FORESEEN

Frontiers between Optics and Rf Extended by Study of Extreme Electromagnetism at Nanoscal

Roadmap

NANOARCHITECTRONICS is a new technology aimed at conceiving, designing and developing reconfigurable, adaptive and cognitive structures, sensorial surfaces and functional "skins" with unique physical properties and engineering applications in the whole electromagnetic spectrum; through assembling building blocks at nanoscale in hierarchical architectures

This document is written by the 40 members of the FORESEEN consortium as a roadmap of Nanorchitectronics

Summary

1. CHALLENGE AND VISION

1.1. GAME CHANGER

European society's grand challenge in Communications, Environment Sensing Systems, Safety and Security, Bio-Sensing Systems and Imaging Nanosystems, brings today to a large variety of platforms, systems and functionalities. Trying to address this broad variety of entities in a unitary frame implies toperation and communications in an extremely broad range of frequencies with high level of functionalities and component integration. This requires an unprecedented level of technological convergence into a revolutionary framework, which has the final vision to unify the interaction between humans or systems with the surrounding environment by providing adaptive, cognitive, sensorial and scalable "skins" (i.e. "smart interfaces", some of them "wearable", well beyond the capabilities of nowadays "connectors", "antennas" and "sensors") connected with the environment. The game-changer, convergent, enabling technology envisaged to develop such new kind of systems and components is called

NANOARCHITECTRONICS (NTX)*:*

The name NTX comes from the merger of three key terms: "nano", "architecture" and "electronics". It is a new technology aimed at conceiving, designing and developing reconfigurable, adaptive and cognitive structures, sensorial surfaces and functional "skins" with unique physical properties and engineering applications in the whole electromagnetic spectrum; through assembling building blocks at nanoscale in hierarchical architectures.

The NTX aims to sensorial interfaces between a subject (person or system) and the environment. In a visionary future, these interfaces will cognitively evolve its functionalities to maximise connections and monitoring/sensing capabilities; it will look like synthetic, mutable skins, which hierarchically assembles nanoparticles and nanosystems into increasingly complex reconfigurable structures.

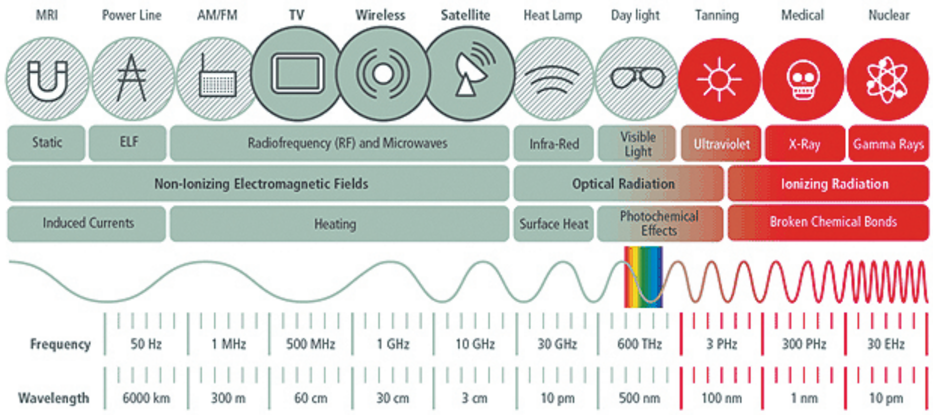


Fig. 1 The Electromagnetic spectrum

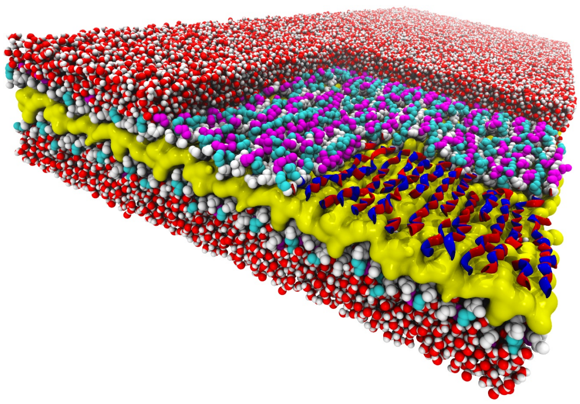


Fig. 2 Rendering of multistrate nanostructured "skin" (from http://phys.org/news/2015-10-newly-nature-inspired-nanostructures-closer.html)

The visionary innovation of the NTX paradigm requires multi-disciplinary efforts made by borrowing concepts, methods and techniques from Physics, Electronics, Electromagnetics, Material Science, Chemistry, Applied Maths, with special emphasis on Nanotechnology, Microwave to Terahertz Engineering, Nanophotonics, Plasmonics, Nanoelectronics, Advanced Materials.

NTX aligns fully with the Future and Emerging Technologies' (FET) mission *to turn Europe's excellent science base into a competitive advantage by uncovering radically new technological possibilities*. It is as well a *science-driven, large-scale, multidisciplinary research initiative oriented towards a unifying goal, aiming at transformational impacts with substantial benefits for European competitiveness and for society*. It also embodies a visionary idea which is emerging from both academic research and high-tech industrial needs: to systematize, homogenize and broaden the connectivity and sensing.

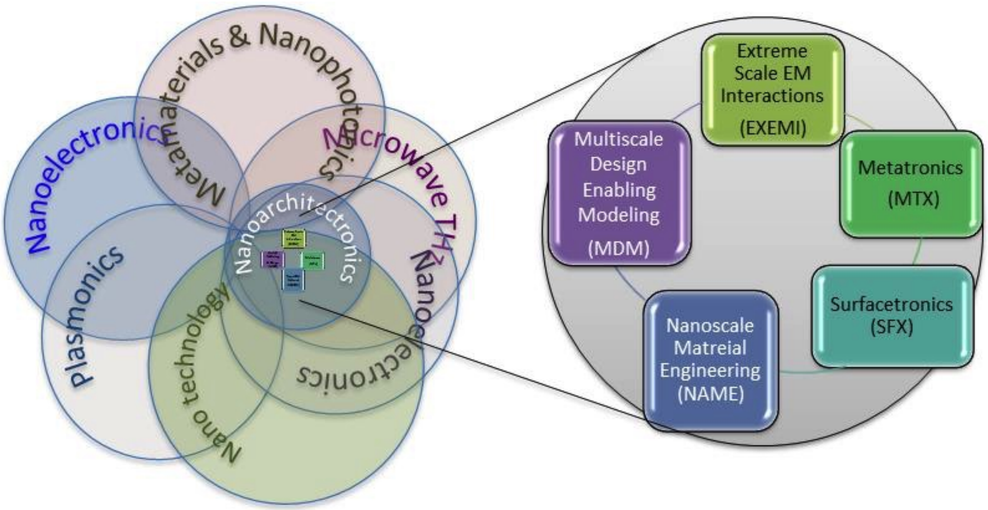


Fig. 3 Nanoarchitectronics multidisciplinarity

1.2. RESEARCH PRIORITIES AND TECHNOLOGICAL ADVANCEMENTS

The research priorities in NTX can be classified into 5 macro-areas (Fig.)4, 3 Focus areas and 2 transversal area

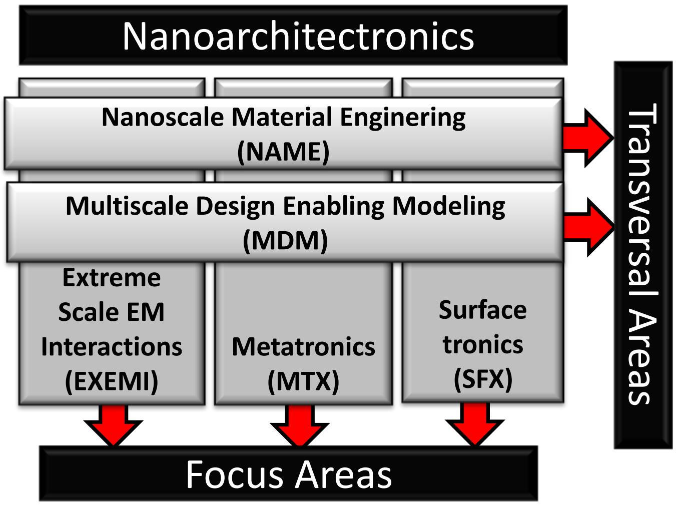


Fig. 4 Focus areas and transversal areas in NTX

1.2.1. Extreme Scale Electromagnetic Interactions (EXEMI).

This research area concerns with NTX systems enabling or improving the performance of electromagnetic (EM) systems over the whole frequency spectrum through wave-matter interaction at sub-optical nanoscale level.

The main issues of EXEMI are: i) to insert quantum effects in the concept of the EM systems, ii) bringing established EM concepts and architectures at nanoscale levels, and iii) to control/reconfigure NTX-based EM system by nanoscale wave-matter interactions. This will enable the design of novel materials at different length scales at which elementary particles/quasi-particles such as photons, electrons, phonons and atoms "communicate", interacting through mutual energy transfer.

The main issues of EXEM are detailed below

- Insert quantum effects in the concept of the EM systems
  - Photoluminescence properties by using nano-structuration and spectral selectivity
  - Enabling anomalous generations of EM waves by non-linear effects
  - Enabling single photon emitters
  - Switching and buffering covering the visible, IR, THz and microwave range.
- Bringing established EM concepts and architectures at nanoscale levels
  - Improving the design on nano-materials on the basis of EM concepts
  - Designing and fabricating nano-antennas, nano-arrays, nano-cavities
  - Designing nanostructured transmission lines and BFN.
- Control/reconfigure NTX-based EM system by nanoscale light-matter interactions
  - Reconfiguring a EM system based on optical interaction with nanostructured material
  - Enabling exceptional confinement of EM waves
  - Integrating optical control in microwave and antenna devices
  - Reconfiguring/controlling ultra high-speed microwave systems
  - Optoelectronic and optically-controlled nanodevices for EM sensing.

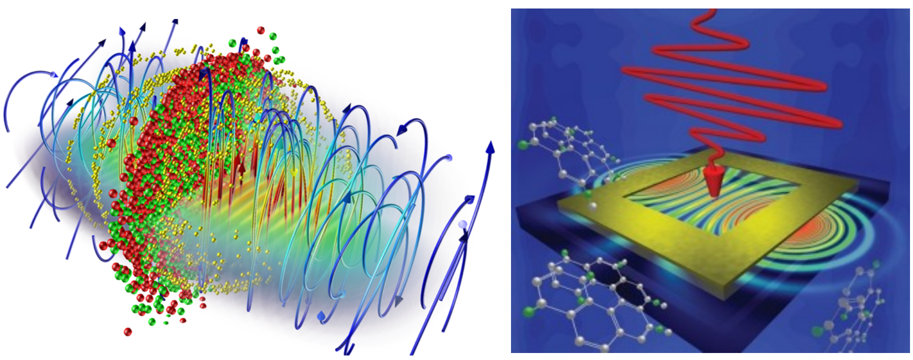


Fig. 5 Extreme EM interaction-artistic rendering (from http://www.materialsviews.com/near-field-enhancements-along-ring-shaped-nanostructures/

1.2.2. Metatronics (MTX)

This area concerns with the generation of space-time varying, controllable nano-structured, new materials exhibiting unusual EM macroscopic properties and functionalities.

MTX brings a new dimension to metamaterial research with emerging challenges to make material properties dynamically controllable in both space and time. This would open a multitude of new applications and scientific explorations like: emulating electronic circuits at optical frequency based upon wave interacting with nanoparticles, creating space/time transformation materials, artificial non-reciprocity, and "computational metamaterials", namely materials that can perform mathematical operations on input signals (e.g. Fourier transform) directly by interacting with signal encoding EM waves.

The original MTX terminology was introduced by Prof. N. Engheta at University of Pennsylvania (UPenn) to indicate the conceptually new electronics inspired by Metamaterials working at optical frequencies based on the ordered motion of photons rather than electrons, as it happens in conventional micro- and nano-electronics. In our conception, MTX has a broader meaning, bringing a new dimension to metamaterial research with the new challenge to make the material properties tunable and dynamically changeable in space and time. This aspect would open a myriad of new applications and scientific explorations.

- Emulating electronic circuits at optical frequency with photons and nanoparticles with the aim of:
    - Ultra-miniaturizing the dimension of electronics in a way different from nano-electronics
    - Introducing new topology of basic passive elements beyond resistor, capacitor and inductor (fractional components)
- Tunable and transformative materials. The aim is:
    - Integrating nanostructured materials with nanostructured electronic elements which confer them new EM properties
    - Combining the concept of Transformation Optics (TO), proposed by Prof. John Pendry, and the use of dynamic materials. With the term Transformation Optics (or, more in general, Transformation Electromagnetics) we refer to a theoretical framework where the solution of a given problem is found in a transformed space, characterized by unconventional material parameters.
    - Creating time-variable metalenses
- Space-time-modulated and non-reciprocal materials
    - Obtaining non-reciprocal materials without using magnetism and permanent magnets. The idea is based on the employment of artificial materials whose electromagnetic properties (e.g. the refractive index) are modulated in space and time. The interaction of the electromagnetic field with such material modulations is non-linear and leads to non-reciprocity.
    - Time-modulated materials can simulate the effects of moving media
- Topological MTX
    - The application of topology, the mathematics of conserved properties under continuous deformations, is creating a range of new opportunities throughout photonics. This field was inspired by the discovery of topological insulators, in which interfacial electrons transport without dissipation, even in the presence of impurities.
- Computational metamaterials
    - This new concept is capable to further enhance signal processing at optical wavelengths, making a step forward towards superfast optical computing.

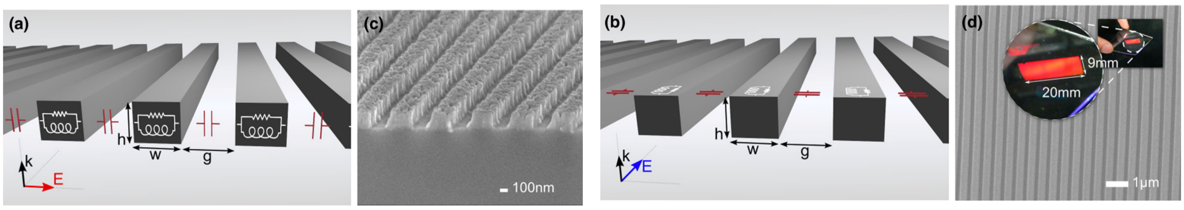


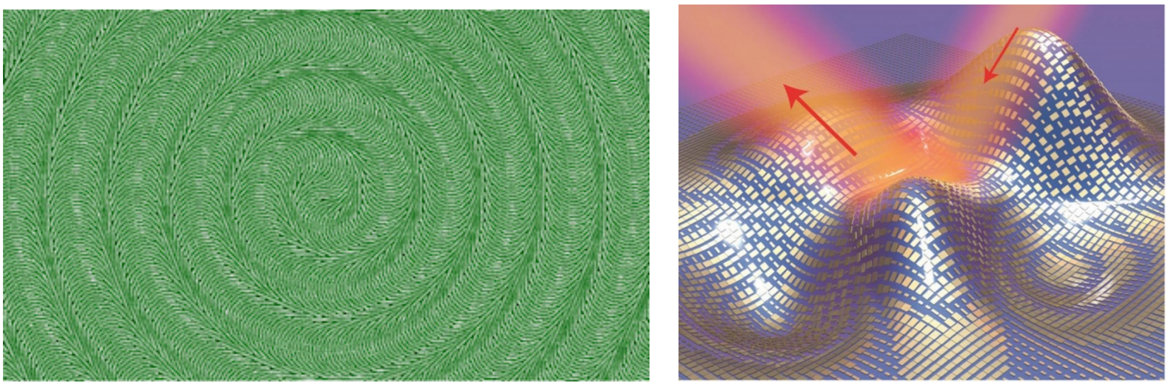
Fig.6 Near Infrared Metatronics nano circuit by design ìH Caglayan, S-H Hong, B Edwards, C R. Kagan, N Engheta Phys. Rev. Lett. 111, 073904

1.2.3. Surfacetronics (SFX).

This area concerns with the conception, analysis and realization of reconfigurable, sensorial, adaptive and cognitive "skins" for sensing and communications.

Various technologies are emerging to provide with modulation of metasurface responses using mechanical, electrical, or optical control. Reduced dimensions allow realizing unconventional devices whitout volumetric counterparts. We aim at developing a next generation of nanostructured metasurfaces as artificial and bio-inspired "skins", able to adapt themselves to the environment, being cognitive and reconfigurable as well. SFX is aimed at combining radiating and sensing functions for future communication beyond 5G, namely antennas, radars, and body area networks. Furthermore, various technologies are presently emerging to provide modulation of metasurface response using mechanical, electrical, or optical control. Although the general purpose of these approaches is to obtain tunable versions of static metasurfaces, recent studies have uncovered that the impact of dynamic metasurfaces far exceeds tunability alone and comprises new physical effects such as Lorentz non-reciprocity. We will denote all the area of dynamic metasurfaces to achieve time-varying properties and their conceivable applications as "Surfacetronics" . SFX can be divided in "phase variable SFX" , "Sensing/radiating SFX"

- Phase variable SFX. (control and address space or surface/plasmonic waves)
    - Phase gradient changing SFX by stretching or heating.
    - Phase gradient changing by light-surface interaction
    - Phase gradient changing Fluid based SFX
    - Phase gradient changing SFX by Micro- or nano-mechanical actuations
    - Huygens type SFX
    - Dispersion SFX (for surface/plasmonic wave control)
    - Transformation Optics SFX
    - Subwavelength focusing lenses
    - Non-reciprocal and time reversal lenses
- Sensing/radiating SFX. receive (RX)/transmit (TX) signals or power in free space
    - Leaky-wave SFX
    - RX distributed conformal surfaces
    - Adaptable and stretchable receiving surfaces
    - Variable radiating apertures
    - Energy harvesting SFX
- Cloaking SFX



(a) (b)

Fig. 7. Examples of SFX (a) nanoroad lens, (b) cloacking reconfigurable MTS (artistic rendering)

1.2.4. Nanoscale Material Engineering (NAME)

This area concerns with the technologies for the realization of new engineered materials like hierarchical nano-composites and combination of them. These materials will be lightweight and will exhibit multifunctional mechanical, thermal and electrical properties.

Recent advances in Nanotechnology made possible realizing nano-composites, a class of composites where one or more separate phases have dimension in the nano-scale range (<100nm). Nanocomposites are of great interest because they are intrinsically multifunctional materials, and by the joining of different phases they generate themselves unique and high performance materials. Consequently, it is, in principle possible, to design a composite (or hybrid) material for specifically targeted properties with a precise and specific combination of phases, also aiming at creating a new generation of photonic crystals. The use of different kinds of composites, starting from the classical combinations of two or more different materials, can bring a superior and unique material with new *valleytronics* features (i.e. featuring controlled presence of a local maximum/minimum on the valence/conduction band) exploitable for improved mechanical, thermal and electrical properties. This technology is likely compatible with future generation of 3D printing technology.

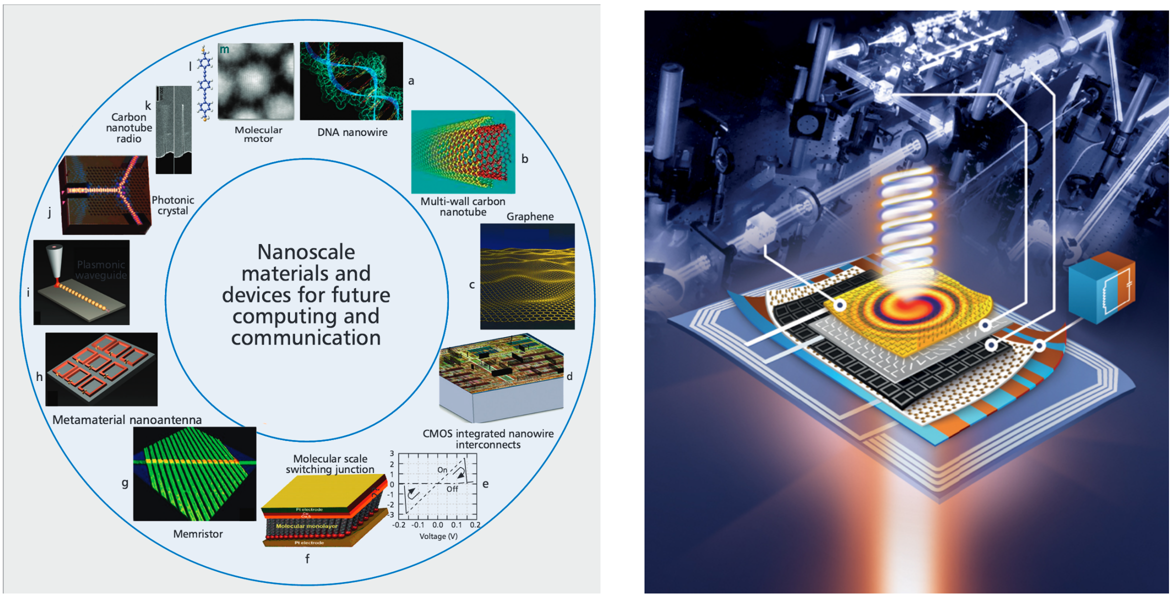


Fig. 8. A) Examples of new Nanomaterial for computing and communications http://web.ece.ucdavis.edu/~saif/pub/papers/NanomatIEE7ECOM.pdf b) construction of NTX devices (artistic rendering from Nature Nanotechnology 10, 11–15 (2015) doi:10.1038/nnano.2014.314)

1.2.5. Multiscale Design Enabling Modeling (MDM).

This area covers theoretical and computational methods, which unifies multilevel, quantum and EM methods, and system by design methods.

NTX development is hindered by both technology limitations and limited availability of modelling and design tools covering an extremely large range of spatial and time scales. MDM's goal is the investigation, modelling and design of a new generation of integrated, smart, multi-functional materials, devices, circuits and systems. This requires a bridge across the gap between nano-science theoretical foundations and the implementation of advanced numerical tools.

Interleaved with the modeling, system architecture by design constitutes the engineering technique on which the framework, as well as several current and innovative design methods and algorithms, can be merged to enable the design/optimization of engineering NTX systems. SAD involves task-oriented design, definition, and integration of Nanoarchitectronic system components to achieve desired performance with minimum costs, maximum scalability and optimal reconfigurability.

Incorporating advanced tools for electromagnetic analysis based on Maxwell's equations at the appropriate scales. The concepts of interfacing different phenomena and/or extending the space-time scales of single models are employed to provide a new paradigm of modelling, aimed at investigating the border region

- from ballistic to non-ballistic,
- from nano- to the millimeter-scale,
- from electronic/atomistic/mesoscale level to continuum level,
- from linear to non-linear responses.

The computational platform deals with the full-wave modelling of the combined quantum transport- in nanostructured materials and low dimensional systems, ranging from atomistic and nanoscale, to mesoscopic and continuous scale.

In the short/medium-term, it will also include PDE systems governing:

- thermal effect and heat transfer,
- mechanical and opto-mechanical phenomena (phonon-photon interaction)
- analysis of time transients in the describing the behavior of high energy carriers,
- onset and prediction of non-linear phenomena.

A limit for the design of some classes of artificial materials is less evident: the need for a theoretical approximate model at “intermediate” or mesoscale level for the conception of functionalized materials, that could be seamlessly integrated into the computational framework for subsequent optimization. The above challenges can be addressed by extending in various ways existing models and codes, and by proposing a general multi-resolution multiscale framework to unify individual and multiphysics modelling endeavors.

On the other hand, the fundamental feature of SAD is represented by its capability to integrate and enhance existing methodologies as well as to exploit their features/mitigate their drawbacks (thanks to their integration) to overcome the limitations of current design and synthesis techniques. Such a characteristic will therefore enable the exploitation of the existing skills in the areas of modelling, synthesis/design, simulation, optimization, multi-scale analysis, and multi-physics evaluation of NTX devices. Moreover, it will represent a key factor for the development and integration of the FORESEEN network (in terms of unification of the scientific methodologies and languages). SAD will enable major advancements over existing design approaches and solution techniques for complex systems thanks to its capability to exploit (in a synergistic manner) the integration of state-of-the-art approaches in a unified “platform”. More specifically, the expected impact in this framework will be the possibility to address synthesis/design problems which cannot be addressed with current algorithms because of their computational complexity, large number of degrees-of-freedom (which in turns result in very wide search spaces for the design methodologies), or intrinsic theoretical features (e.g., ill-posedness, or modelling complexity). The capability to decompose a complex design task into sub-problems, as well as the possibility to exploit state-of-the-art techniques to solve each one of these sub-tasks, will represent the key theoretical feature to afford such advancements.

2. BENEFITS FOR EUROPE

2.1. INNOVATIONS FOR EUROPEAN ECONOMY AND RELEVANCE FOR THE EUROPEAN INDUSTRY

Application drivers for NTX cover fields included in the Gartner hype cycle 2015 (http://www.gartner.com/newsroom/id/3114217), from autonomous vehicles and IoT with the highest expectations, smart robots and IoT platforms to the upstream area of smart dusts. However, NTX may include technologies not even predicted in the upstream part of the diagram, whose innovative impact and possible evolutions in European Economy and Society are described below, indicating possible demonstrators. The latter are just possible examples of success measure, and many other can be conceived and proposed in the NTX framework.

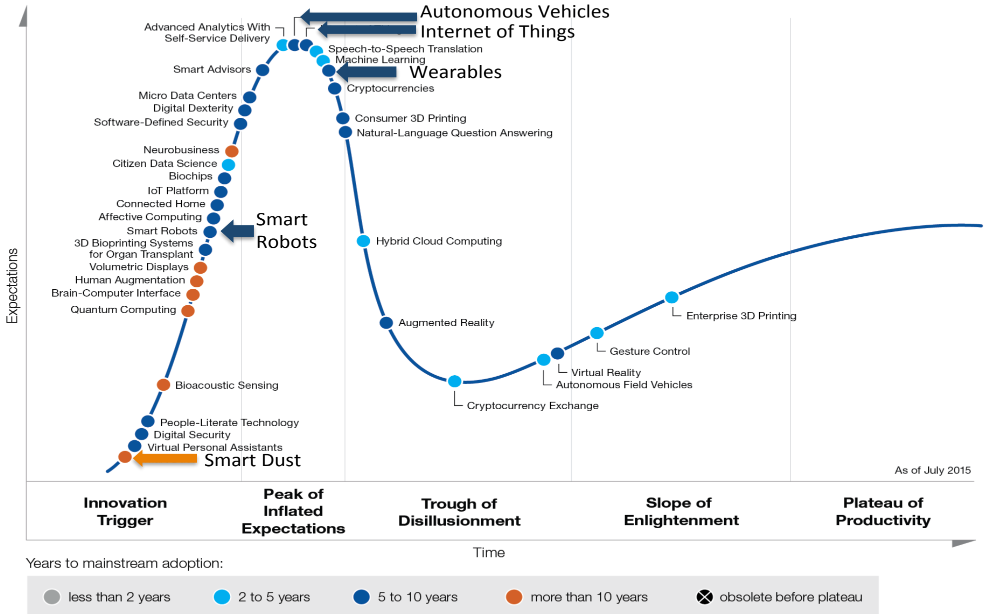


Fig. 9 Gartner hype cycle for future emerging technologies (http://www.gartner.com/newsroom/id/3114217)

2.1.1. High data-rate communications: beyond 5G

Future 5G systems will seek for high area throughput efficiency in order to meet the exponentially growing requirements for data. After 2030 and following the analysis of the NetWorld organization and the 5G PPP Vision, beyond 5G architectures and systems will address ultra-dense networks, fragmented frequency management, fundamental techniques for Tb/s communications, enabling techniques and technologies for higher carrier frequencies, realizable Massive MIMO architectures, Device-to-device (D2D) networking, wireless and optical fronthaul/ backhaul. These high-speed systems in frequency band ranging from microwaves to THz could help to mesh extremely dense urban areas to bring high-speed internet access, or high-speed networks (typically 10Gbps). Optical wireless communications (Infra-Red (IR) and optics (visible) spectrum region) will be extremely useful to access to ultra-wide spectrum bandwidth. NTX research program is well aligned with massive MIMO architectures requirements, by covering the design and development of novel device architectures such as custom antennas, transmitters, amplifiers, switches, filters, transceivers, linearisers throughout the radio frequency (RF) up to THz and to IR and optics domains.

Measure of success: demonstrator of a low cost, highly-directive, large bandwidth, scanning-beam, nanoelectronic-integrated antenna system in millimetre-wave bandwidth.

2.1.2. Remotely piloted aircraft systems (RPAS)

An extremely challenging example in the field of autonomous vehicles are remotely piloted aircraft systems (RPAS). The main challenge is the integration of the RPAS into the European Aviation Systems. Following the road-map realised by the European RPAS Steering Group, it appears that functions such as detect-and-avoid will be mandatorily included in the air traffic. NTX technologies will provide opportunities to extend the coverage of the sensing systems through integration into the “skin” of the RPAS. Benefits for the citizens cover the missions related to: civil protection (management of natural disasters), security (costal surveillance or sensitive sites monitoring) and environment protection. According to ASD (AeroSpace and Defence) international organisation, the industries in Aerospace and Defense business employ about 800,000 people with an overall turnover of almost €200Bn. ASD foresees that RPAS might represent 10% of this.

Measure of success: demonstrator of a smart “skin” for detect-and-avoid radar system on dedicated RPAS at the end of project.

2.1.3. Smart Dust

Smart dust networks (i.e. extremely miniaturized wireless sensor networks) will play a role complementary to the one of RPAS. Smart dusts might be deployed over a region, allowing ground based distributed sensing and communications systems to monitor events and environmental conditions together with massive MIMO architectures. Smart dust dense networks environment are envisaged as potential solutions for deep distributed sensing of the environment. Applications to biological research or to bio-sensing are also envisaged for these kinds of sensing units.

Measure of success: demonstrator of a sensing and communicating smart dust system, with particles of a few micron cube size at the end of project.

2.1.4. Security Sensors

A further candidate for NTX application relates to security sensors. Sub-millimeter and millimetre-wave and THz imaging technology, as opposed to X-ray imaging, can provide solutions for safe, accurate and fast security screening of people, parcels, luggage and shipped goods. However, current systems still show severe limitations for widespread use in public areas, such as safety concerns, throughput rate, resolution, complexity and cost. Novel concepts based on Multiple-Input-Multiple-Output (MIMO) radar topologies can achieve the required the high resolution images required with a considerable reduction in the number of transmitters and receivers, and thus reducing costs. NTX aims at achieving an extreme modularization of the approach in scalable systems with unprecedented flexibility towards different operational requirements enabling the use of hybrid RF and photonic technologies. NTX can also have a strong impact on the area of biological hazard, enabling the realization of reliable, sensitive, selective and noise protected biosensors, comparing thermodynamics and kinetics of DNA and RNA hybridizations both in the bulk and when immobilized on the surface of a substrate.

Measure of success: demonstrator of NTX composed by nanostructured electrode obtained by polymers – nanocarbon composites, equipped with agents for the detection of hybridization.

2.1.5. Impact on Semiconductor Industry

Reducing costs and time-to-market are essential factors to sustain the current capabilities in the technology roadmaps for the semiconductor industry. This must be done while simultaneously maintaining reliable nano-manufacturing processes. The process geometries and device dimensions are shrinking to the level that conventional technologies currently used for production and quality control are approaching physical boundaries and a further reduction will soon appear neither technologically nor economically feasible. Besides shrinking the critical dimensions even further, 3D scaling is expected to introduce new functionalities and to optimise the available space. Moreover, introduction of 3D architectures requires a breakthrough in the manufacturing process potentially based on a hybrid 3D nano-manufacturing. Using only optical/electron subtractive technologies is insufficient to manufacture the 3D nanoarchitectures at the required scale because of limited resolution or, when the resolution is high enough, limited scale of the processed field.

The rapid development of semiconductor technology places demands not only on lithography, but also on inspection, in particular for the localisation of nano-scale defects. The major requirements that NTX could solve are: very high resolution and sensitivity to be able to detect 3D structures down to ~10 nm and high aspect ratio; very high speed of measurement on large area such as 100 cm2 / hour; the ability to flexibly manufacture and resolve 3D features below 10 nm with high aspect ratio; and low cost per surface area.

2.1.6. Impact on Space technology Industry

Applications of space technologies dedicated to providing civil systems and services has a turnover of around €5Bn and counts more than 15,000 employees in Europe. Main areas of activity are satellites for spacecraft and ground segments, solutions covering secure and commercial satellite communications (SatCom) and networks, high security satellite communications equipment, bespoke geo-information and navigation services worldwide. The European Space Agency identifies SatCom as the mainstay of space industry, with market value estimated as €100Bn, including launchers, user terminals and derived services. Simultaneously, the market of micro-, nano- and pico-satellites, with emphasis on cube-sat, is drastically increasing with mainstream in science mission and earth observation. Thousands of vectors will be launched before 2020, and multibillionaire investments have been carried out especially in USA (http://www.spaceworksforecast.com). Through this value-chain, NTX could represent a key future technology in ultra-broadband chip-sets, highly-integrated packaging for flexible, high performance and low-cost SatCom transceivers. However, paradigm-shift introduced by NTX consists in changing the technology of antennas for space, almost not evolving since many year, into SFX "skin" that use the entire satellite surface as an antenna. This, not only in the perspective to reduce weight and volumes in SatCom on board applications, but also for enabling communications in a swarm of pico/nano satellites. NTX, at optical frequencies, can be also an enabling breakthrough technology for innovative space scientific instruments. MTX and STX, for example, can provide new ways to build optical components simpler and easier to be manufactured and integrated and/or with improved performances compared to conventional optics. Examples are polarizers, polarization scramblers, ultra-selective filters, zero-reflection coatings.

2.1.7. Impact on robotic industry

The impact of NTX on robotics is also relevant, especially within haptic communication, namely the technology that recreates the sense of touch by applying forces, vibrations, or motions to the user. Sensorial SFX skins can link mechanical stimulation minimizing the degrees of freedom of the mechanic machines in tactile sensors that measure forces exerted by the user on the interface. This will allow a drastic improvement in assisting the creation of virtual objects in a computer simulation, to control such virtual objects, and to enhance the remote control of machines and devices), as well as system to assist disabled persons.

2.2. IMPACT ON SOCIETY

2.2.1. Health and well-being

Late diagnoses, as well as incorrect adherence of patients to the prescribed medications are two major causes of mortality. The availability of miniaturised and personalised monitoring systems to be implanted into or positioned on the human body could drastically reduce the incidence of these. The improved miniaturisation levels offered by the use of metamaterials/metasurfaces, and simultaneously their capability to control and manipulate electromagnetic wavefronts at nanoscale offer the possibility to create miniaturised sensors to be permanently inserted in or positioned on the human body; e.g., using oligonucleotides/antibodies on a nanostructured biochip and surface enhanced Raman scattering allowing to detect even extremely low concentrations of specific markers from cancer cells, even in the case of unknown cancerous sources. These sensors can provide a continuous monitoring of important vital parameters, as well as the presence of specific compounds through enhanced spectroscopic analysis. This constant monitoring can guarantee timely diagnoses and trigger prompt corrective actions.

2.2.2. Energy Efficiency

Efficient use of energy and waste reduction are current and future political, societal and technical challenges, as our environment is flooded with waste and unused energy. Energy harvesting devices that convert ambient energy into electrical energy have attracted interest from both the industrial and commercial sectors. Solar energy has been used for years, and the harvesting of solar energy can be revised by using antenna concepts new materials and nanosciences. Therefore, the EXEMI area of NTX is pertinent to this topical issue.

2.3. POSITION OF EUROPE AND EXISTING LINKED INITIATIVES

2.3.1. Position of Europe

The proposed research, in its complexive framework, is interdisciplinary and involves material science, classical EM, quantum effects, manufacturing processes, multi-physics and multi-scale numerical modelling and design. The coordination and integration of the existing European know-how of leading research institutes in academic and non-academic environments, driven by hi-tech industries, will provide new understanding, new processes, and new tools. Thus, the proposed activity will promote European competitiveness in heterogeneous integration and encourage the networking and strengthening of related but scattered industrial efforts across Europe. A further important output will be establishing a new level of post-graduate education.

2.3.2. Existing international research initiatives linked to this proposal

FORESEEN (https://eledia.science.unitn.it/foreseen/) already counts research groups of 36 institutions (20 universities, 8 research centres, 8 industries) coming from 9 EU countries. The numerous and highly qualified European industries employing a highly-skilled workforce constitute differentiated and competitive all-embracing value chains in the Smart Systems sector which cannot easily be transferred to other world regions in the near term. The leading position of Europe results from the existence of R&D cooperative organisations aimed at developing innovative solutions for the technical and technological domains needed in the today applications and system solutions such as ECSEL, PHOTONICS 21, CATRENE, ITEA, EURIPIDES and EPoSS focussing on Smart Systems modules and their application using a broad range of micro-technologies aim to advance complex functionalities and further miniaturisation. Other national or European research initiatives are linked to this proposal; in particular, i) METAMORPHOSE Virtual Institute on metamaterials (http://www.metamorphose-vi.org), ii) the European Association on Antennas and Propagation (EURAAP), iii) SYMETA - Synthesizing 3D Metamaterials for RF, microwave and THz applications is a UK-based 5-year project launched in 2016 comprising 5 universities - led by Loughborough University - and over 15 companies. Members of FORESEEN also belong to the consortium RPLAS (www.reactiveplasmonics.org)

2.3.3. Comparison with other initiatives in the world

In the U.S., the Multidisciplinary University Research Initiative (MURI) "Active Metasurface for Advanced Wavefront Engineering and Waveguiding" has been launched in 2014 with support of AFOSR (Air Force Office for Science and Research, http://projects.iq.harvard.edu/muri_metasurfaces/overview ; this project involves: Harvard University (leader), Columbia University, Purdue University, Stanford University and University of Pennsylvania. It explores the underlying physics with focus on the connection between active metasurface design and the control of surface polaritons and reflected/transmitted beams and on the interaction of device building blocks (optical antennas, dielectric resonators, quantum emitters, etc.) with metasurfaces including nonlinear metasurfaces for broadband frequency conversion. *This MURI project has many affinities with a portion of the NTX Initiative.*

3. ADDED VALUE AND SCALE OF EFFORT

3.1. ADDED VALUE

For the creation and establishment of this new discipline, the Nanoarchitectronics, we need first the integration and the harmonization of the current research, actually scattered among the European research centres for unifying concepts, methodologies, technologies, facilities, pertinent to a huge extension of the wave spectrum from microwave to THz and optics, and next to boost the future application-driven research in this new area through the establishment of an accepted language among physicists and engineers, a shared way of thinking, a common theoretical foundation and a common strategy for the future.

3.2. SCALE OF THE EFFORT REQUIRED

The Nanoarchitectronics initiative is also aiming at association with other European research initiatives . Including all the main European actors in this field, we aim at reaching in one year more than 50 academic and industrial research groups with a global effort estimated in the range of €200M over the 10 coming Years.