Building the defense of tomorow together

Opportunities in nanostructures and nanomaterials for Defense applications

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RÉPUBLIQUE FRANÇAISE

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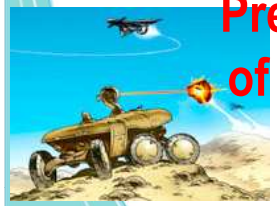
DGA MISSIONS

Equipping
the Armed Forces



Preparing the future
of Defence systems

Promoting Defence
equipment exports

MINISTRY
OF
DEFENCE

DGA
Chief
Executive
of the DGA

CEMA
Chief of the
Defence Staff

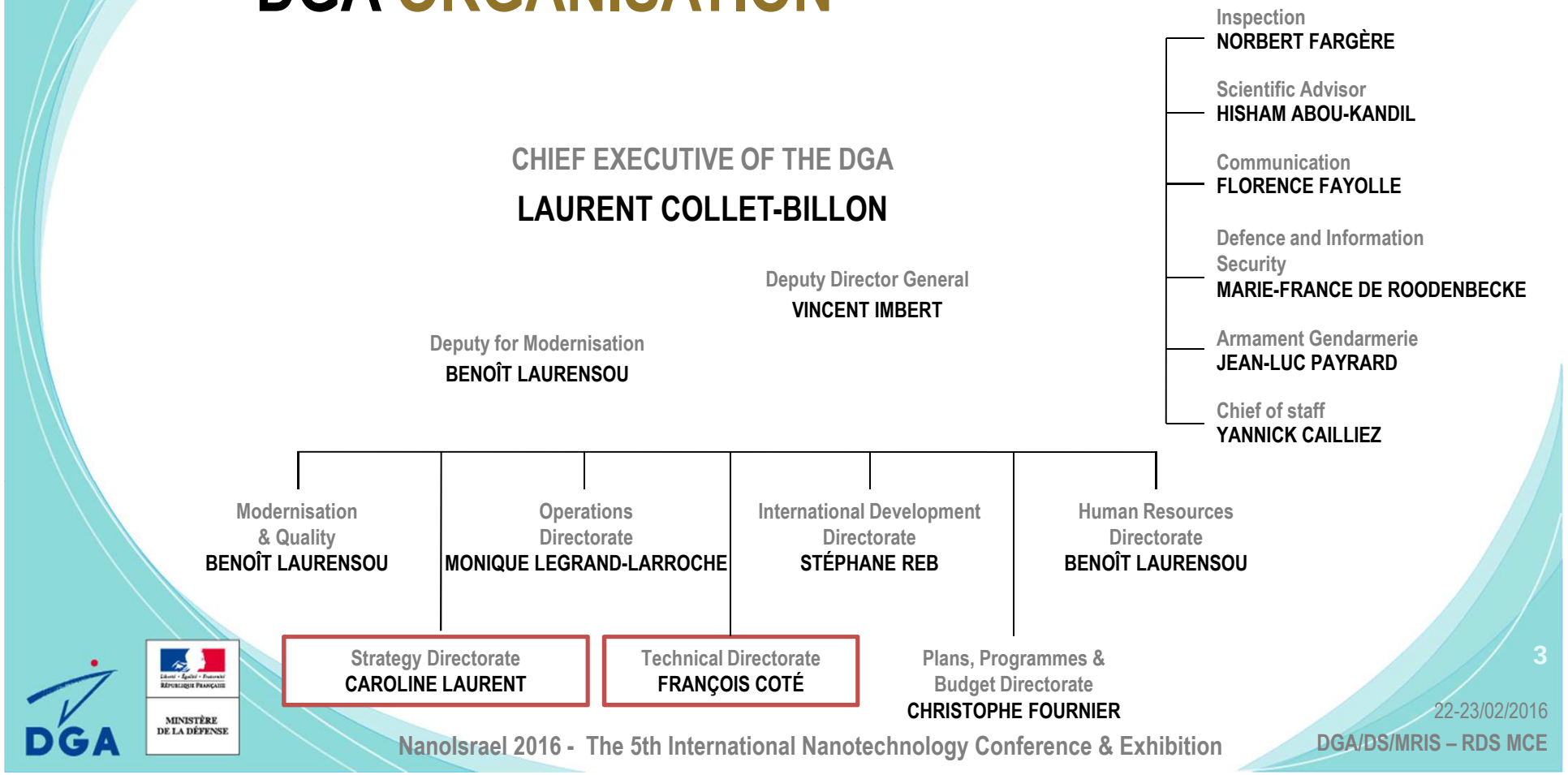
SGA
Secretary General
for Administration

CEMAT
Chief of Staff
for the Army

CEMM
Chief of Staff
for the Navy

CEMAA
Chief of Staff
for the Air Force

DGA ORGANISATION



LOCATIONS IN FRANCE

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Strategy directorate : Missions of MRIS*

***Office for Advanced Research and Innovation**

- Explore New Scientific Ideas, identify future threats
- Identify and Orientate Research with Defense Interest ; detect emerging technologies
- Create and Monitor a Scientists and Engineers Community ;

  Manage a complete ecosystem
  - **a chain of stakeholders :** research laboratories, academic and industrial partners
  - **a strategy :** sciences & technologies for the Ministry of Defence
  - **tools and systems :** from the laboratory to the demonstrator (ASTRID, RAPID, PHD, investment programs)
- Facilitate Transfer of Research Results ; Promote Scientific Policy of DGA
- Share the Effort with Civil Research (Dual Use)

  and with Foreign Countries (international)

Scientific domain : Materials, Chemistry & Energy

Materials

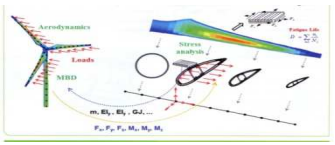
Materials for structures

Thermal and mechanical sollicitations - Microstructures
Composites – Superalloy - Ceramique

Fonctional materials

Multi functional surfaces, Electromagnetisme
Nanomaterials, Metamaterials, Piezoelectric

Process, simulation - experimentation, bonding, NDC



Chimistry

Surfaces

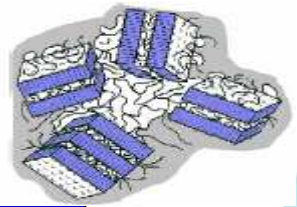
Surface behaviour, interface
Chemical and biochemical behaviour
Catalysis

Detection - Decontamination

Environment : Alternative products & concepts
B & C detection and identification

Energetic materials

Microstructure



Energy

Material behaviour

Electrochemical behaviour
Thermodynamical phenomena

New sources - Stockage

Photovoltaïque, PAC

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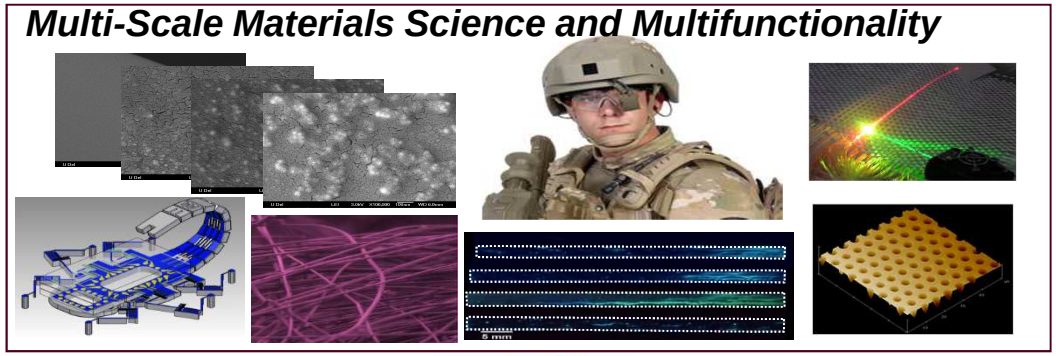
Interest in nanoscale :
new properties; multi-functionality of materials



Q Dots: colour = size

Surface

Optical

New behaviour appears at the nanoscale

Thermal

Electronic

Magnetic

Mechanical

R & D : Operational aspects

- **Protection of combatants (infantry and platforms)**
  - Optimize the compromise : Cost - Protection (efficiency) - Weight (mobility)
- **Platforms: vehicles / aircraft / ships**
  - Lighweight structure (improve mobility / autonomy)
    Maintenance (involved cost)
  - Ensure time life
    - Protect surfaces (fight against corrosion) complying with environmental regulations
    - Control the wear of rotating parts (tribology)
    - Ensuring controllability of new structured
  - Increase stealth to improve protection : materials signature
  - Improve tolerance to battle damage and know-how in terms of repairs (on the theater of operations)
- **Ensure the independence and energy security (mobility)**
  - Energy Storage
  - Storage efficiency
  - Pyrotechnic safety, compliance with regulations: environmental, transportation, H & S etc

Nanotechnologies domain : technical sub-themes

Nanoelectronics
Integration of Nano Devices

Communications
- Increase rate/reach
- Agility/stealth
- Decrease the size
- Wireless communications

Soldier Protection
- CBRN threats
- Others threats : shots, detection…
- Smart textiles
- IFF

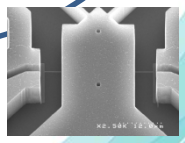
Nanobiotechnologies
- Nanoelectronic
- Nanomaterials
- Integration of Nano Devices

Threats detection :
Radar, electronic warfare
- Decrease the complexity of FE architectures
- Increase frequencies up to the sub-mm
- Drastic reduction of size, weight, costs…

(evolution to drones)

Guidance/Navigation
Indoor localisation
- Decrease size, costs…
- Improve performances

MEMS/NEMS
- Nanoelectronics
- Integration of Nano Devices



- Nanoelectronics ; •Nanophotonics
- Nanomaterials ; •MEMS/NEMS
- Integration of Nano Devices

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Materials, Chemistry, Energy --- Main Technological priorities

- Multifunctional materials: Structure / properties /processing /durability relationships
- Materials for lightening structures
- Advanced Concepts for armor and ammunition
  - New projectiles (nanomaterials, metallic glasses, multi materials)
  - New protections (composites, transparents)
- Development processes (SPS, additive manufacturing, Thermal spraying, sol-gel deposition...)

- Surface treatments and catalytic processes
- Propellants and highly energetic materials
  - Securing ammunition and increased performance
- Renewable energy harvesting in non-cooperative environment
- Energy Storage : Electrochemical and thermochemical behaviour
- Supply chains availability : eco-design, sustainable alternative methods

Impact of Nano- Science & Technology for Defence

Ultra-high speed, high capacity, low power electronics

Secure Communications

Quantum Cryptography

Quantum Computing

Distributed, networked sensors

Novel medical treatments

Wound repair

Personal monitoring

Chemical and Biological agent detection

Decontamination

Nanoelectronics, Molecular electronics, (nano)photonics

Intelligent, autonomous systems

Explosives detection

Structural Materials

Light /strong /tough

Armour/Protection

Nano-composites

Functional Materials

Signature control / Camouflage

Adaptable optical/electromagnetic properties

Multifunctional sensors

Active / smart structures, adhesives, textiles, coatings

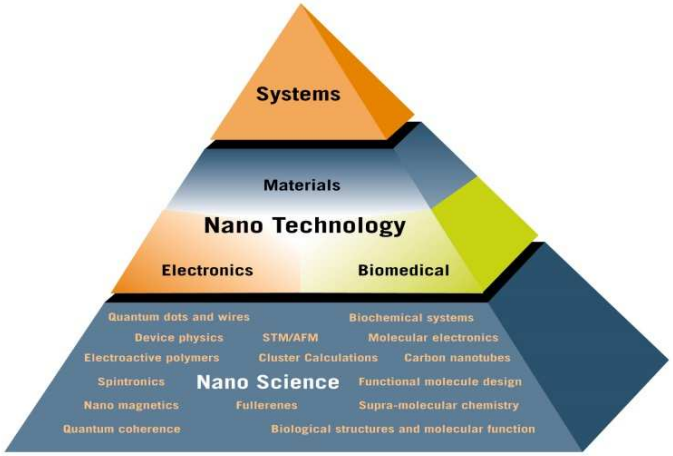
Energetic materials

Insensitive munitions

High capacity batteries

Energy harvesting

Novel Thermoelectrics, Photovoltaics



Information

Defence Capabilities

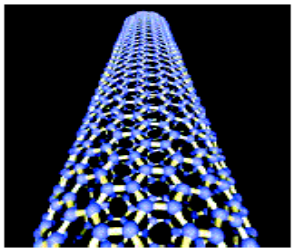
Bio-medical

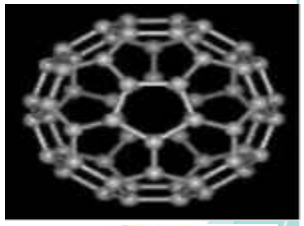
Materials

2 scientific domains : Materials – Chemistry - Energy, Nanotechnologies - Electronics

Dual use 2016 research on Nanomaterials

- Material to improve capability to withstand corrosion
- Bioinspired structures (hydrophoby, surface aspects, reinforcement…)
- New processes : additive manufactoring, Spark Plasma Sintering (nanoscale control)
- Thermal and Electrical conduction
- Chemical synthesis with catalysis





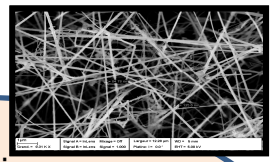
Military applications

- **Nanomaterials, metallic glasses for armor or war heads**
- **CNT Reinforce to enhance structural performances**
- **High temperature materials (MMC or CMC) for aircraft engine; Self-repairing materials**
- **Functional materials based on pigments, nanoporous materials for reduced SER or SIR**
- **Nano structural Surface for corrosion control, hydrophobia, high performance antireflexion coating**
- **Lab on chip for biological trace detection**
- **Nanomaterials for catalytic decontamination**

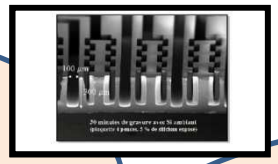
Energetic Applications

- Nano architectural Catalysts for Fuel Cells
- Nano composites for Hydrogen Storage
- Nano charges for pyrotechnic components

Scope of Nanotechnologies domain : scientific sub themes



Micro & Nanoelectronics:
- Nanoelectronics
- Molecular electronics
- Organic or flexible electronics
- Spintronics
- Nanomagnetism
- 3D integration(wafer level)
- Microwave Photonics
- Thermal management

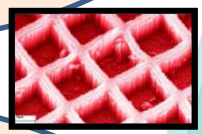


Micro & Nanosystems
- MEMS RF
- Inertial MEMS/NEMS
- Chemical and biological MEMS/NEMS

Nanophotonics
- Microwave photonics components
- Nano-systems with optical functions

Reliability

Harsh environment



Nanomaterials
- Functionalized and smart textiles
- New materials for components

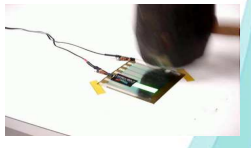
Nanobiotechnologies
- Chemical and biological sensors
- Micro fluidic devices

Integration of Nano (micro) devices
- Autonomous and communicating sensors
- Micro-Nano antennas
- Miniaturized inertial measurement unit
- Labs on chips

Focus on main technological priorities for electronic

- **New technologies for soldier's equipment:**
  - Devices for detection and identification of CBR-E threats, fast and reliable preparation of complex samples;
  - innovative technology for in-field fast sequencing
  - Very low light level CMOS imagers. Embedded intelligence closer to pixel
  - Smart and functionalized textiles: protection, filtering, self decontamination, camouflage, integration of antennas and sensors…
- **New components for microwave chains and communications:**
  - Miniaturized components, high flexibility, down to sub millimeter wavelength; innovative microwave photonic components
  - RF MEMS and associated packaging .Superconductivity.
  - 3D printing and related specific materials
- **New components for inertial systems:**
  - New materials, innovative design. Medium or higher class performance
- **Integration of Nano devices:**
  - Autonomous sensors with wireless communications, nanodrones
  - Micro/nano-antennas reconfigurable in frequency and directivity
  - Ultra-miniaturized inertial measurement unit.

Flexible Display



OLED Pixel

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Some exemples on nanomaterial developments

- Manufactoring : Additive technologies, SPS, microwaves, sol gel deposition
- Biomimetisme : mechanical properties, microstructure, surface aspect
- Stealth, antennas : metamaterials
- Chemistry detectors
- Energy : new sources
- Soldier protection
- ….

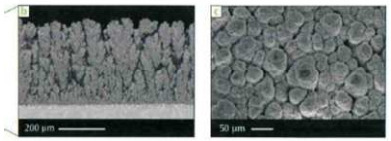
Manufacturing :

High temperature materials : ceramics and metals
Organic materials – blocks copolymers

- **Additive manufacturing :**
  - Architectured structures cooled by transpiration

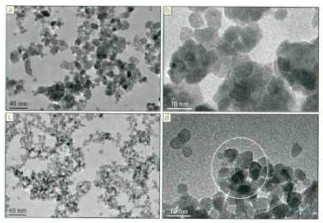
Combustion chamber made in one piece by SLM : dilution holes and multi-perforation . Inconel 718 metal (EADS IW)

  - Powder projection : macrostructure at 2 scales (micro and nanometrique)



columnar thermal barrier deposited on moving turbine blade

- **Microwave process**
  - Powders melting
  - Solidification of sol gel deposition - controlled solvent evaporation
    - The coupling of microwave heating with the sol-gel process strongly influences the solid formation process, allowing control of particle size, size distribution and their crystal structure.

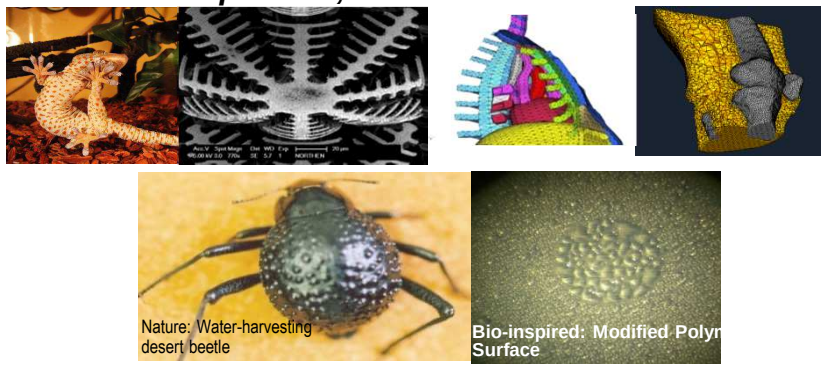


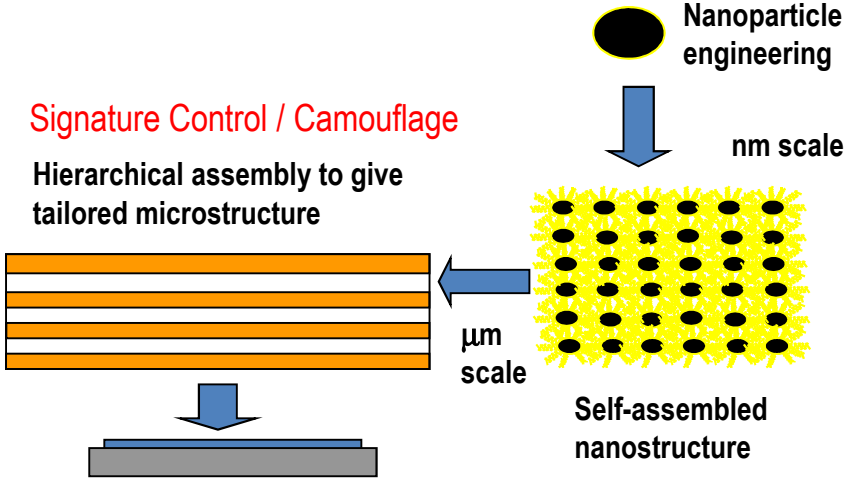
ZrO2 (CEA)

- **NANOTM :** Application of nanomaterials for warheads
  - *« Spark Plasma Sintering – SPS » process technology*

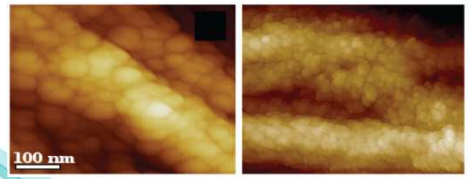
“Bio-inspired” new materials by self- and directed assembly

Bio: -materials, -mimetic, -inspiration, -mechanics





Europeen centre on biomimetisme : CEEBIOS at senlis, near Paris



Nanostructuration of bones

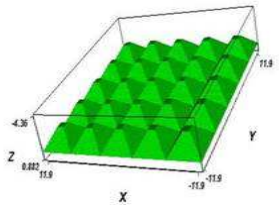
Mussels

Mechanical properties, bonding

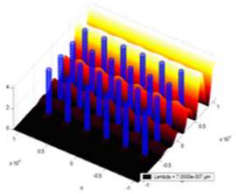
Metamaterials

- Metamaterials or forbidden band gap Materials to have singular effects applied to optical and EM properties control

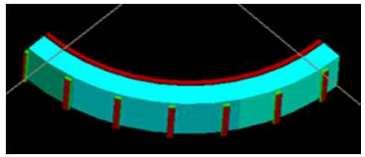
Stealthy materials



Protection

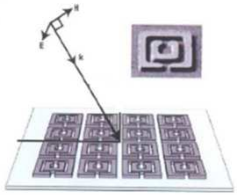


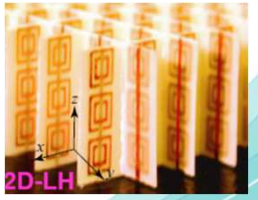
Windows



Improving the antennas and develop new stealth concepts - masking: control the optical or electromagnetic coupling

- **EHRHARDT Kévin (Bordeaux) :** Measurement and modeling of effective properties of meta self-assembled materials formed of resonant metal nanoparticles
- **MIMICRA : Metamaterial Inspired Microwave Conformal Radar Antennas (MIMiCRA 2)**
  - Increase the capacity and potential of radar detection of aeronautical platforms by using new metamaterials to manufacture antennas.





Soldier protection

- Nanocrystalline ceramics
- Hierarchical nanocomposites
- Nanocrystalline metals
- Novel fibres
- Shear thickening fluids
- Novel dielectrics
- Sensing

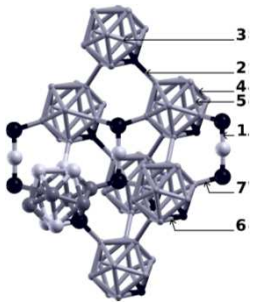
Equipment for effective deployment, protection and survivability

- Power provision and management
- Reduce heat burden
- Body armour, CBRN Protection
- Network communications
- Camouflage, Signature control
- Biological protection

Structural material : balistic protection and kinetic warheads

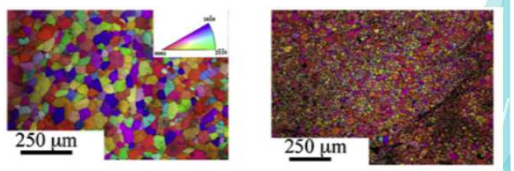
PhD thesis

- **Aharonian Charles (CIFRE Limoges):**
  - Development of ceramic matrices composite and / or layered architectures for ballistic protection of persons
- **Jay Antoine** :
  - Theoretical study of the effect of defects on the physical properties of ceramics
- **Zinszner Jean Luc** :
  - Identification of material parameters governing shielding performance ceramics



Structure of B_4C

- **MAUDE :** metallic materials with Ultra-thin grains produced by dynamic plastic deformation
  - Scale-up, mechanical properties and deformation mechanisms**)**
- **CERAMBALL :** Light weight ceramics for ballistic protection
- **FLECHE :**
  - New materials for High Performance kinetic energy penetrator (OFL)
  - Study of nano-powders and metallic glasses solutions

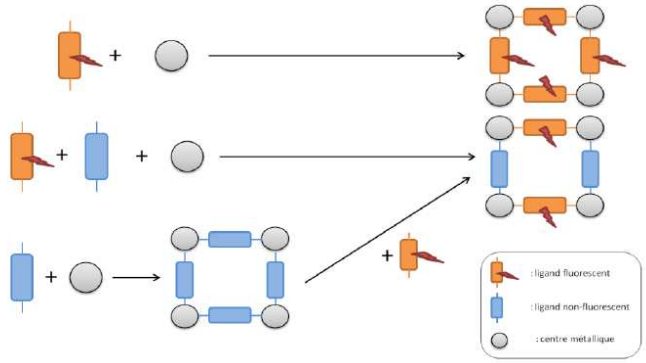


Filtering size of polycrystalline Zn grains after impact in fast dynamics sollicitation

Chemistry : detection systems - decontamination

B &C sensors: alerte and identification

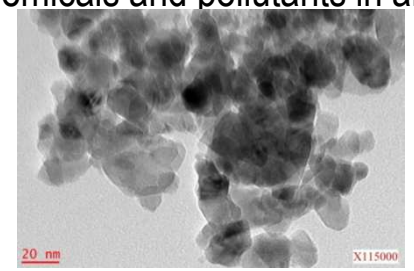
- PhD thesis Paul Rouschmeyer (Univ. Versailles) : hybrid porous solids photoactive



Schematic diagram of the two MOF synthesis routes mixed ligands

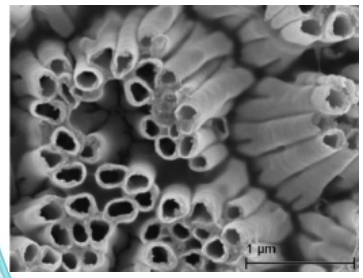
Decontamination, Protection

- **PhD thesis Armelle Perard (univ. Strasbourg) :** Decontamination and remediation Photocatalytic. Production of a device for eliminating toxic chemicals and pollutants in air and water



TiO2 : sol gel synthesis with calcinetion at 500°C and directly doped with Sn4+

Energy – material behavior and new sources



Pt nanotubes

- **Noémie ELGRISHI** :
  - Towards a photoelectrochemical cell for the reduction of fuel into carbon dioxide
- **Mathieu LEPESANT :**
  - Study and implementation of multi-metallic catalysts for nano-organized PEM fuel cell
- **Léonnard THOMMY :**
  - Development of new electrode for high temperature electrochemical converters materials: fuel cells and electrolysers

Conclusions

Nanomaterials will lead to new capabilities for defence and security technology applications

A lot of applications :

- Protective Systems
- Communications (covert, secure) and information processing
- Camouflage, ‘stealth’, mimicry / disguise
- Sensors and surveillance systems
- Power provision and usage

Importance

- to develop a knowledge on materials « structure- process – properties » relationships including modelisation at different scales (micro – meso – macro)
- to optimize and control the nanostructure

Thank you for your attention !

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francois.barthelemy@intradef.gouv.fr

GLOBAL ANALYSIS, ON THE BASIS OF REFERENCE DOCUMENTS

Type of research funding tools for defense