Imperial College
London

Materials and Manufacturing

Application of advanced materials

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Module leader

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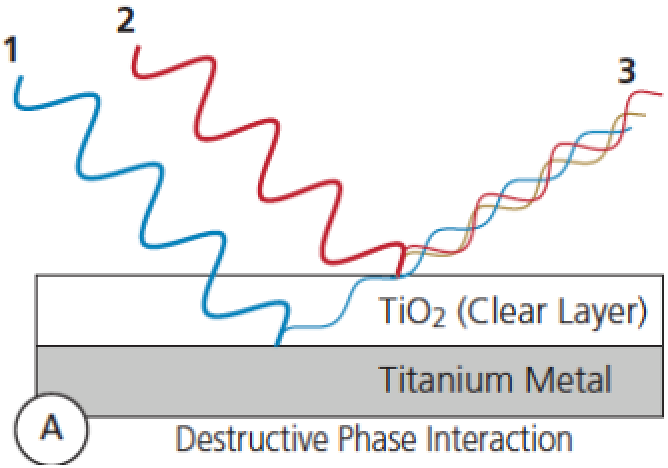
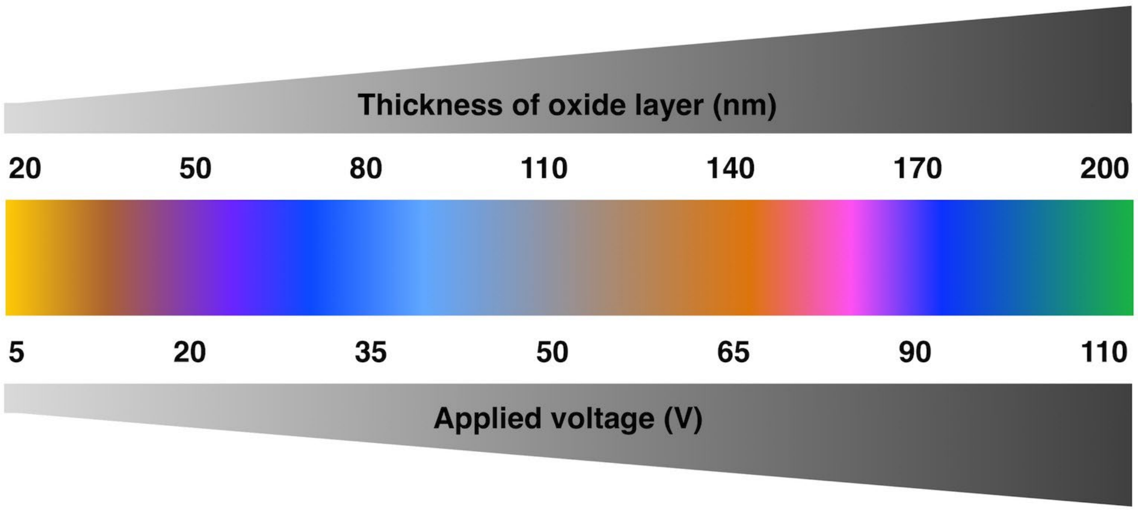
Dyson School of
Design Engineering

Titanium colours

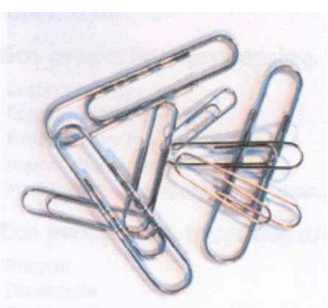


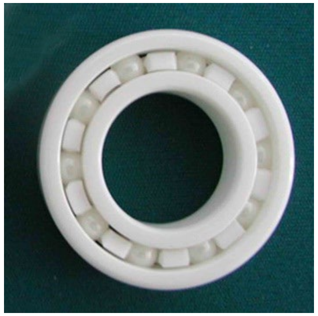


Last time on M&M…

Engineering materials

- **Metals & Alloys**
  - **Ferrous**: e.g. Steels, Stainless steels, Cast irons
  - **Nonferrous**: e.g. Aluminium, Copper, Titanium, Tungsten
- **Plastics**
  - **Thermoplastics**: e.g. Polyethylene, PVC, Nylons, Acrylics
  - **Thermosets**: e.g. Epoxies, Phenolics, Polyimides
  - **Elastomers**: e.g. Rubbers, Silicones, Polyurethanes
- **Ceramics & Glasses**: e.g. Oxides, Nitrides, Carbides, Glass ceramics, Graphite
- **Composites**: e.g. Polymer matrix, Metal-matrix, Ceramic-matrix, Sandwich





Learning objectives

- Appreciate how materials and design link together
- Look at innovative applications of materials
- Gain an appreciation of the applications of materials at the cutting edge
- Have visibility of new material developments and where they might go

Transilience map

4 types of innovations

Disruptive Innovation

Disrupts exiting links
Creates new links

Niche creation
(adapt to new market)
Re-design for another market

Architectural
(new technology, new markets)
Automobile vs horse drawn cart

Entrenches existing competencies

Disrupts existing competencies

Regular
(incremental development)
Faster computer processor

Revolutionary
(new technology, established market)
MP3 vs minidisc

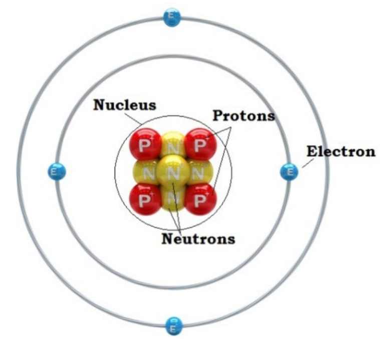
Conserves existing links

Market and consumer links

Observation Innovation

Technology and production issues

The elemental library



Key

29 — Atomic number
Cu — Symbol
63.54 — Atomic weight

Metal

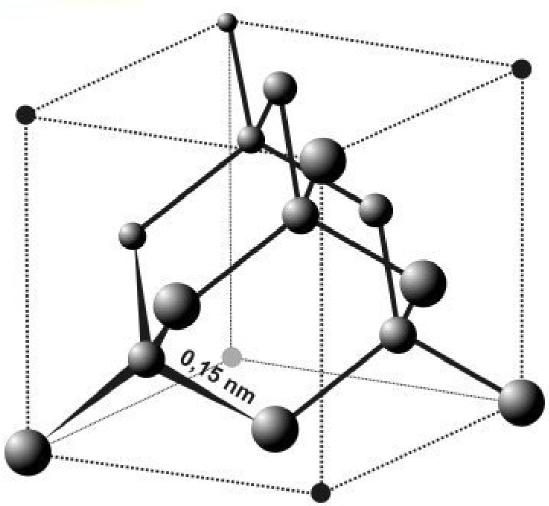
Nonmetal

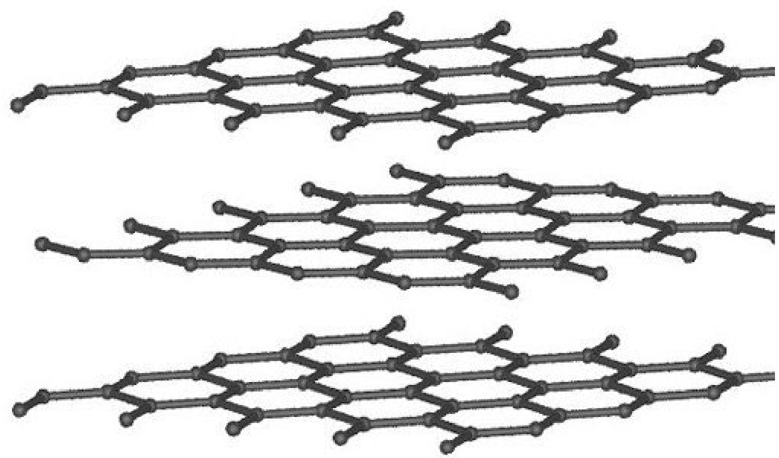
Intermediate

IA	IIA	IIIB	IVB	VB	VIB	VIIB	VIII	VIII	VIII	IB	IIB	IIIA	IVA	VA	VIA	VIIA	0
1 H 1.0080																	2 He 4.0026
3 Li 6.941	4 Be 9.0122											5 B 10.811	6 C 12.011	7 N 14.007	8 O 15.999	9 F 18.998	10 Ne 20.180
11 Na 22.990	12 Mg 24.305											13 Al 26.982	14 Si 28.086	15 P 30.974	16 S 32.064	17 Cl 35.453	18 Ar 39.948
19 K 39.098	20 Ca 40.08	21 Sc 44.956	22 Ti 47.87	23 V 50.942	24 Cr 51.996	25 Mn 54.938	26 Fe 55.845	27 Co 58.933	28 Ni 58.69	29 Cu 63.54	30 Zn 65.41	31 Ga 69.72	32 Ge 72.64	33 As 74.922	34 Se 78.96	35 Br 79.904	36 Kr 83.80
37 Rb 85.47	38 Sr 87.62	39 Y 88.91	40 Zr 91.22	41 Nb 92.91	42 Mo 95.94	43 Tc (98)	44 Ru 101.07	45 Rh 102.91	46 Pd 106.4	47 Ag 107.87	48 Cd 112.41	49 In 114.82	50 Sn 118.71	51 Sb 121.76	52 Te 127.60	53 I 126.90	54 Xe 131.30
55 Cs 132.91	56 Ba 137.34	Rare earth series	72 Hf 178.49	73 Ta 180.95	74 W 183.84	75 Re 186.2	76 Os 190.23	77 Ir 192.2	78 Pt 195.08	79 Au 196.97	80 Hg 200.59	81 Tl 204.38	82 Pb 207.19	83 Bi 208.98	84 Po (209)	85 At (210)	86 Rn (222)
87 Fr (223)	88 Ra (226)	Acti-nide series	104 Rf (261)	105 Db (262)	106 Sg (266)	107 Bh (264)	108 Hs (277)	109 Mt (268)	110 Ds (281)								

Rare earth series	57 La 138.91	58 Ce 140.12	59 Pr 140.91	60 Nd 144.24	61 Pm (145)	62 Sm 150.35	63 Eu 151.96	64 Gd 157.25	65 Tb 158.92	66 Dy 162.50	67 Ho 164.93	68 Er 167.26	69 Tm 168.93	70 Yb 173.04	71 Lu 174.97
Actinide series	89 Ac (227)	90 Th 232.04	91 Pa 231.04	92 U 238.03	93 Np (237)	94 Pu (244)	95 Am (243)	96 Cm (247)	97 Bk (247)	98 Cf (251)	99 Es (252)	100 Fm (257)	101 Md (258)	102 No (259)	103 Lr (262)

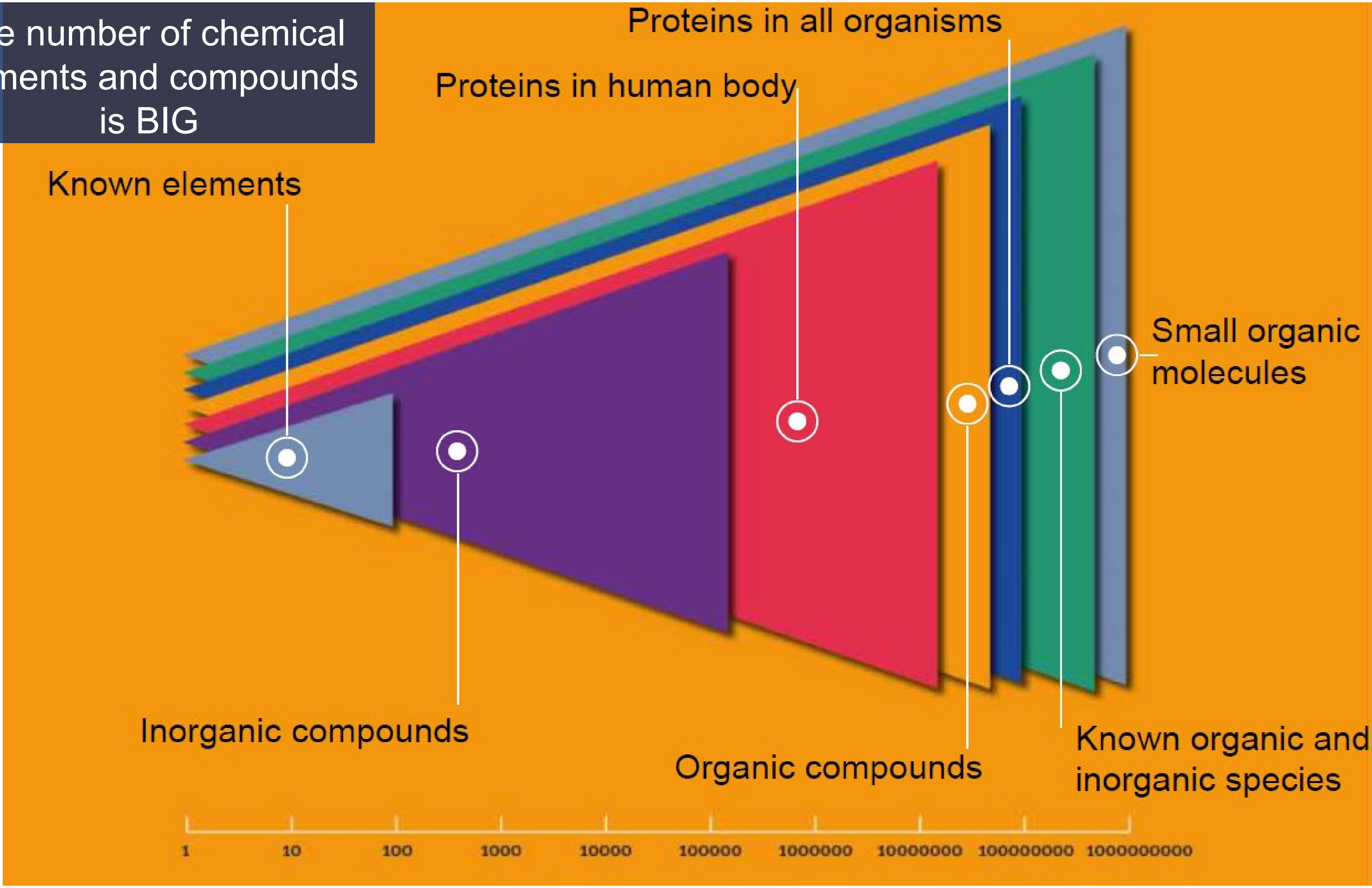
Structure matters





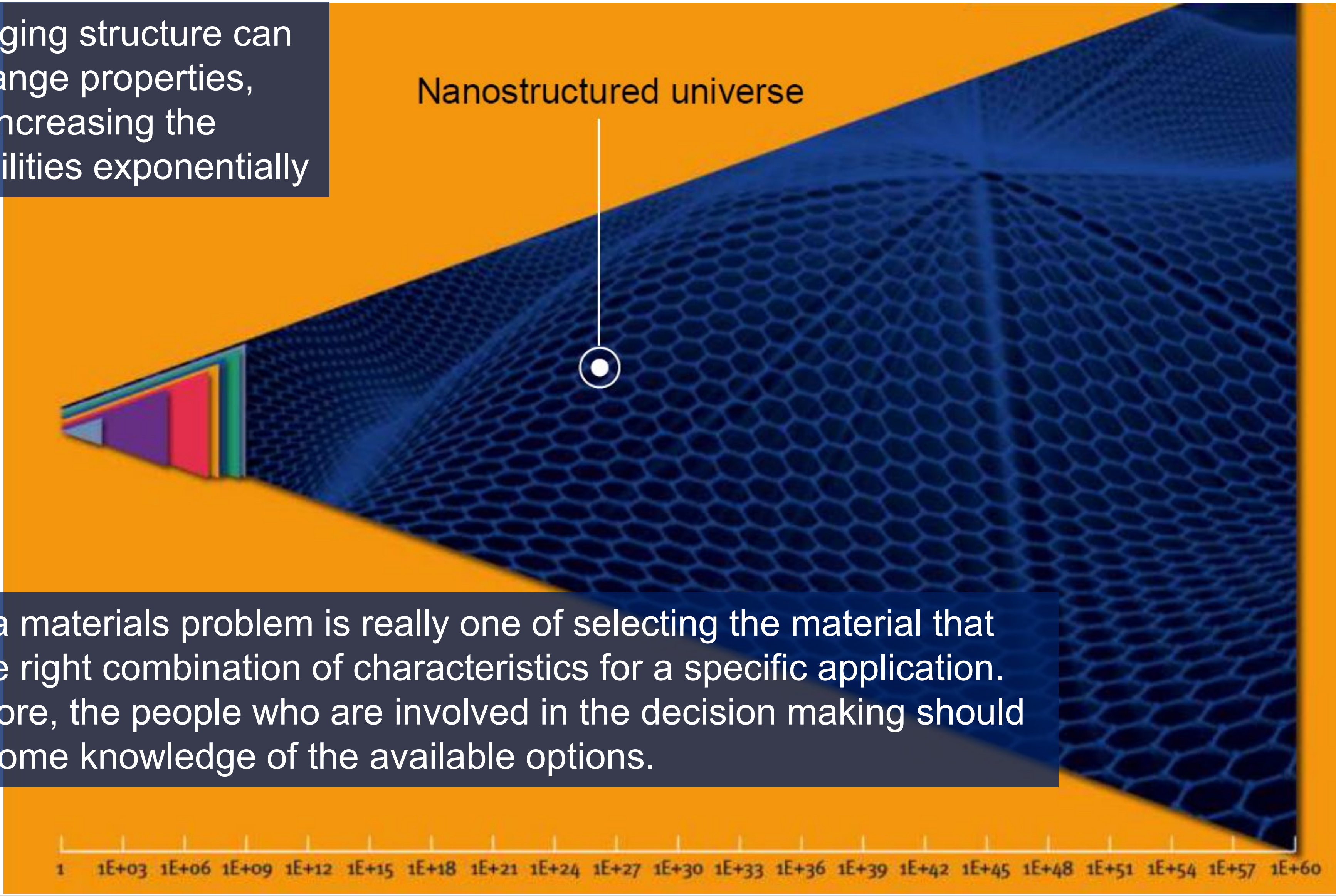
Combining elements

The number of chemical elements and compounds is BIG



Periodic hypertable

Changing structure can change properties, increasing the possibilities exponentially



Often a materials problem is really one of selecting the material that has the right combination of characteristics for a specific application. Therefore, the people who are involved in the decision making should have some knowledge of the available options.

Materials in the design process

Technical Design

100,000 materials

Create limits for mechanical, thermal, and other technical attributes:

10-50 materials

Model technical performance and evaluate results:

5-10 materials

Create working prototypes, virtual and real, based on a detailed CAD database:

1 or 2 materials

Limited understanding of material options

Increasing knowledge of possible materialization of the product

Final selection of material(s) and manufacturing process(es)

Industrial Design

100,000 materials

Outline desired aesthetics, behavior, perception and association:

10-50 materials

Explore sample collections, looking at analagous products and experiences:

5-10 materials

Create surface prototypes by 3D visualization in a digital file:

1 or 2 materials

Evolution of materials and design

- Electric hairdryers became popular around 1945
- Early hairdryers were made fro zinc die castings or pressed steel sheets
  - Heavy and bulky
  - Needed insulation to prevent burns and electrocution
- Engineering dominated by the "metal mentality"
- Polymer development (Bakelite led to plastic handles and casings
  - Fewer fasteners were needed (snap fits)
  - More variations possible over aesthetics
- Design innovations were underpinned by new material developments

Evolution of materials and design

Kettles







Cameras

Linking materials and design

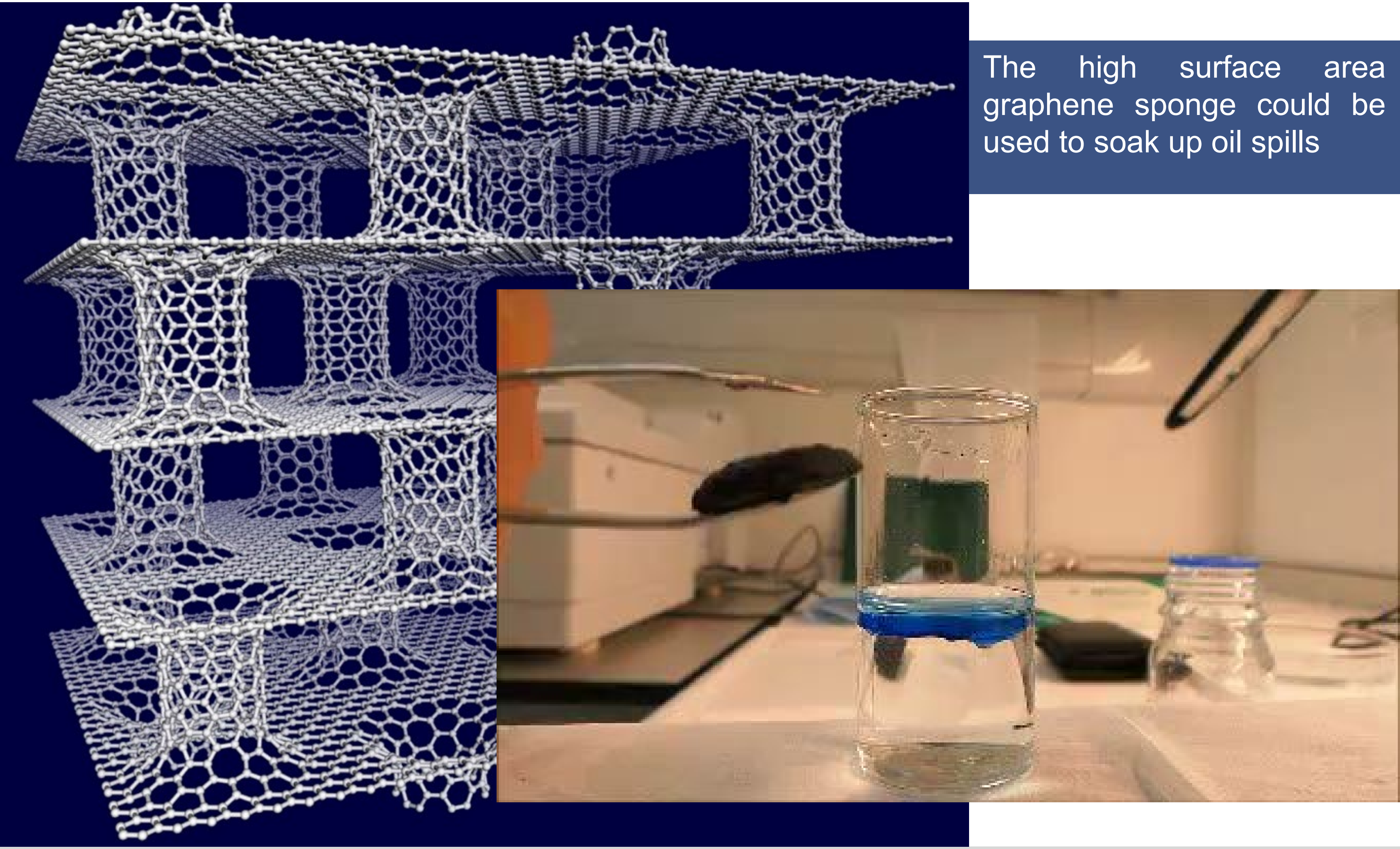
Materials in aerospace

- Wright brothers flew the first plane in 1903
- Originally built with spruce and ash wood with muslin coverings over the wings
- Materials progressed then to aluminium and steel
- Engineers then started working on composites in the mid 1960's
- Carbon fibre is now used but had a tough time starting as it wasn't impact resistant enough to handle a bird strike

Wright brothers

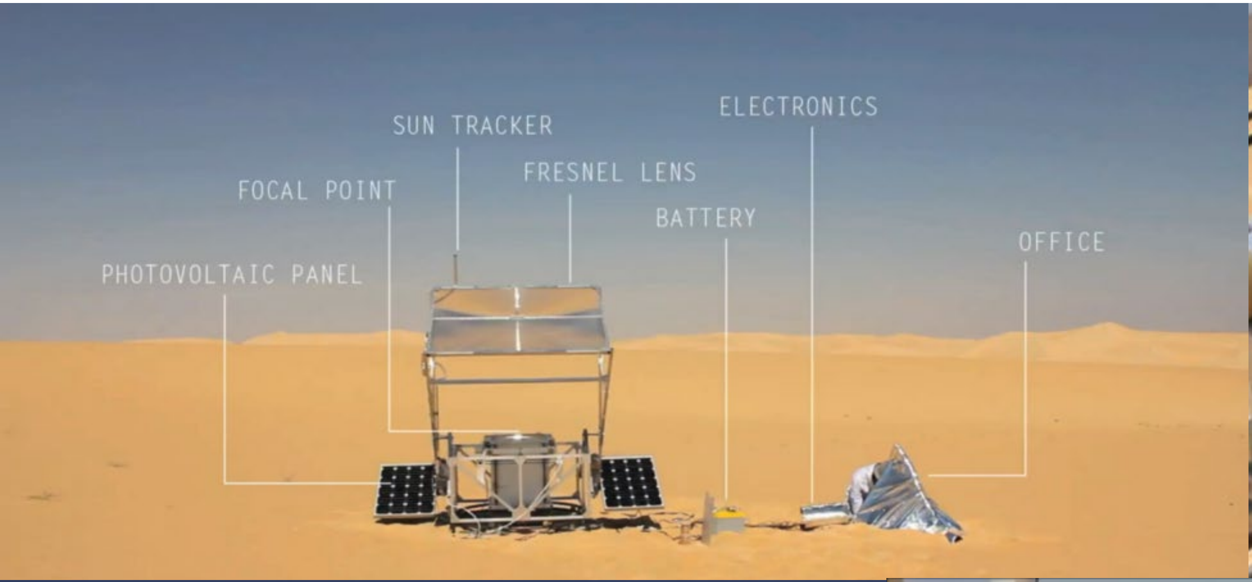
Boeing 787

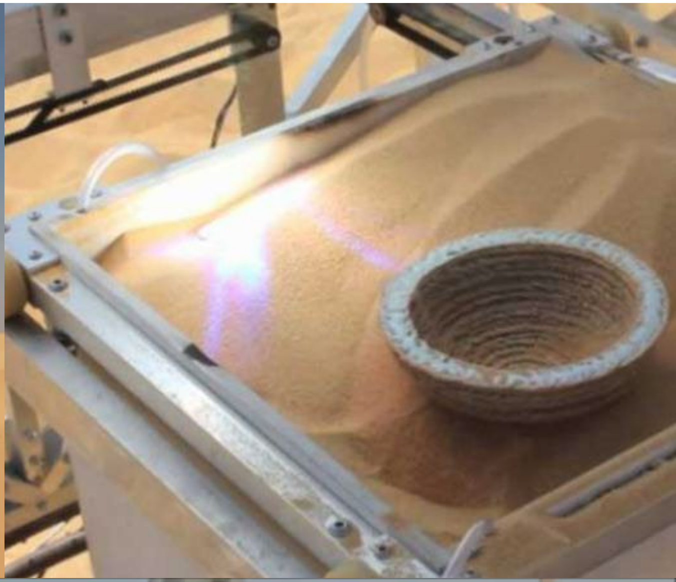
Graphene sponge



The high surface area graphene sponge could be used to soak up oil spills

Processing links to the materials

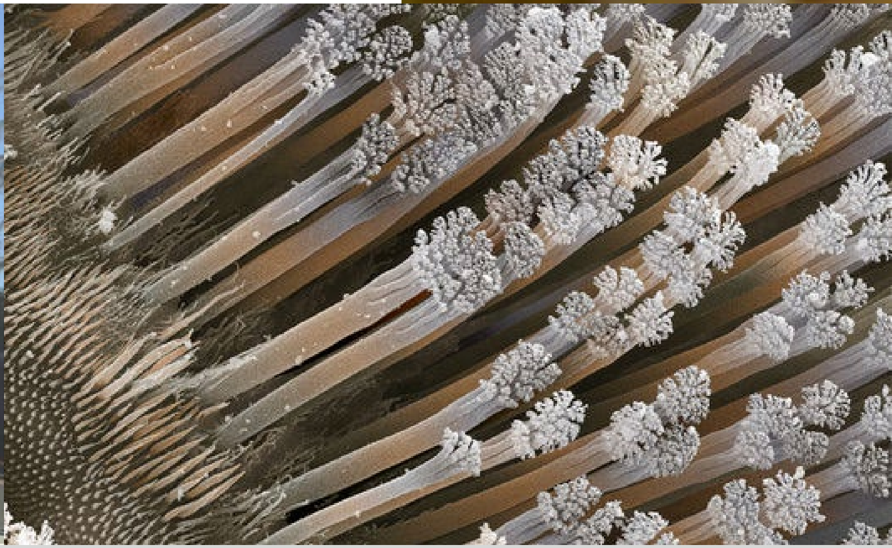




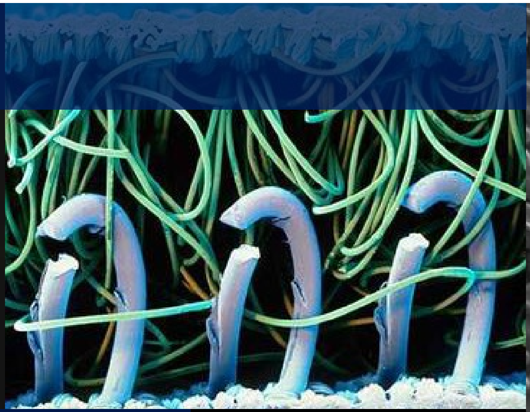
Solar sinterer
Markus Kayser et al Royal College of Art

Bio-inspired: Gecko hands

- Tiny hairs on the gecko hands gives them very high surface area
- Hairs are attracted to surfaces due to the van der Waals forces which are generated
- Means the gecko hands are ‘sticky’ without the need for an adhesive
- The Gecko removes its feet from the wall by peeling away the tiny hairs (each one providing a small amount of force)

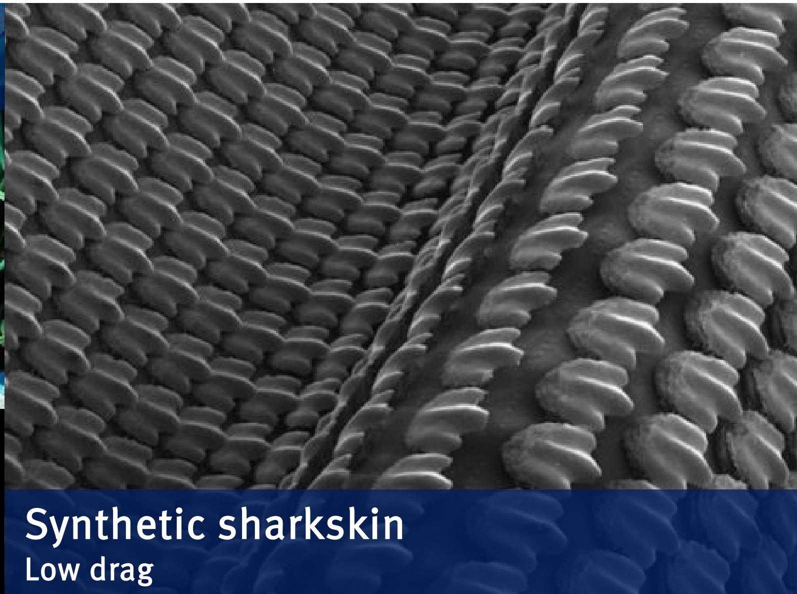


Biomimicry

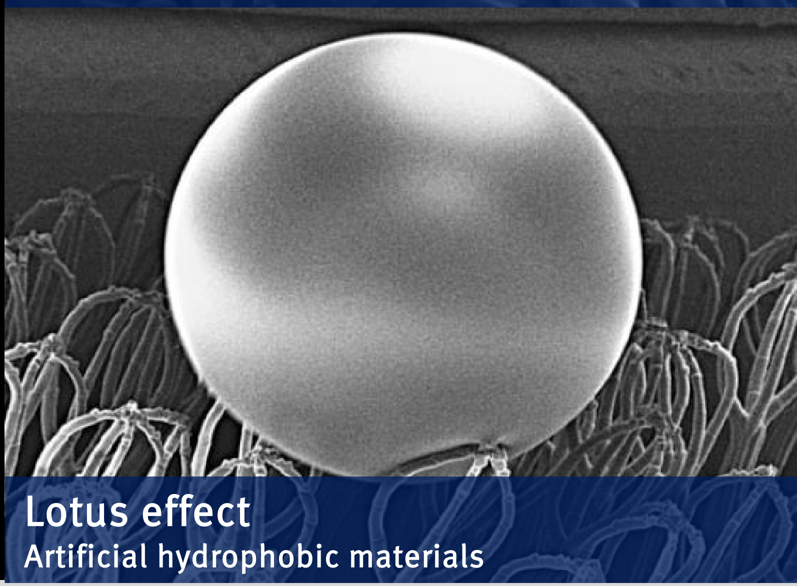


Velcro
Inspired by burs

Softworm
Shape memory alloy actuated worm

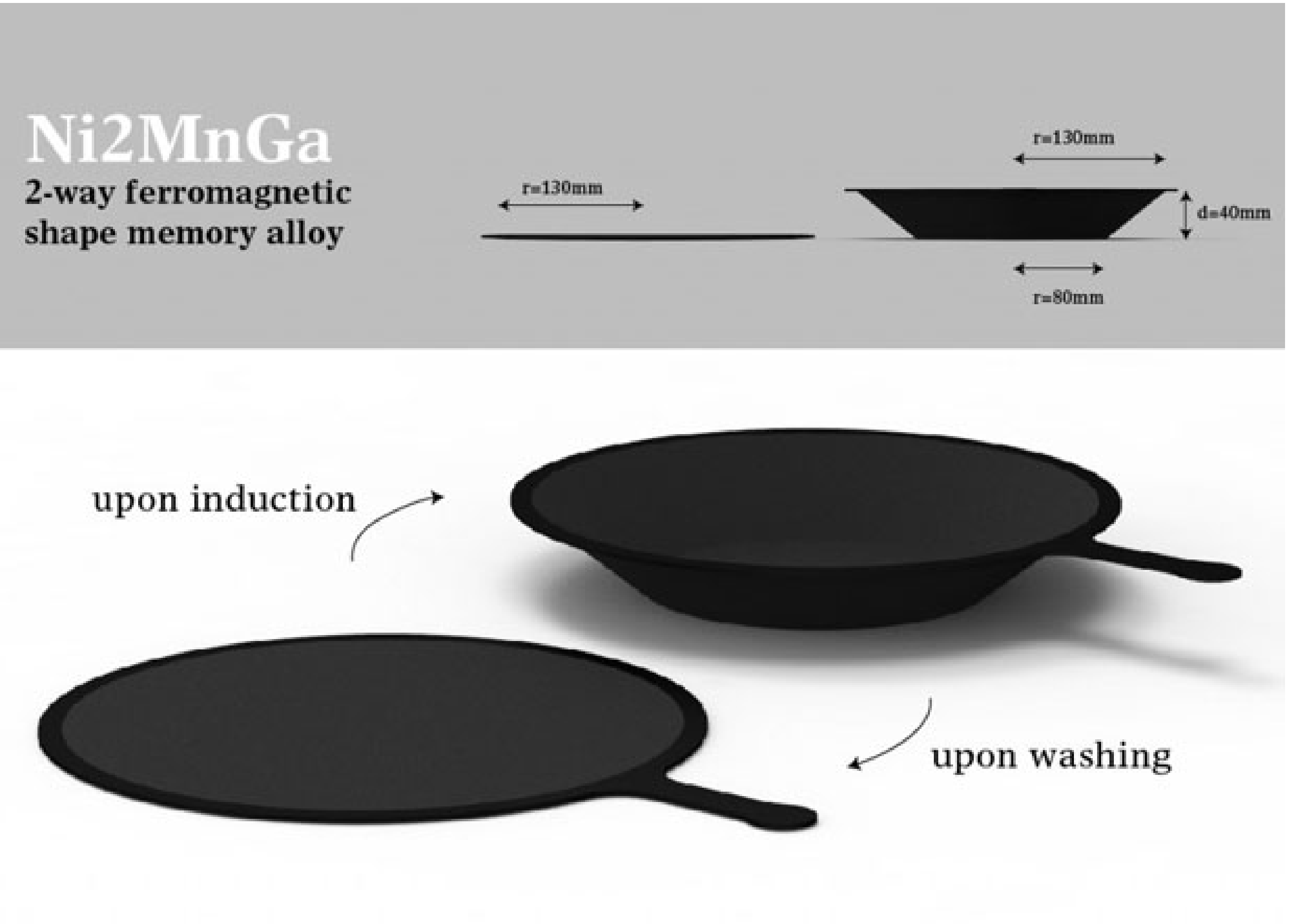


Synthetic sharkskin
Low drag



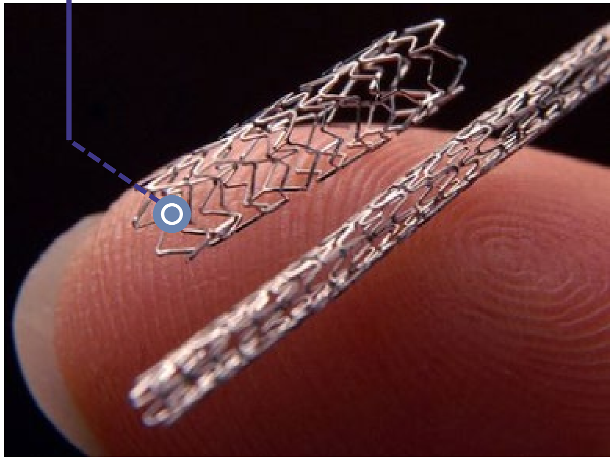
Lotus effect
Artificial hydrophobic materials

Shape memory alloys

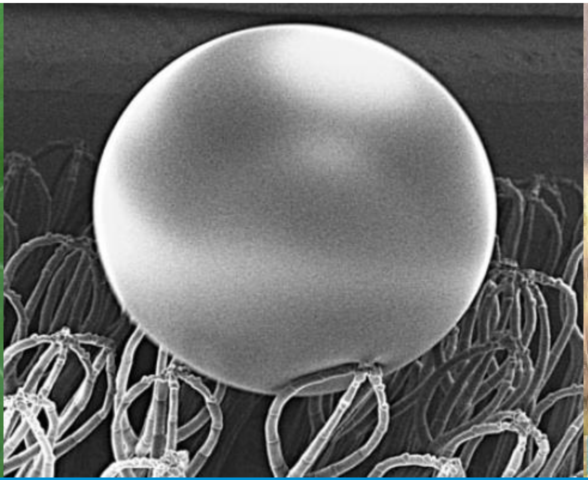


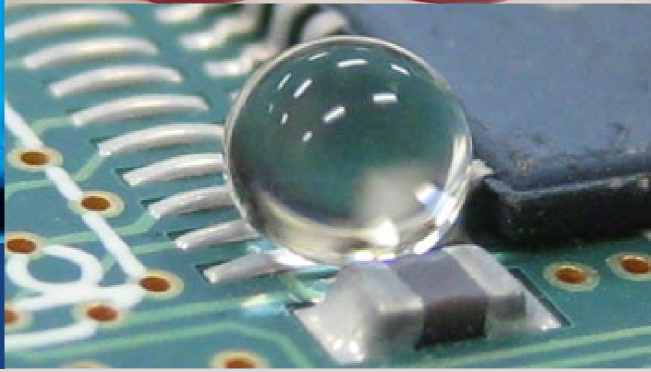
Applications

Variable geometry fan nozzles
Vibration damping
Passive actuators
Intelligently reinforced concrete
Pipe coupling



Super-hydrophobic coatings



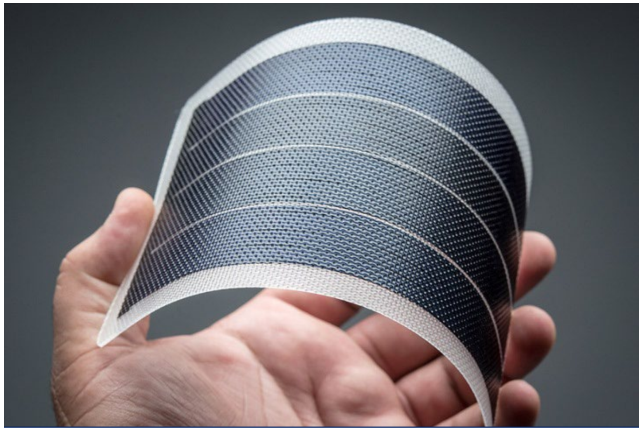


A super-hydrophobic coating is a nanoscopic surface layer that repels water

Applications of nanomaterials

Quantum nanodots for next generation TV displays

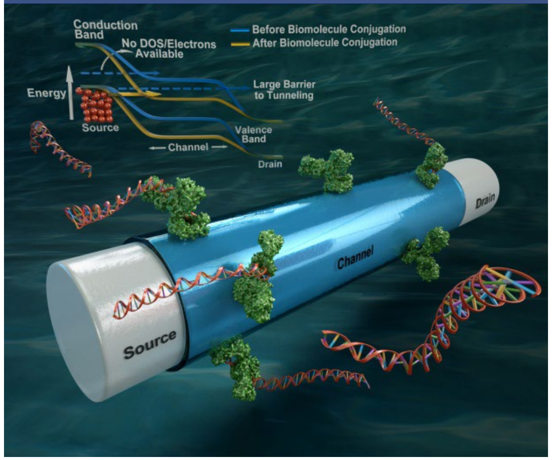
Silver chloride nanowires to decompose organic molecules for water purification



Zinc oxide nanowires for flexible solar cells

Nanocrystalline zirconia - Machinable and tough implants

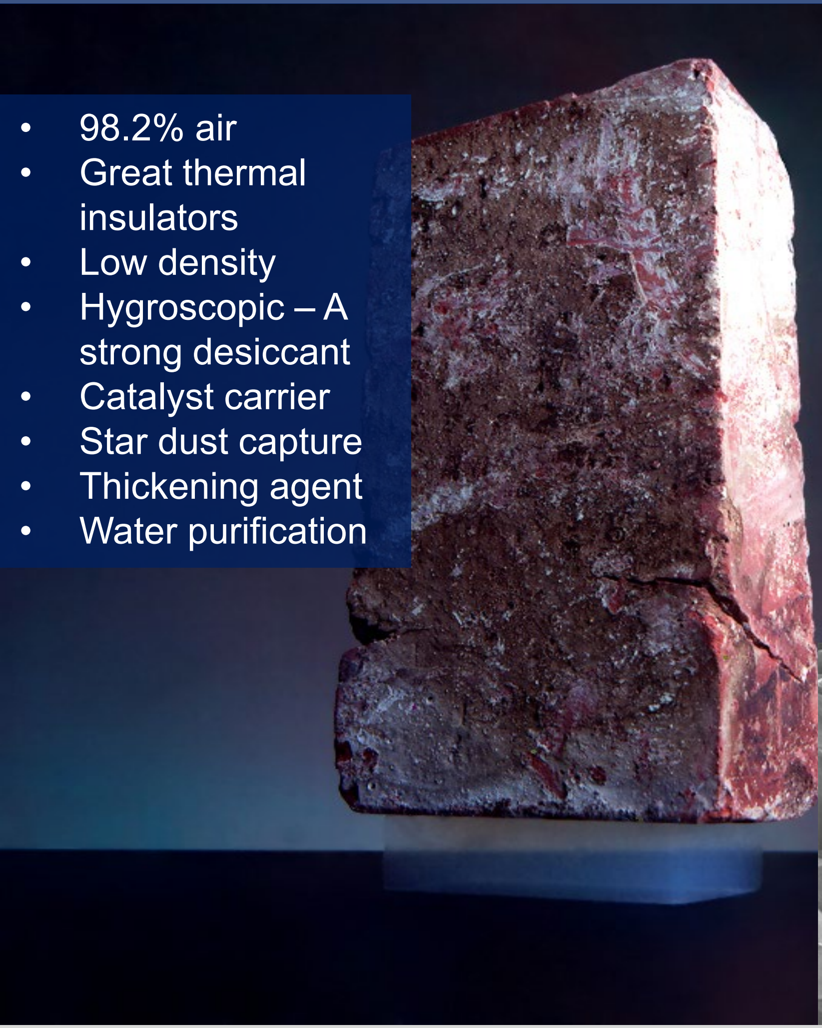
Graphene based biosensors for detecting viruses



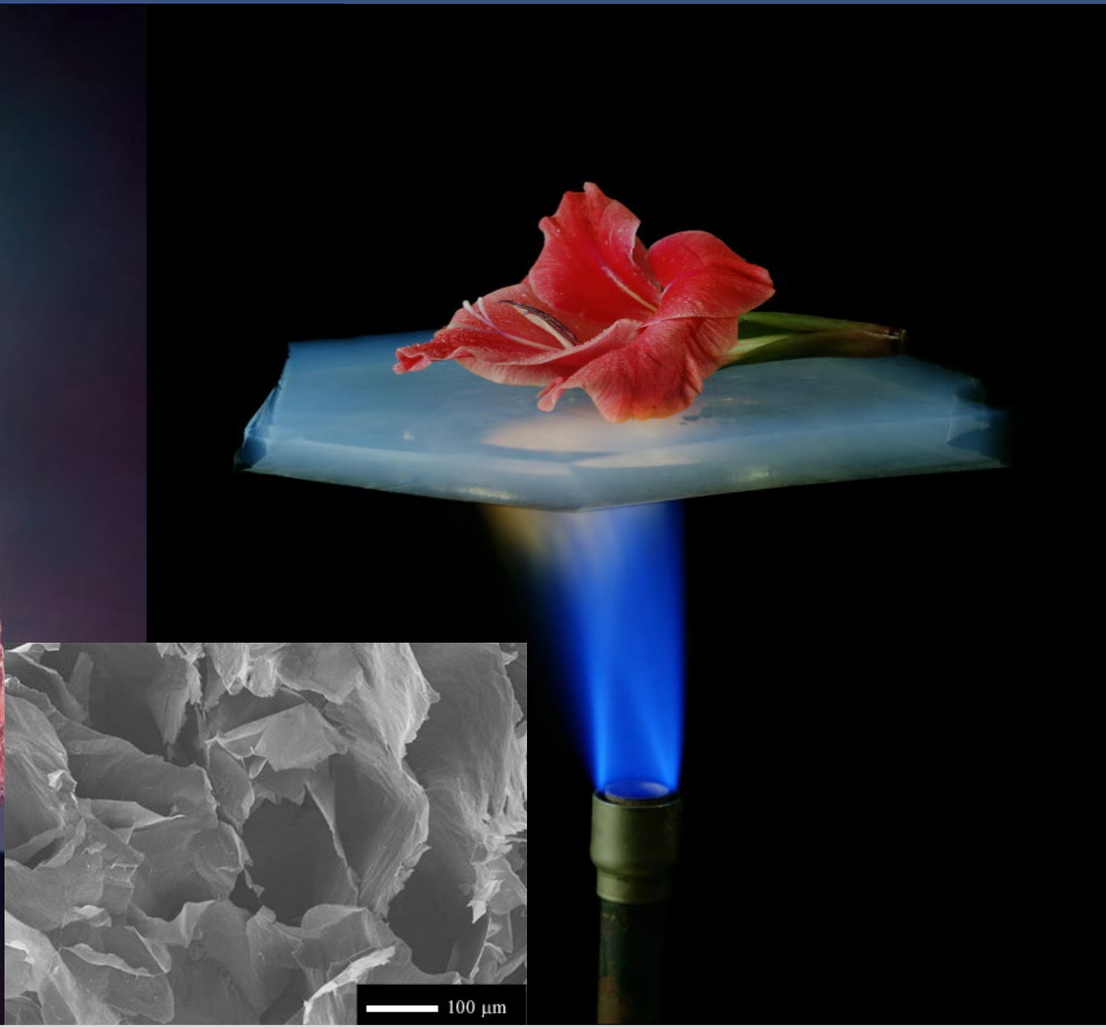
Carbon nanotubes in lithium-ion batteries for longer range electric vehicle

Aerogels

Aerogels are synthetic porous ultralight materials derived from gels but the liquid has been replaced by gas - Frozen smoke



- 98.2% air
- Great thermal insulators
- Low density
- Hygroscopic – A strong desiccant
- Catalyst carrier
- Star dust capture
- Thickening agent
- Water purification

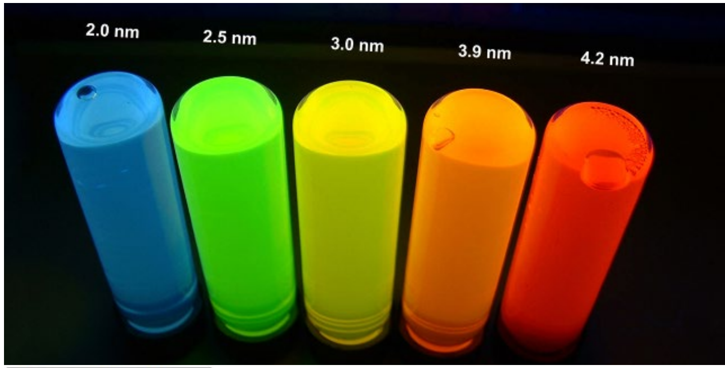


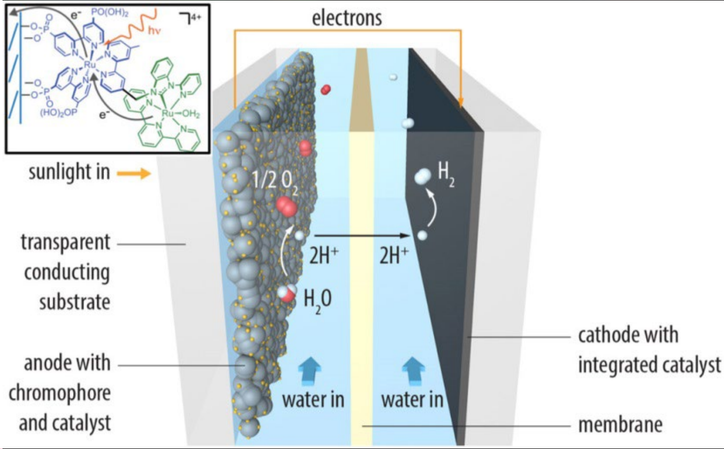
Quantum nanodots

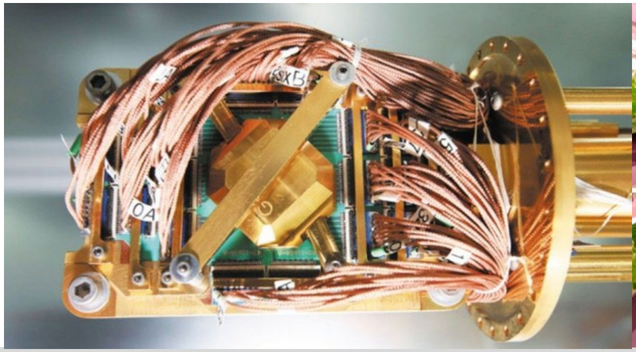
- Quantum are nanoscale semiconductor devices
  - Properties can be tuned as a function of particle size and shape
  - Photoluminescenece of a QD can manipulate wavelengths of light to control colour

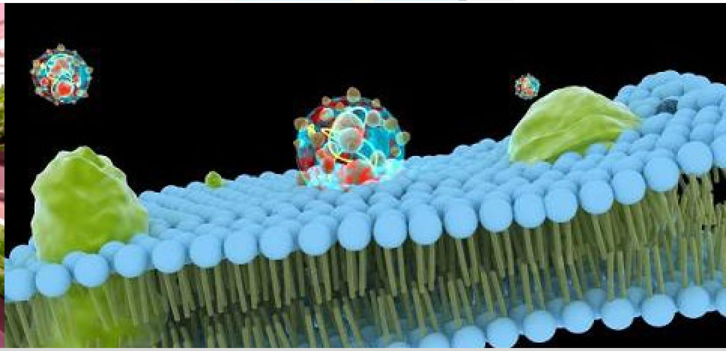
Applications

- Solar cells – Tuneable absorption spectrums
- LEDs – Naturally monochromatic
  - Removes the need for filtering
- Drug delivery – targeting cancer cells
- Photocatalysis – Light driven chemical reactions
  - Water into hydrogen – solar fuels
- Quantum computers - qubits

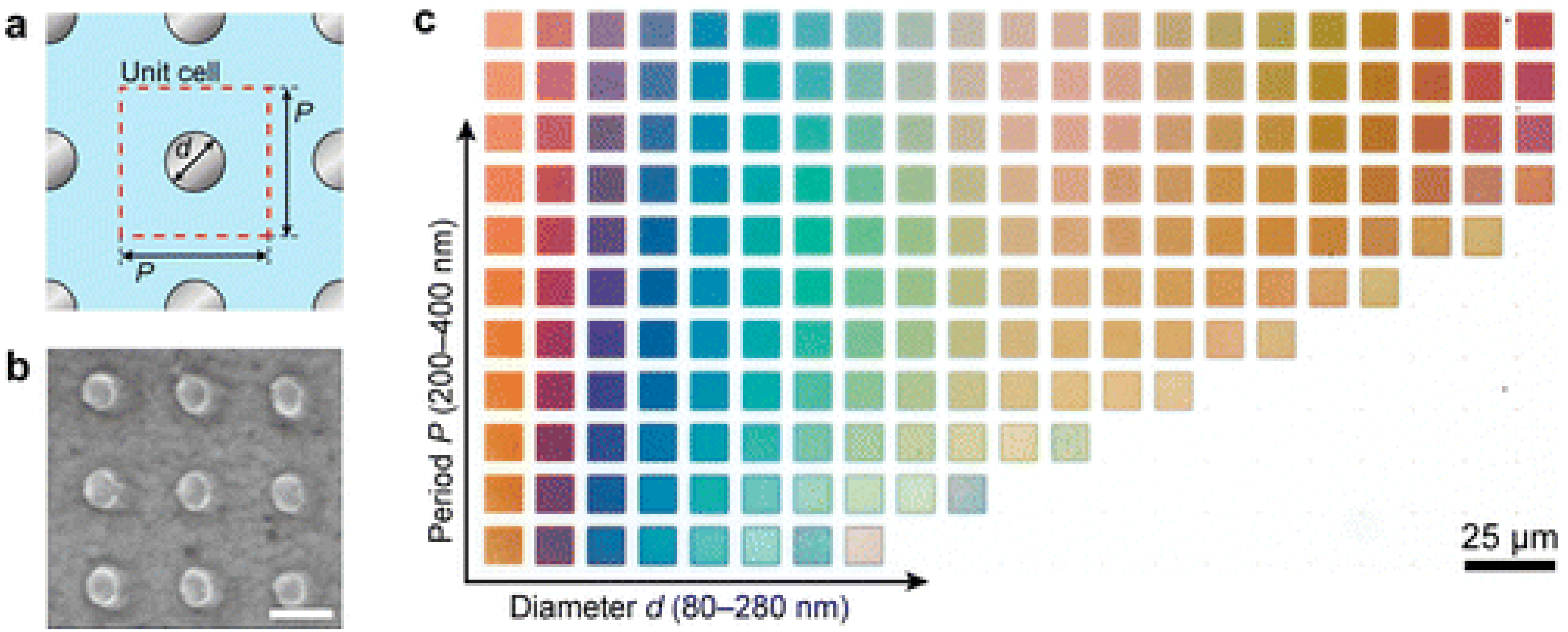






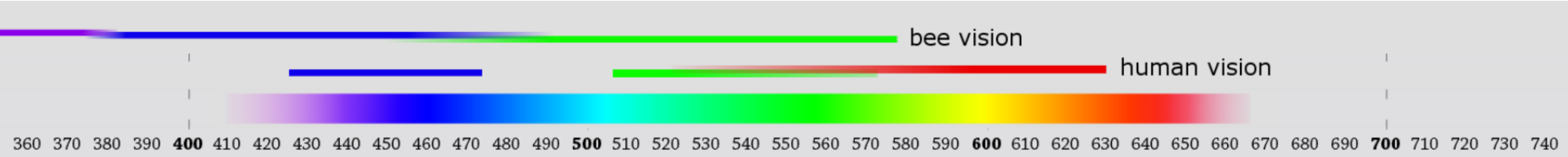


Structural colouration - Iridescence

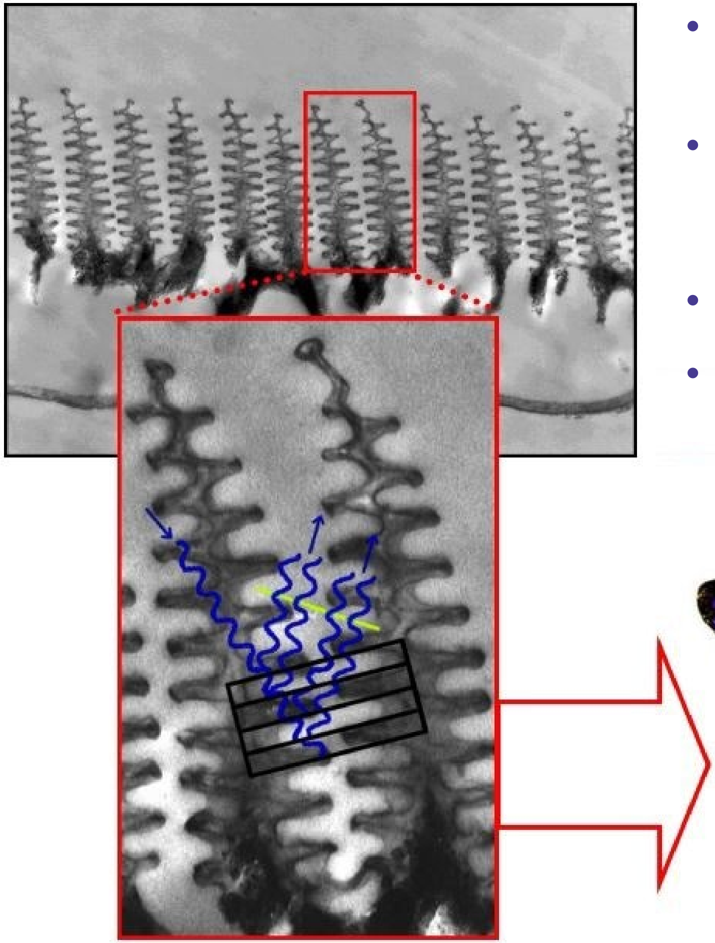


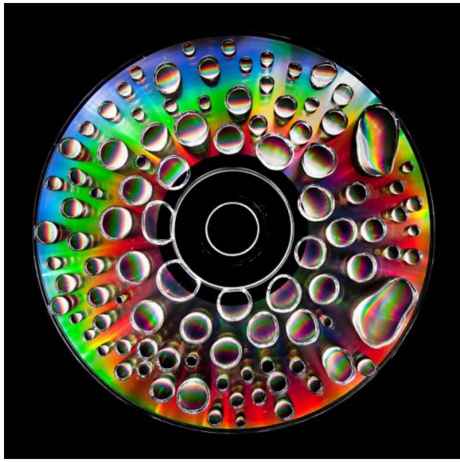
Nano Lett., **2016**, *16* (5), pp 3166–3172

Structural colouration - Iridescence



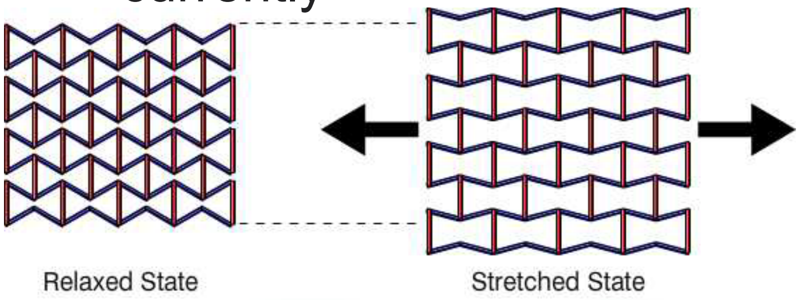
- The human eye senses light which is a wave with colour set by the wavelength
- Colours can also arise from diffraction and interference
  - Soap bubbles are colourful due to interference between light reflected at the front and back
- The structure can affect the colour due to diffraction
- **Iridescence** is due to structural colouration
  - The colour changes depending on the direction you look at it

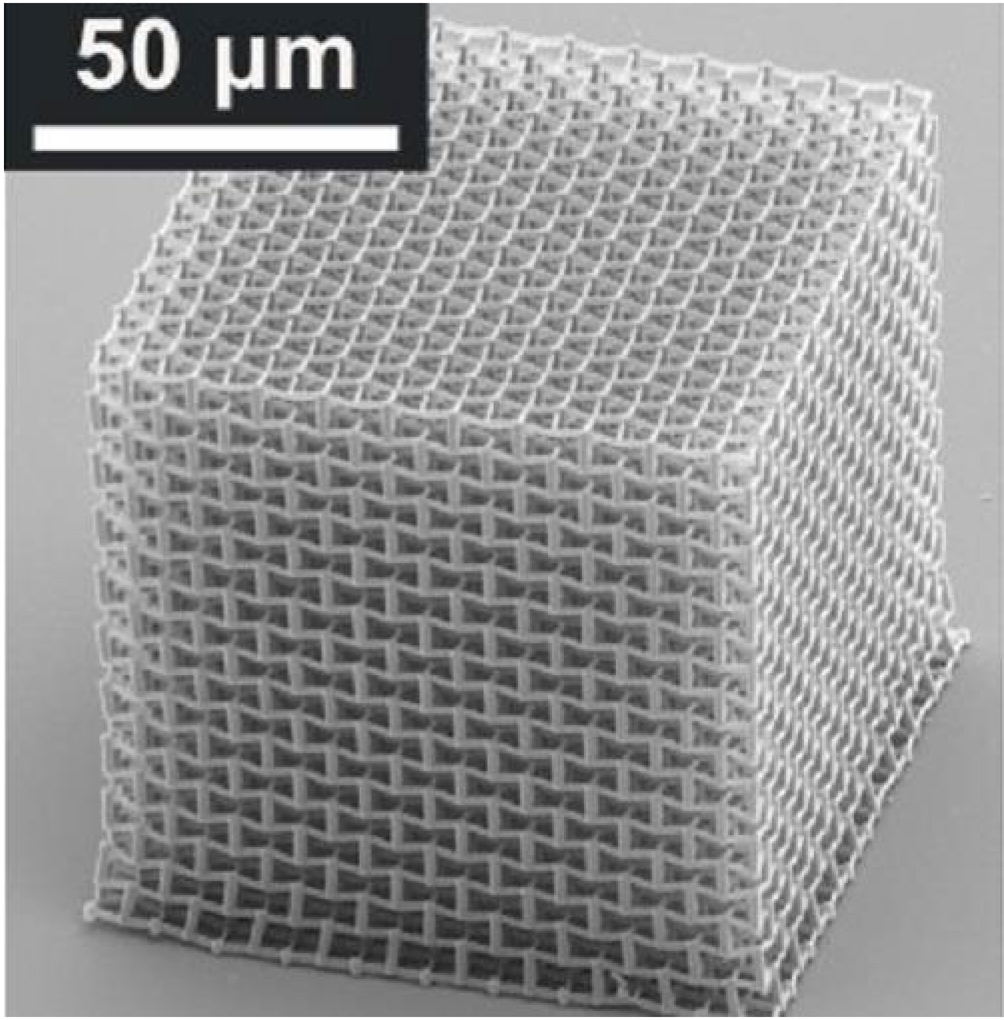




Mechanical metamaterials

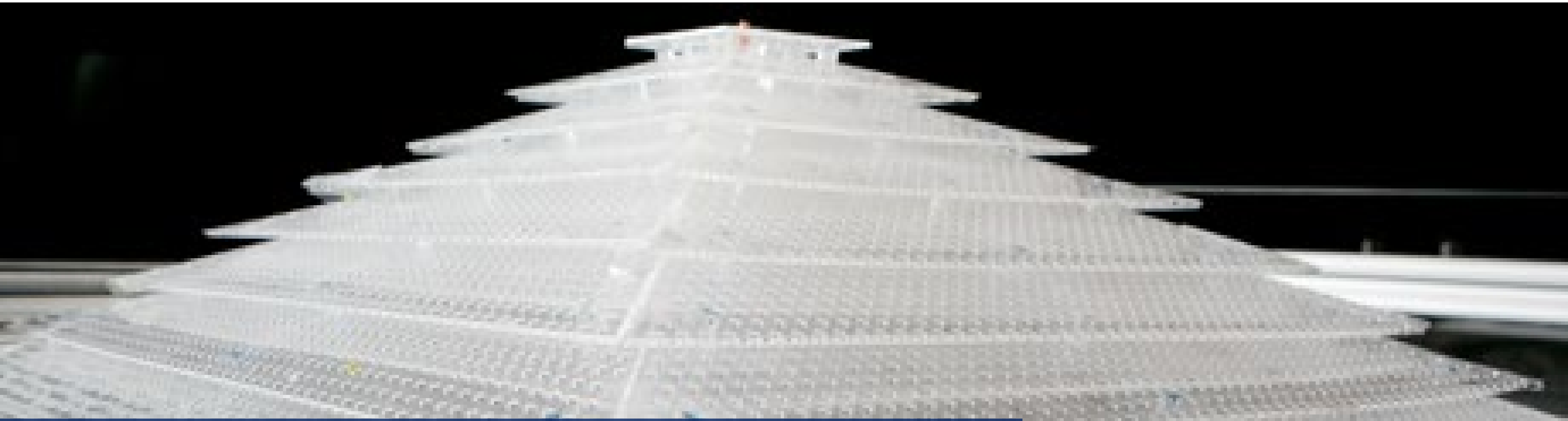
- Auxetics
- Tuneable Poisson's ratio
- Not many applications currently





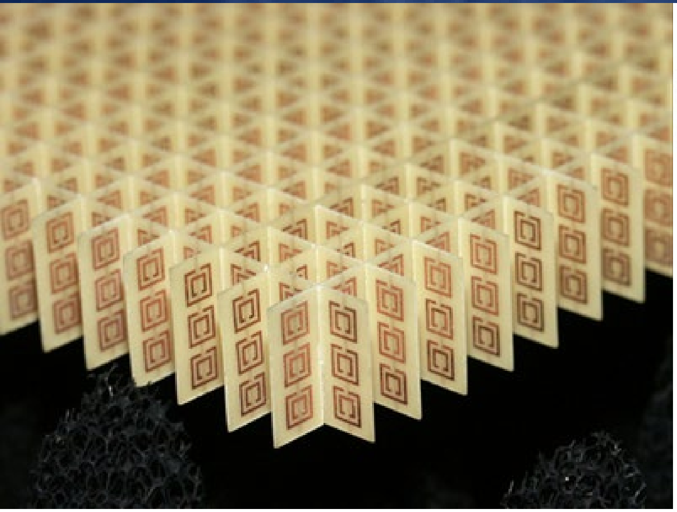
T. Bueckmann et al., Advanced Materials 24 , 2710 (2012)

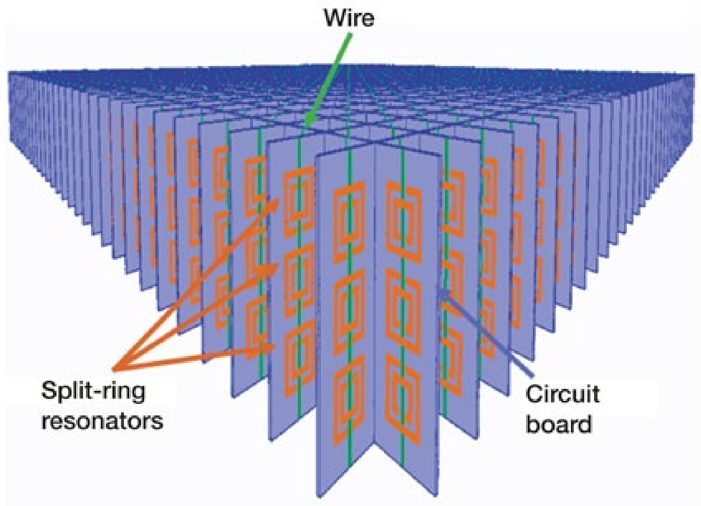
Acoustic metamaterials



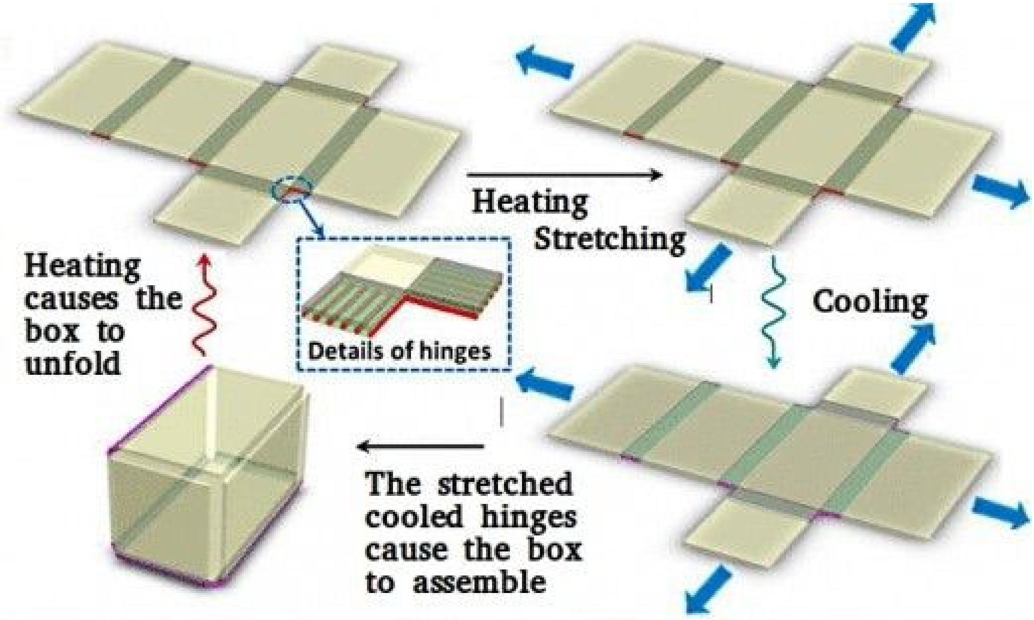
The sound of silence

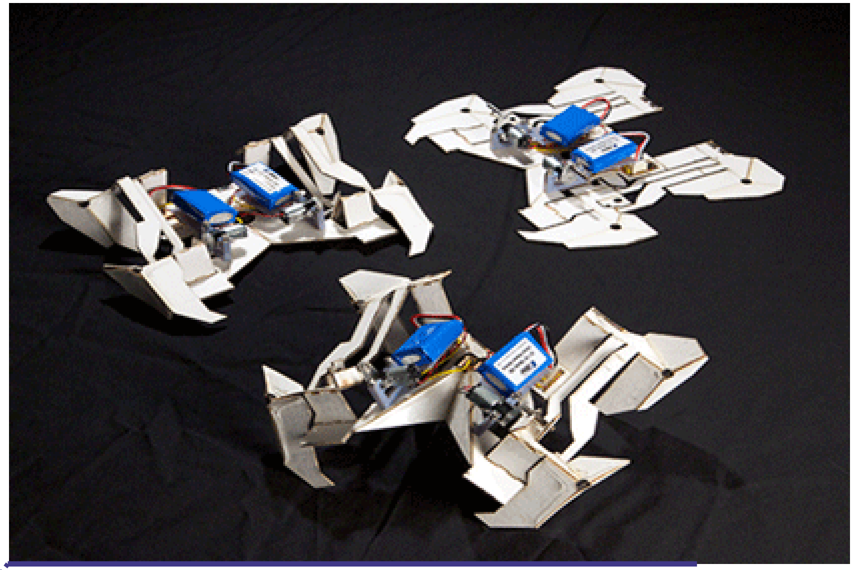
Metamaterials to absorb vibrations and for thermal management *via* phonon control





Programmable matter – Into 4D





Summary

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