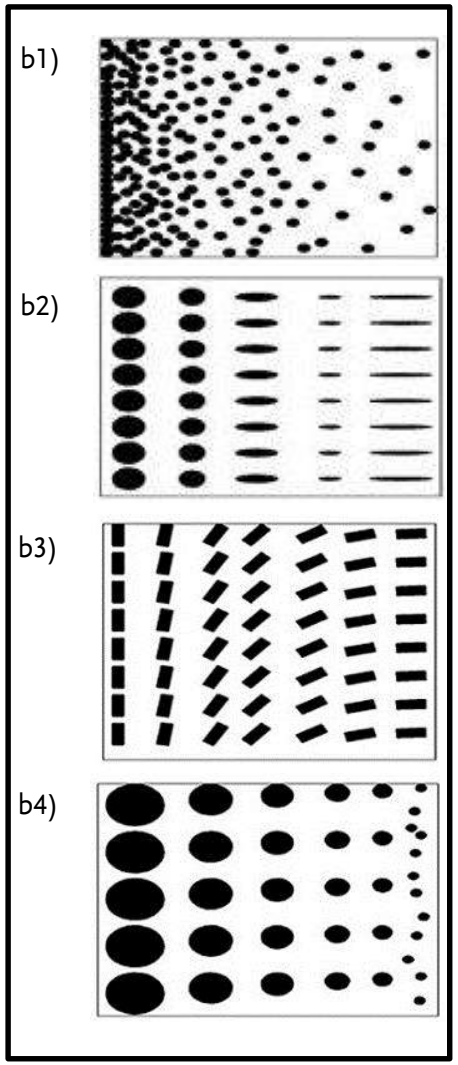
[25,26]

Main applications: Properties gradation, ?

Functionally Graded Materials

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b1)-b4): [26]

Piezoelectric Materials

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Materials

Polycrystalline ceramic (PZT, $PbTiO_3$, $BaTiO_3$)

Single crystals (SiO_2, $LiNbO_3$, LiTaO)

Polymeric (PVDF, co-polymer)

Main applications: sensing, actuation and energy harvesting

Structures

Monolithic

Thin films

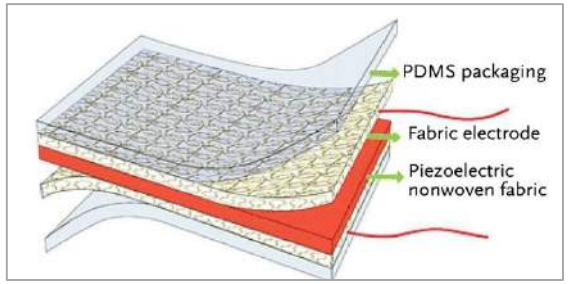
Wafers

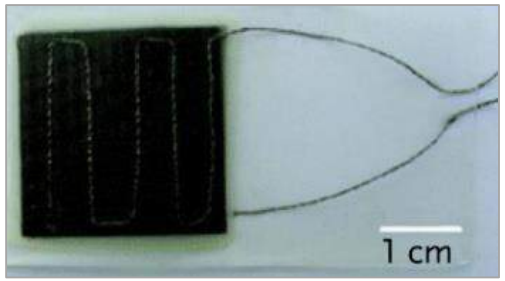
(Nano)fibers/wires

- Solid/hollow
- macro and active fiber composites (MFCs and AFCs)

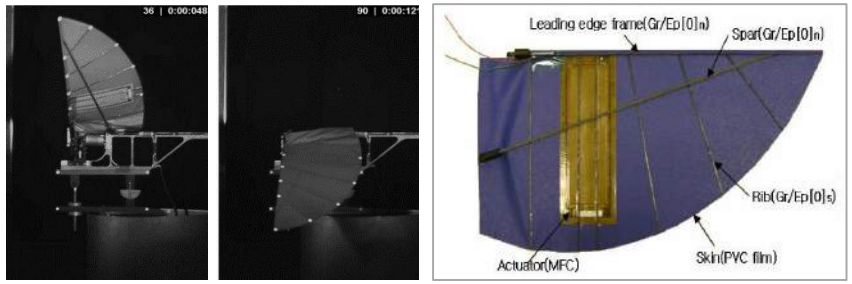
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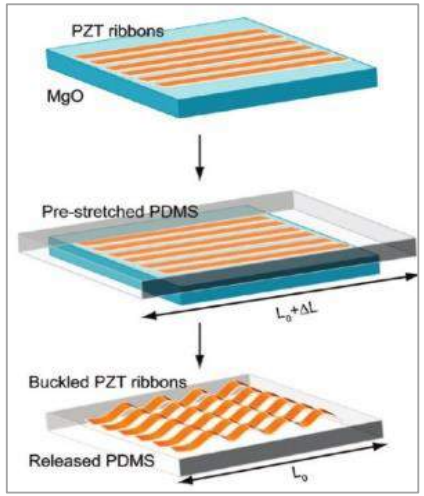




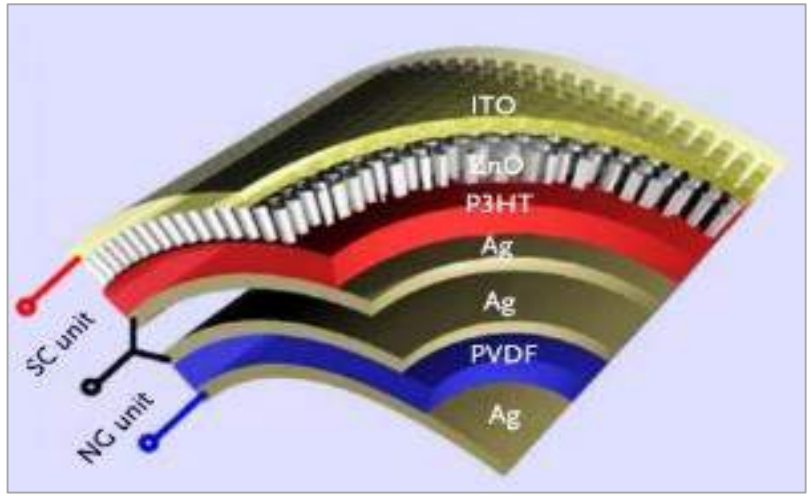
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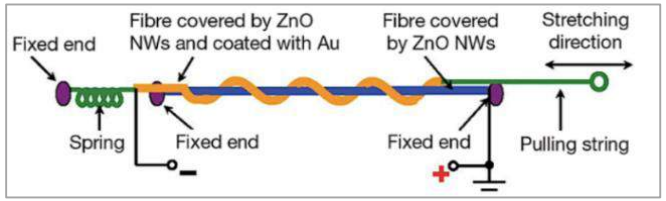
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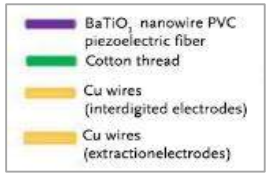


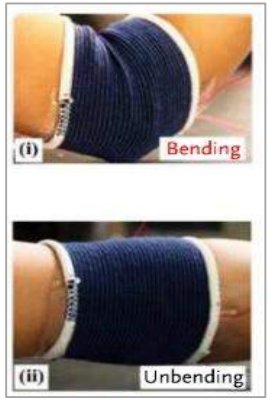
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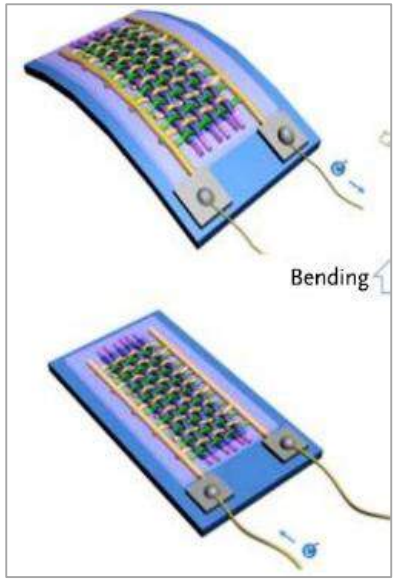


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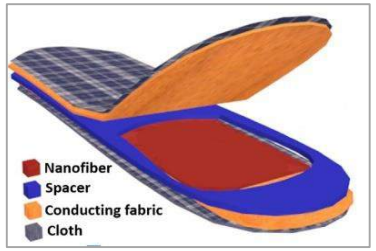


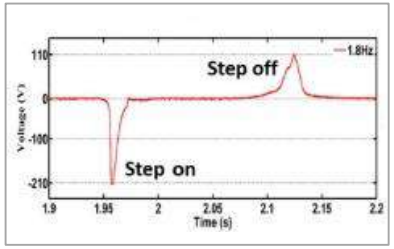




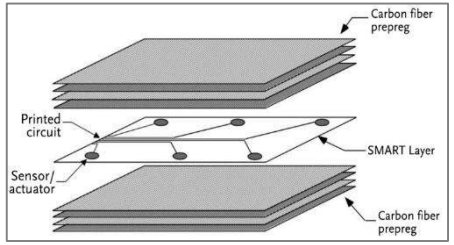


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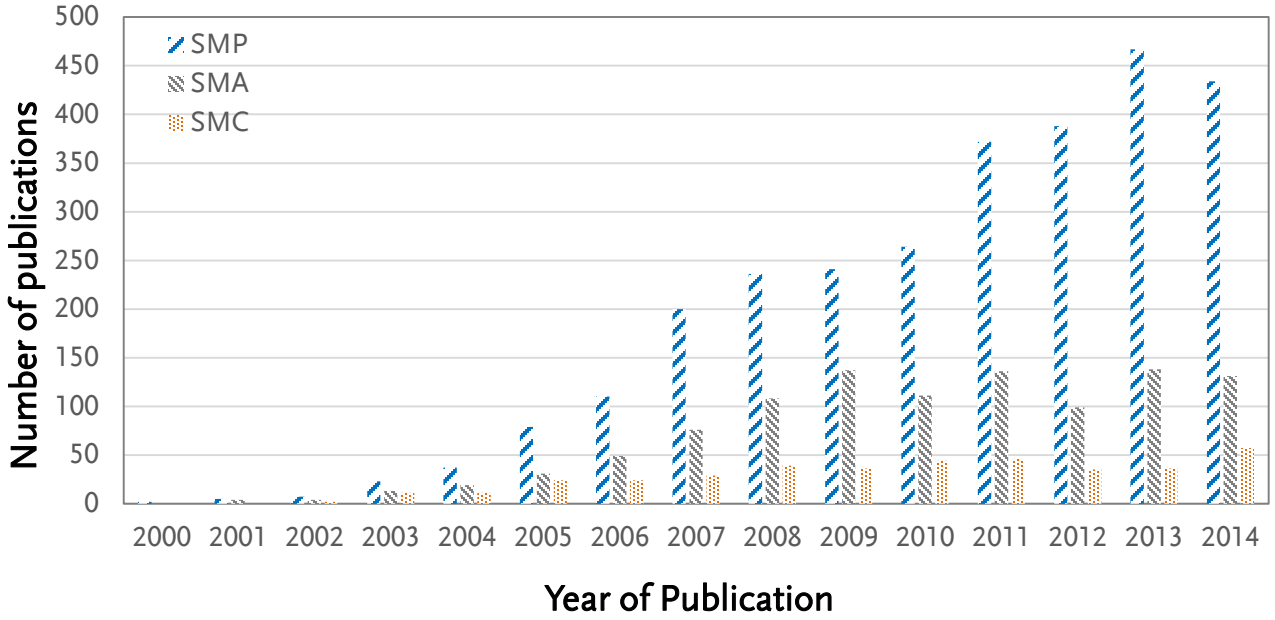
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[33]

Shape Memory Materials

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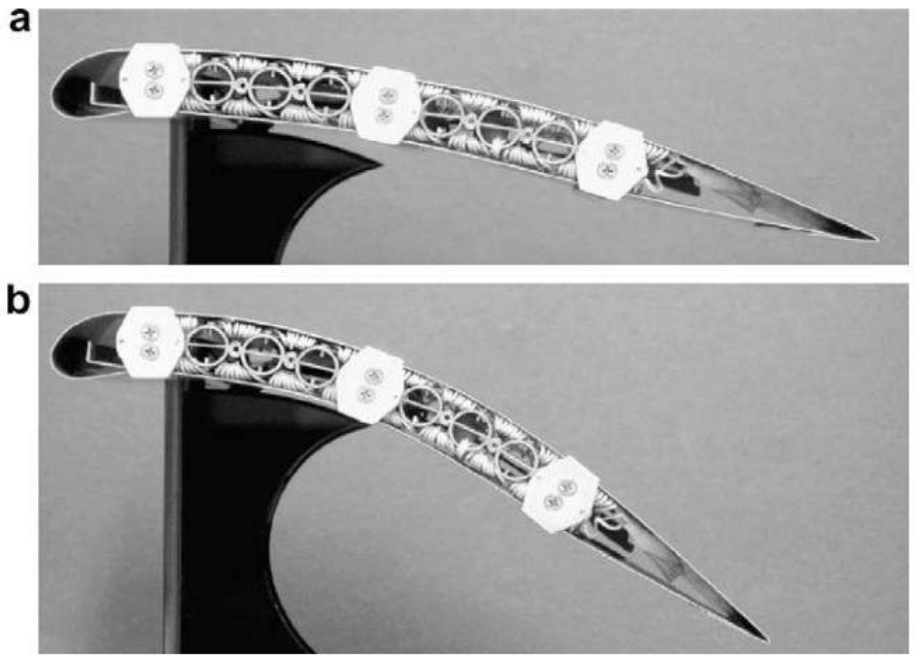
In March 2015, data from EngineeringVillage.com

Main applications:

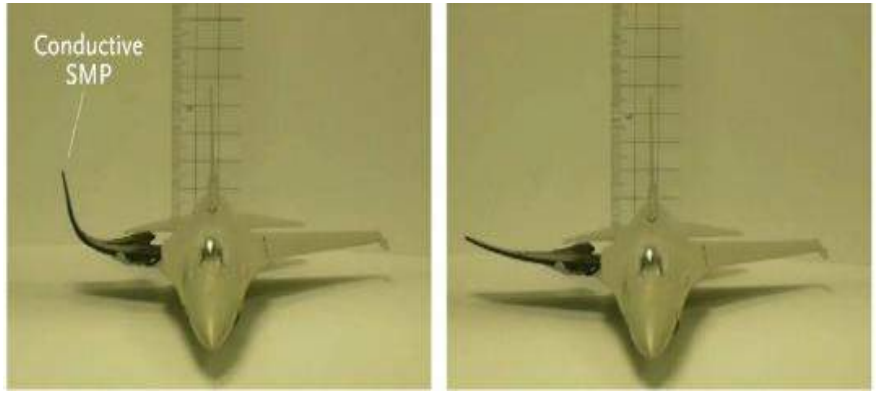
•Actuation – a direct effect from the SME;
•Magnetic sensitivity – by using ferromagnetic fillers;
•Radiation sensitivity/opacity, namely RF, IR and UV – arise from the UV absorption properties of CNTs;
•Electrical sensitivity/conductivity – by using electrically conducting fillers such as CNTs and carbon black;
•Ability to change optical properties namely color and transparency;
•Ability to change its water sensitivity/permeability – by changing the microstructure of the polymer;
•High thermal conductivity – by using thermally conducting fillers as CNTs;
•Self-healing;
•With magnetic interference shielding – allowed by reinforcement with MWCNTs.

Shape Memory Materials

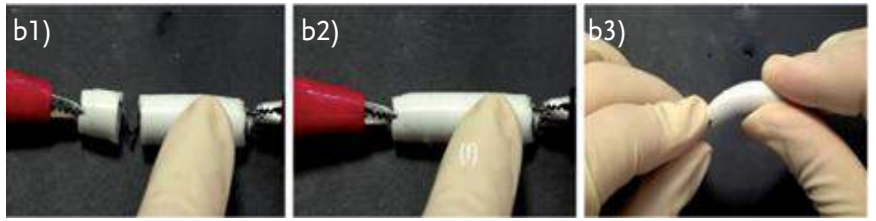
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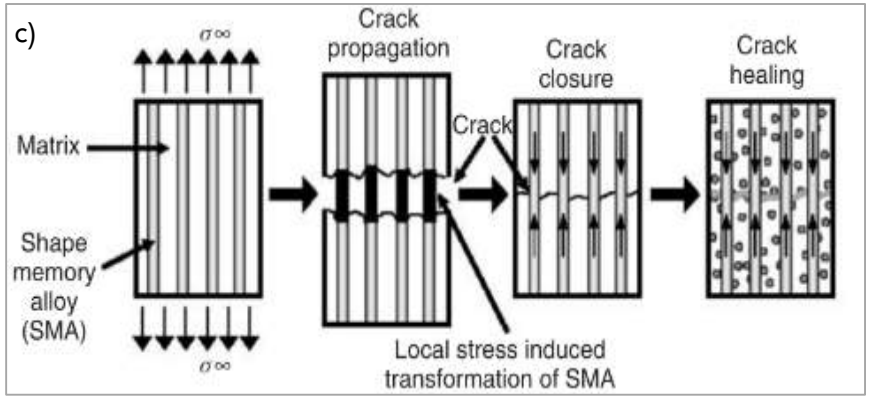


[35]



*[36]



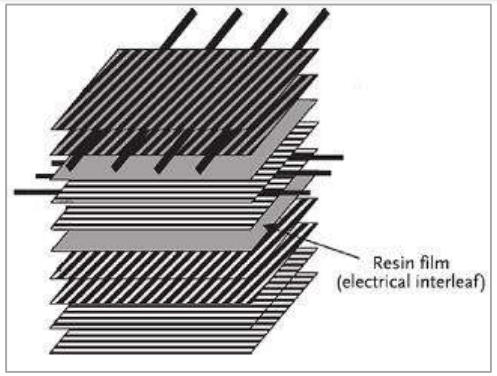


[38,39]

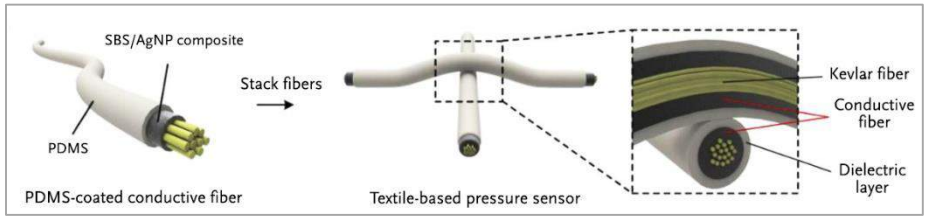
Others

1. Introduction
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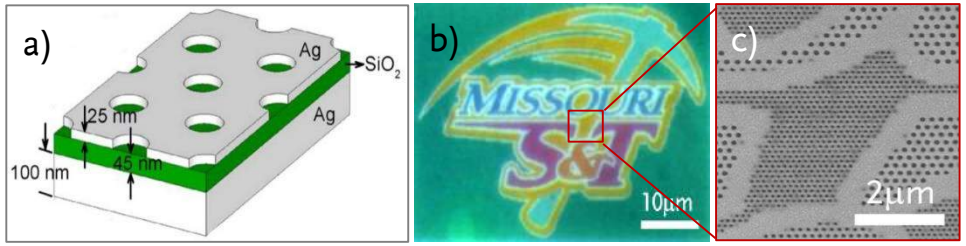
- Aptamer based
- Carbon Fiber Reinforced Composites for Energy Storage and Sensing
- Cement-based and conducting elastomer
- Commercial 3D Printing Materials
- Copper Nano-ink
- Foams
- Glass Fiber
- Kevlar Composites for CLAS
- Kevlar Fibers Coated With Polymers
- NiF_2 on PET
- Materials with Sandwich Structures for Increased Thermal Properties
- Metallic-Intermetallic Laminate Composites
- Polyaniline
- Porous Silicon
- Silver-Silica-Silver Material System
- Zinc Oxide



*[40]



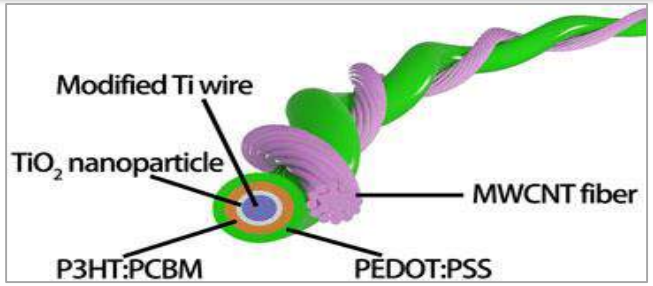
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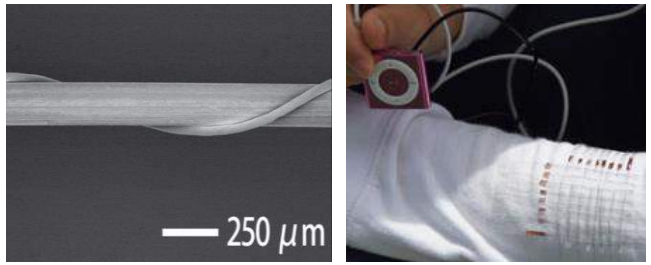


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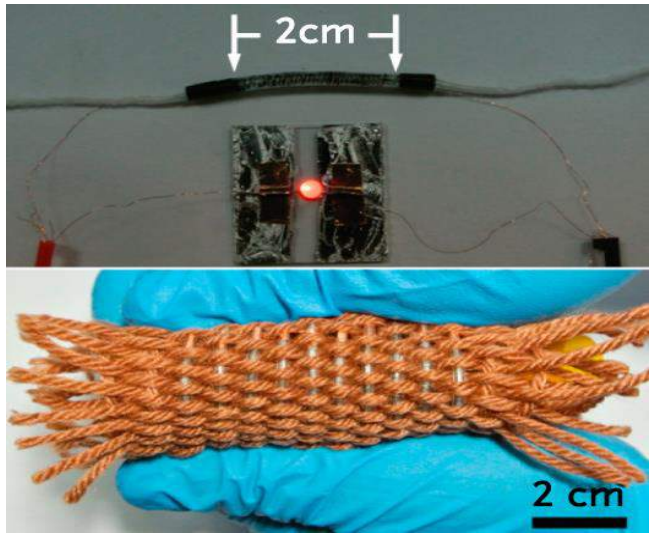
Others

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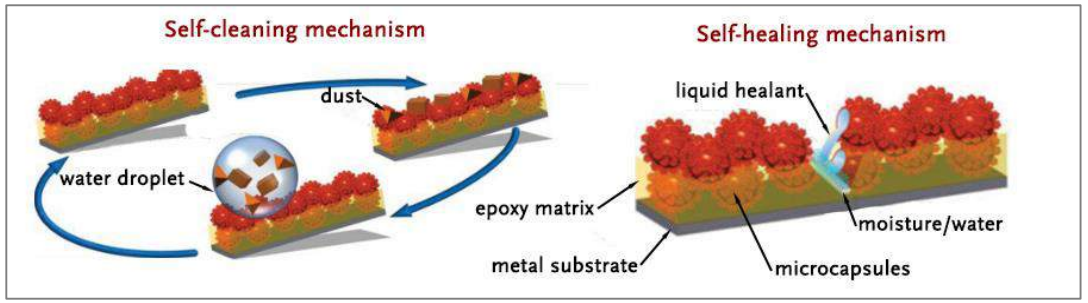




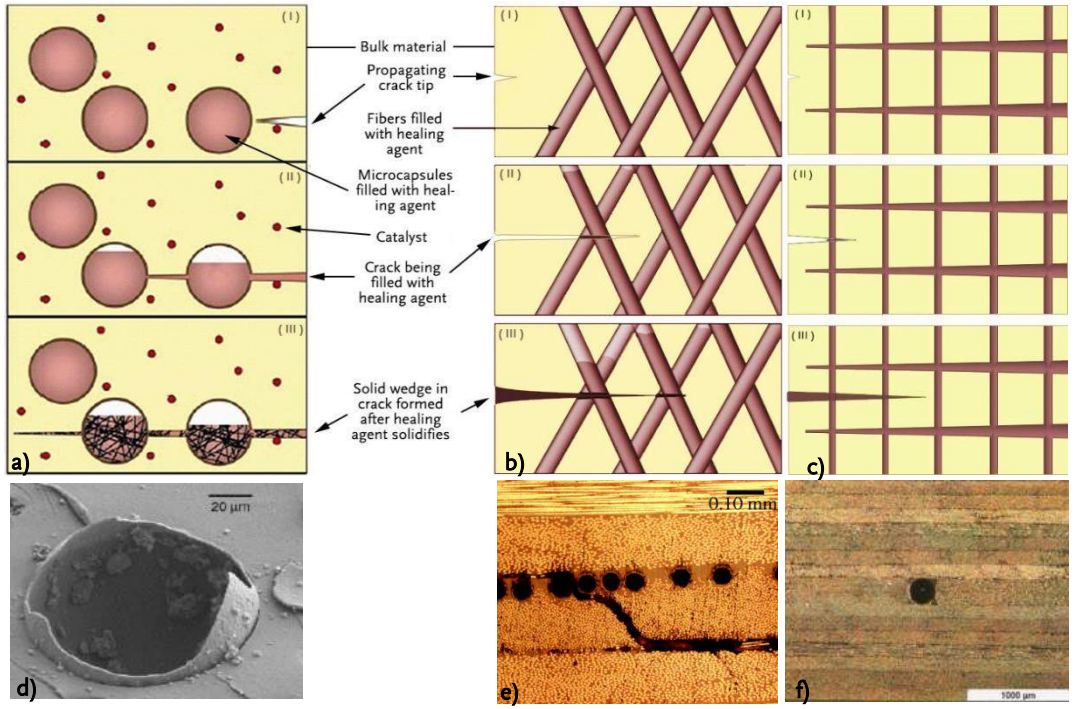
[43]



[45]



*[44]



*[46-50]

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Challenges

7min

Main Identified Challenges

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4. Methods
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- Innovative Multifunctional Material Systems Development and Integration in Products:
  - Idea generation systematization;
  - Satisfying engineering requirements for MFMS adoption in products;
  - Multidisciplinarity;
  - Sustainability.

- Manufacturing:
  - Increasing scalability;
  - Obtaining hierarchical structures and multiscale composites;
  - Specific case challenges: obtaining good alignment, achieving good dispersion

Requirements for MFMS Adoption in Products

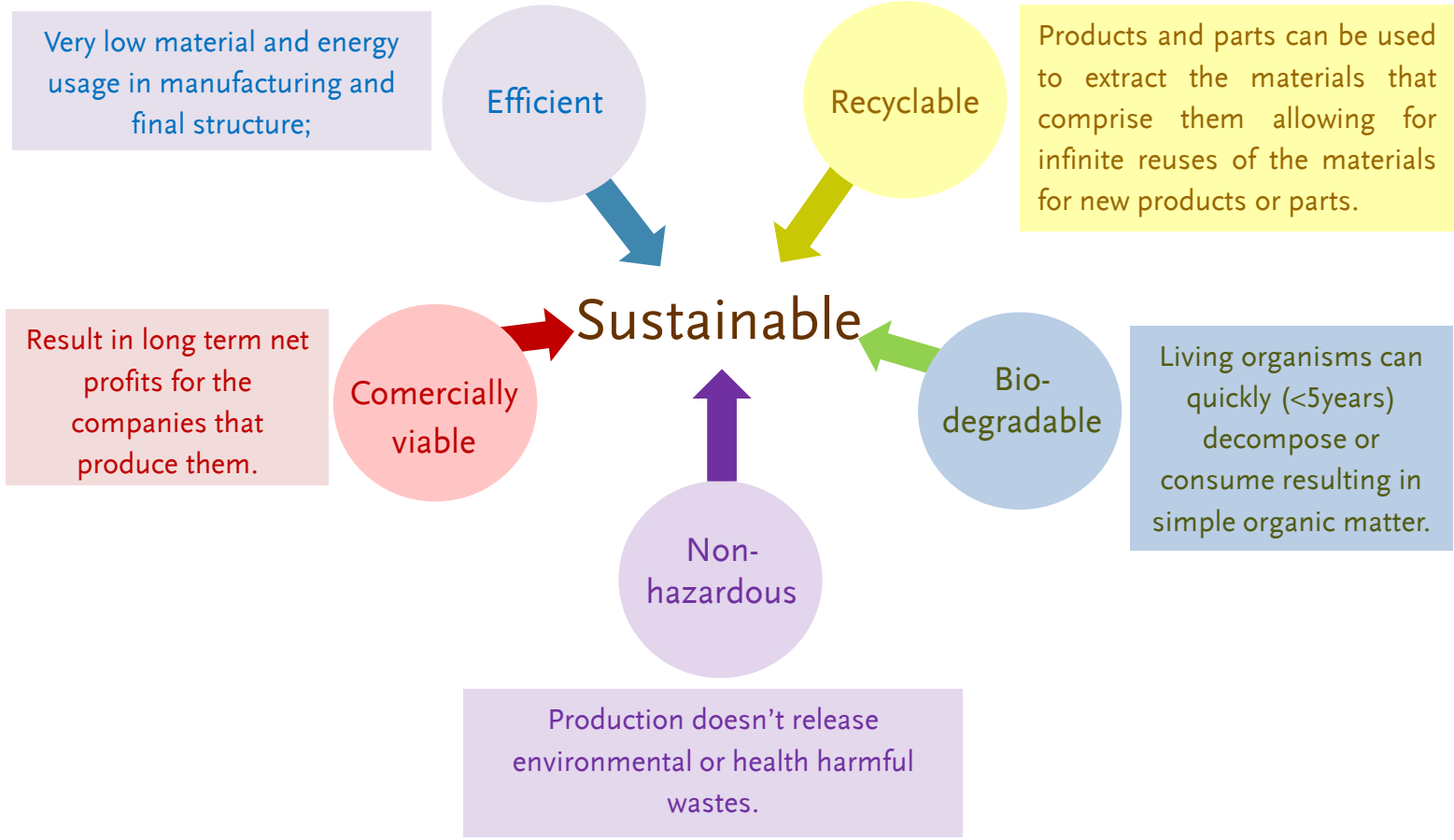
1. Introduction
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I – Information	(I_1)	Extensive and reliable property data provided by the manufacturer
	(I_2)	Literature offering detailed descriptions of product development using MFMS.
	(I_3)	Networks involving scientists and engineers including from areas such as biology, environment and medical.
P – Performance	(P_1)	Equations that describe the MFMS behavior.
	(P_2)	Equations that describe system-level efficiency depending on the included functions'.
M – Material and Structural	(C_1)	Stable properties. It can be consistently manufactured in order to obtain the desired properties.
D – Design Tools	(D_1)	Design guidelines, such as guidelines regarding fatigue protection, control of operating temperature, joule heating.
	(D_2)	Design tools describing the functional behavior, such as computerized constitutive material models, product geometry models and material property databases.
O – Operation	(O_1)	Adaptive systems measuring the changes of material or product behavior and adapting the operational conditions to the properties and / or behavior changed.
S – Standardization	(S_1)	Standardized nomenclature (material 1/material 2-function A, function B, hierarchy if applicable…)
	(S_2)	Standardized test procedures for each function.

Inspired on [51]

Sustainability

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back

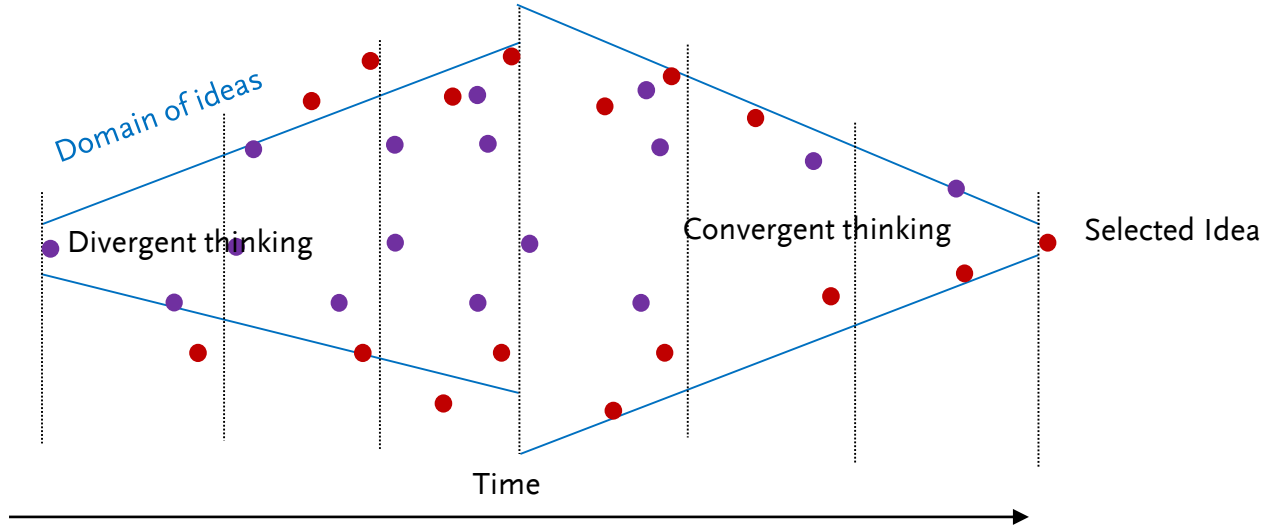
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Methods

8min

Ideation

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Tools

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Brainstorming
Challenging the Status-quo
Combining Ideas
Concept Fan
Connecting the Unconnected
First Principles Thinking
Imitating
Looking at the Extremities of the Gauss Curve
Provocation
Separating Ideas from Concept
Simple Language Reframing
Shifting Perspective
Visual Thinking

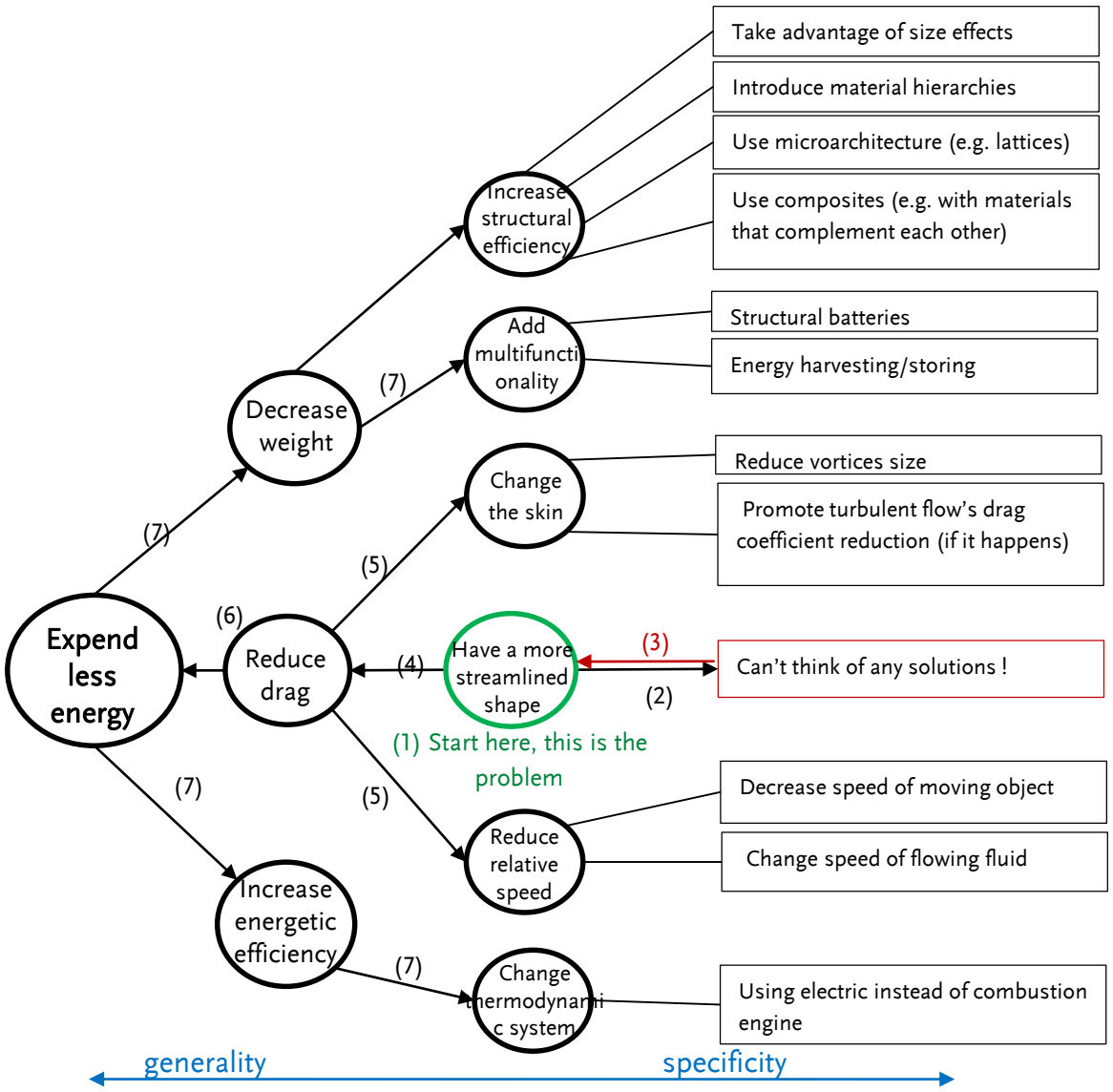
Allowing a certain amount of time for side projects.

On Information Sharing

Awards

Concept Fan

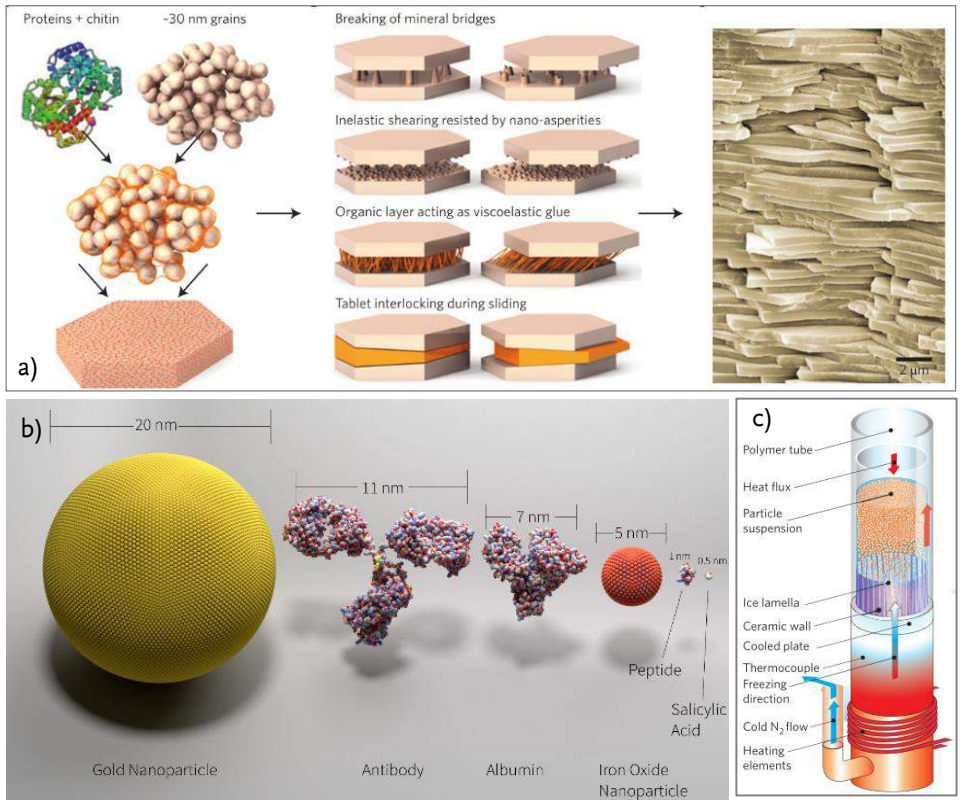
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Visual Thinking

1. Introduction
2. State-of-the-art
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More of this



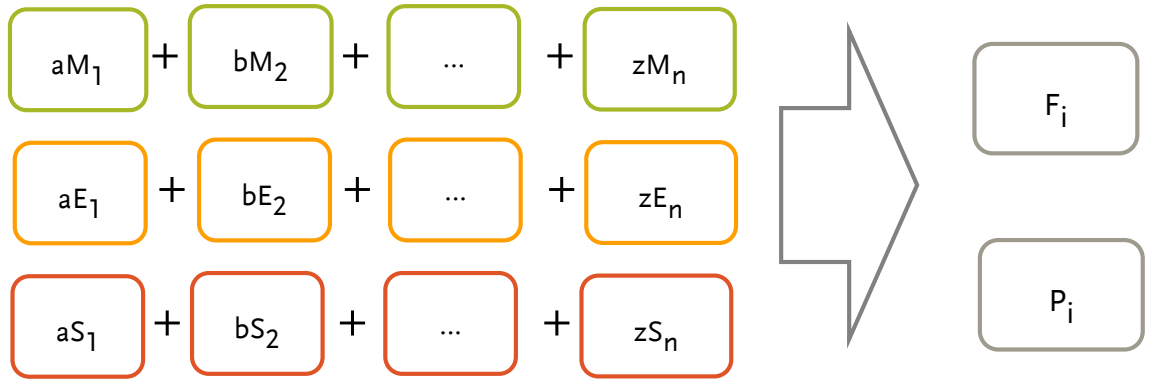
Less of this



[52,53]

Combination

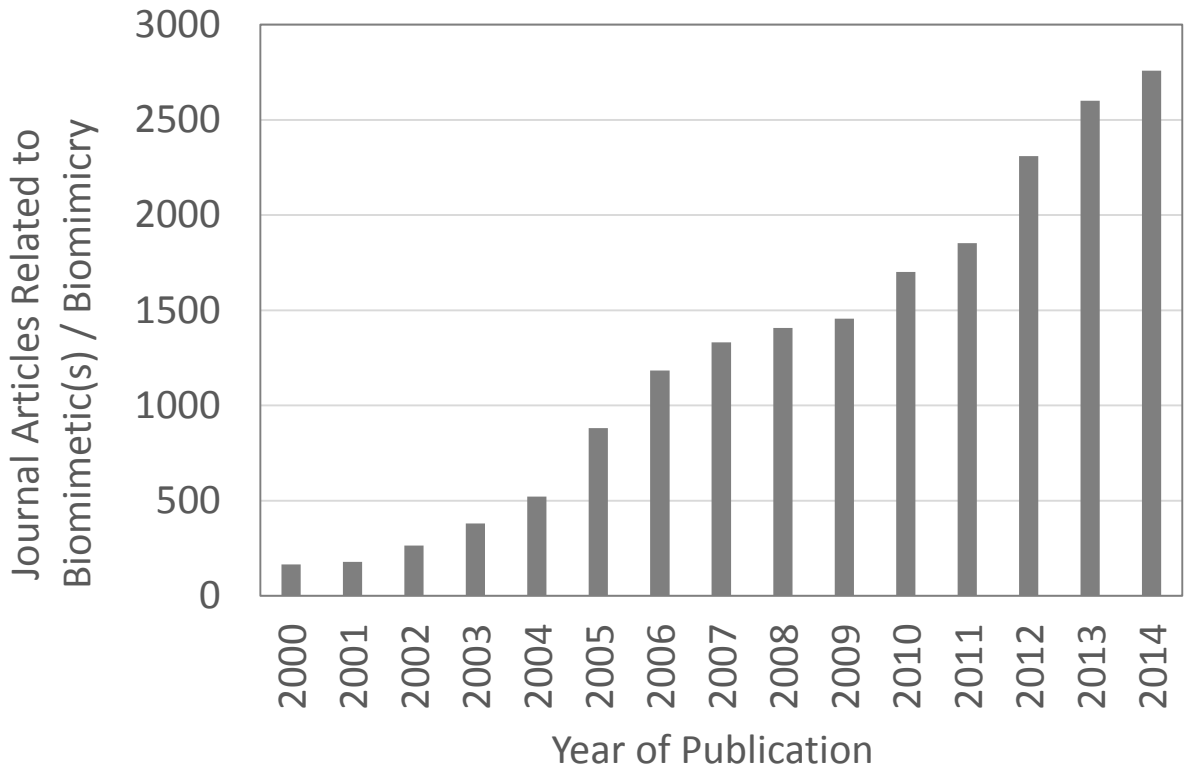
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Combination	Possible Desirable Function(s)	Possible Desirable Property(ies)
Aligned CNTs in a nanolattice	Structural ; Sensing	High specific strength and Young's modulus; High electrical and thermal conductivity.
Layered (PVDF + MFC + Li-ion)	Energy harvesting; Actuation; Energy storing.	Good multifunctionality
Graphene coated MFC	Structural; Actuation; Cooling;	High strength, actuation rate, thermal and electrical conductivity.
Graphene as outer layers of honeycomb structure with an elastomer and piezoelectric material	Energy harvesting; Damping	High in-plane electrical and thermal conductivity; High damping coefficient.
Fibers (CNT-Si/CNT+CNT-LMO + NiTi)	Energy storage; Actuation	High degree of autonomy
Geothite reinforced myocelium	Structural; Biodegradable	High strength and Young's modulus.
Asymmetrical PDMS tube (outside) with ZnO nanowires and polymer solar cell fiber (the one on **Fig. 59 a**) and air.	Actuation; Energy harvesting	High solar convention rate; High actuation sensibility and very low actuation force; High controllability.

Bio-inspiration

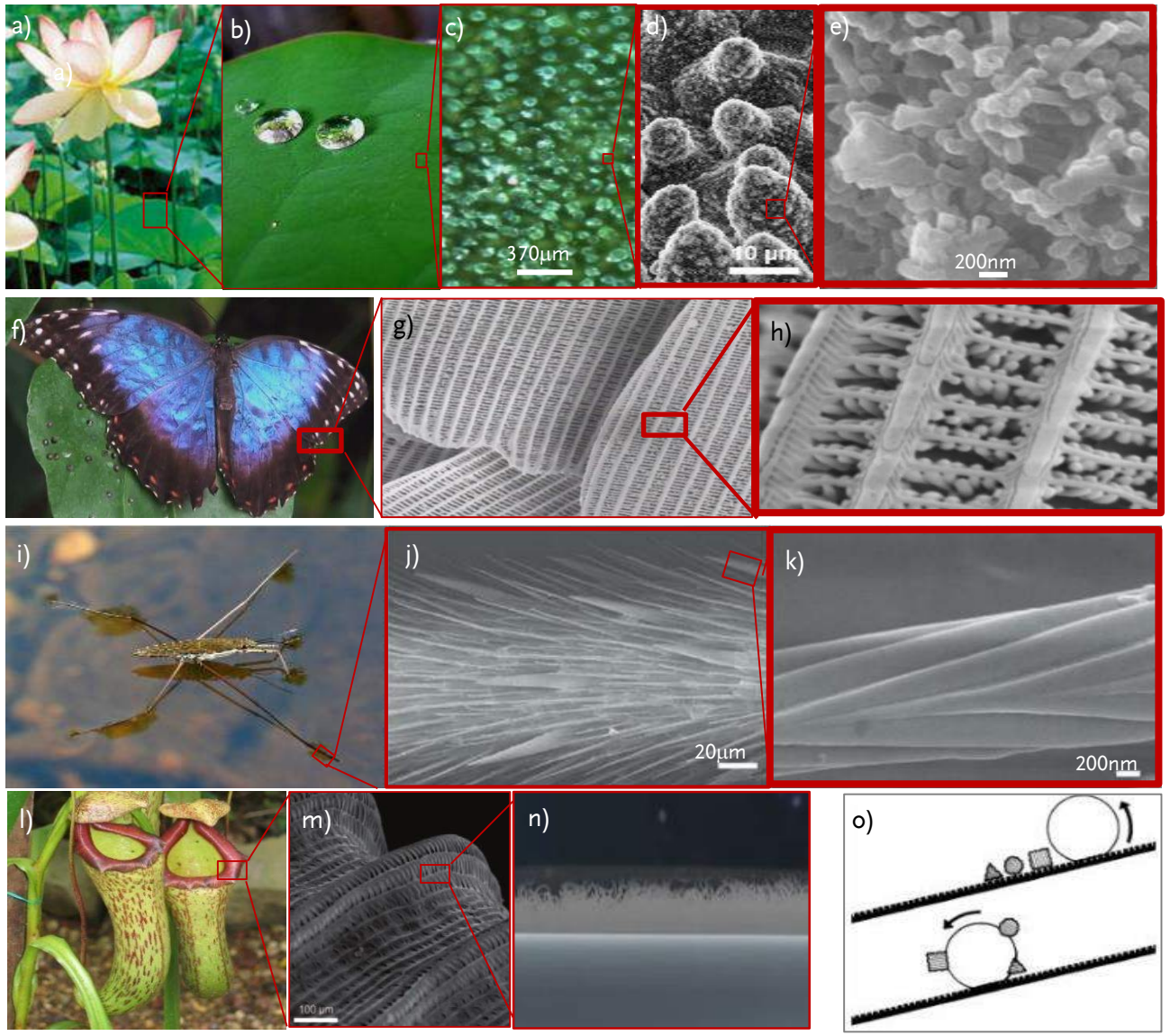
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In June 2015, data from EngineeringVillage.com

Hierarchichal Organization

1. Introduction
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*[54-59]

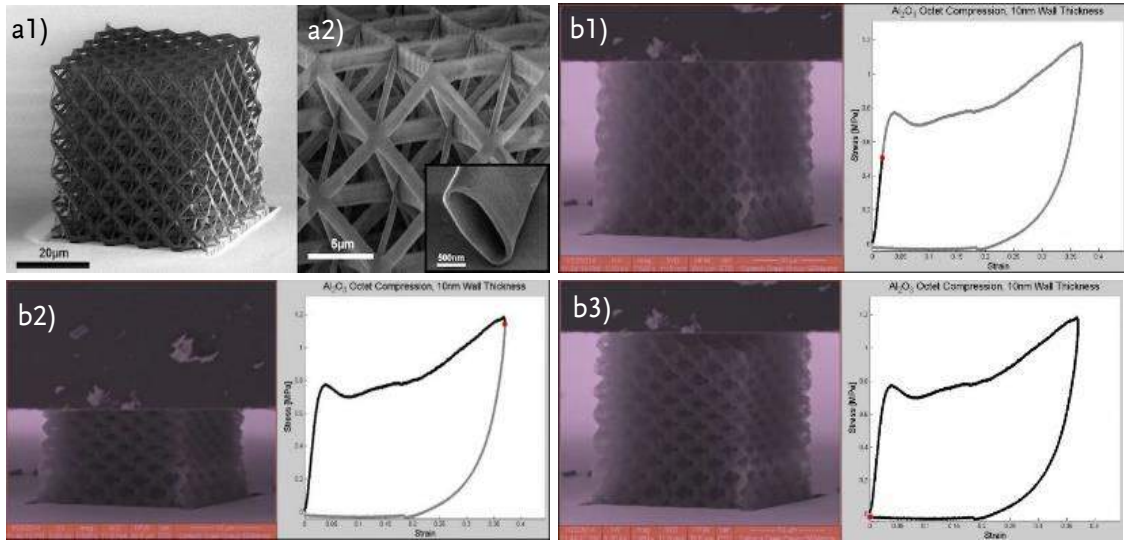
Utilizing Size effects

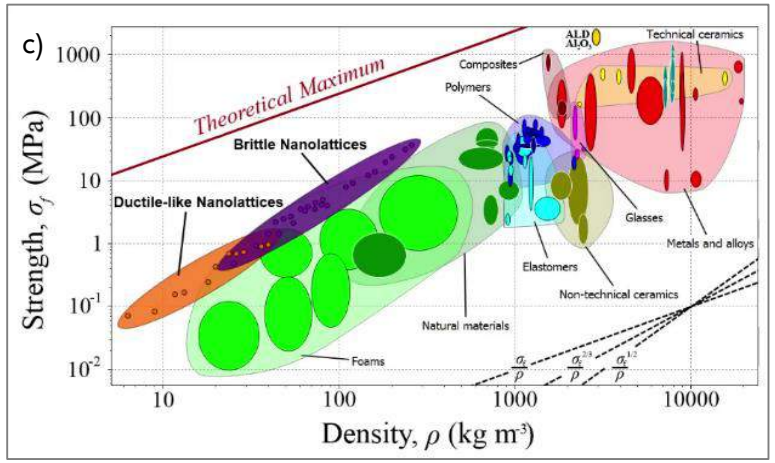
1. Introduction
2. State-of-the-art
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[60]

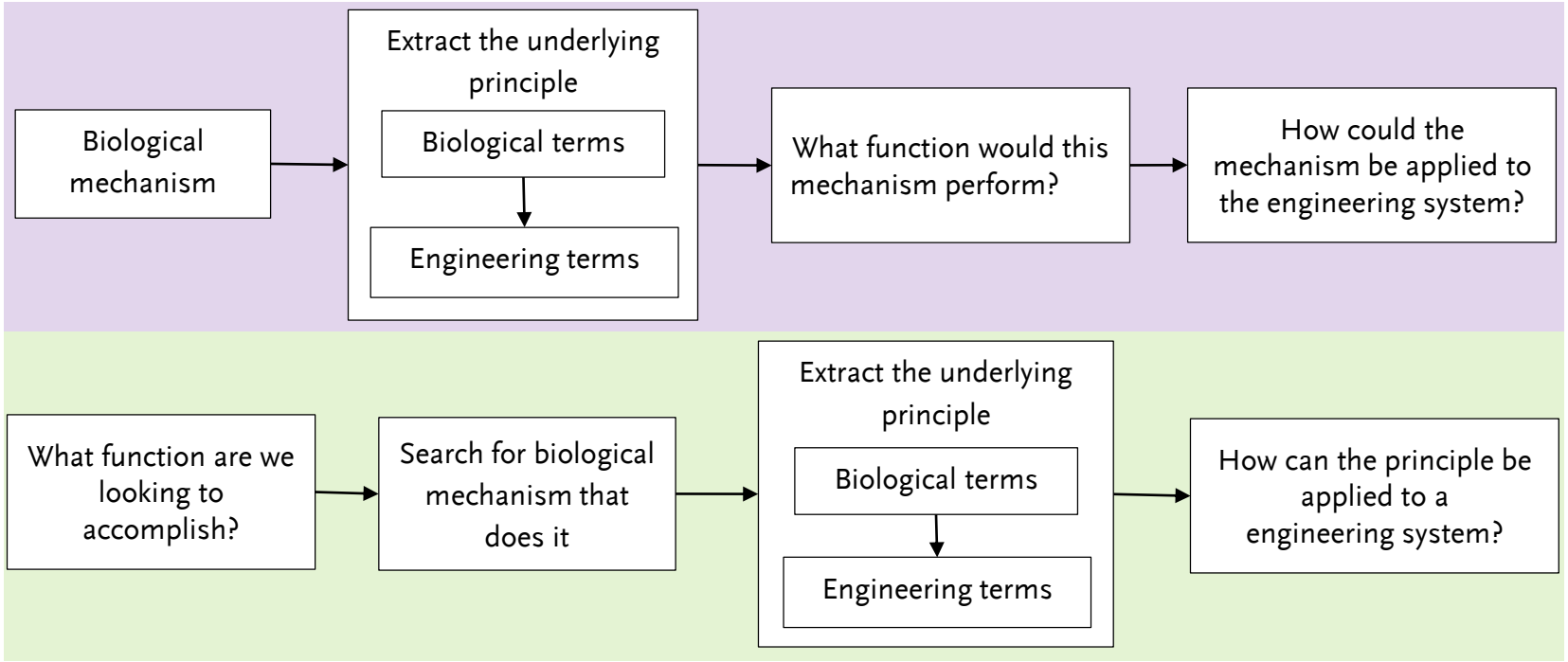




[61,62]

Bio-inspiration General Method 1

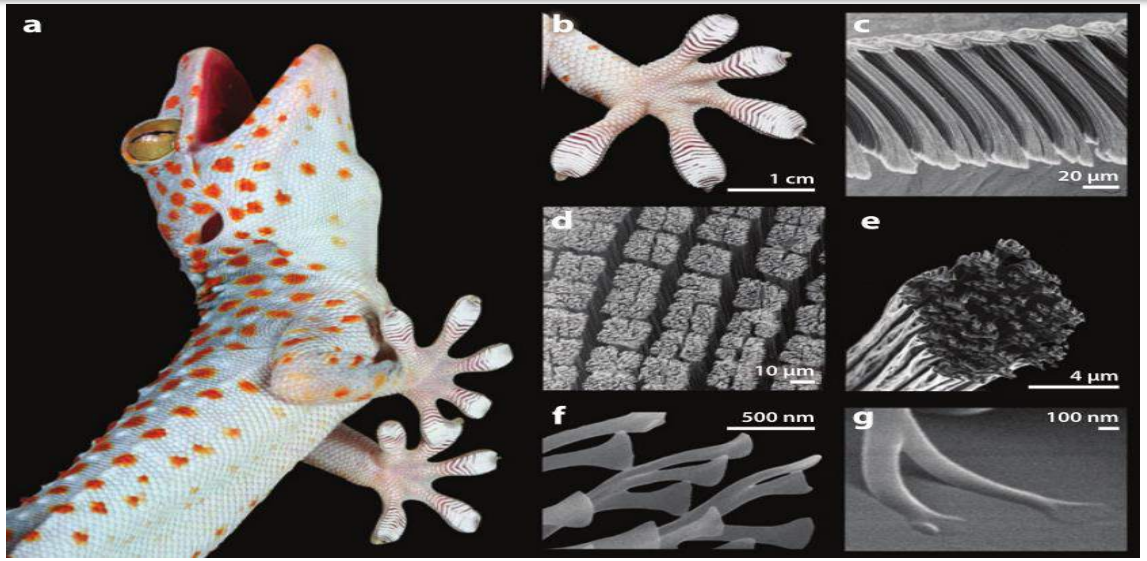
1. Introduction
2. State-of-the-art
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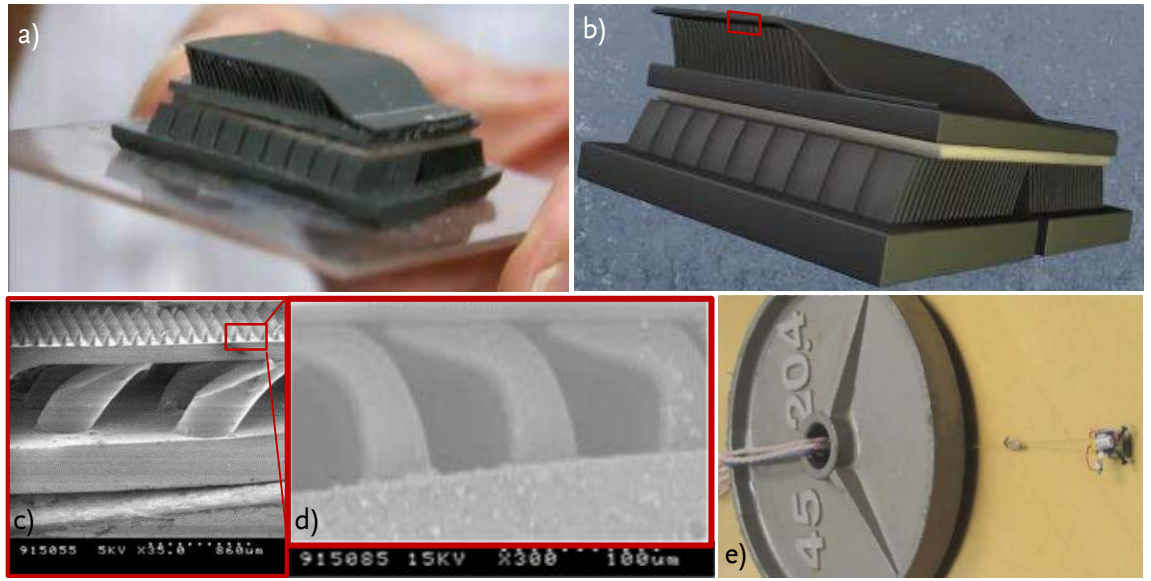


Bio-inspiration

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Underlying principle: An anisotropic hierarchical structure that has a very high surface area which causes it to generate a great amount of van der Waals forces.

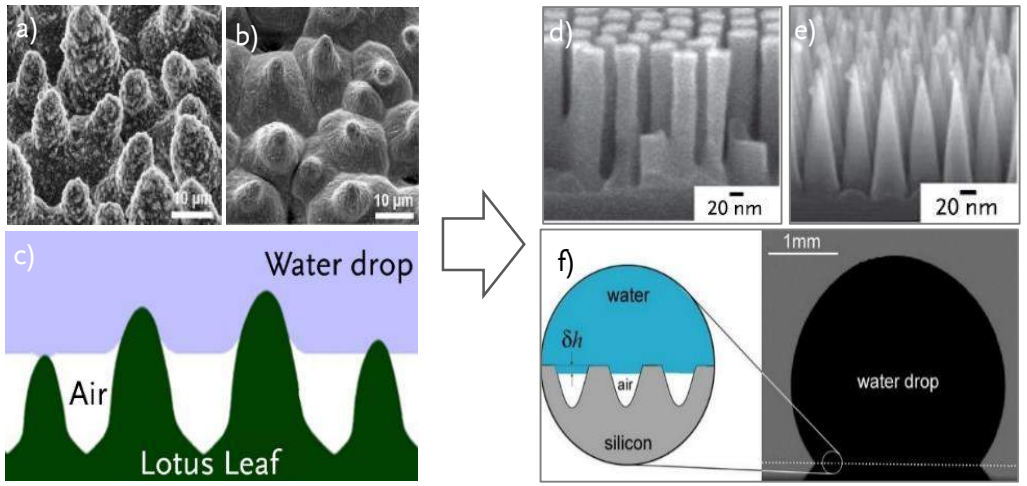




*[63-66]

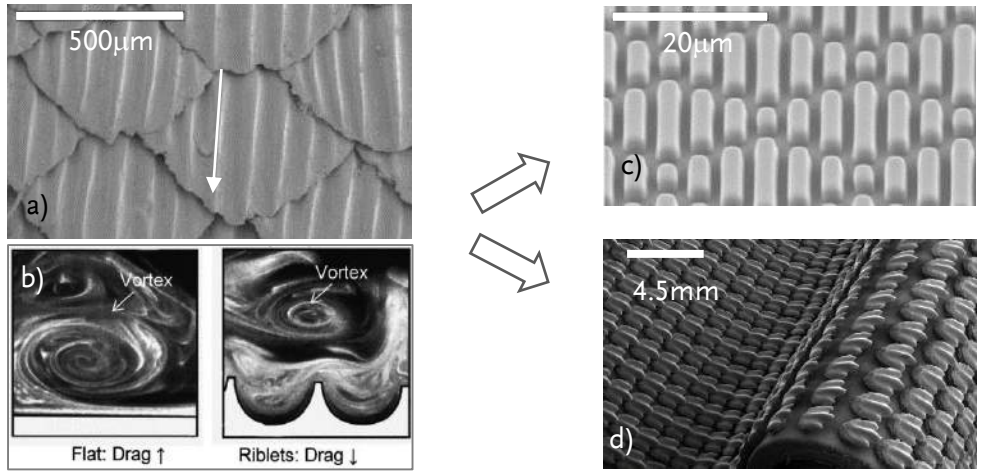
Bio-inspiration

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Underlying principle 1: Anisotropic surface topography in the direction of the sliding movement;
Underlying principle 2: Liquid filled and trapping bundles of fibers that are able to create a thin film of the trapped liquid.

*[67-69]

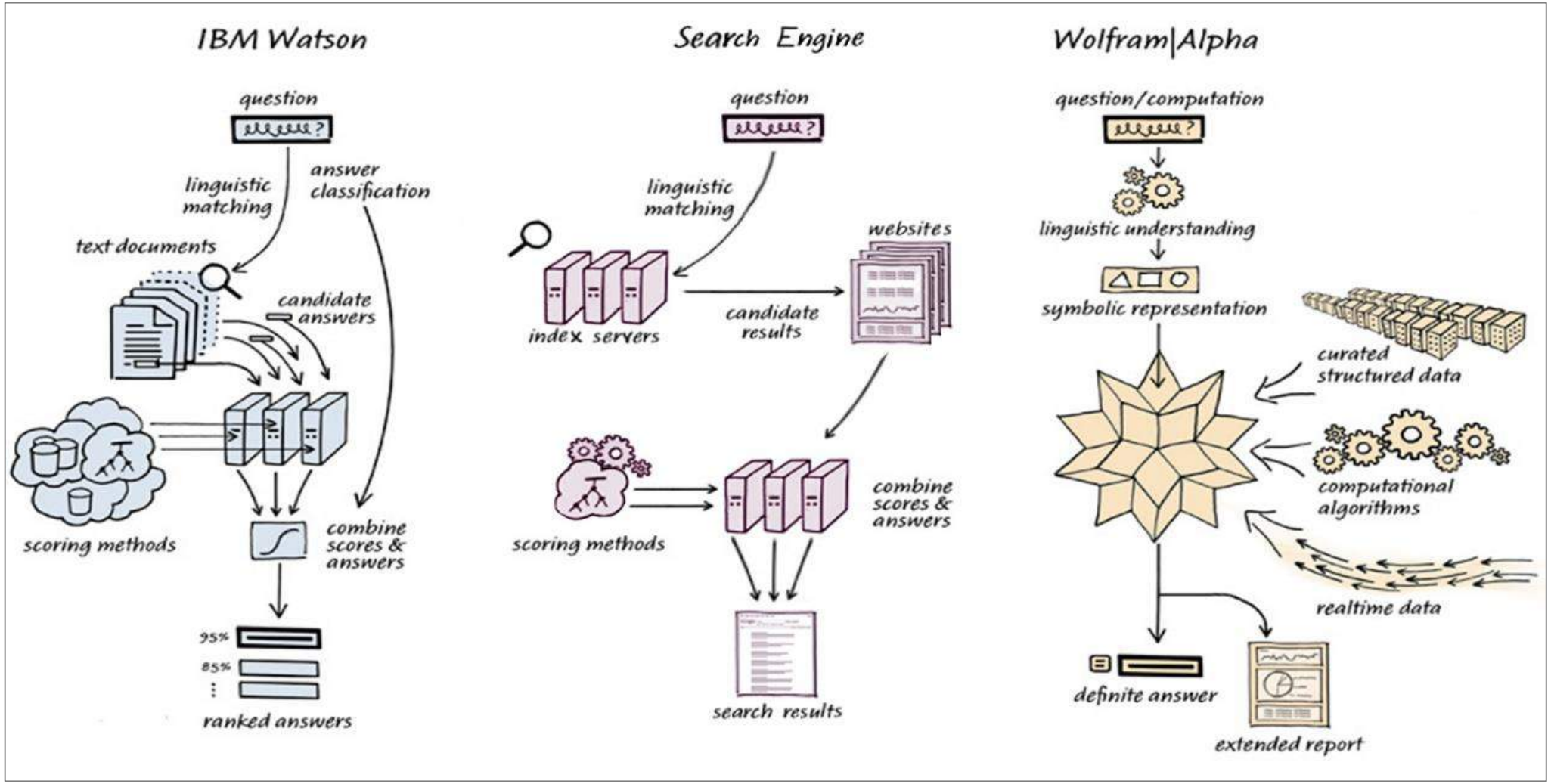


Underlying principle: Ridges of sub-micron size or size that best reduces bacteria attachment aligned in the flow direction and forming among them diamond shapes.

*[70-72]

Bio-inspiration General Method 2

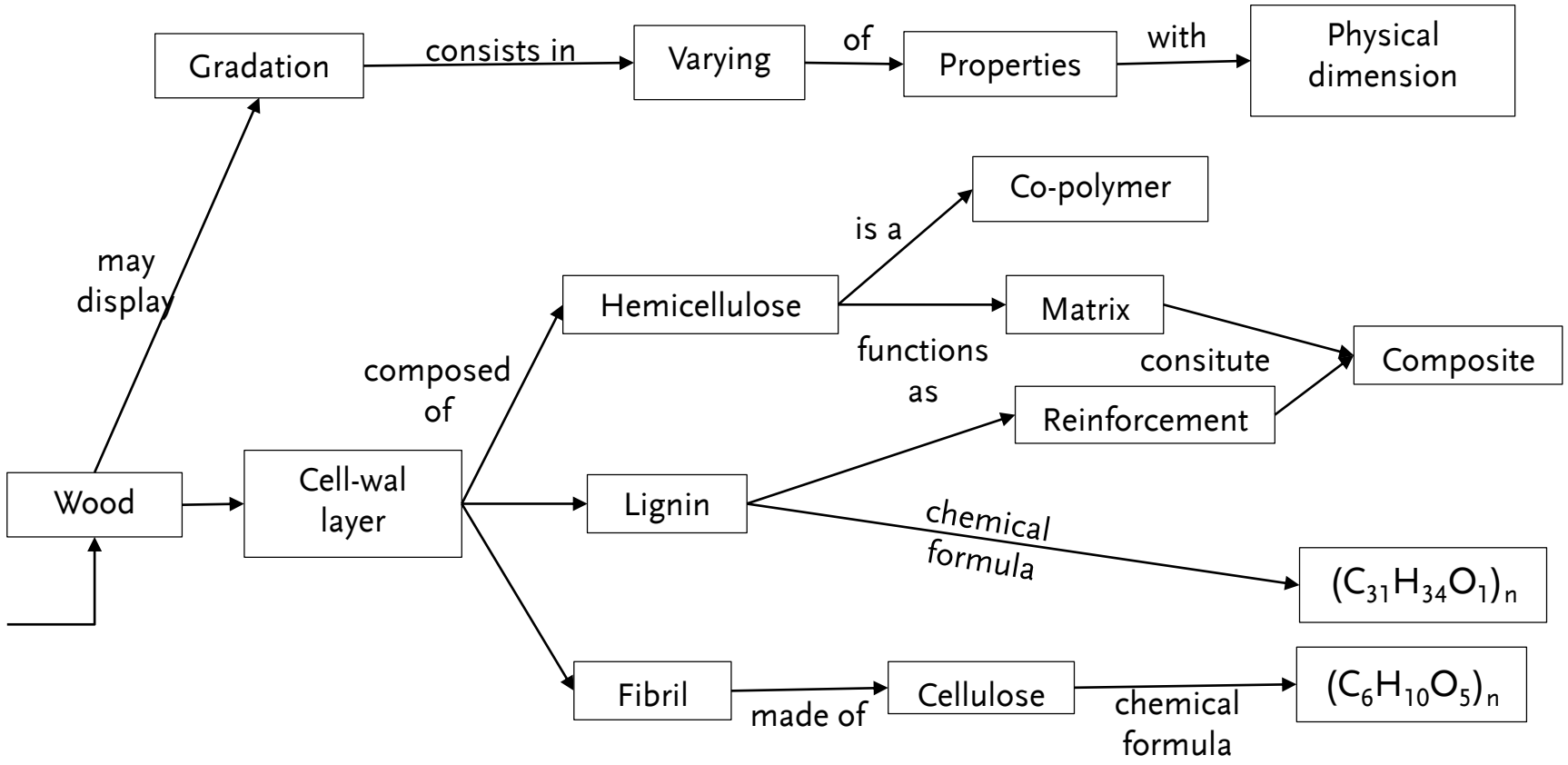
1. Introduction
2. State-of-the-art
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*[73]

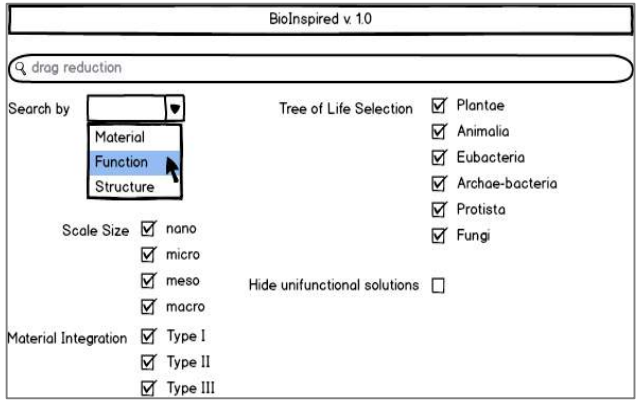
Bio-inspiration

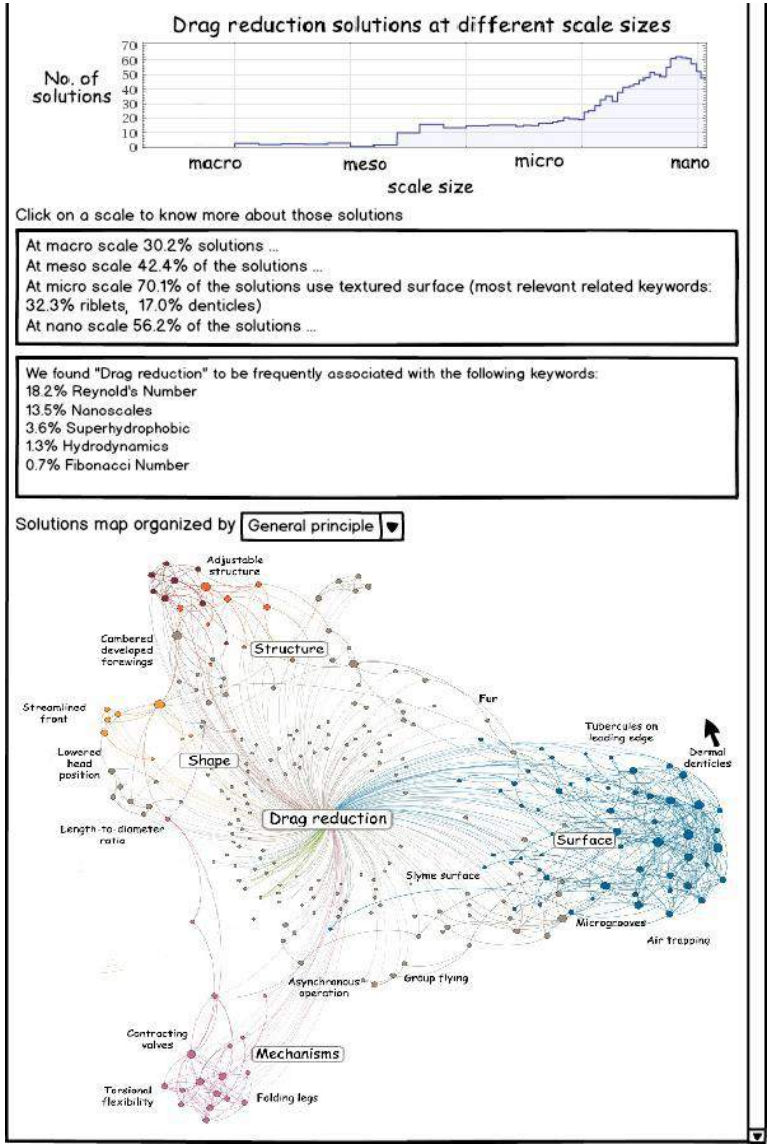
1. Introduction
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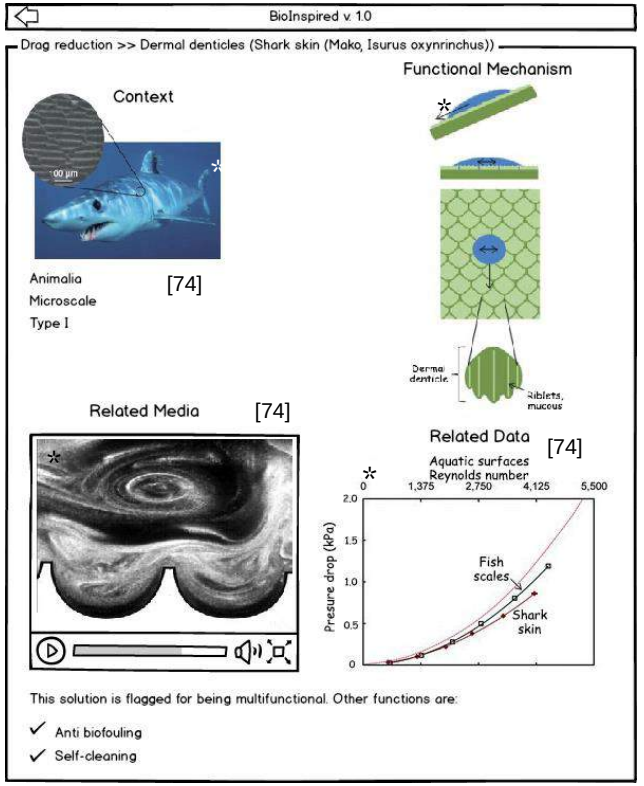


Bio-inspiration

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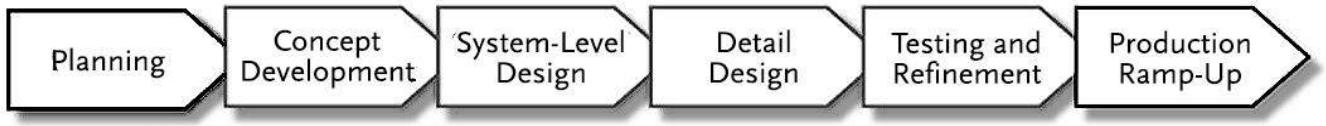




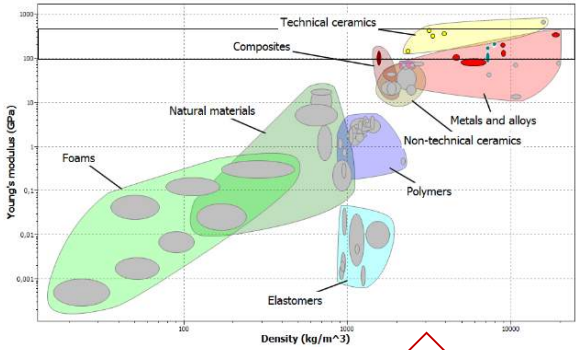


Concurrent MS and Product Design

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Material Selection





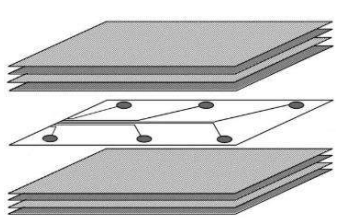
System

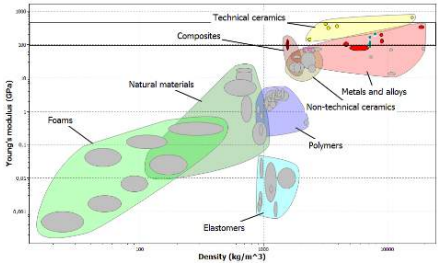


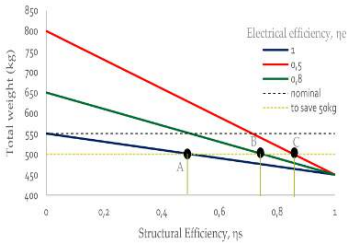
Assembly



Part







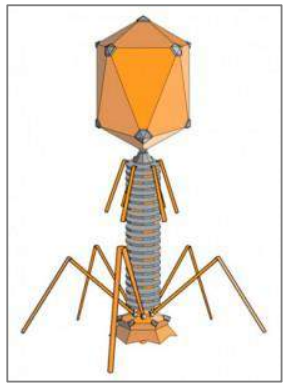
Material Design

*[75,76]

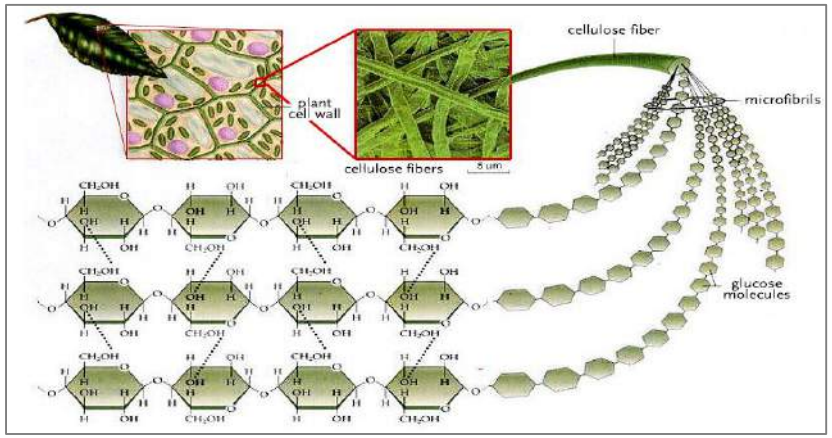
Sustainability

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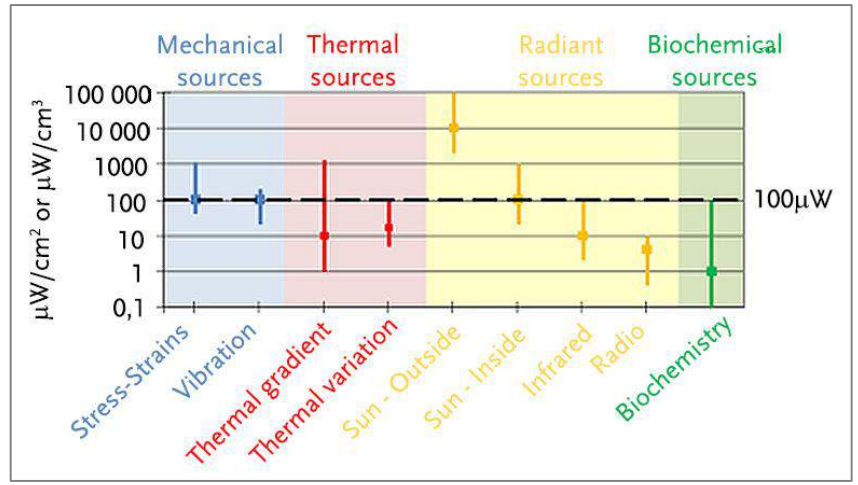
Growing Materials and Structures
Using Natural Materials in Different Ways
Using Material Systems to Harvest Energy



[78]



[77]

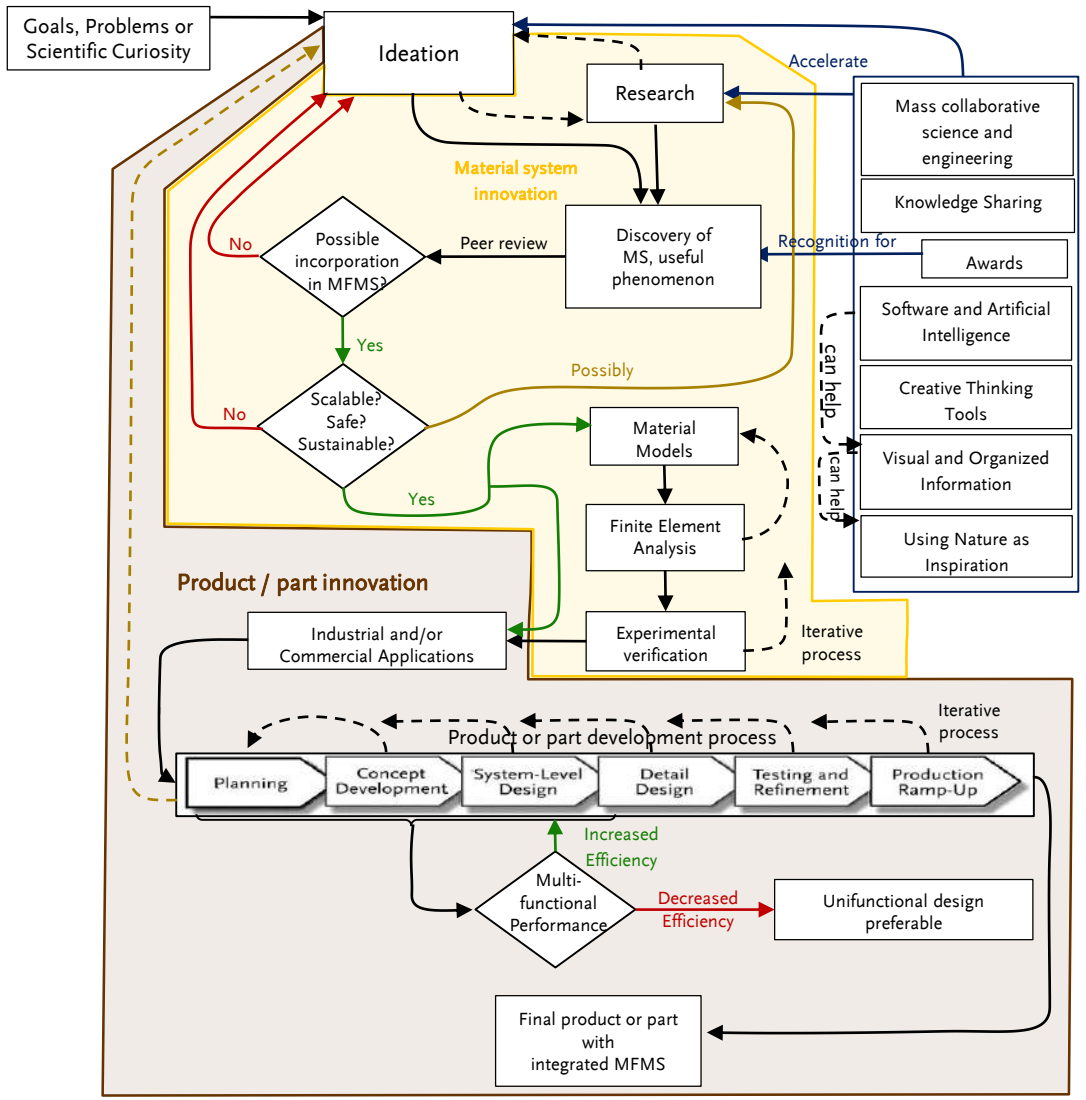


*[79]

Sust. image

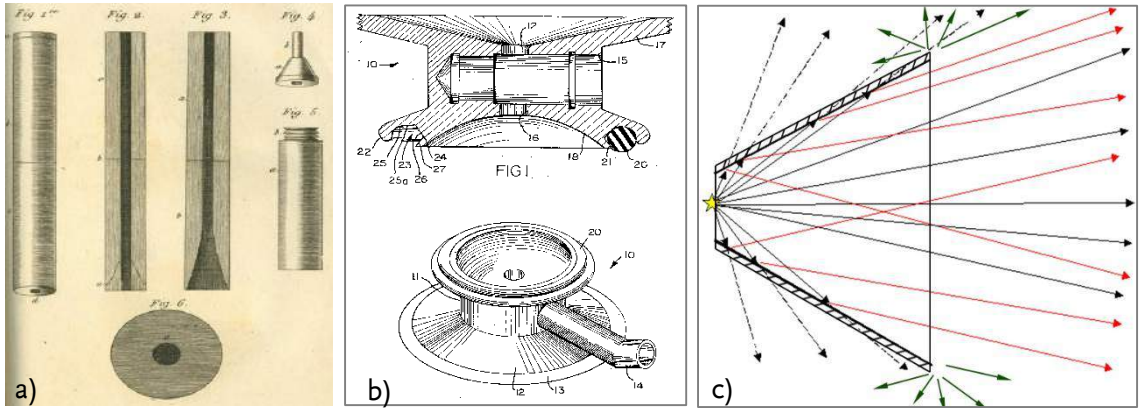
Synthesis of MFMS and Product Development

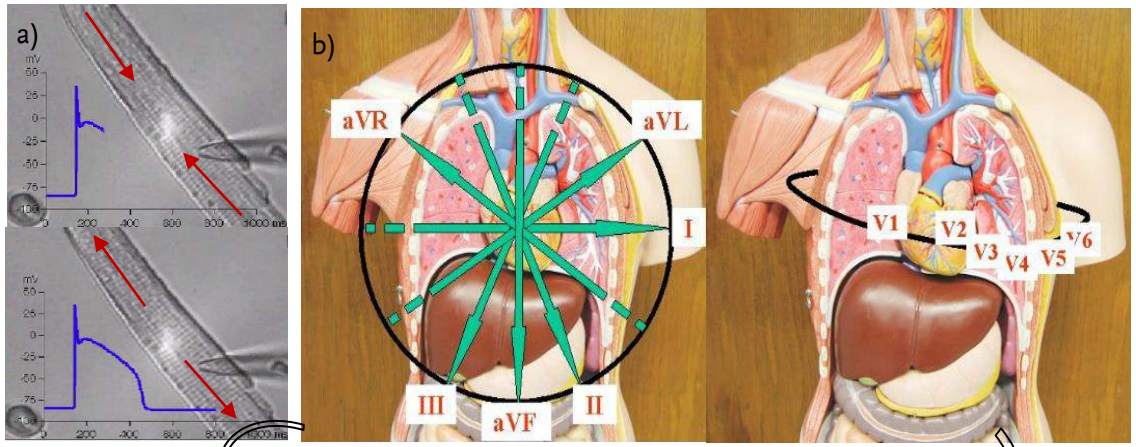
1. Introduction
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Example

1. Introduction
2. State-of-the-art
3. Challenges
4. **Methods**
5. Future Work
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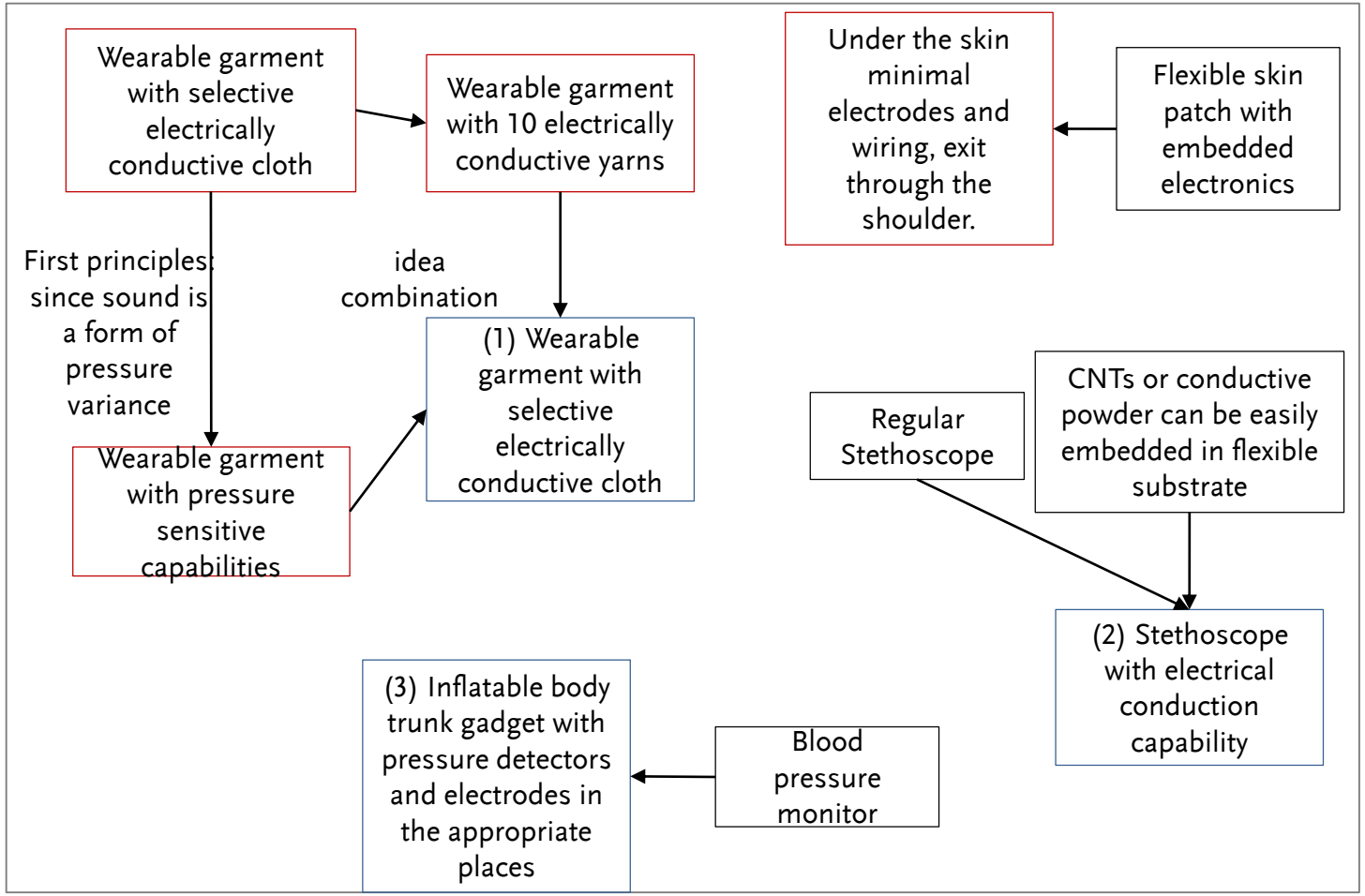




*[81-86]

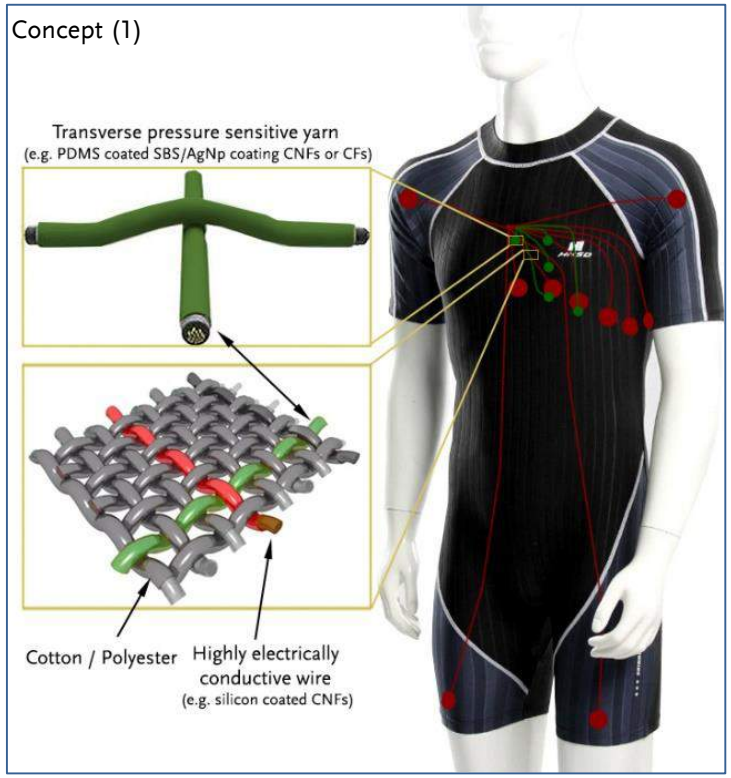
Ideation

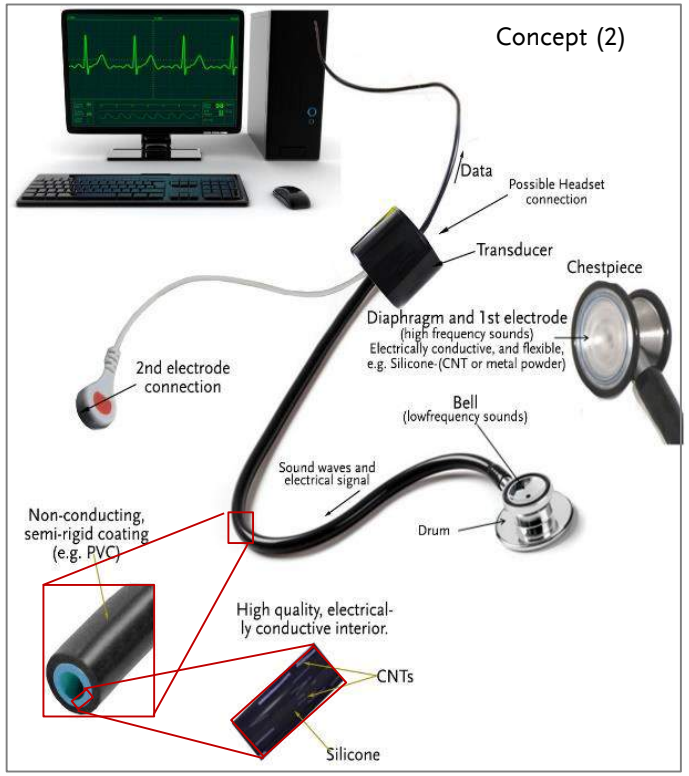
1. Introduction
2. State-of-the-art
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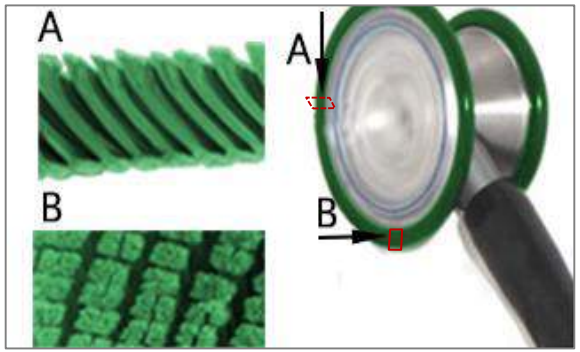


Exemplificative Solutions

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5. Future Work
6. Conclusions







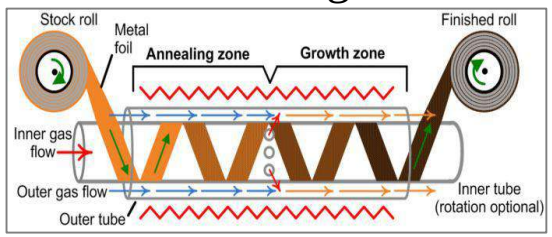
*[89-93]

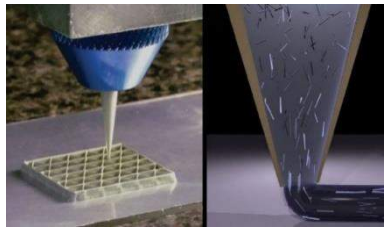
Suggested Future Work

1. Introduction
2. State-of-the-art
3. Challenges
4. Methods
5. **Future Work**
6. Conclusions

16min

- Manufacturing





[23,24]

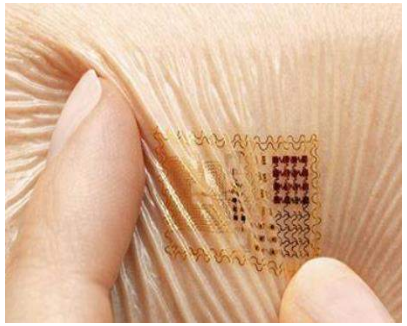
- Civil-Engineering Applications



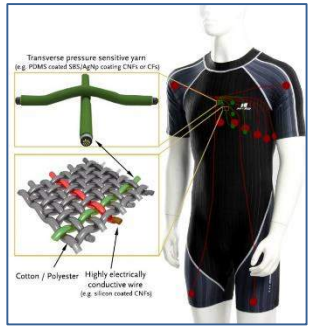


[97,98]

- For Medical Applications

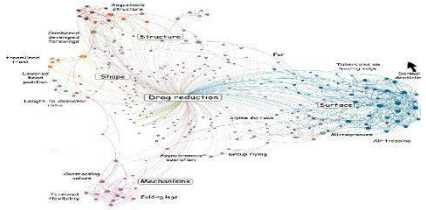


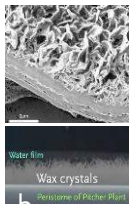


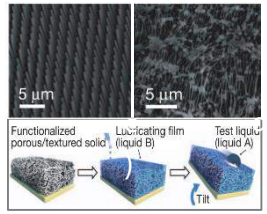


[88-90,101,102]

- AI-based bio-inspiration







*[94-96]

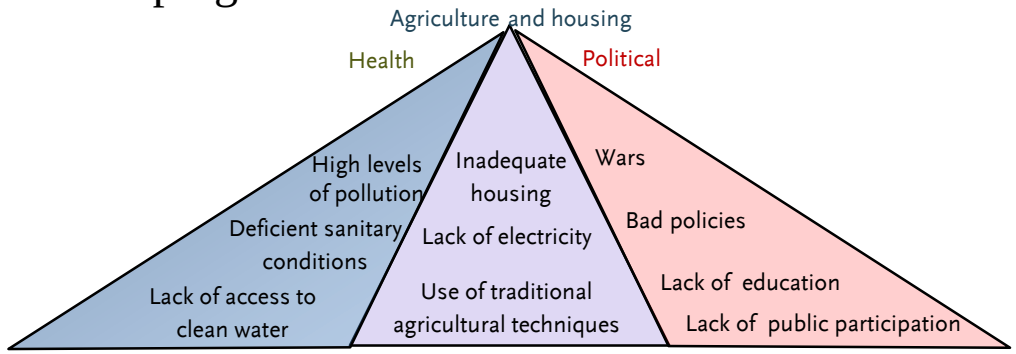
- In Transportation





[99,100]

- Helping Those in Greater Need



Final Remarks

1. Introduction
2. State-of-the-art
3. Challenges
4. Methods
5. Future Work
6. **Conclusions**

17,5min

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