UoW Made Nano-Ceramic Materials For Advanced Applications

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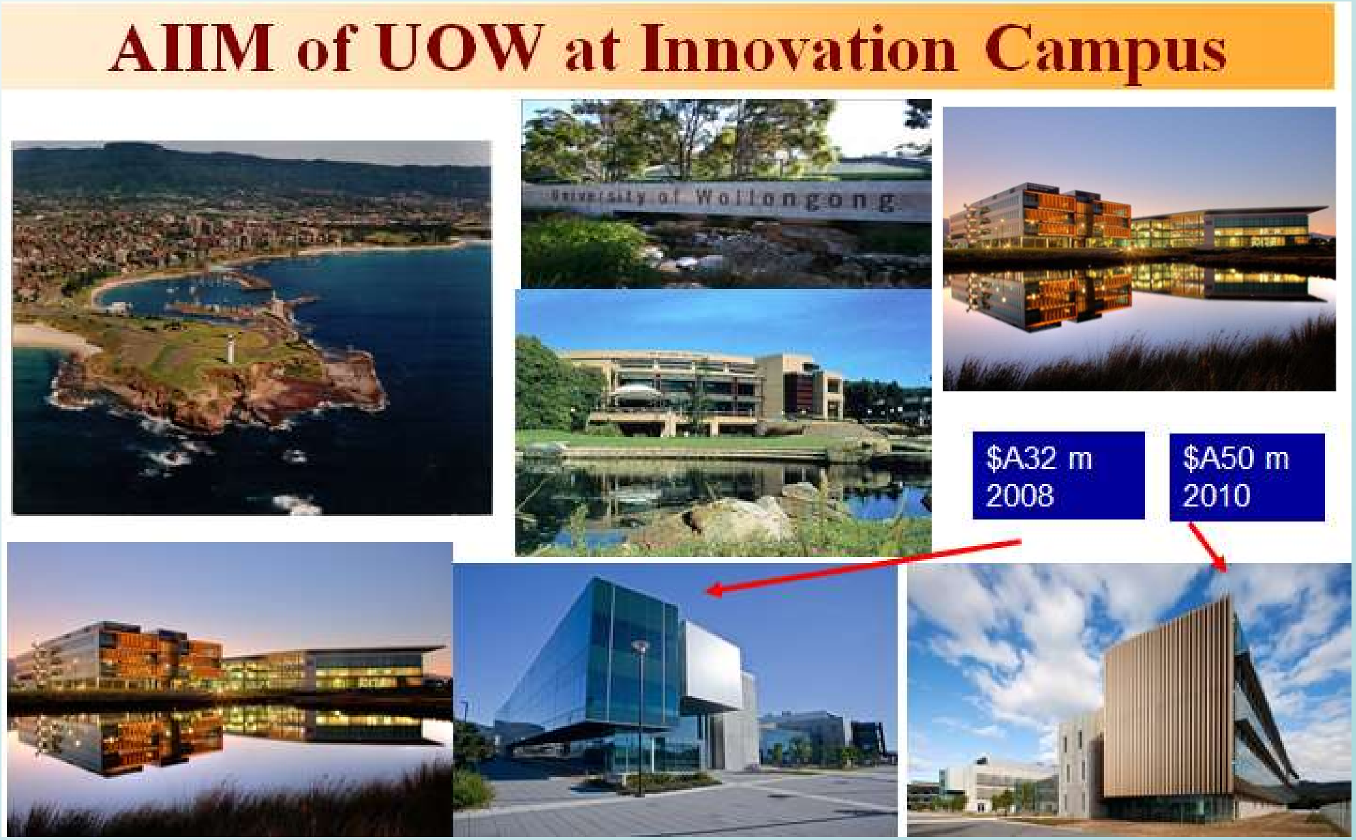
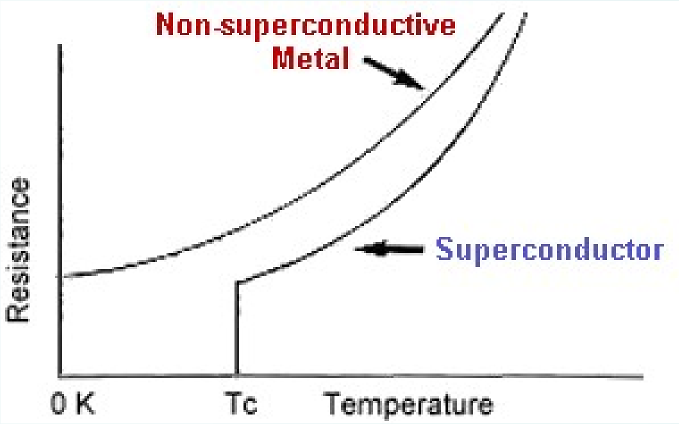
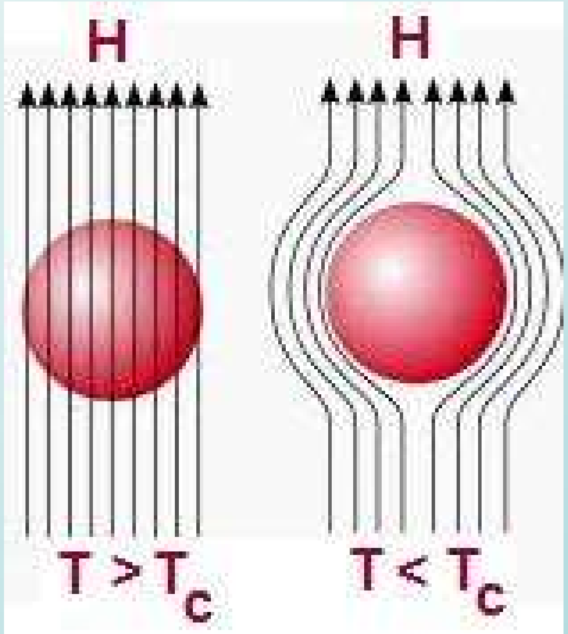


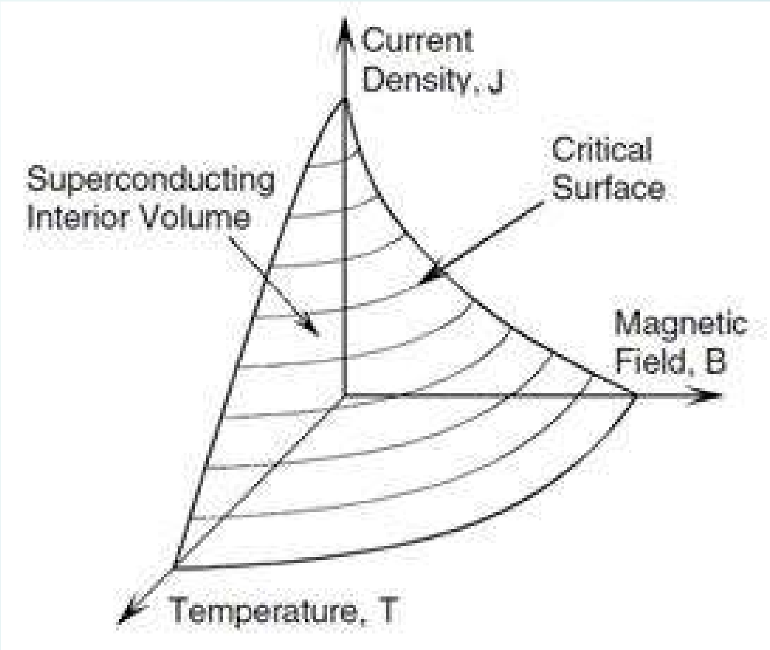
Brief overview of this talk

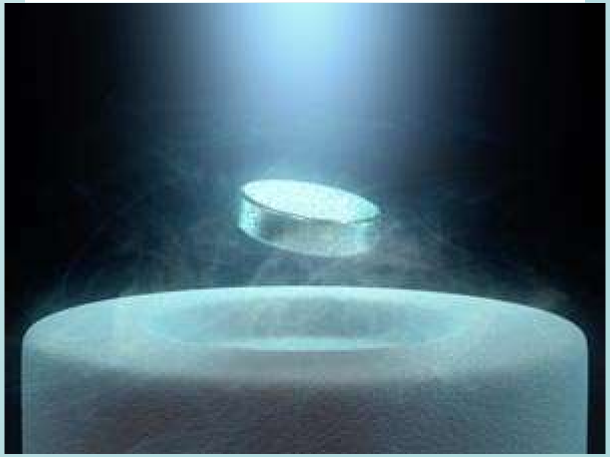
- **UoW/ISEM made superconducting ceramics**
- **Importance of the nano-structured ceramic materials, main areas of applications and examples of fabrication methods**
- **UoW advanced synthesis techniques**
- **Nanoceramics for energy storage applications. Examples of UoW/ISEM achievements in batteries and supercapacitors**
- **Nanoceramics for biomedical applications. Examples of UoW/ISEM achievements in cancer treatment and UV radiation protection.**
- **Conclusions**

High Temperature Superconducting Ceramics. Superconductivity Basics

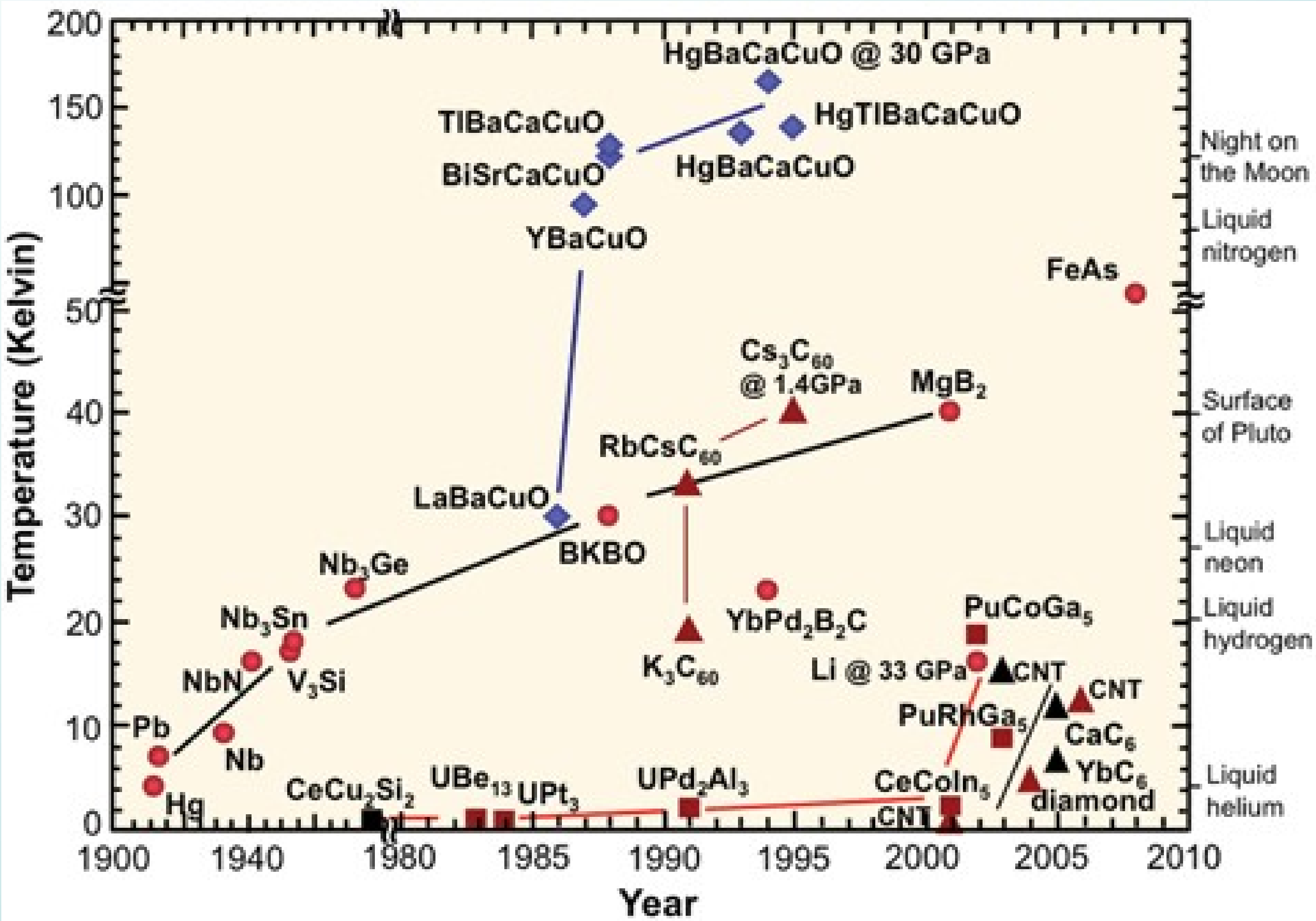








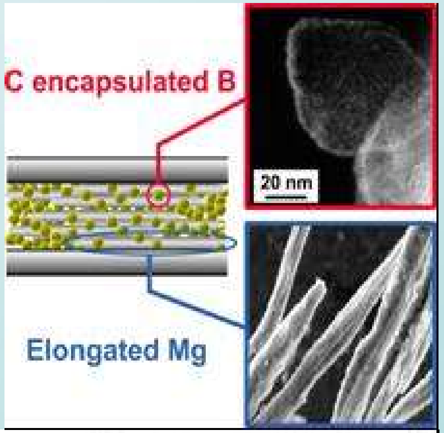
High Temperature Superconducting Ceramics. History of SC Materials

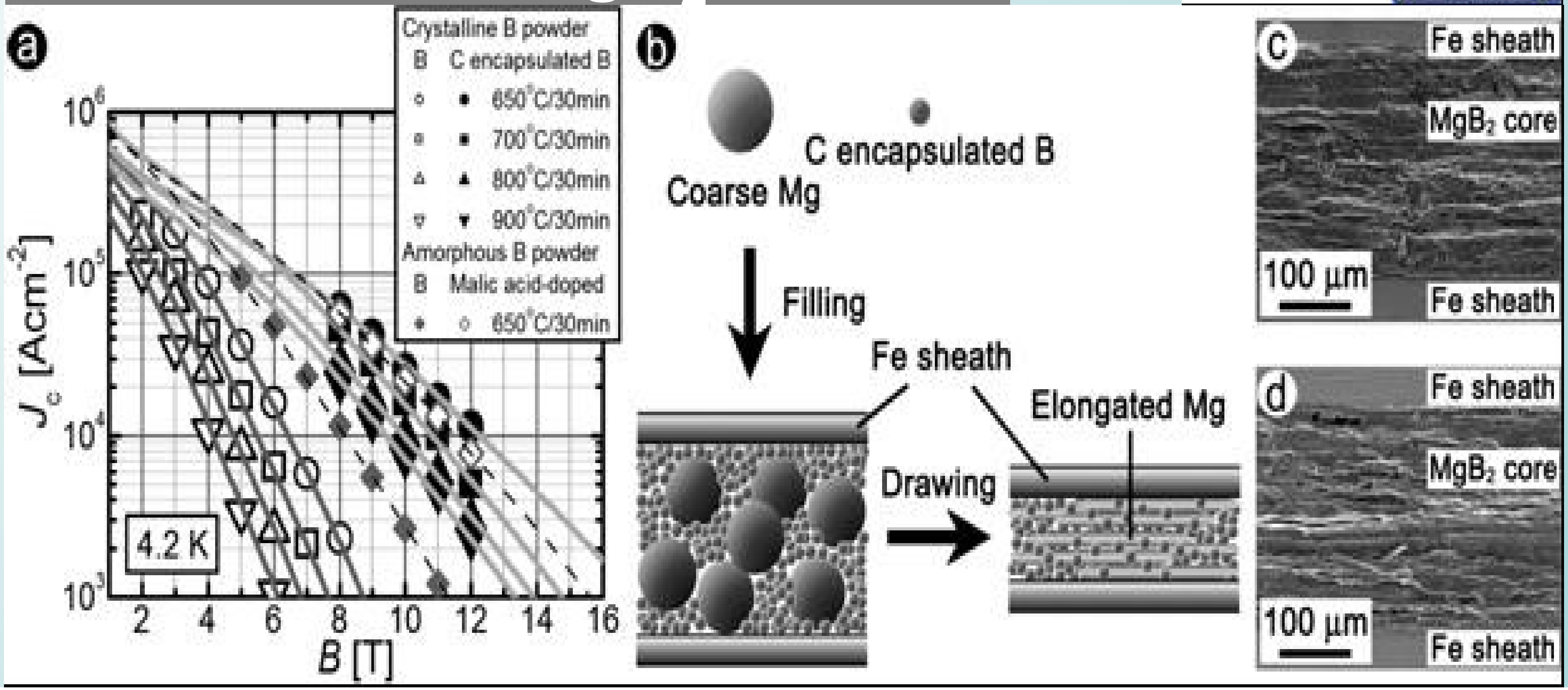


High Temperature Superconducting Ceramics. Applications

High Temperature Superconducting Ceramics. UoW/ISEM Advances

C encapsulated B nanopowder and Mg coarse powder for the fabrication of MgB_2 wire

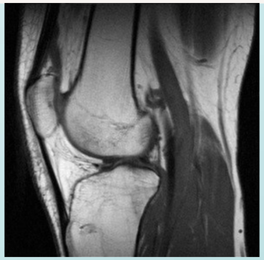




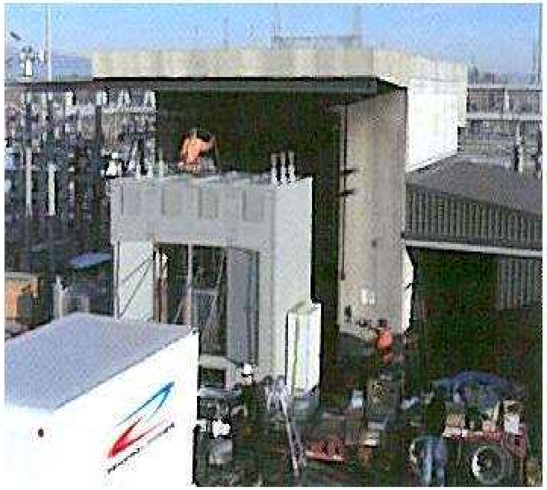
Devices Applications

- UoW and Zenergy Power design and construct MgB_2 Fault Current Limiter (FCL) at UoW Innovation campus for power grid security
- UoW- Ningbo Jansen set up LP to design and construct an 0.7 T open MgB_2 MRI
- Huge MRI market in China. MRI alone will be $2 billion market per year in China

MgB_2 coil for MRI by our partner Hyper Tech Research Inc



Open MgB_2 MRI Collaboration between UoW and overseas partners



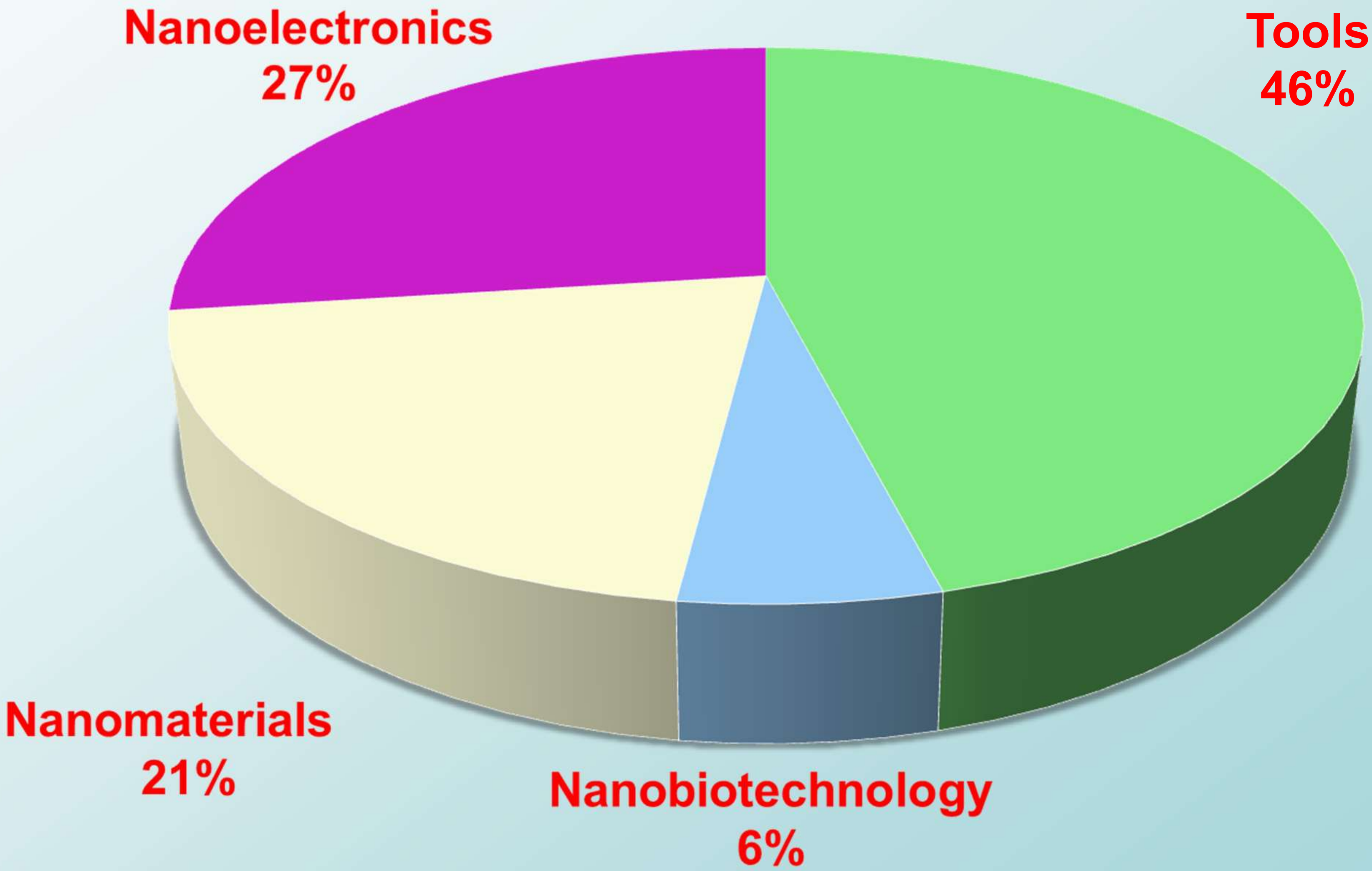
Fault Current Limiter

Image Courtesy of Zenergy Power

Fault Current Limiter for electric power grid based on UoW model and installed at Southern California

Image courtesy of Zenergy Power

Importance of Nanostructured Materials
World Market Distribution for Nanotechnologies



Source: The economic development of nanotechnology, European Commission 11/2006

Importance of Nanostructured materials

Applications

- **Now:**

- Tires and other rubber products
- fillers
- pigments
- synthetic bone
- polishing slurries
- pharma additives
- sunscreen lotions
- nano- electronics
- polymer composites

Importance of Nanostructured materials
Applications

- **Soon:**

- Advanced computing – nanoelectronic devices based on quantum dots
- Electronics – CNT conductors or semiconductors
- Cancer Treatment - nanoparticles for targeting cancer cells
- Energy Storage – electrodes made from nanomaterials
- Engineered Textiles - Nanofibres
- Environment - nanomaterials based photocatalysts
- Metalworking - nanoengineered Cu, nanophase Ti alloys
- Packaging - nanocomposite plastics
- Pharmaceuticals – antimicrobial nanocoatings on wound dressings

Importance of Nanostructured materials

Ceramic nanopowders – above 50% from all nanomaterials

- Nanoceramics are available commercially in the form of dry powders or liquid dispersions.
- The most commercially important nanoceramic materials are simple metal oxides, silica (SiO_2), titania (TiO_2), alumina (Al_2O_3), iron oxide (Fe_3O_4, Fe_2O_3), zinc oxide (ZnO), ceria (CeO_2) and zircona (ZrO_2).
- Silica and iron oxide nanoparticles have a commercial history spanning half a century or more
- Of increasing importance are the mixed oxides and titanates
  - indium-tin oxide (In_2O_3-SnO_2 or ITO)
  - antimony-tin oxide (ATO),
  - barium titanate ($BaTiO_3$).
- Nanocrystalline titania, zinc oxide, ceria, ITO, and other oxides have more recently entered the marketplace.

Main gas phase synthesis techniques for production of bulk nano-structured oxides and particles

- Vapour sublimation & condensation processes
- Vapour chemical reactions
- Flame synthesis

Some popular liquid phase techniques for production of bulk nano-structured oxides and particles

- **Precipitation method**
- **Sol-gel method**
- **Reverse micelles/microemulsion method**
- **Template method**
- **Hydrothermal/Solvothermal method**
- **Spray precipitation technique**
- **Spray pyrolysis method**

New Direct Spray Precipitation method for High Surface Area Nanoceramics

Materials Letters

Volume 117, 15 February 2014, Pages 279–282

Highly porous hematite nanorods prepared via direct spray precipitation method

Dean Cardillo[a, b], Moeava Tehei[b, c], Michael Lerch[b, d], Stéphanie Corde[d, e], Anatoly Rosenfeld[d], Konstantin Konstantinov[a,]

- Previously unreported synthesis method

used to prepare α-Fe_2O_3 nanomaterials

- Two-fluid spray nozzle and peristaltic pump

used in precipitation of iron oxide

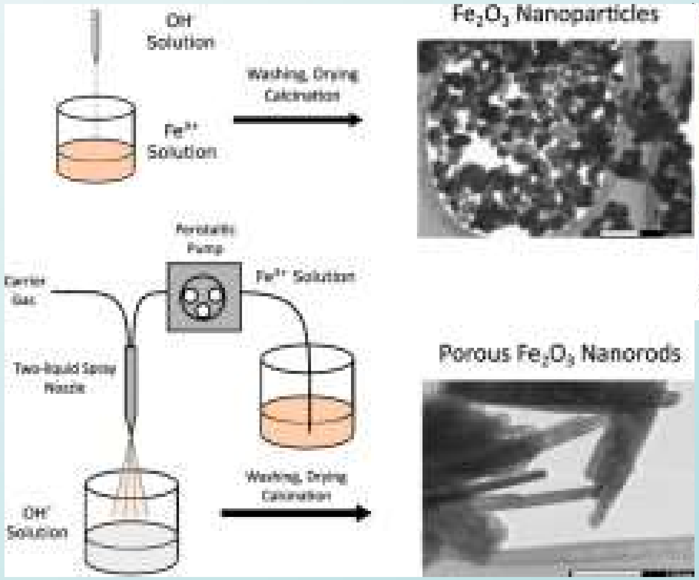
- Porous α-Fe_2O_3 nanrods obtained instead of spherical

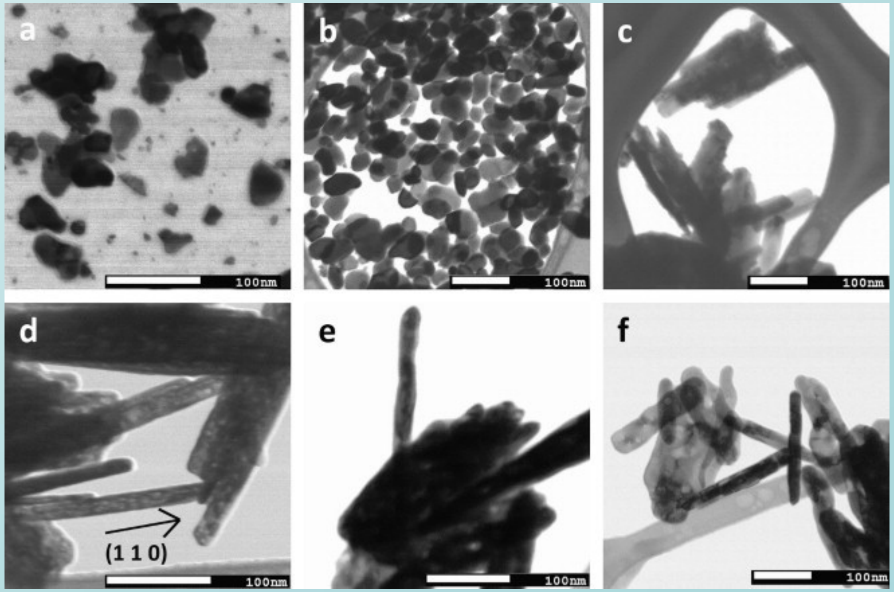
Nanoparticles

- Surface areas as high as 165 m^2/g obtained for rods

compared to 54 m^2/g for spherical particles

- Enhanced optical properties, potential use as photocatalyst





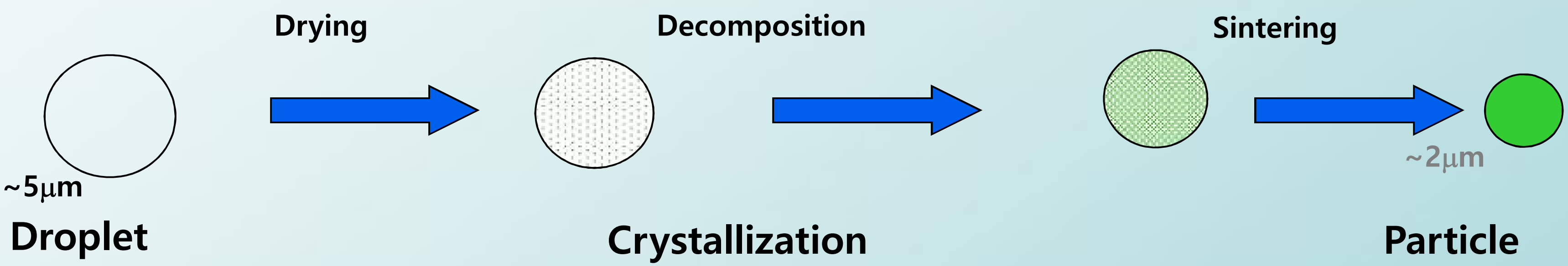
a) & b) Precipitation nanoparticles, c)-f) nanorods prepared through spray precipitation

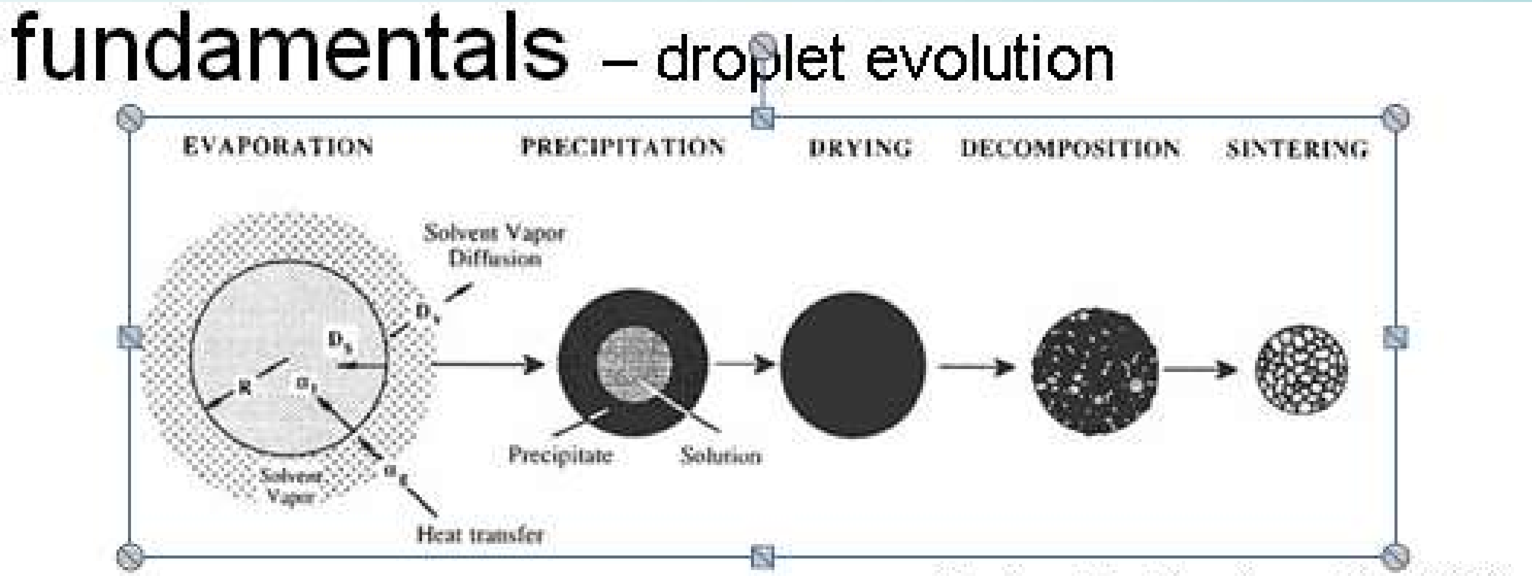
Spray Pyrolysis Method - principle

A mixed solution of initial components is sprayed in heated chamber

Spray Pyrolysis

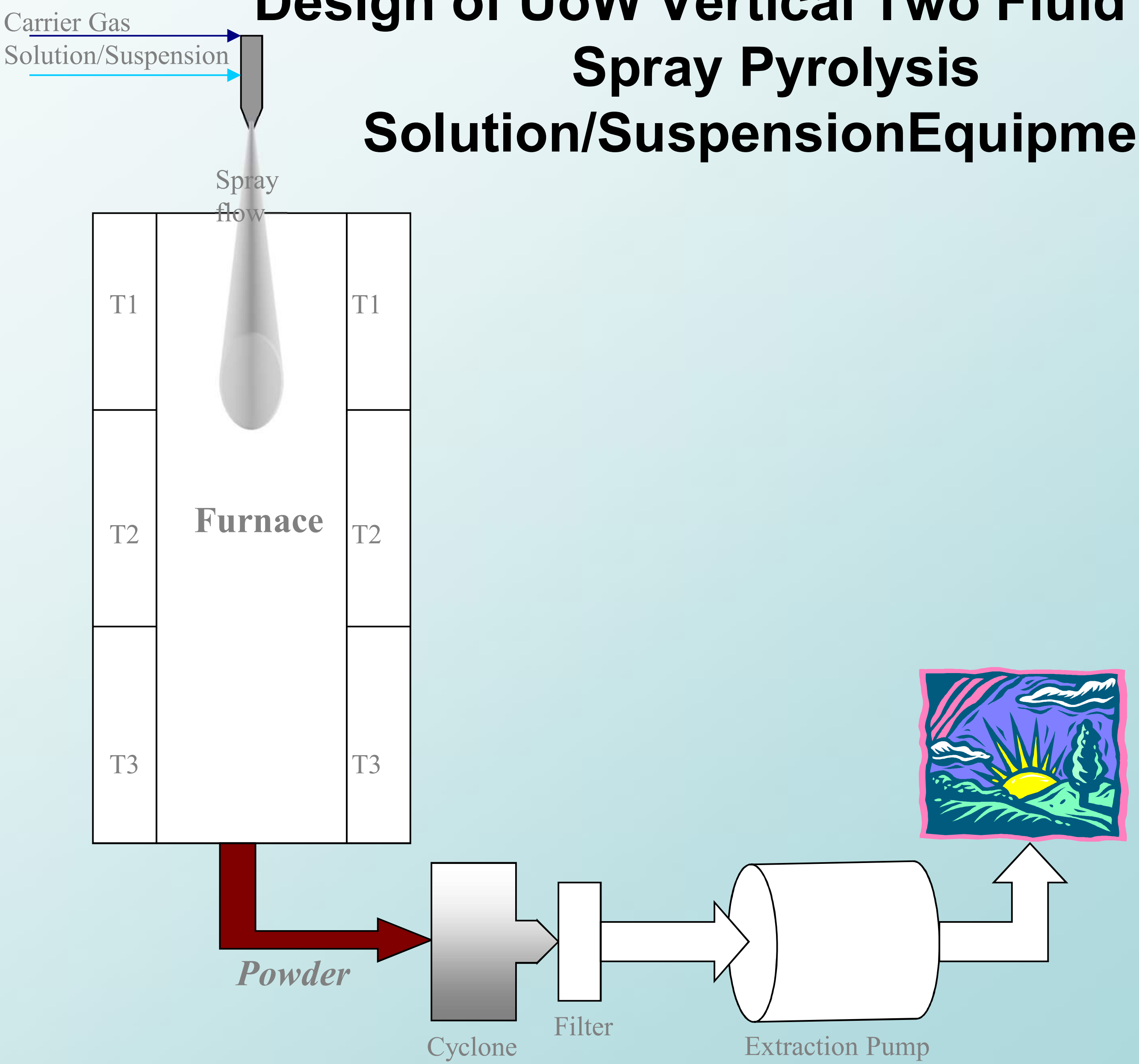
(one step process)





Messing et al, J. Am. Ceram. Soc., 1993

Design of UoW Vertical Two Fluid Nozzle Spray Pyrolysis Solution/SuspensionEquipment



Commercial Spray Pyrolysis system

Spray Synthesis Advantages

- Perfect homogeneity at the atomic level between the components.
- Flexibility to use either a solution or a suspension.
- The powders can be produced in spherically shaped agglomerates with a Gaussian particle size distribution.
- Possibility to prepare either high density materials or powders with a highly developed specific surface area.
- Applying ultra-short sintering time, it is possible to prepare few nanometers crystallites.
- Possibility to obtain nano-structured ceramics or composites, which require conventional high-temperature sintering process.
- The nano-structured powders are soft agglomerated and more easily dispersed.

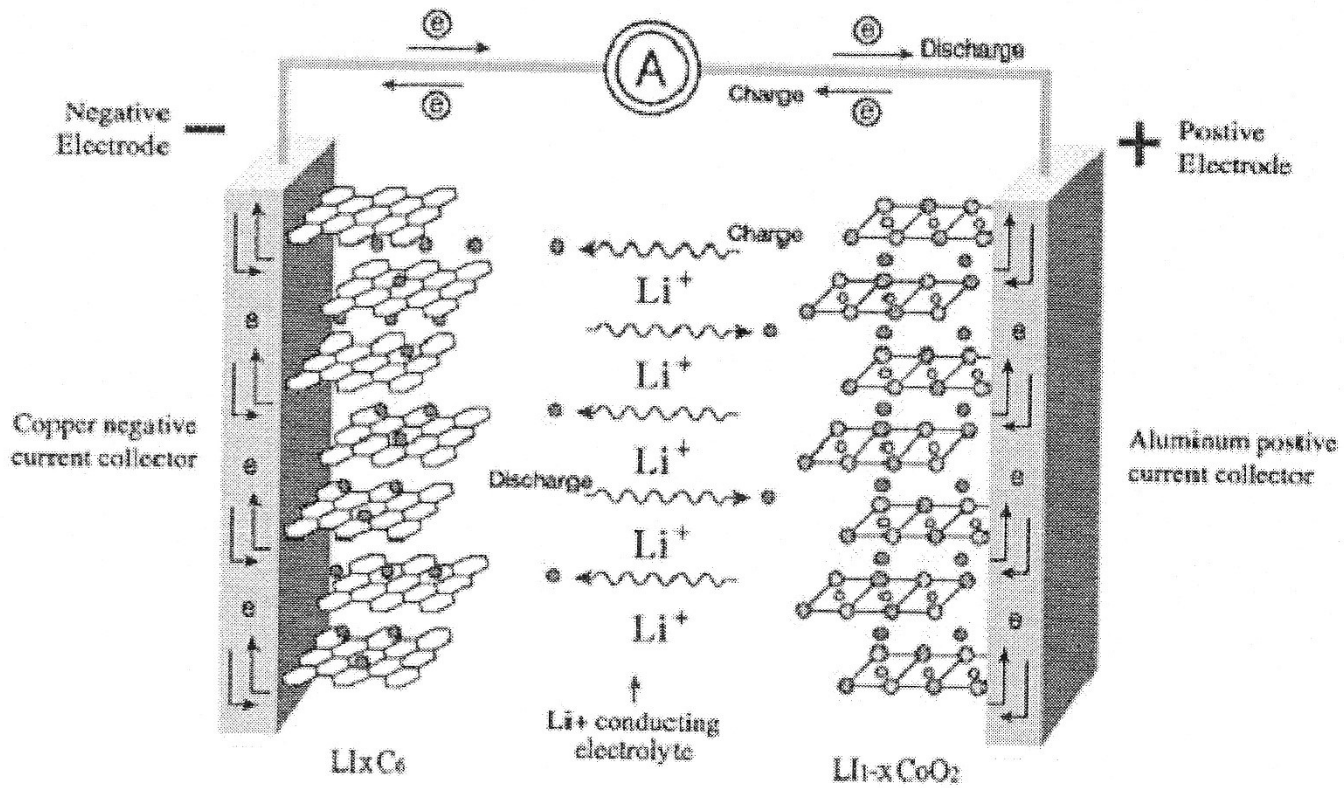
ISEM Research on Multifunctional Nanoceramics for Application in Li-ion Batteries, Supercapacitors and Biomedical Applications

- CoO, Co_3O_4, NiO, CuO, Fe_2O_3, Mn_3O_4, MnO_2, $Ni(OH)_2$, $LiCoO_2$, PbO, V_2O_5, SnO_2
- Carbon composites with Si, $LiFePO_4$, Sulphur, Co_3O_4, Fe_2O_3, NiO, V_2O_5, TiO_2, $Li_4Ti_5O_{12}$, SnO_2
- Graphene Oxide/Metal Oxide Composites
- MCNT/GO/Metal Oxide Composites
- Ta_2O_5, CeO_2

Examples of UoW/ISEM Nanoceramic Materials for Energy Storage Devices

- Batteries
- Supercapacitors

The batteries use ceramic materials!



- Anode material: carbon

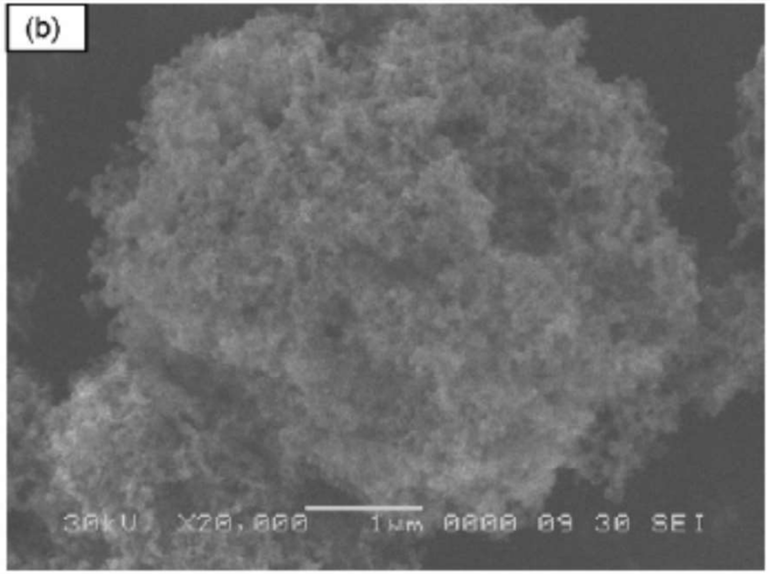
- Cathode : transition metal oxide. $LiCoO_2$, $LiNiO_2$, $LiMnO_2$, etc.

$$C_6 + LiMO_2 \leftrightarrow Li_xC_6 + Li_{1-x}MO_2$$

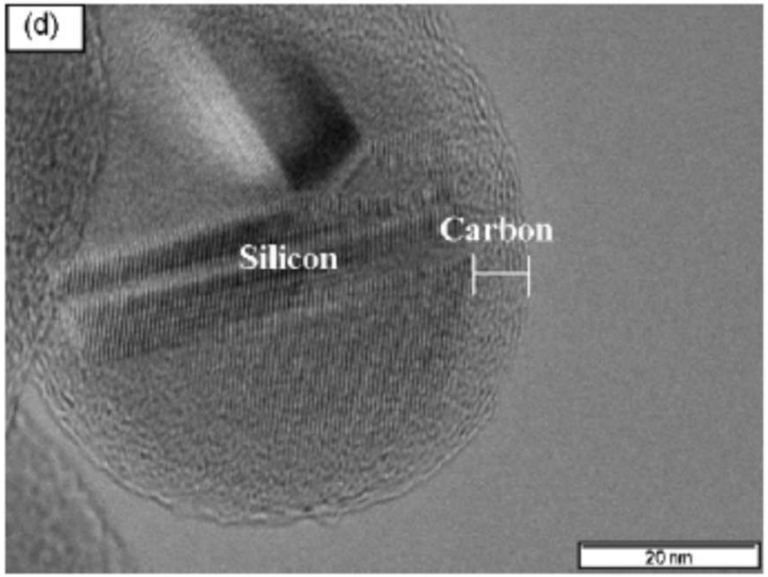
Intercalation/deintercalation

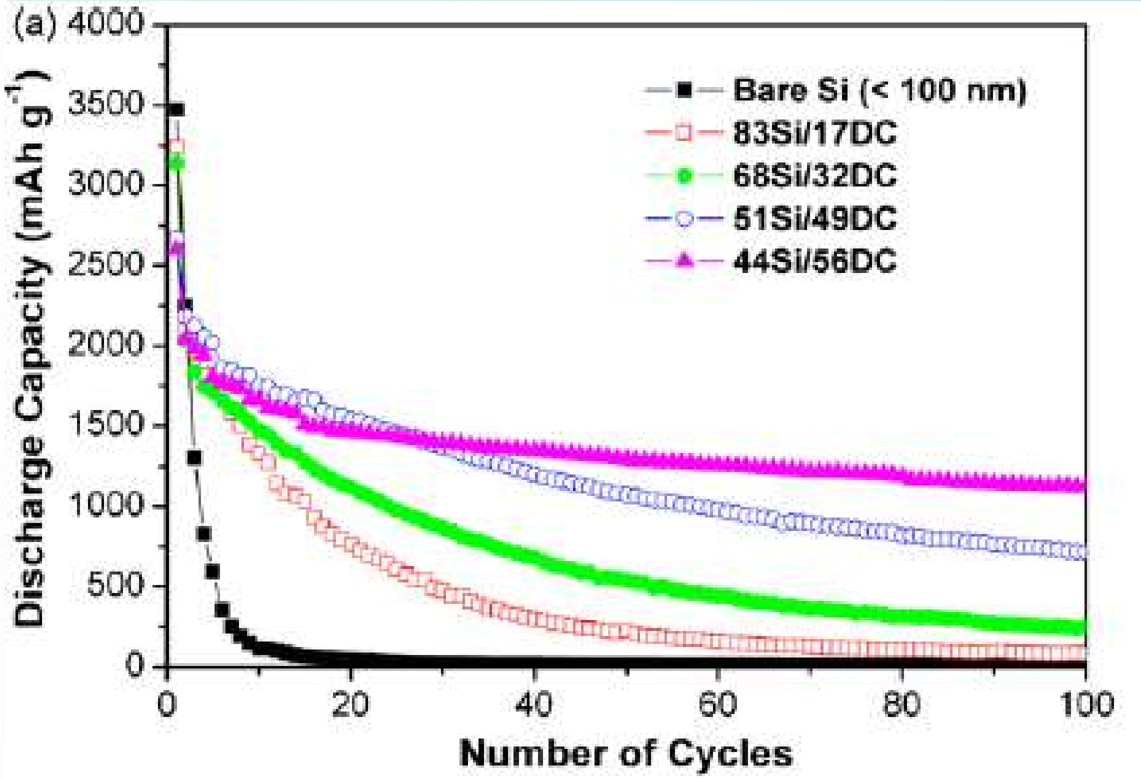
Li-ion battery construction

UoW High performance anode materials for Li-ion Batteries – nano Si/Carbon composites

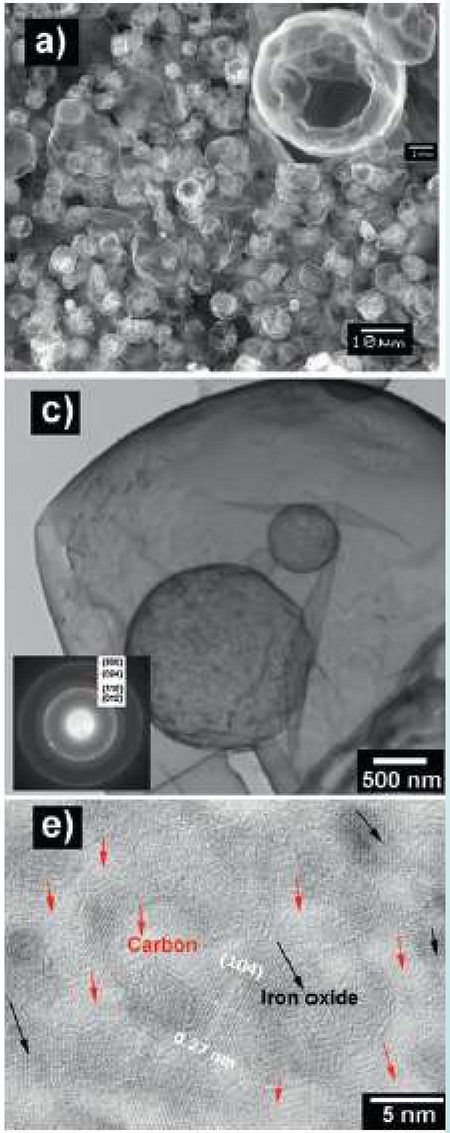


See-How Ng, J. Wang, D. Wexler, K. Konstantinov, Z. P. Gou, H. K. Liu, Highly reversible Lithium Storage in spheroidal Carbon-coated Silicon nanocomposites as anodes for LI-ion batteries, Angew. Chem. Int. **45** (2006) 689

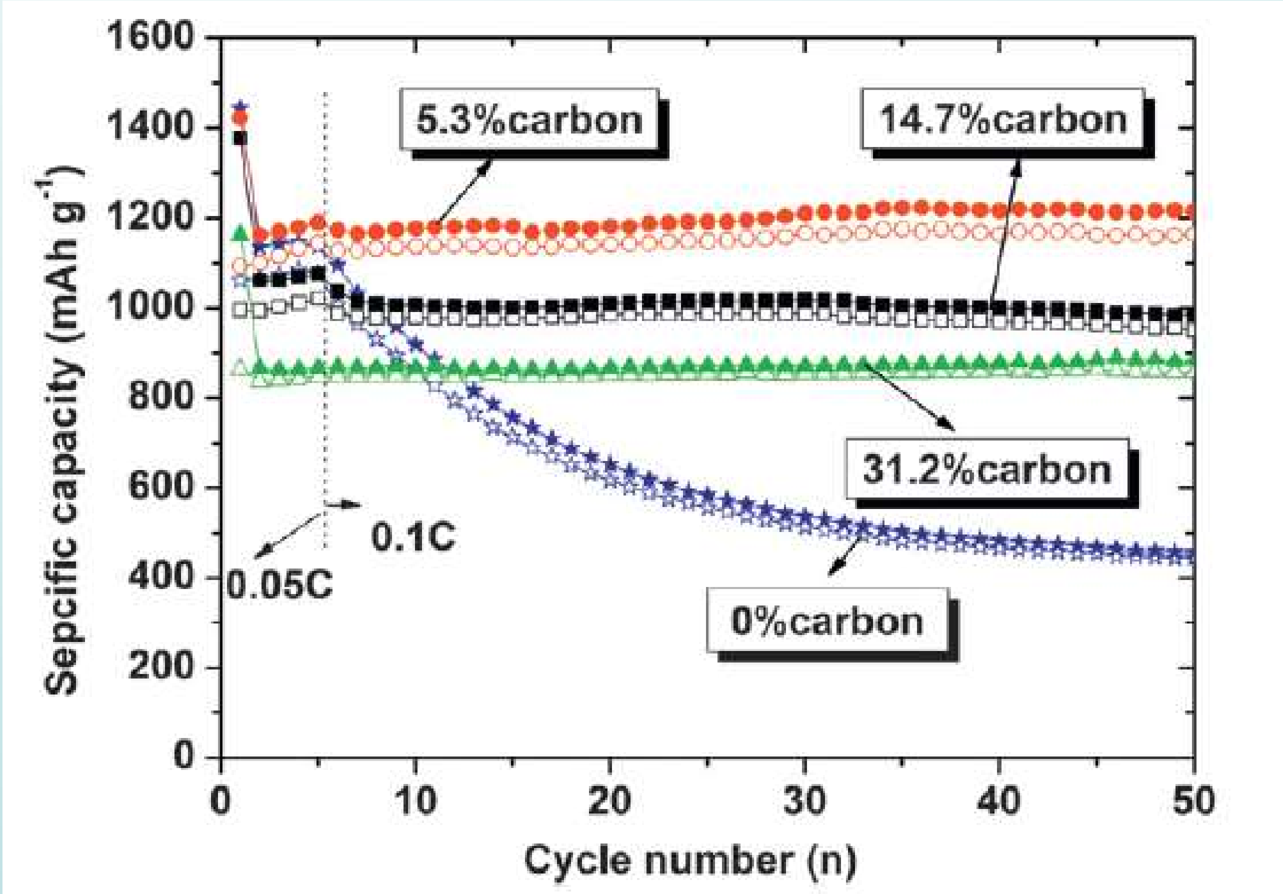




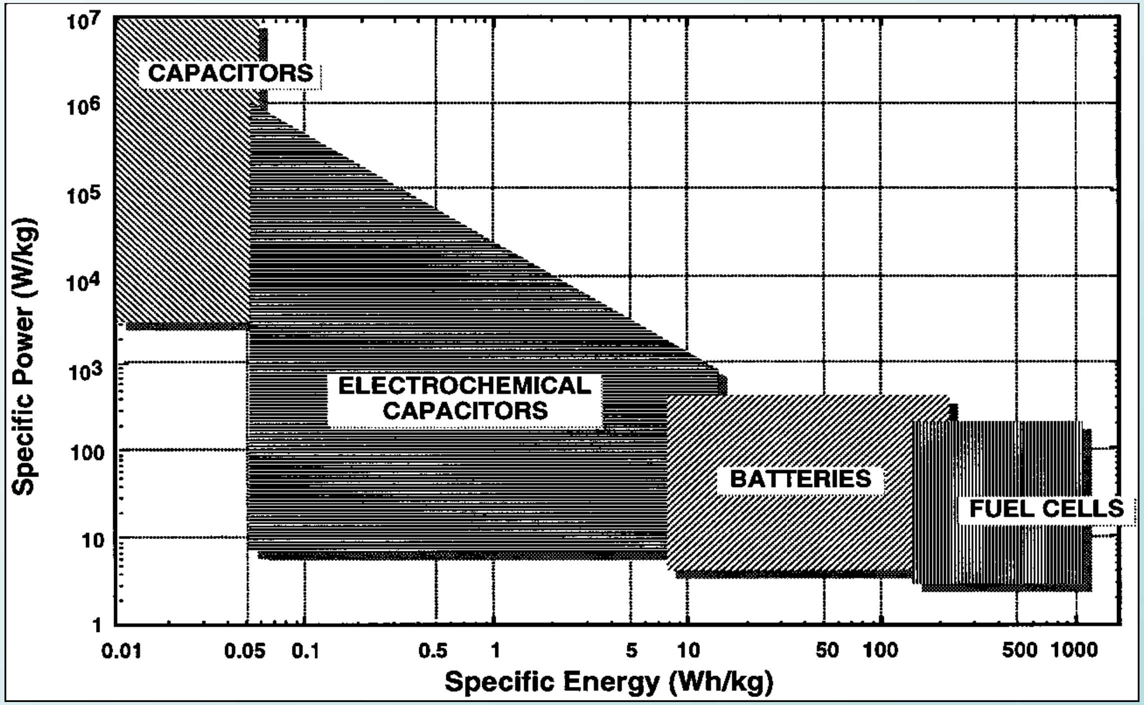
Fe_2O_3/Carbon sprayed composites for Li-ion batteries



S.-L. Chou, J.-Zh. Wang, D. Wexler, K. Konstantinov, C. Zhong, H.-K. Liu and S.-X. Dou, High-surface-area a-Fe2O3/carbon nanocomposite: one-step synthesis and its highly reversible and enhanced high rate lithium storage properties, J. Materials Chem. **20** (2010) 2092



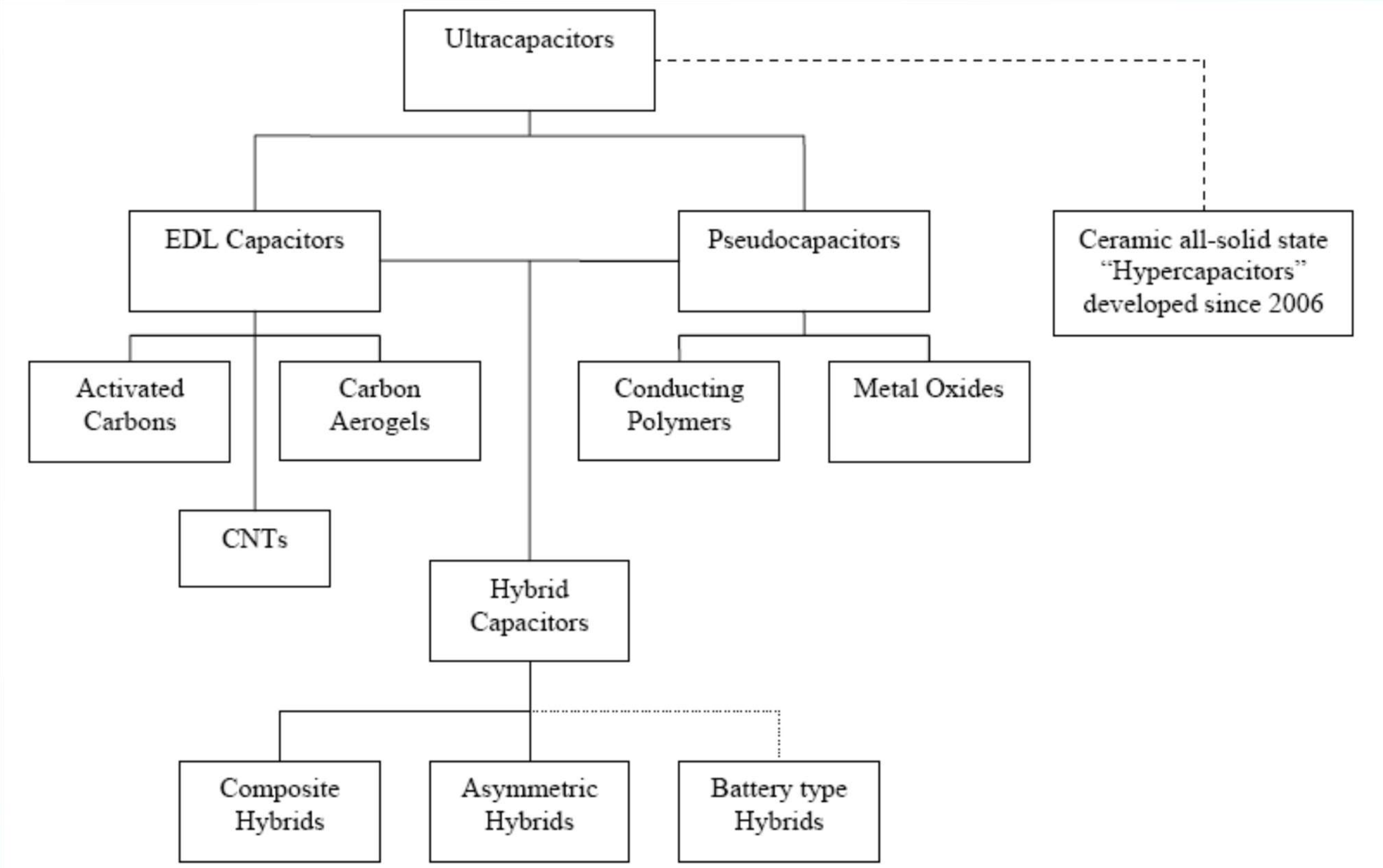
Supercapacitors (Ultracapacitors)



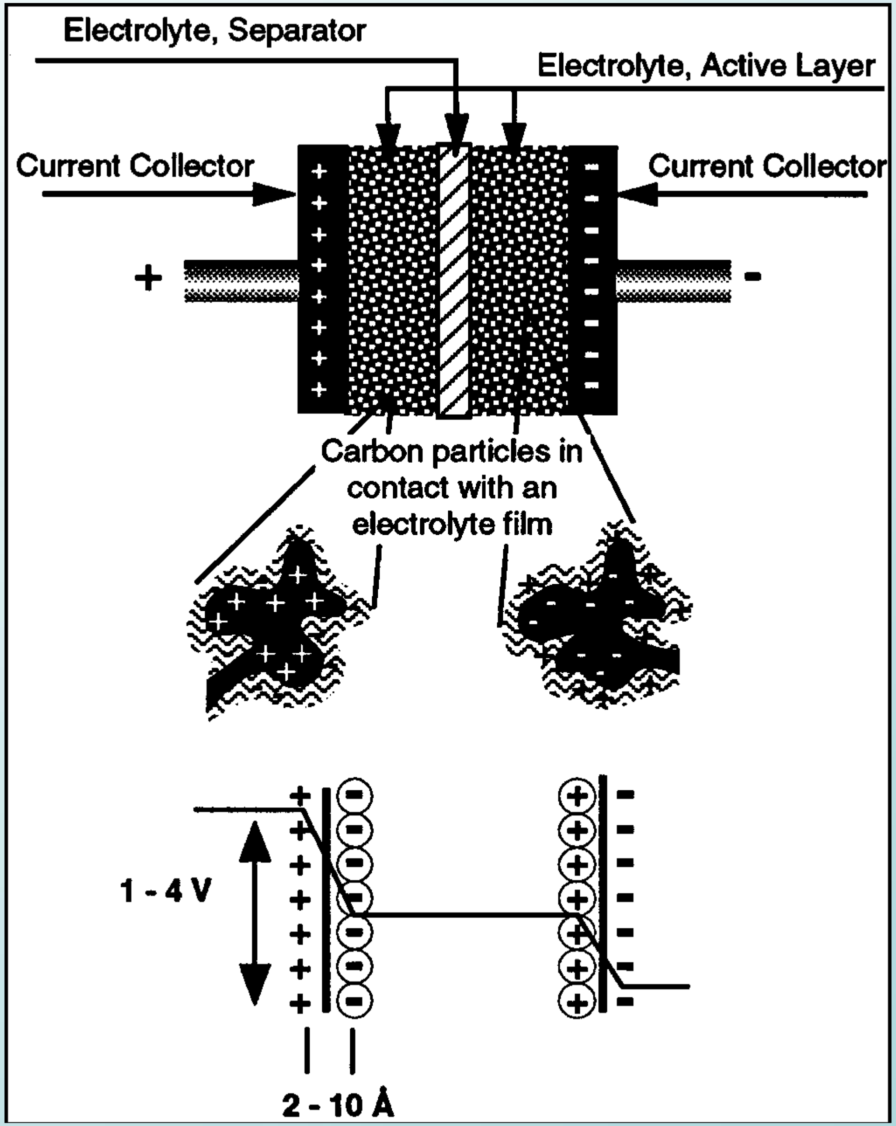
- **Definitions:**
- **Capacitor:** a device for accumulating and holding a charge of electricity, consisting of two equally charged conducting surfaces having opposite signs and separated by a dielectric.
- **Supercapacitor:** a capacitor standing in between batteries and conventional capacitors in terms of energy density.

Ragone charts are used for performance comparison of various energy storage devices.

Supercapacitors (Ultracapacitors)



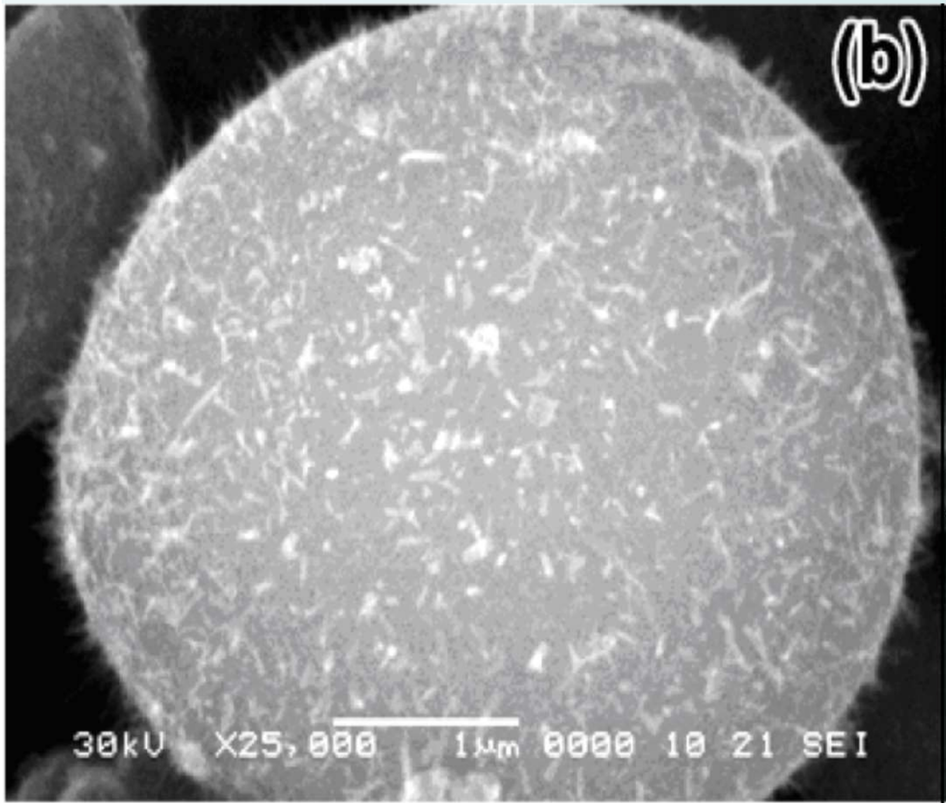
EDLC Electrochemical Supercapacitors

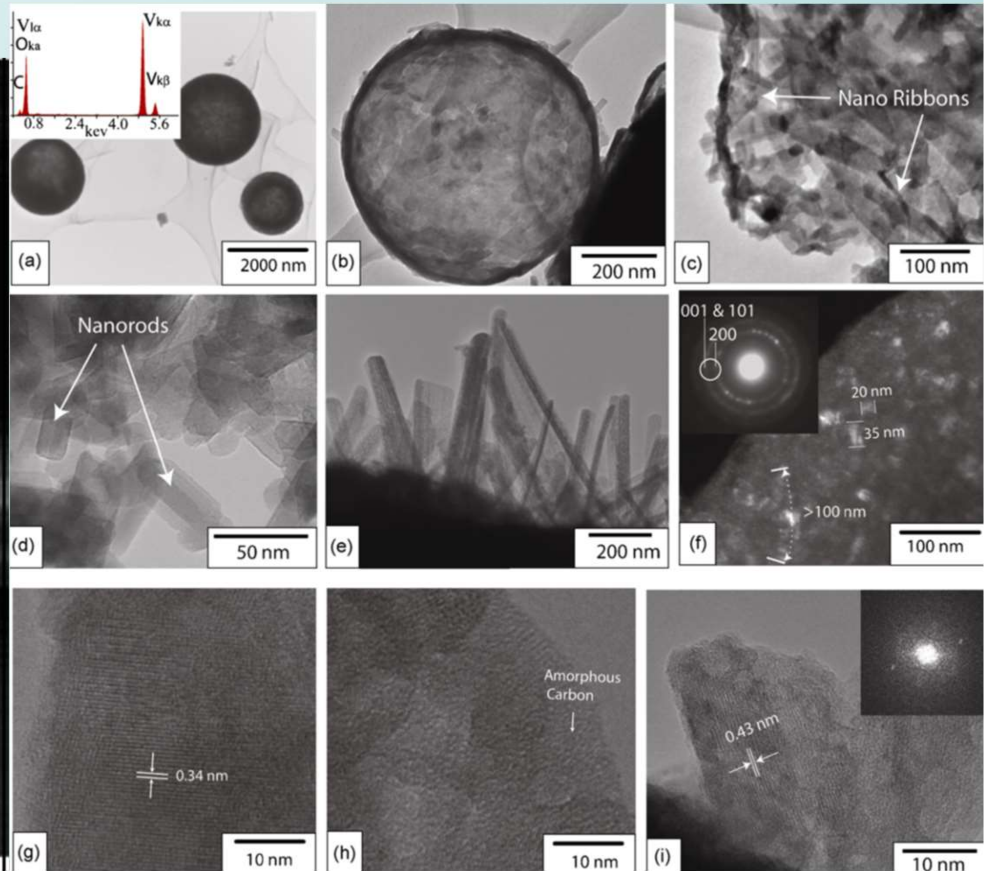


Sprayed Materials for Electrochemical Supercapacitors
In-situ Sprayed V_2O_5/Carbon Composites

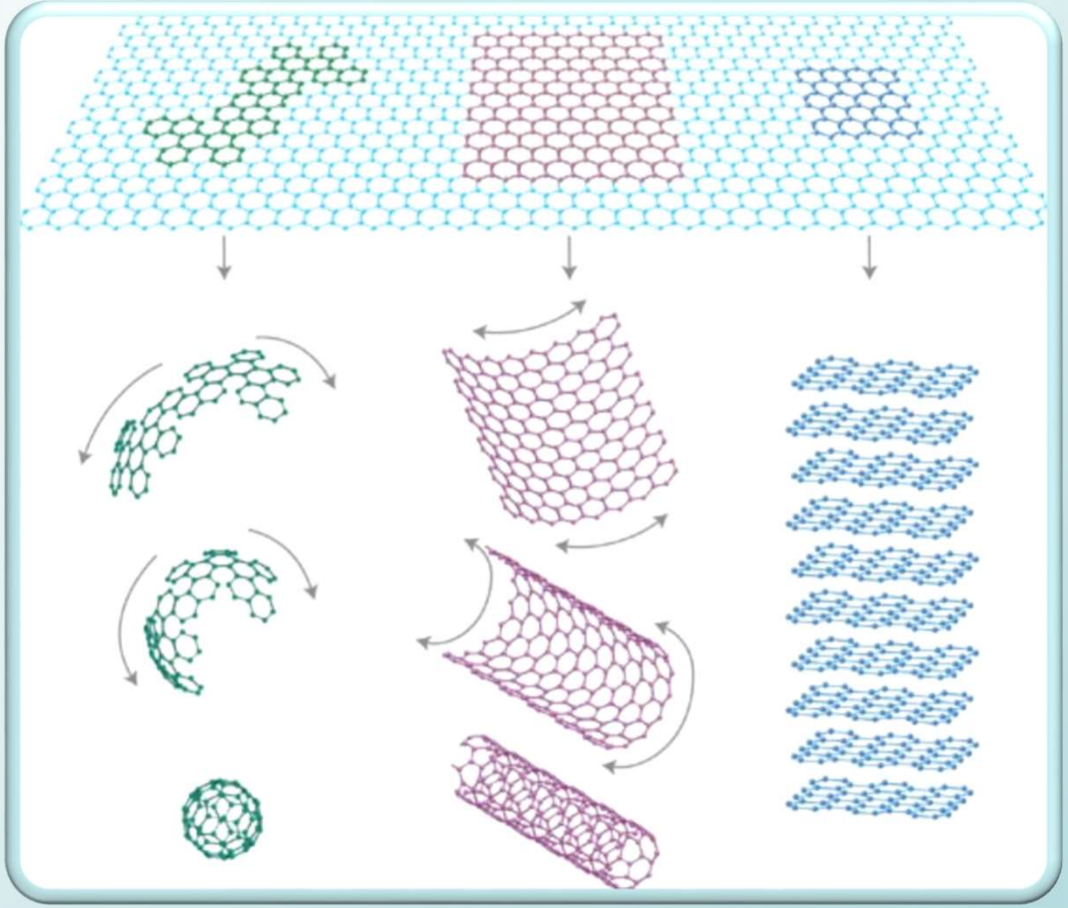
B. Wang, K. Konstantinov, D. Wexler, H. Liu, G.X.Wang, Synthesis of nanosized vanadium pentoxide/carbon composites by spray pyrolysis for electrochemical capacitor application, Electrochimica Acta **54** (2009) 1420

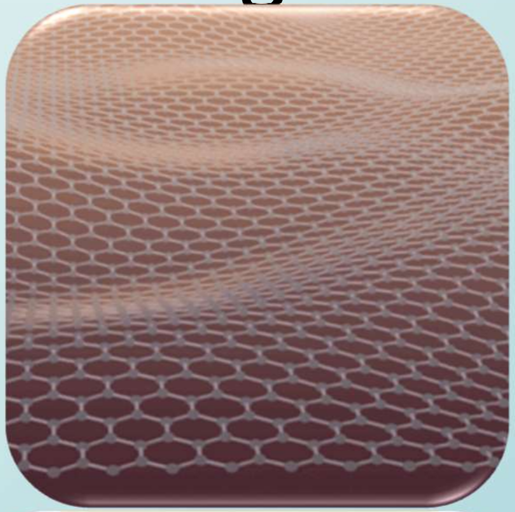
Up to 295 m^2/g and 295 F/g in 2M KCl

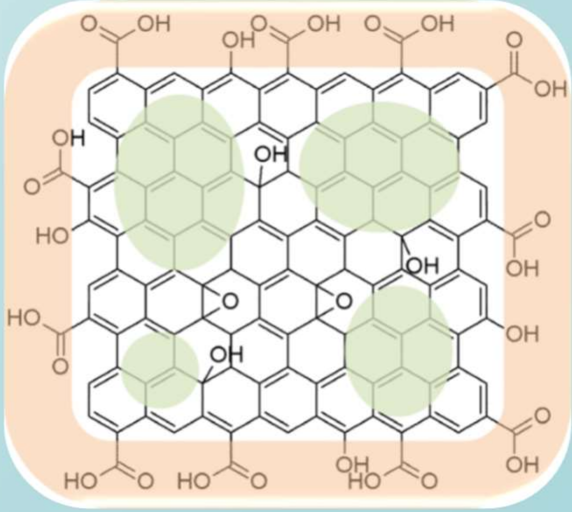




Graphene Based Ceramic Nanomaterials for Ultimate Energy Storage







Buckyballs

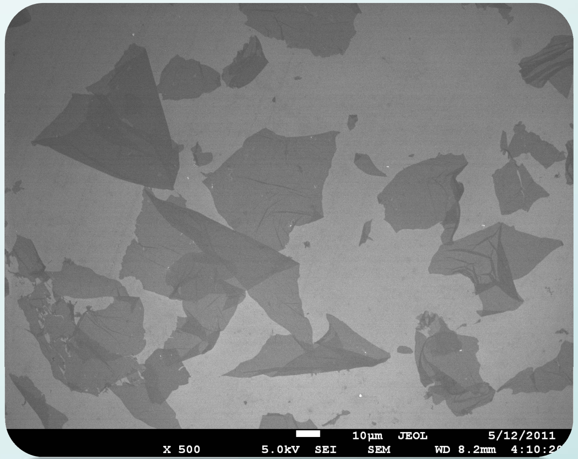
CNTs

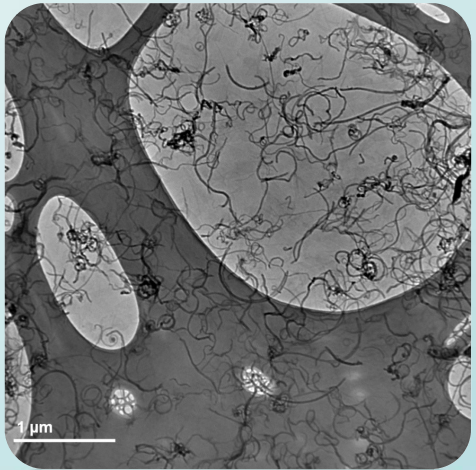
Graphite

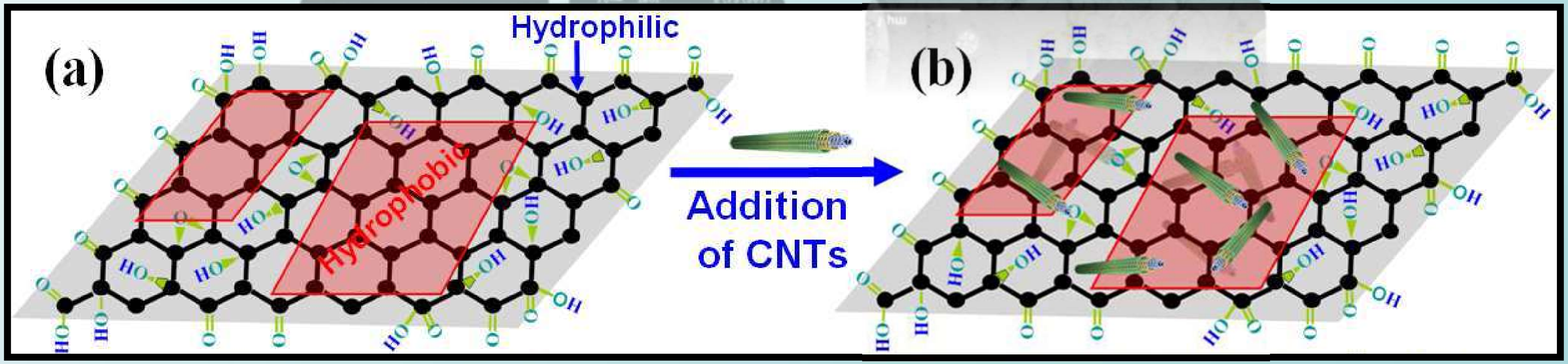
[2] *A. K. Geim,& K. S. Novoselov* **The rise of Graphene,** *Nat. Mater.* 2007, **6** , 183

Graphene Based Nanocrystalline Ceramics for Supercapacitors

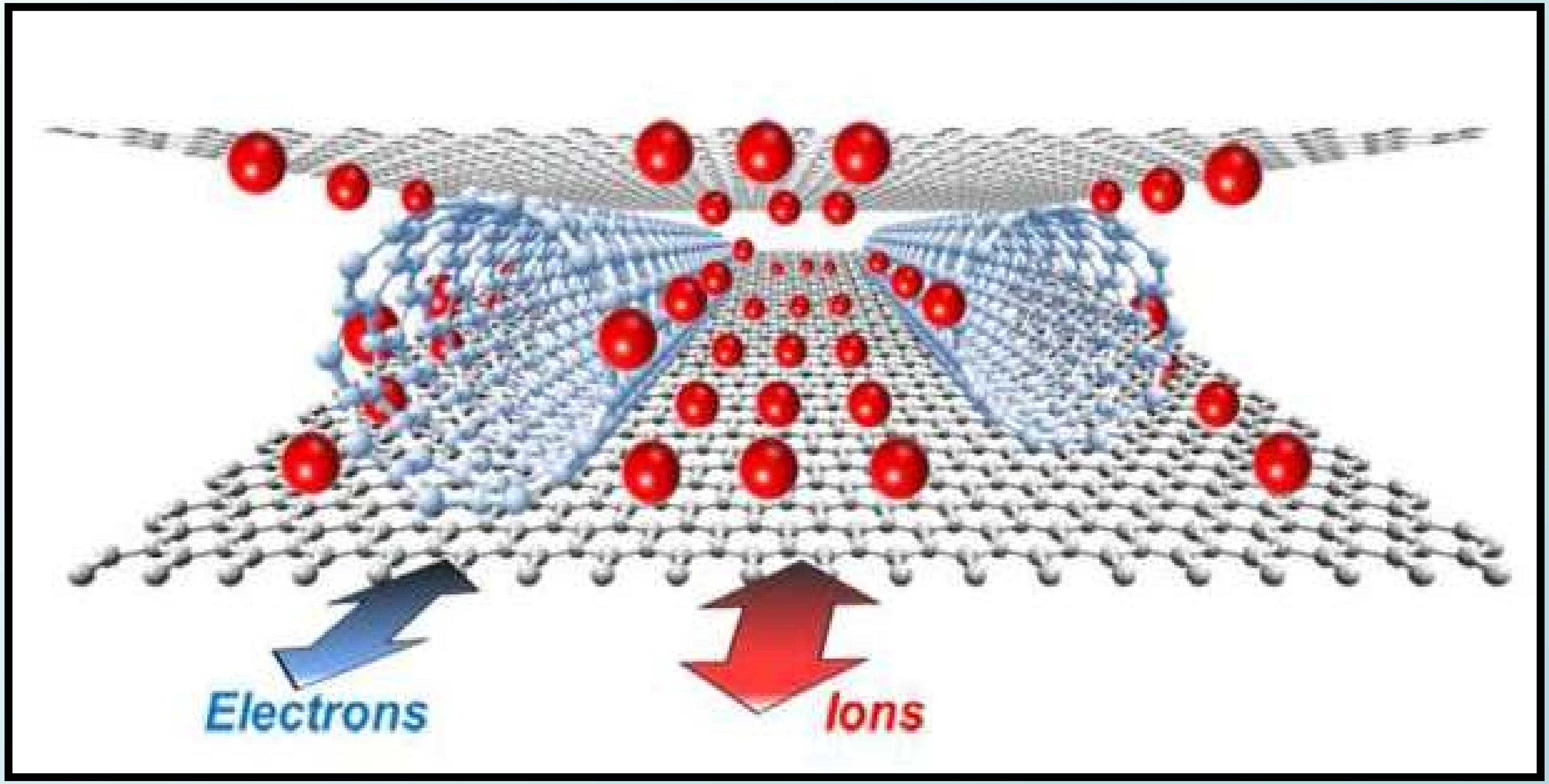
S. H. Aboutalebi, A. T. Chidembo, M. Salari, K. Konstantinov, D. Wexler, H. K. Liu, S. X. Dou, Comparison of GO, GO/MWCNTs composite and MWCNTs as potential electrode materials for supercapacitors, Energy Environ. Sci. **4** **(**2011) 1855.



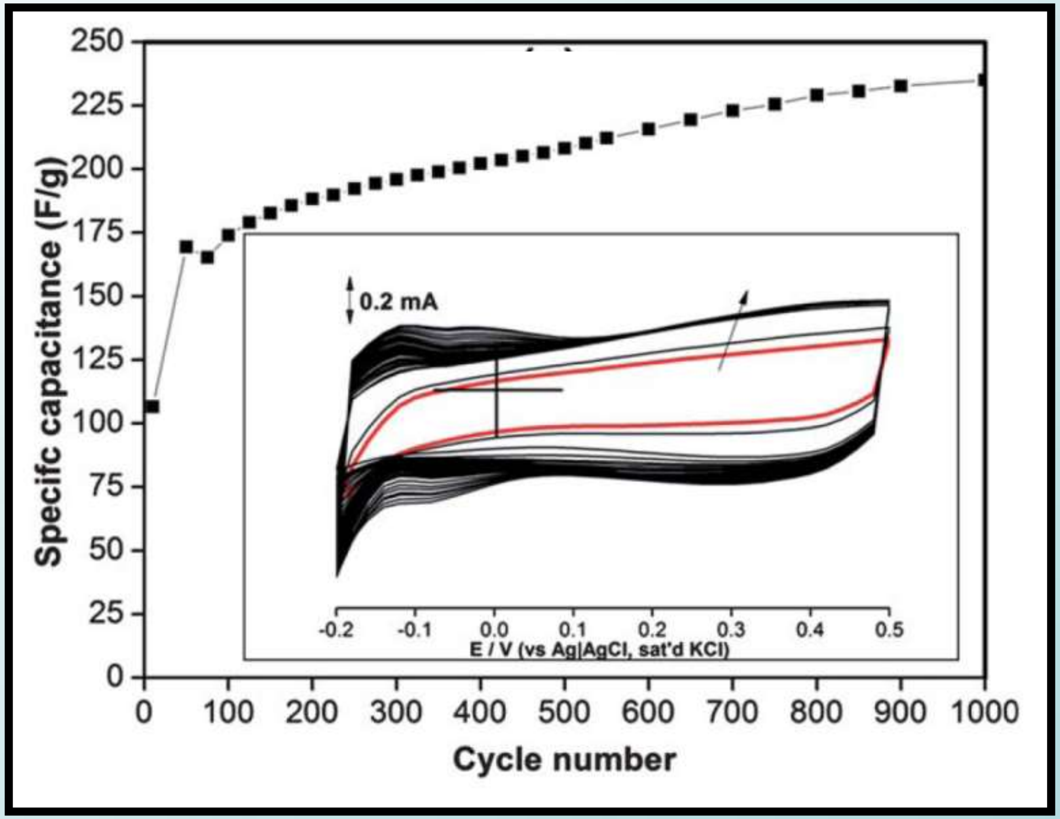




GO-CNT Supercapacitors



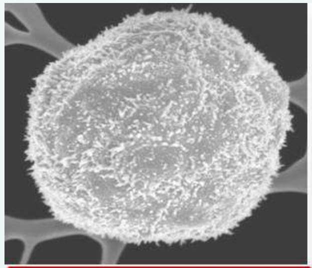
GO-CNT Supercapacitors

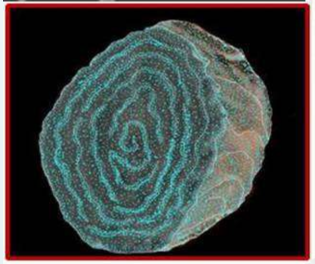


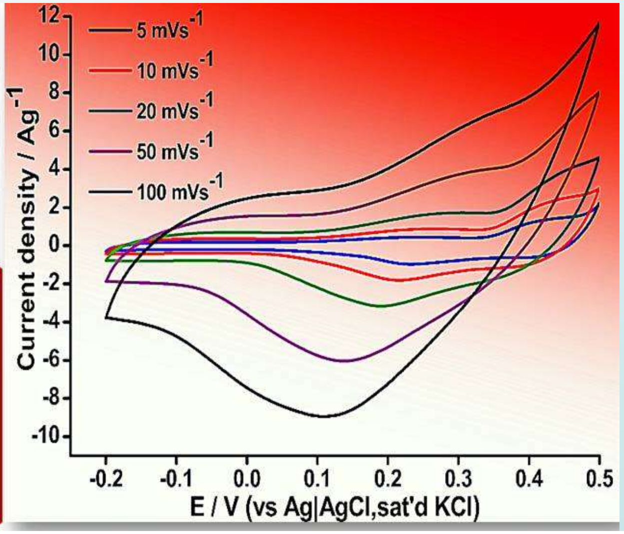
Change in specific capacitance with increase in cycle number, calculated from cyclic voltammetry data at 20 mV s^{-1}. Inset shows the growth of CV's with increase in cycle number

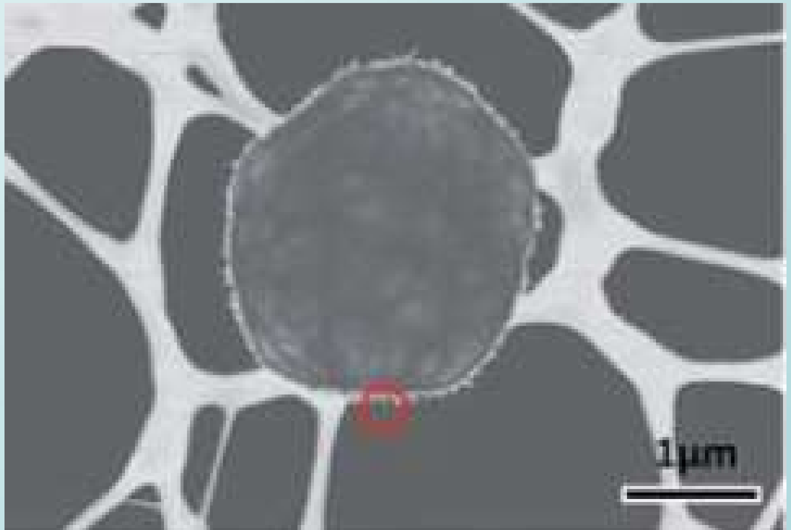
Novel Spray Pyrolysis MetalOxide/reducedGO Materials for Energy Storage

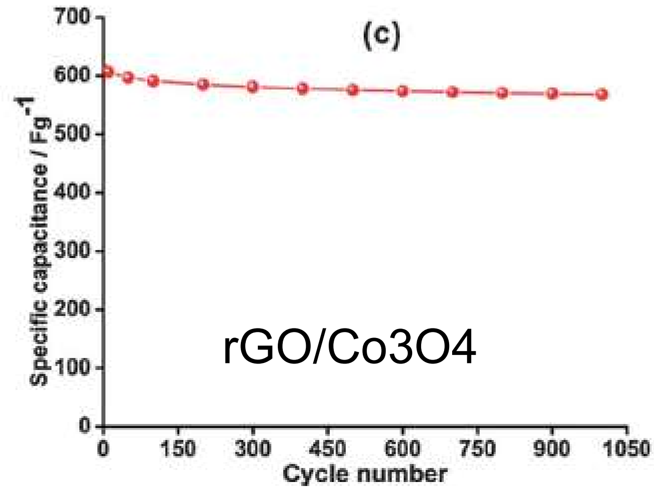
A. Chidembo , S.H. Aboutalebi, K. Konstantinov et al., Globular reduced graphene oxide-metal oxide structures for energy storage applications, Energy & Environmental Sci. **5** (2012) 5236.

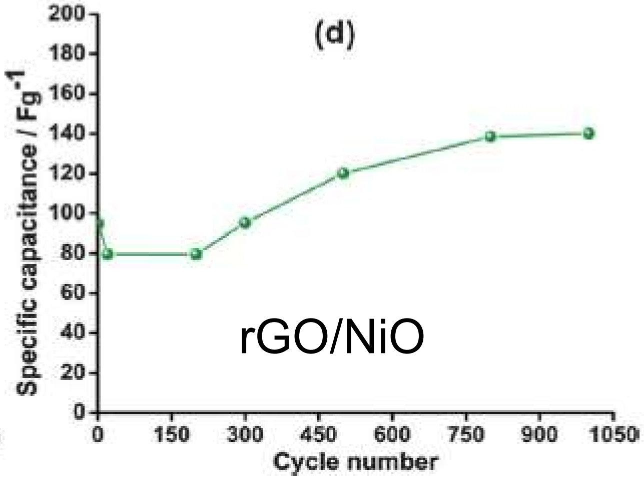


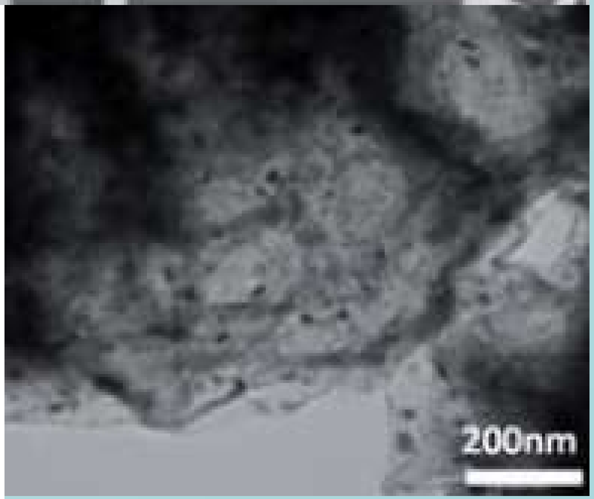




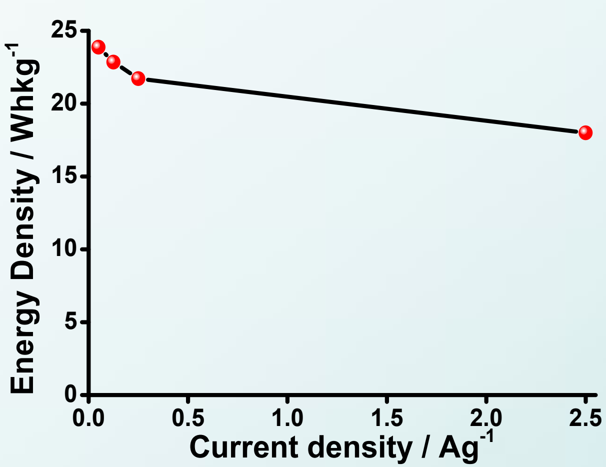


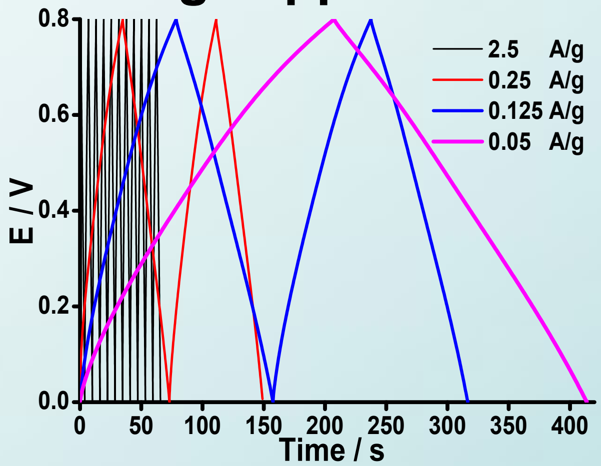


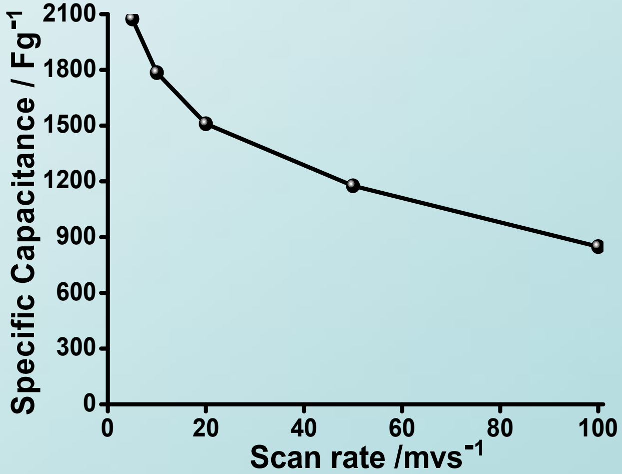


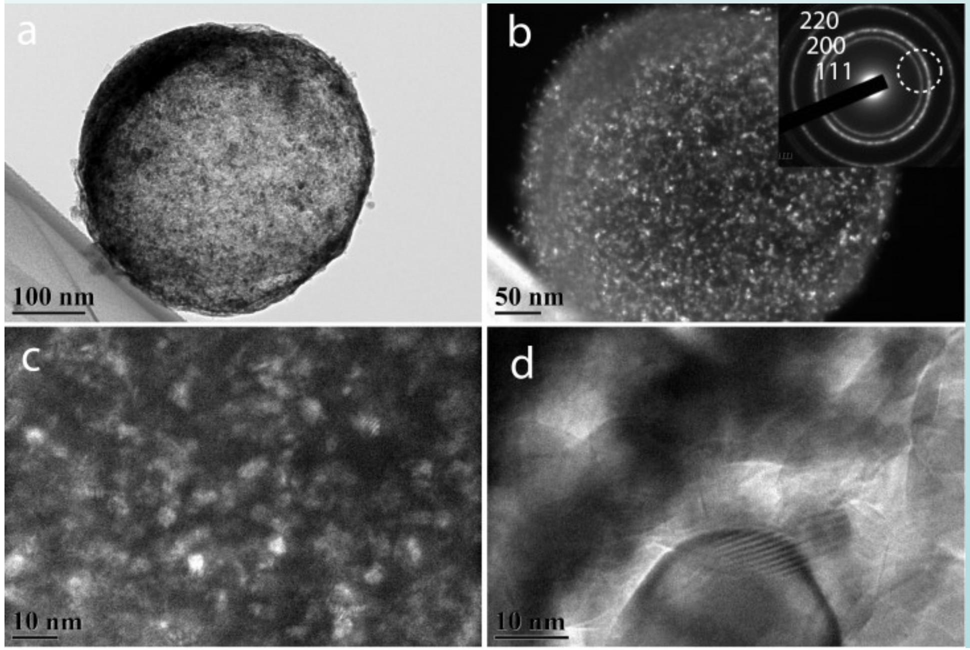


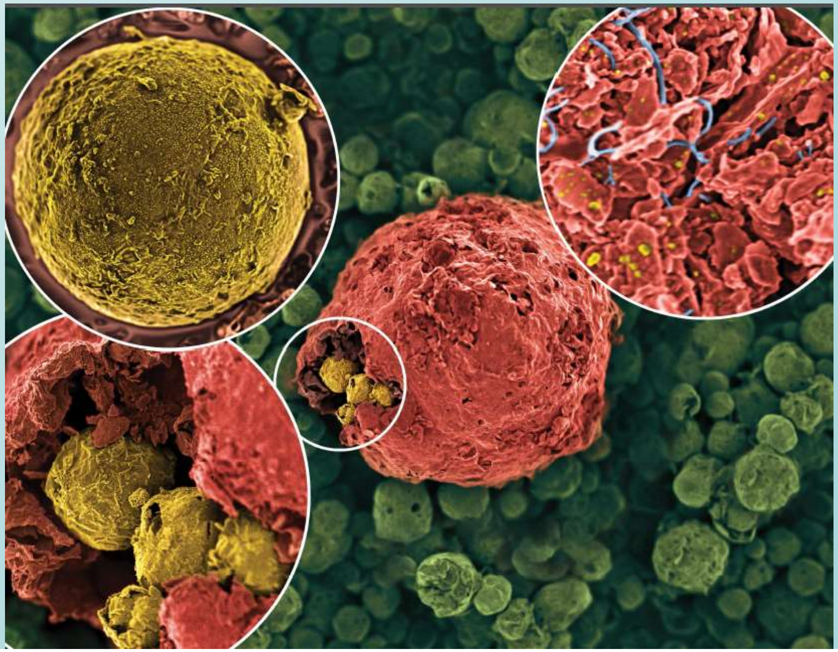
Spray pyrolysis of graphene oxide based liquid crystalline dispersions: a practical approach towards ternary 3D isotropic architectures for energy storage applications











Spray pyrolysis of graphene oxide based liquid crystalline dispersions: a practical approach towards 3D isotropic architectures for energy storage applications

ISEM hybrid energy storage device comparison performance

ISEM made capacitors provide remarkable performance and cyclability. Energy density as high as 23 Wh/kg and only a 6% loss in capacity over 2000 cycles

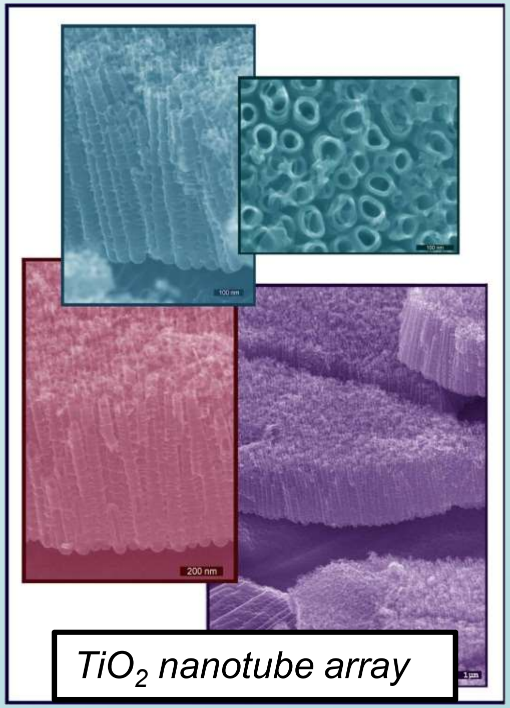
Characteristics of 10 KW module for fuel cell car application using classical supercapacitor

50 industrial EDLC 2.5 V / 800 F supercapacitors manufactured. 50 supercapacitors were connected pair wise in a 25 series to obtain a module with 60 F and 60 V. The maximum specific power and energy measured for the 800 F supercapacitor is 5 kW/kg and 2.5 Wh/kg, respectively

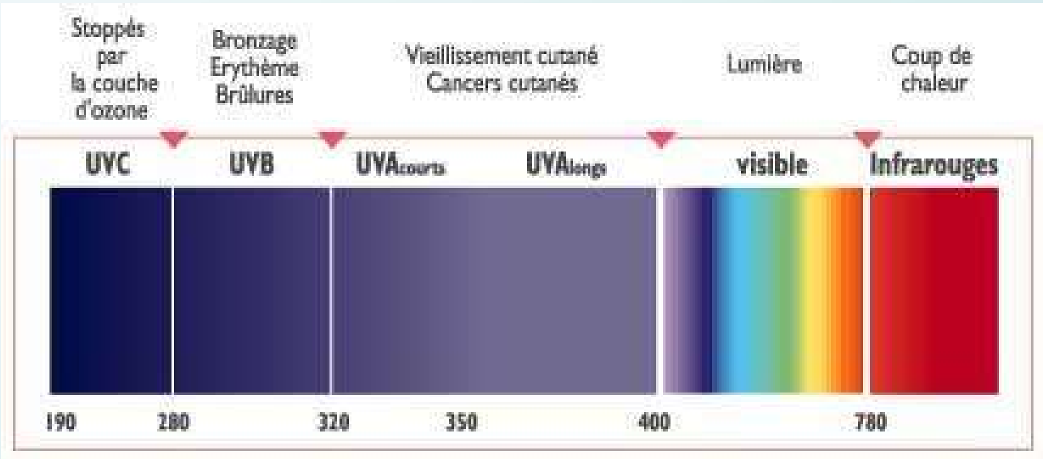
	Premlis LIC	ISEM hybrid capacitor
Capacitance	2000 F	2074 F
Energy density	15Wh/kg	23 Wh/kg
Electrode size	100 mm	10.5 mm

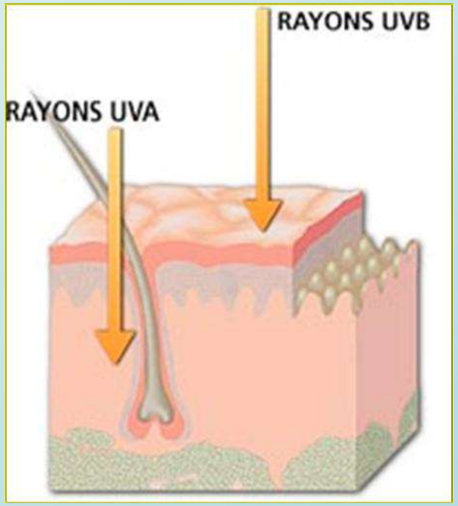
Nanoceramics for Health Protection

- Advanced nanoceramics in cosmetics for UV blocking and skin cancer protection
- Ceramic nano-particles and composites for cancer treatment and oxidative stress related diseases
- Radiation assisted cancer therapies using inorganic nanomaterials and nanoceramics for radiation protection drugs in space
- Ceramic based drug delivery and theranostic systems for cancer or neurodegenerative treatment



Skin cancer - UV filtration problem



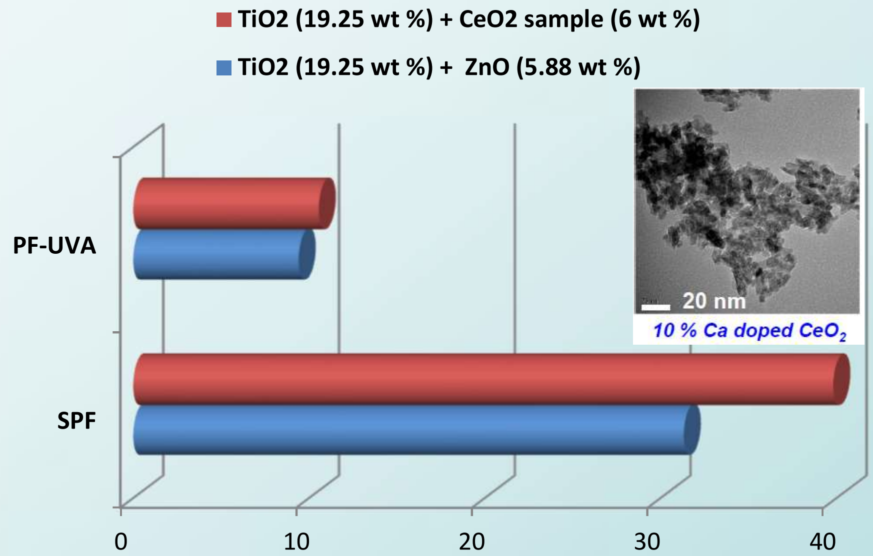


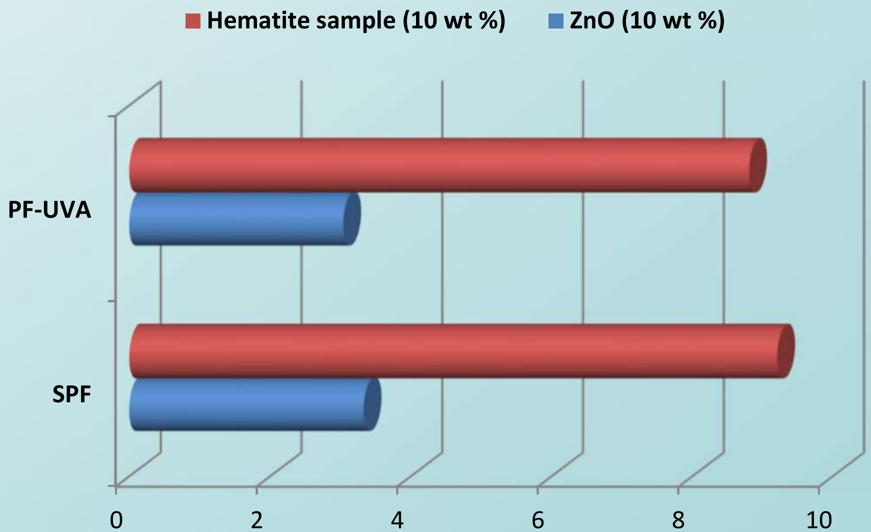
- UV radiation
  - UVC : very harmful, but entirely stopped by the ozone layer.
  - UVB : harmful for the skin, carcinogenic, filtered by nano TiO_2 and ZnO
  - UVA (more penetrating into the skin, it is present in a higher dose compared to UVB) : suntan agent, the carcinogenic potential was unknown for a longtime but nowadays is confirmed.
  - **Organic & inorganic filters are used for UVB and UVA radiation.**

Bioactive Nanoceramics for UV Filtration in Cosmetic Products

1.Truffault Laurianne et al., Cerium oxide based particles as possible alternative to ZnO in sunscreens: Effect of the synthesis method on the photoprotection results, *Materials Letters.* **68** (2012) 357-360
2.Truffault Laurianne et al., Synthesis of Nano-Hematite for Possible Use in Sunscreens, *J. Nanoscience & Nanotechnol.* **11** (2011) 2413-2420
3. Truffault Laurianne et al., Synthesis and Characterization of Fe Doped CeO(2) Nanoparticles for Pigmented Ultraviolet Filter Applications, *J. Nanoscience & Nanotechnol.* **11** (2011) 4019-4028
4. Truffault Laurianne et al., Application of nanostructured Ca doped CeO2 for ultraviolet filtration, *Mater. Res. Bull.* **45** (2010) 527-535

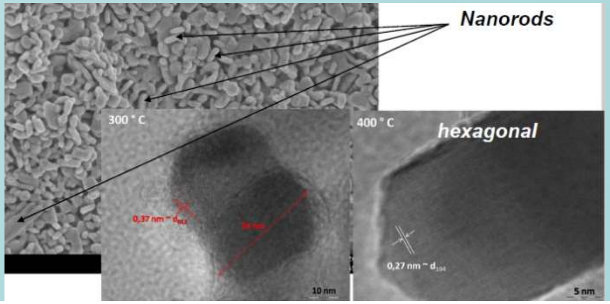
In vitro **Sun Protection Factor** (SPF) and **Protection factor-UVA** (PF-UVA) tests





- Better UV protection than most commercial products
- No use of potentially carcinogenic nano-ZnO particles
- Cosmetic companies Interested in further collaboration

Dr. Laurianne Truffault



Ceramic nano-particles and composites for cancer and oxidative stress related diseases

Understanding the Oxidative Stress

- **It has been revealed that a large number of human disorders, as well as radiation, lead to creation of free radicals including ROS and to appearance of "oxidative stress" in the body. This is observed in various systems/disorders:**

- ***Brain***: Alzheimer's, Parkinson's, Multiple Sclerosis, Stroke: Ischemia, and others
- ***Circulatory System***: Atherosclerosis, Hyperlipidemia, Cardiovascular and Vascular disorders, Hypertension
- ***Endocrine System***: Diabetes, Metabolic Syndrome
- ***Musculoskeletal System***: Arthritis, Physical injury, Joint disorders
- ***Immune System***: Allergic disorders, Autoimmune disorders, Inflammatory disorders
- ***Respiratory System***: Asthma, Emphysema, Bronchitis
- ***Digestive System***: Inflammatory bowel disease, Crohn's disease
- **Oxidative stress is also related to radiation induced pneumonitis and to the radiation damage** to healthy cells during tumor radiation therapy or radiation from other sources.
- **Contribution to the Ageing Process**

Key Nanoceramics in Health Protection Applications

Ce-based Nanoceramics for Oxidative Stress Treatment

Fluorite-structured ceria has proved to be a material of exceptional technological importance due to its unique properties, including high mechanical strength, oxygen ion conductivity and oxygen storage capacity. It is currently being used for preparing high temperature ceramics, catalysts, fuel cells, solar cells, UV blocks and polishing materials.

Ceria is used in exhaust catalysis and can act reversibly as oxidizing or reducing agent.

Under fuel lean condtions

$Ce_2O_3 + 0.5\ O_2 \leftrightharpoons 2CeO_2$

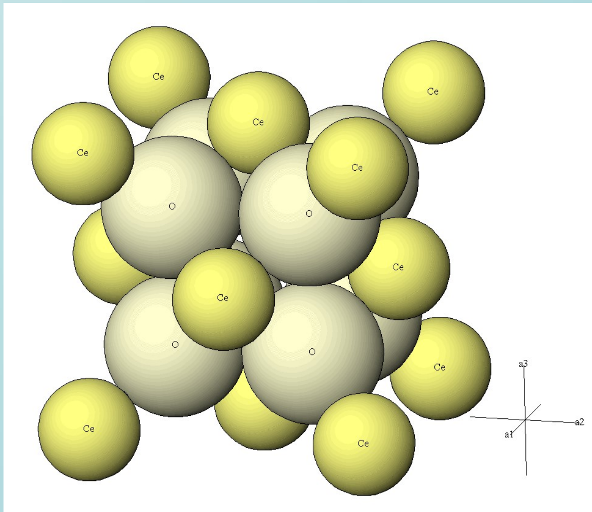
$Ce_2O_3 + NO \leftrightharpoons 2CeO_2 + 0.5\ N_2$

$Ce_2O_3 + H_2O \leftrightharpoons 2CeO_2 + H_2$

Under fuel rich conditions

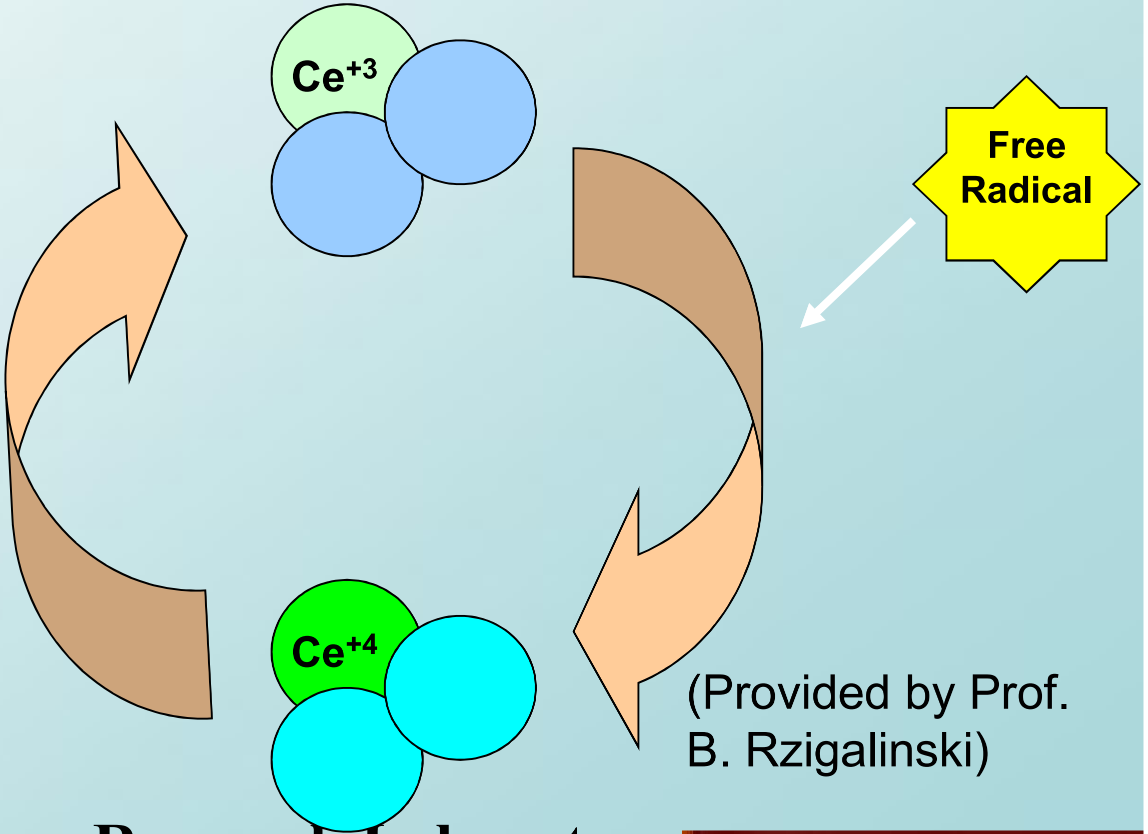
$2CeO_2 + H_2 \rightarrow Ce_2O_3 + H_2O$

$2CeO_2 + CO \rightarrow Ce_2O_3 + CO_2$



Nanoceramics in Health Protection Applications

Ce-based Nanoceramics for Oxidative Stress Treatment



Regeneration: Lattice Rearrangements

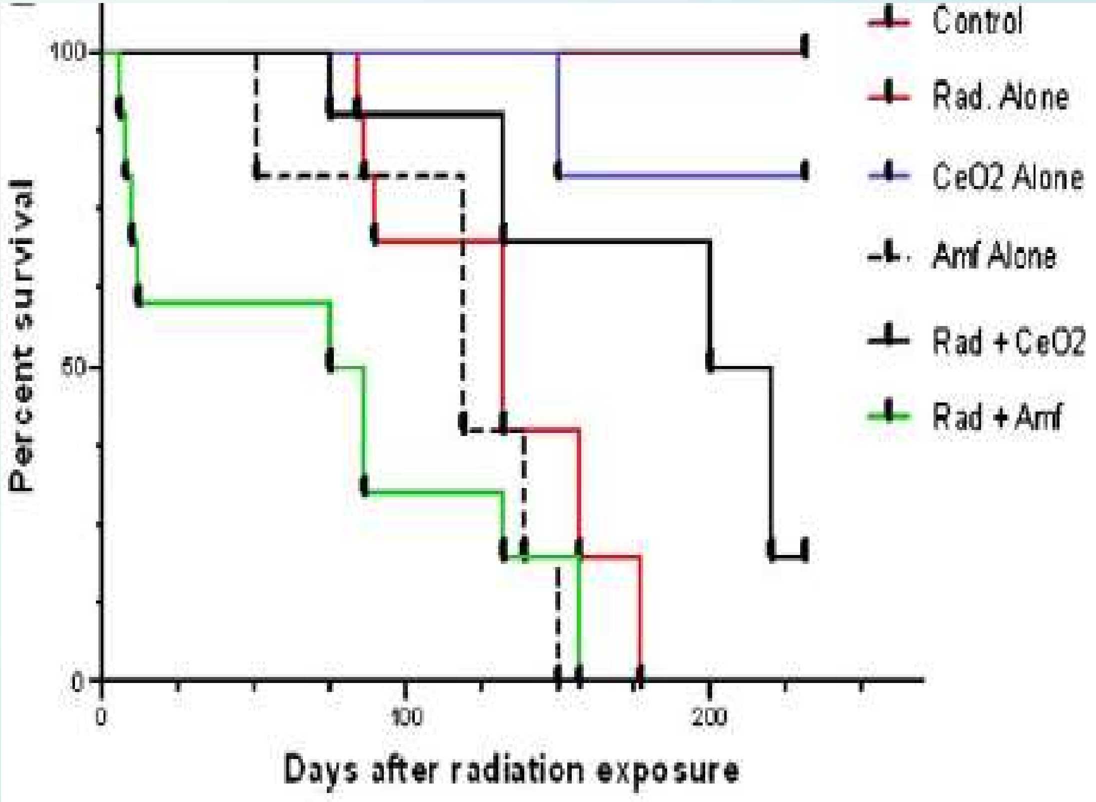
- **Reaction with H_2O?**
- **Adsorption of OH or H+?**
- **Other cellular reactants?**

(Provided by Prof. B. Rzigalinski)

Nano-Neuro Science Research Laboratory

The Health Protection Role of Ce-Based Nanoceramics Radiation Protection

Jimmie Colon,,Luis Herrera, Joshua Smith, et al. Protection from radiation-induced pneumonitis using cerium oxide nanoparticles, Nanomedicine: Nanotechnology, Biology and Medicine, **5**, issue 2, June 2009, Pages 225–231

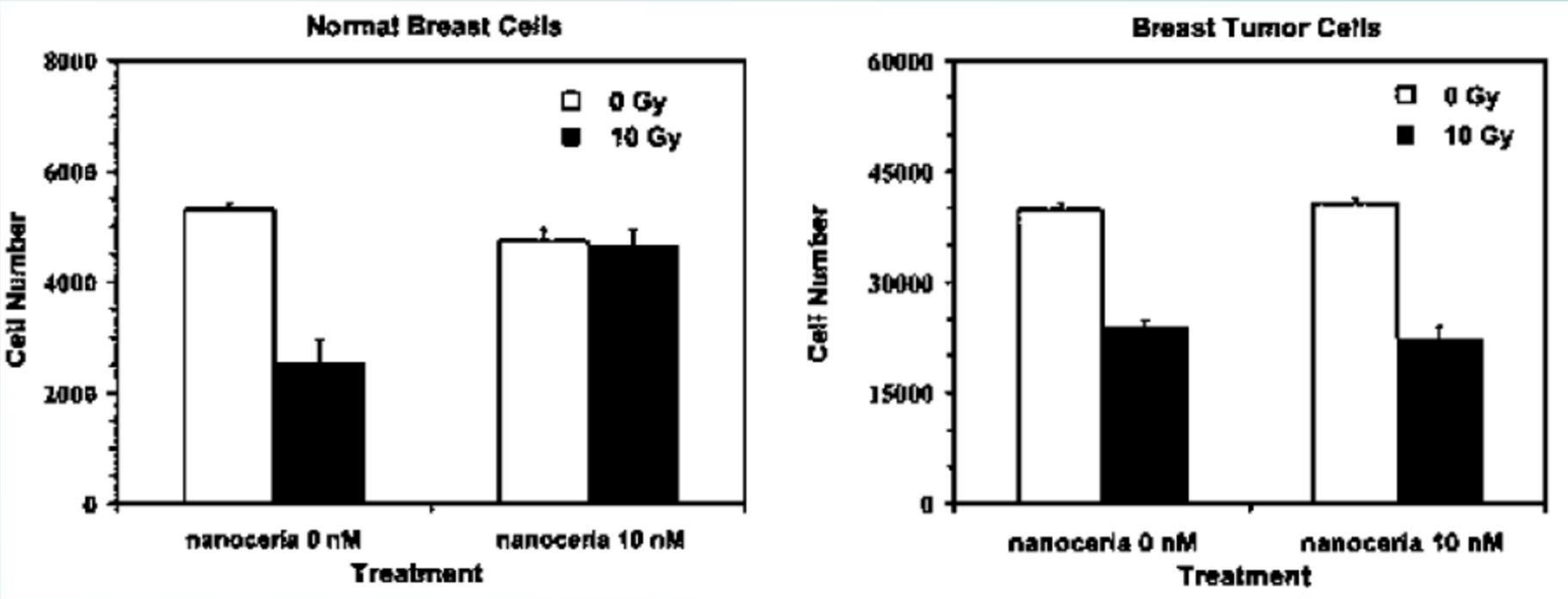


Therefore, the potential benefit of radioprotection using CeO_2 nanoparticles is of great importance on multiple levels—most importantly its potential impact on human life. This research is relevant to the health and quality of life of humans worldwide who are exposed to radiation environments such as those listed below:

- Patients receiving radiation treatments for cancer
- Astronauts exposed to particle radiation
- Military and civilians potentially exposed to radiation in battle, terrorism, or occupational exposure

The Health Protection Role of Ce-Based Nanoceramics Radiation Protection

- Protection from Radiation-Induced Cellular Damage
- Selective Protection between Normal and Cancer Cells
- R.W. Tarnuzzer et al. Nano Lett. 5 (2005) 2573-2577.



Colon Cancer Treatment with Ceramic Nanoparticles –Trailblazer Finalist 2010 certificate
(in collaboration with Prof. X. F. Huang)

- **Novel Mechanism of Action -** We can control the oxidative stress inside the body by using nanoceramic composites as selective ROS scavengers/generators
  - We let oxidative stress appear selectively only in cancer cells
  - We keep oxidative stress away from healthy cells

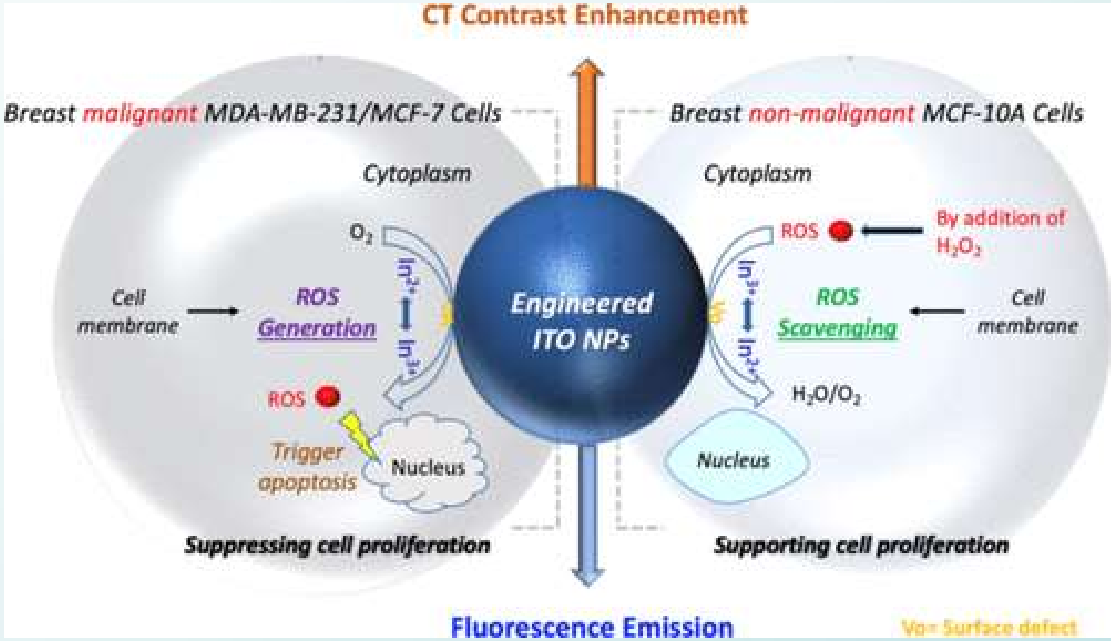
  selectivity triggered by the different environmental factors (pH, water and oxygen content) existing in all cancer types vs normal tissues

- **Universal action** – Kills many kinds of cancer cells

- **Very efficient** – Our early studies showed **above 50% reduction of cancer cells survival vs. control, which is very promising.**

- **Cost-effective and simple synthesis** – Simple to manufacture materials by easily scalable technology

Oxi-redox Selective Breast Cancer Treatment: An In-vitro Study of Theranostic In-based Oxide Nanoparticles for Controlled Generation or Prevention of Oxidative Stress



Nai-Sheng Hsu, Moeava Tehei, Md Shahriar Hossain, Anatoly Rosenfeld, Muhammad J. A. Shiddiky, Ronald Sluyter, Shi Xue Dou, Yusuke Yamauchi*, and Konstantin Konstantinov*

ACS Appl. Mater. Interfaces 2021, 13, 2, 2204–2217

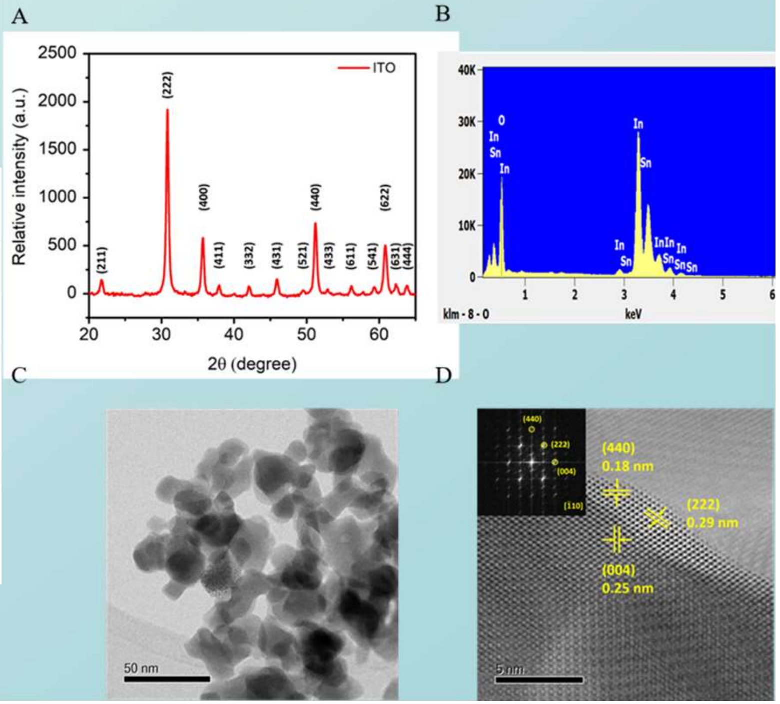
Table 3. Quantitative results on ITO NPs obtained by XPS calculations.

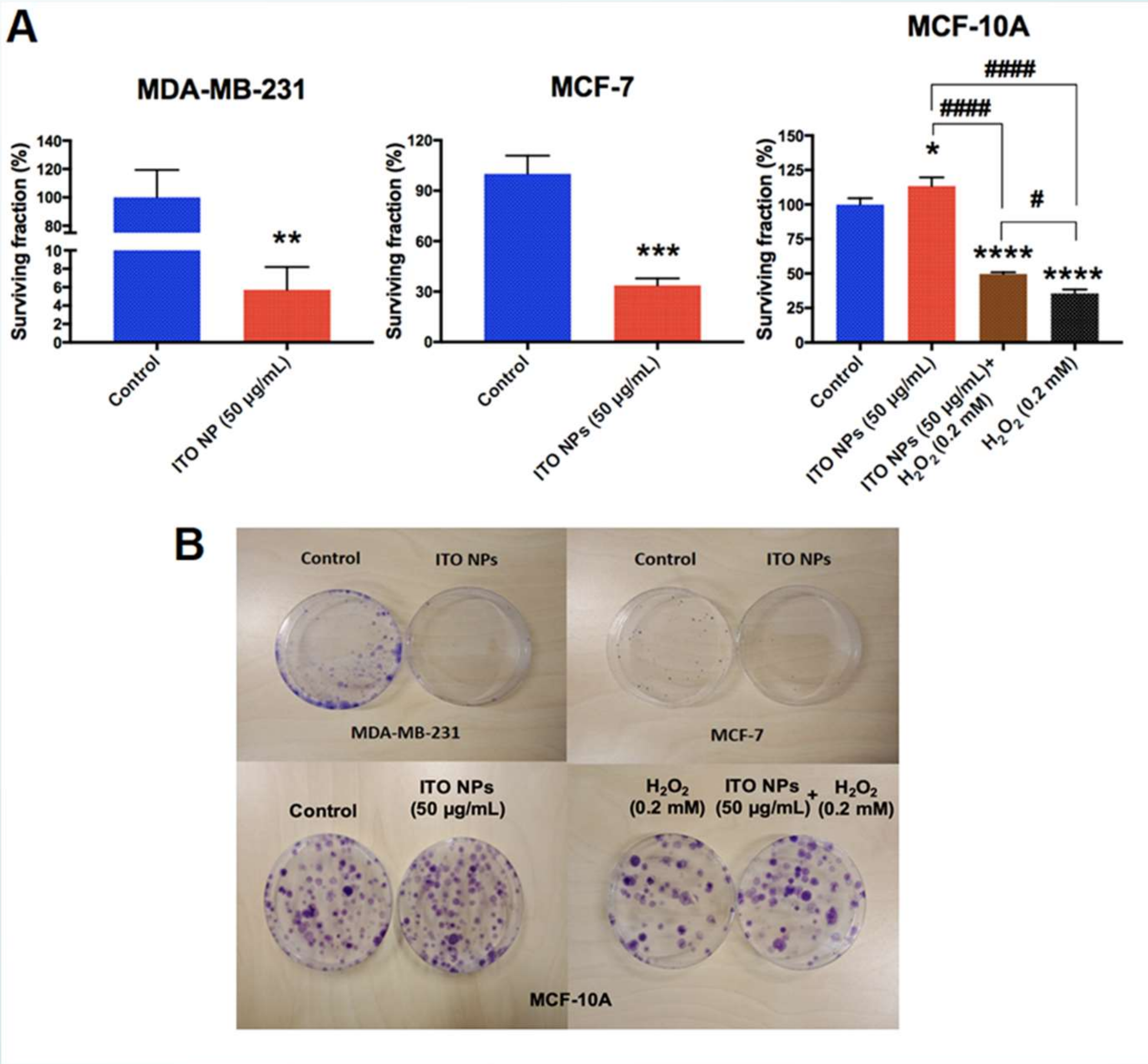
Sample	O (at %)	In (at %)	Sn (at %)	Sn / In	*Vo / O total* (Oxygen deficiency %)
ITO-1 (Present studied)	66.25%	27.58%	6.17%	22.37%	25.03%
ITO-2	65.60%	28.44%	5.96%	20.96%	20.36%

Note: ITO-1 NPs are the material that we studied in this article.

ITO-2 NPs are the material synthesized under the same conditions as ITO-1 but annealed in air.

ITO-2 NPs induced ROS generation in both types of cancer cells, but not in normal cells, and they did not show any ROS-scavenging behaviour in normal cells. Data is shown in Supporting Figure S1.





Clonogenic results of ITO NPs mediated cell apoptosis in breast cancerous MDA-MB-231 and MCF-7, and normal breast cell protection in MCF-10A cells.

Radiation Assisted Cancer Therapy Using Nanoceramics

- UoW Novel concept – Application of High Z ceramic nanoparticles (NPs) as radiation enhancers instead of Au and Pt

Radiation Therapy

- **Enhancement of radiation**
  - Bismuth (III)-oxide (Bi: Z=83)
  - Gold (Z=79)
  - Platinum (Z=78)
  - Tantalum(V)-oxide (Ta: Z=73)

$$\boxed{\text{Photoelectric effect} \propto \left(\frac{Z}{E}\right)^3}$$

- **Generation of reactive oxygen species (ROS)**
  - **OH•, ROO•, H_2O_2, O_3**

Diagnostics and imaging

– Computed tomography (CT)
- Contrast agent: Iodine (Z=53), Gold (Z=79), Bi (83)

Mass attenuation coefficient

Transmitted intensity

$$\boxed{I = I_0 \cdot e^{-\mu \cdot x}}$$

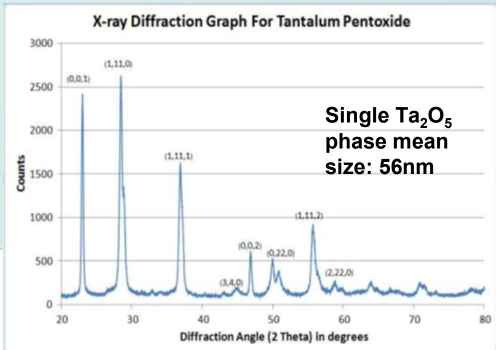
Thickness of absorber

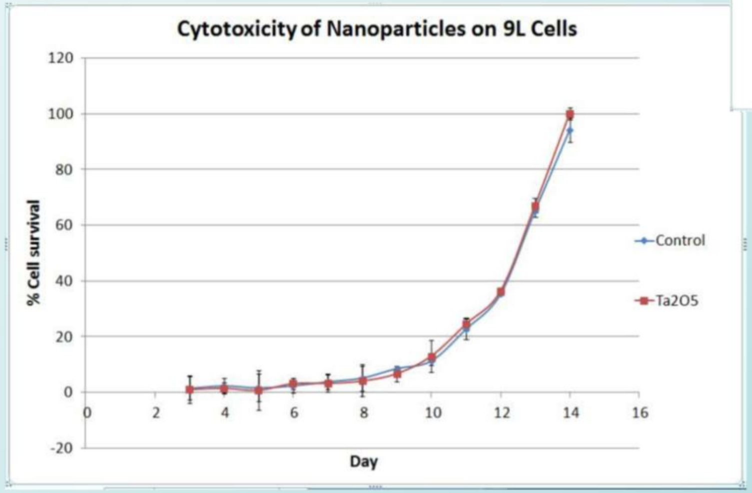
Incident intensity

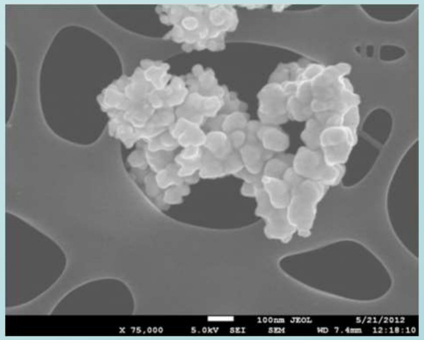
$$\boxed{\mu \propto Z^3}$$

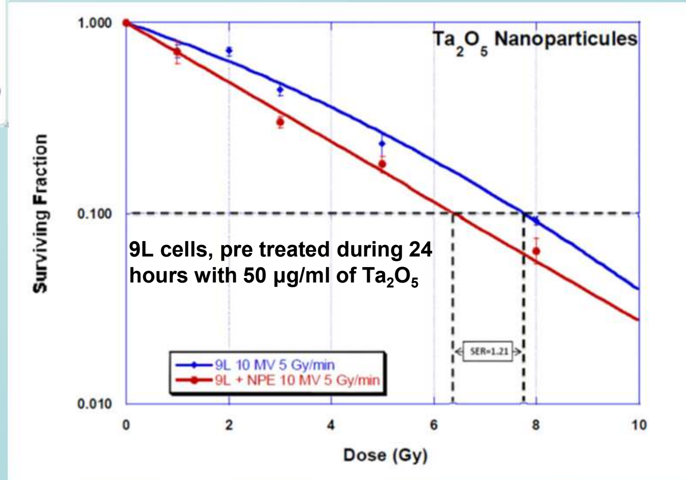
Application of High Z Ta_2O_5 Ceramic Nanoparticles Instead of Au and Pt

High-Z Nanostructured Ceramics in Radiotherapy: First Evidence of Ta_2O_5 -Induced Dose Enhancement on Radioresistant Cancer Cells in an MV Photon Field, *Ryan Brown, Moeava Tehei , Sianne Oktaria, Adam Briggs, Callum Stewart, Konstantin Konstantinov,* Anatoly Rosenfeld , Stephanie Corde , and Michael Lerch,* **Particle (2013) in press, DOI:0.1002/ppsc.201300276**





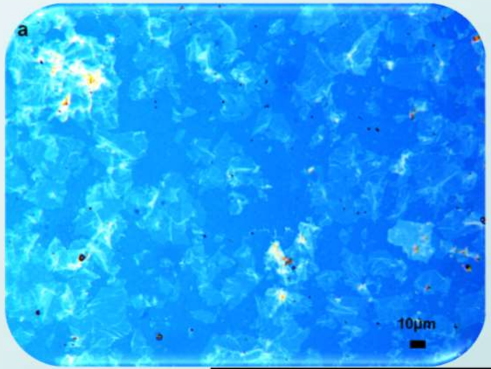




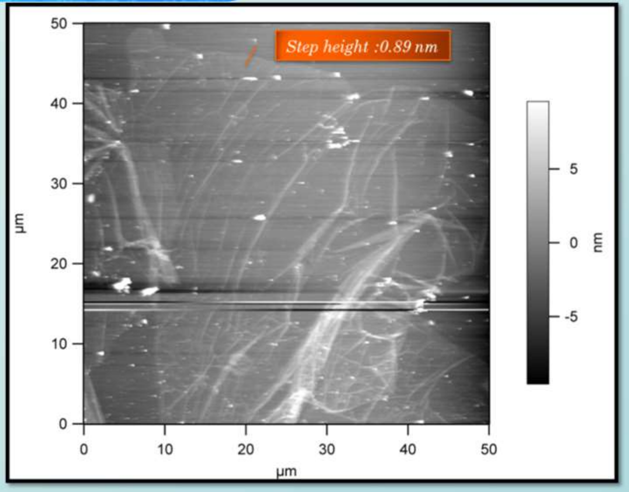
Sensitisation enhancement ratio at 10% survival: 1.21

Liquid Crystallinity (LC) based Extra Large XL–GO drug carrier system novel concept

Three times larger than the largest Sheets reported so far



These large sheets can induce LC transition at concentrations as low as ***0.075 wt. % (almost an order of magnitude lower than others')***

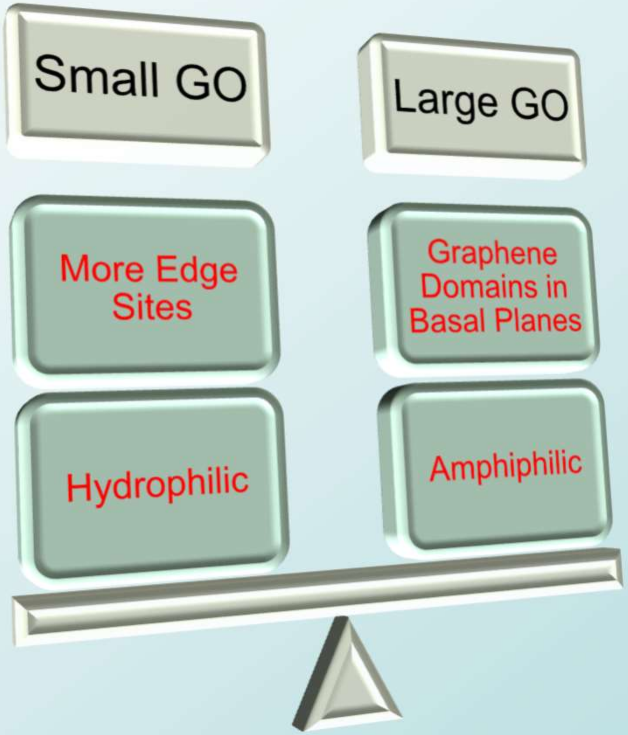


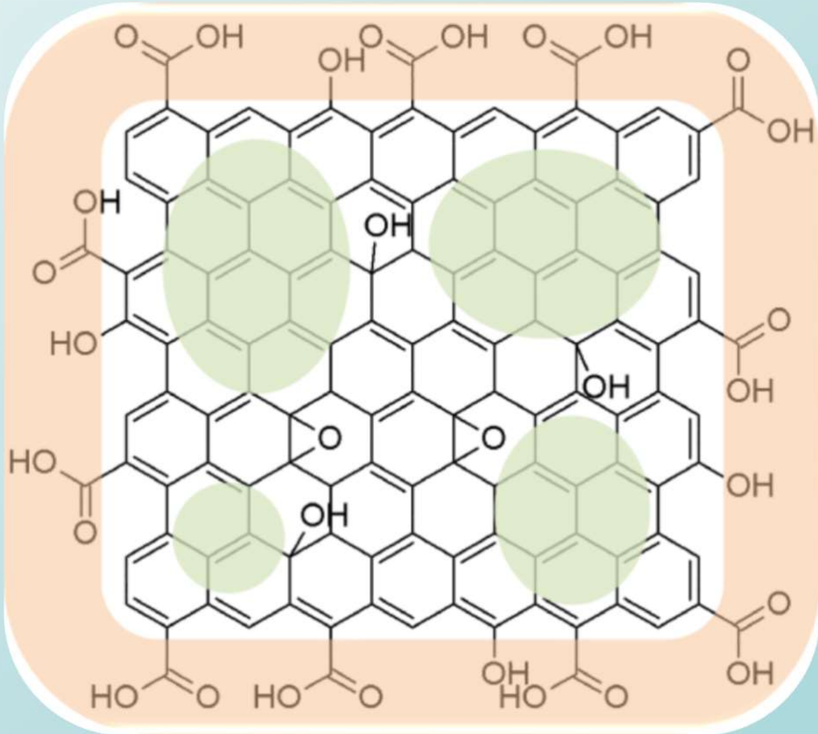
We are first to report LC behaviour in body solutions including PBS.

Mr. Seyed Hamed Aboutalebi, ISEM PhD student

S. H. Aboutalebi, et al., *Spontaneous Formation of Liquid Crystals in Ultralarge Graphene Oxide Dispersions*, **Advanced Functional Materials**, 2011, **21**, 2978-2988

Graphene oxide: Structure

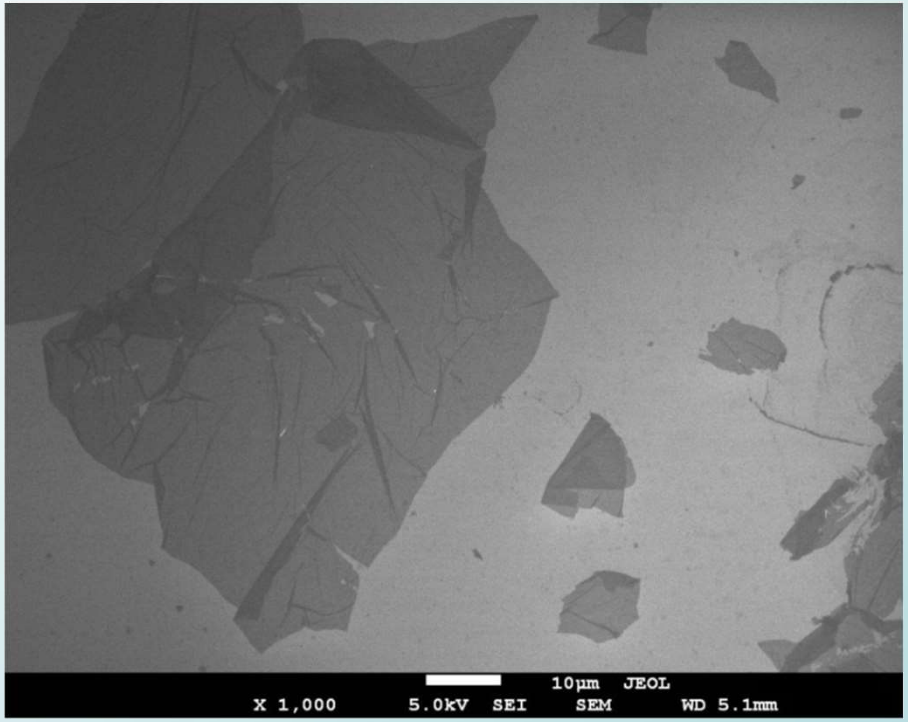




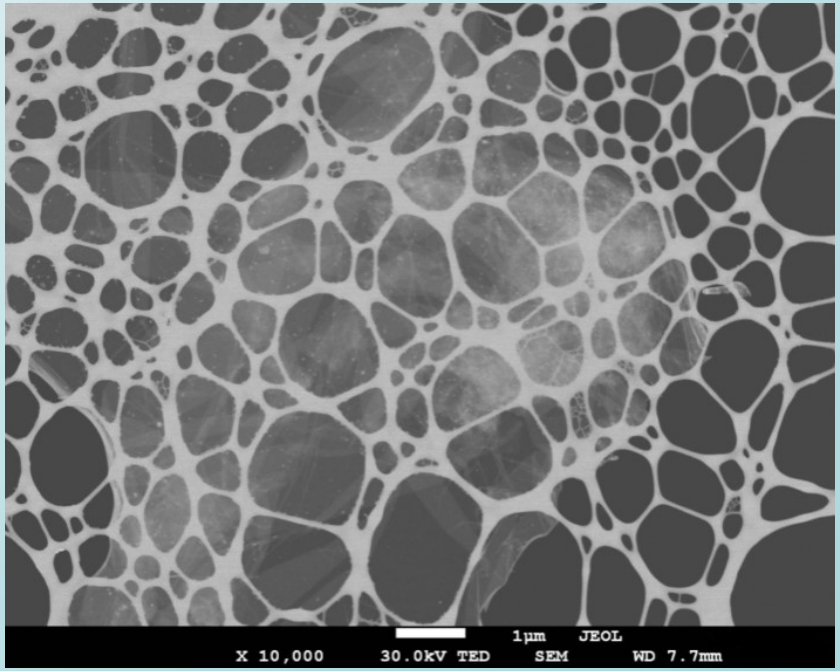
Similar to water, graphene oxide can easily incorporate polar solvents such as PBS

LC XL/GO-5 fluorouracil drug-carrier system

Ms. Isabell Jonas



FE-SEM of as-prepared XL-GO



STEM image of graphene oxide loaded with 5-Fluorouracil on a holey carbon grid

LC XL/GO-5 fluorouracil drug-carrier system

In vitro testing of GO-5-FU on B16 breast cancer cells

Concentration: 1.5 mg 5-Fluorouracil/1 ml of graphene oxide suspension (with a concentration of 3 mg/ml) equivalent to 0.5 mg 5FU/1 mg LC_XL_GO – 30% more than reported in the article

Table A 1: Mortality rates determined from cytotoxic experiments over 24 hours and 48 hours.

	5–FU	GO1	GO2	GO3	GO4
24 hours	7.5 %	0.2 %	3.3 %	8.3 %	15.9 %
48 hours	11.7 %	0.7 %	2.8 %	9.9 %	22.8 %

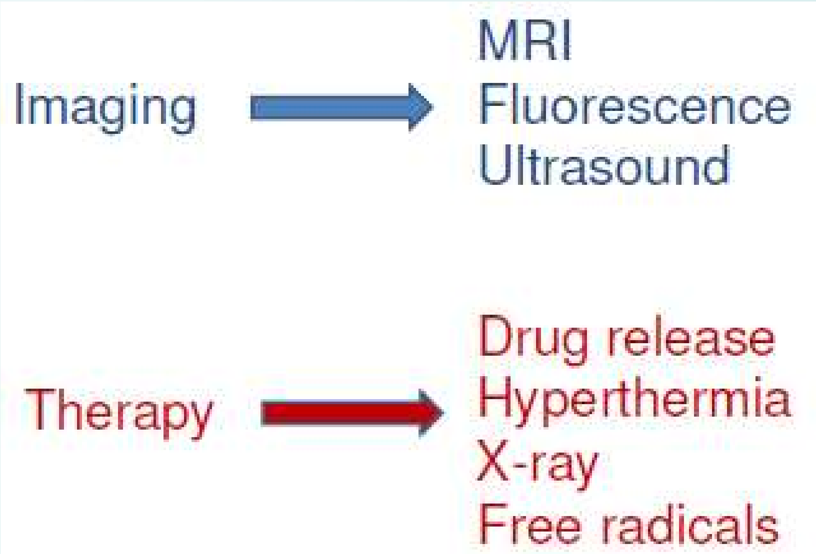
-“5FU” is pure 5-Fluorouracil dissolved in Phosphated buffered saline (PBS);

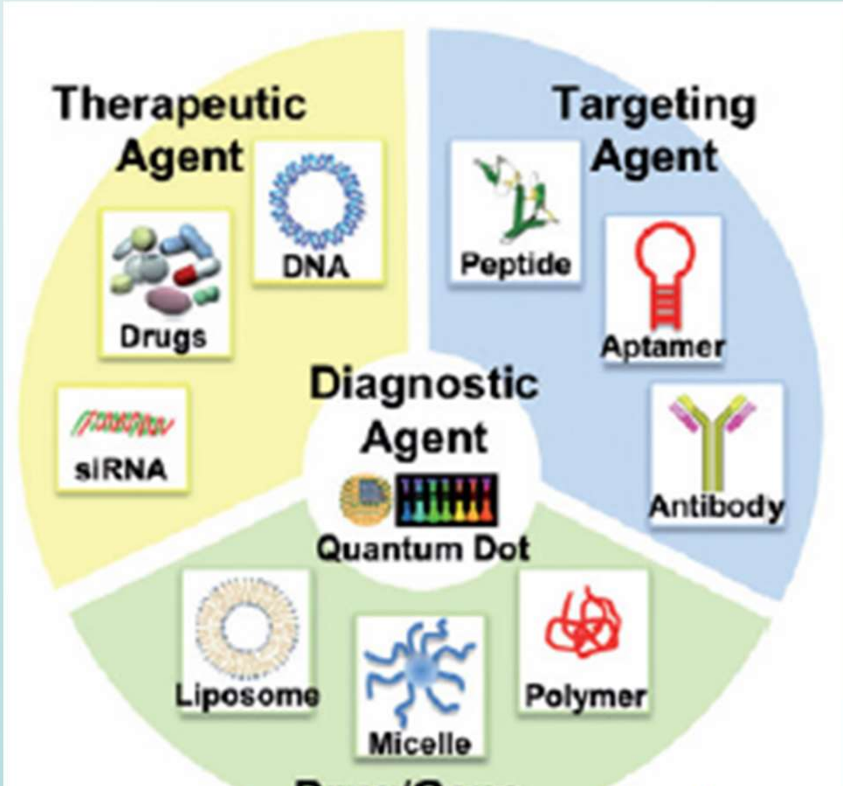
-“GO1” and “GO2” are reference samples of graphene oxide in PBS after gentle centrifuging, “GO1” refers to the clear top phase, containing PBS, “GO2” to the bottom phase, containing the graphene oxide.

-“GO3” and “GO4” refer to the loaded carrier after gentle centrifuging, “GO3” refers to the clear top phase, containing PBS and “GO4” to the bottom phase, containing the graphene oxide loaded with 5-Fluorouracil.

Ceramic based theranostic systems for cancer treatment

Theranostics: a combination of therapy and diagnostics



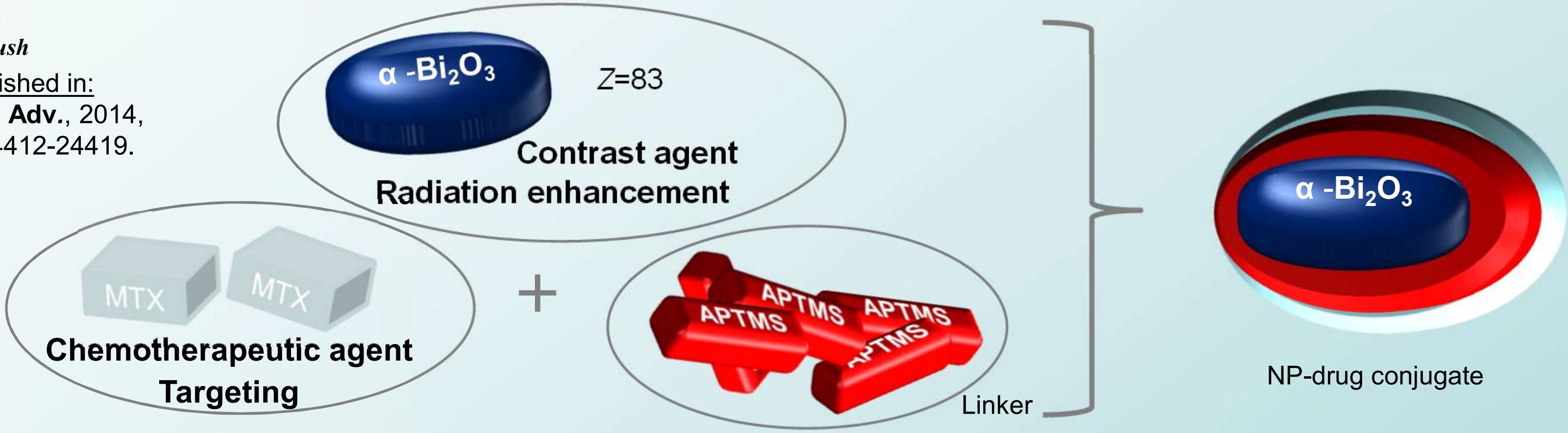


Ho and Leong *Nanoscale* 2, 60-68 (2010)

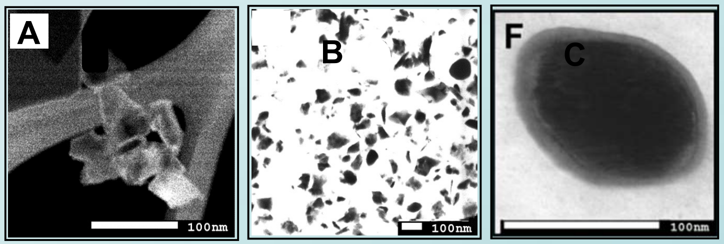
Polymer-free synthesis of potential theranostic system with 4 features for cancer treatment

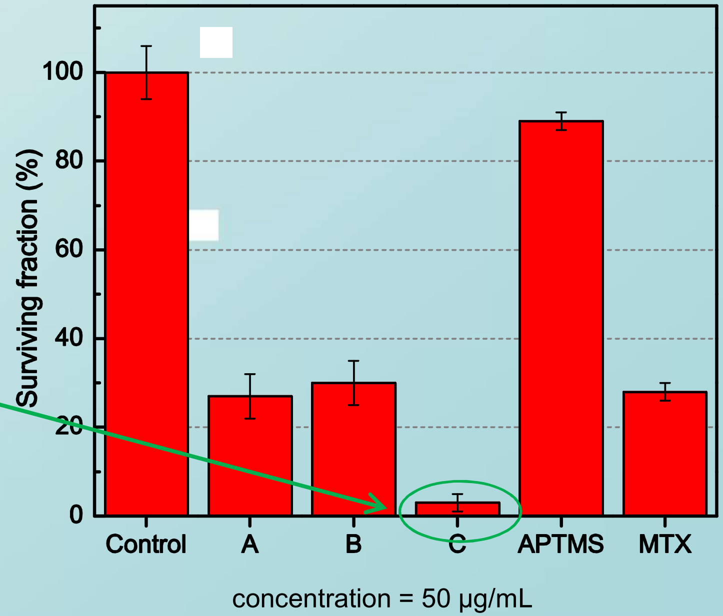
Ms. Kathrin Bogush

Published in:
RSC Adv., 2014,
4, 24412-24419.



- Synthesis of Bi_2O_3 NPs via classical precipitation method **(A)**
  - Plate-like particles, 40-70 nm in size, mostly agglomerated
  - Enhanced anatomical contrast
- Coating with APTMS via hydrolysis and condensation **(B)**
  - Core-shell structure
  - Increased dispersibility
- α-Bi_2O_3-APTMS-MTX conjugate via amidation **(C)**
  - Successful internalization (9L cells)
  - Synergistic effect: 97% cytotoxicity (9L cells)





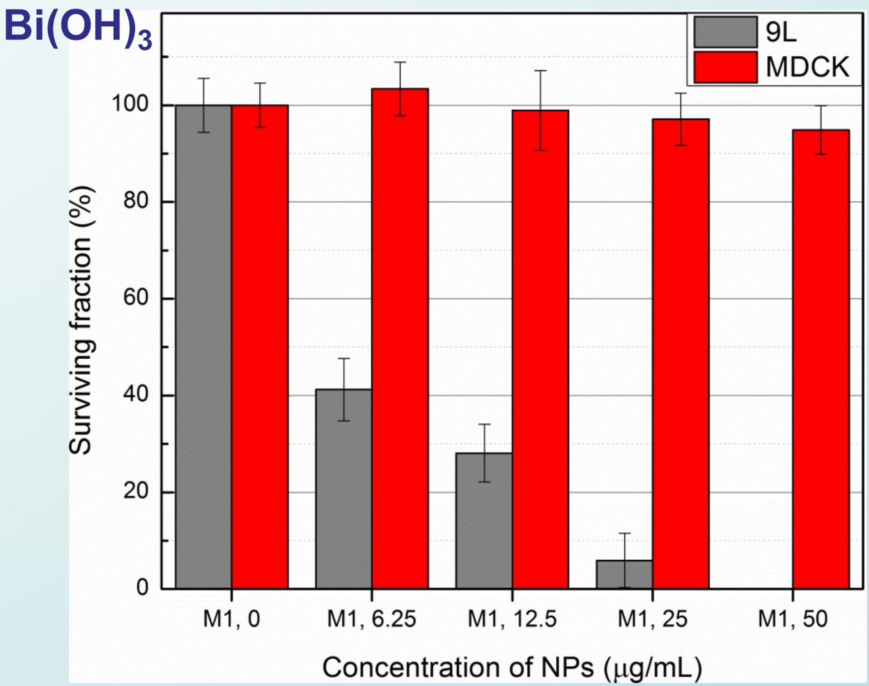
Abbreviations: nanoparticle (NP), (3-aminopropyl) trimethoxysilane (APTMS), methotrexate (MTX)

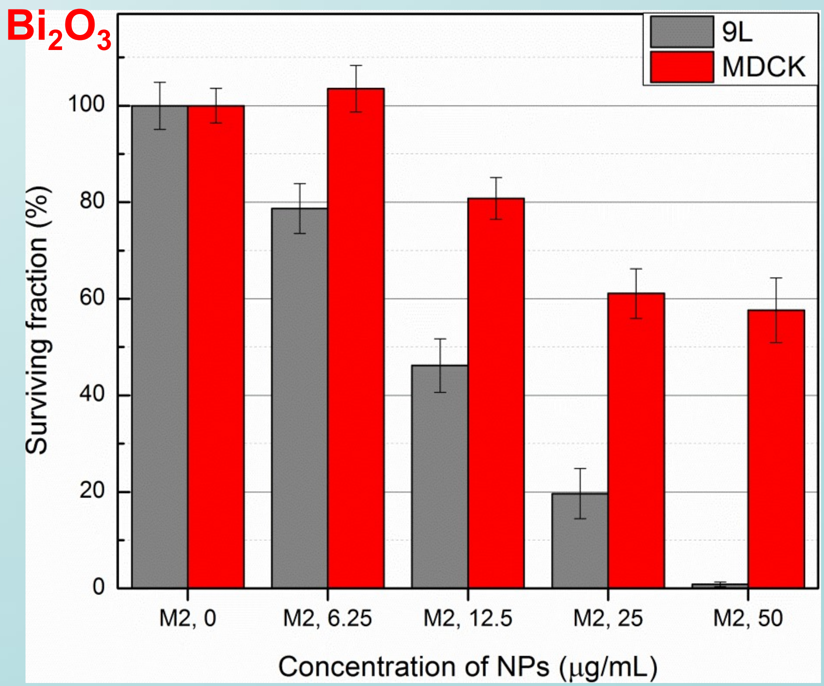
Selective Toxicity of Bi-based oxide NPs in 9L and MDCK cells

9L: rat glioma
MDCK: Madin-Darby canine kidney

Clonogenic assay

- 15 doubling times, [c] = 6.25, 12.5, 25 and 50 µg/mL
- Bi ceramic-based NPs: Bi_2O_3 and $Bi(OH)_3$ (24h incubation)





Higher selectivity

Conclusions

The advanced ceramics have a major influence and contribution to our life and our future and the materials science

UoW is a leading university in advanced materials and processing technologies

The UoW students have excellent opportunities to give a research impact in the field of materials science and flexible background for professional development and future career options

Thank You!