FROM RADAR to NODAR

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***Abstract*-Photonics and Nanotechnologies are emerging revolutionary technologies that will provide a revolution in the sectors of sensors and radar systems. SELEX Sistemi Integrati intends to face this evolution as a leader by proactively supporting and developing its state of the art. One century after the first RADAR "idea" we registered the NODAR (Nanotechnology Optical Detection And Ranging) trademark. Such NODAR, by including both photonic and nano technologies, aims to implement multifunctional, multirole, multidomain sensors, as well as adaptive, flexible, knowledge-based sensors. NODAR requires proactive studies and developments on: I) nanotechnology vacuum tube amplifiers (TX reverse nano triode); II) wide bandwidth Tx-Rx optical beam forming network by means of optical modulator, combiner, analogue optical receive and programmable true time delay; III) broadband photonic analogue to digital converters; IV) thermal management and interconnection by means of carbon nanotubes; V) nanotechnology infrared and chemical state of art sensors. Finally, the insertion of state of the art innovative technologies requires an integrated "multiscale" approach, by combining materials sciences, photonics, nanotechnologies and production technologies with other based technologies**

***Index Terms*- Nanotechnologies, Photonics, Multiscale.**

I. RADAR

One hundred years ago Christian Hulsmeyer patented in Great Britain the first "idea" containing the "DNA" of the sensor, universally known with the acronym of RADAR (RAdio Detection And Ranging). Then, it took more than 30 years to put the idea into practice. Main achievements in radar performances have been developed during the past century; in particular by Guglielmo Marconi', with the British Home Chain in 1937, afterwards by Prof. Ugo Tiberio with the radar GUFO, and eventually up to the modern multifunctional radars, such as EMPAR or MEADS.

From the '60s, the same Company, named progressively as Selenia, Alenia, AMS, and today SELEX Sistemi Integrati, has developed several radar sensors, characterized by the most innovative technology to operate in a huge spectrum of scenarios.

In this continuous evolution, technologies related to antenna and signal processing have increasingly absorbed all the other ones like bulk transmitter, MF and RF. We envision future digital radar with thousands of heterogeneous nodes, highly adaptive and cooperating in real time, with transmitted power generation elements and digital receivers contained directly in the antenna. Key elements are system and software architecture and communication, software based signal processing. These should provide, in hard real time adaptivity, very demanding algorithms such as adaptive hard real time digital beam forming or knowledge based information fusion among other heterogeneous sensors.

New radar sensors could be "multifunctional" such as the EMPAR (European Multifunctional Phased Array Radar) that is capable to perform, in hard real time adaptivity, search, surveillance and tracking operative modes.

In addition we are developing "multi–domain" sensors in collaboration with Elettronica and SAAB. For instance, in the M-AESA, a MoDs funded multi-domain sensor, the RADAR operative functions, the passive and active electronic warfare and the communications functions are managed and completely fused in the same system. On the contrary, at system level we are evolving towards heterogeneous system of systems.

A system of systems is a "super-system" comprised of elements that are themselves complex and independent systems, which interact to achieve a common goal. The resultant operative function is larger than the sum of the single components functions.

We are developing large integrated systems not only for future ATM but also for command and control in defence and homeland protection applications.

Radars, sensors and systems are continuously evolving: what are the technologies that are needed?

II. EVOLUTION OR INNOVATION?

The trend and roadmap of the sensors, and of the new-generation systems require a continuous technology innovation; however it is required a high effort to maintain the mature technologies at the state of the art. Therefore, we are focusing our attention on the nanotechnologies and photonic innovative technologies because, compared to the evolutionary ones, they have a higher ratio between the obtained results and the required efforts (utility function)

These emerging, innovative and enabling technologies improve weight, size, speed, power consumption, efficiency, and so on. In addition they enable new solutions.

The innovative or revolutionary technologies could open new frontiers, being “killer technologies” and requiring a “creative destruction” that is the shifting of capital from falling, mature technologies into those technologies at the cutting edge as clearly depicted by Alan Greenspan.

III. NANOSCIENCE AND NANOTECHNOLOGIES

Nanotechnologies represent an emergent domain having a great potential. It is a flurry of activities due to its attainable results, unimaginable performances, and revolutionary applicability. Theirs importance and potentiality are approved by the European Commission with funds of over 3.5 billion euros in the 7th Framework Program.

Nanoscience and nanotechnologies, as stated in Lisbon 2000, “could open a new era, enable, support and drive the 21th century knowledge-based society”.

Nanoscience, the new theoretic and descriptive domain, from which derive different nanotechnologies, is rightly defined as a “crucial, horizontal, qualifying science”. It allows combining such scientific disciplines that have been wrongly considered separated and different in the past. Nanotechnologies, profiting by interdisciplinary and converging approaches, will contribute to the solution of problems that are typical of the modern society. They will probably give a contribution to medical applications, and to research fields related to food, water, environment, energy production, creation of metamaterials. Nanotechnologies provides optimal performances regarding prognostics, photonics, information technologies (also through organic and inorganic nanodevices), biology, and in the science of cognition.

IV. TOWARDS THE NODAR

SELEX Sistemi Integrati intends to face the evolution of radar, system, and system of systems as a leader by proactively supporting and developing state of the art of enabling and innovative technologies. To do so; a century after the first RADAR “idea”, we registerd the NODAR (Nanotechnology Optical Detection And Ranging) trademark. NODAR ® aims to implement multifunctional, multirole, multidomain sensors, as well as adaptive, flexible, knowledge-based sensors, by including both photonic and nano technologies.

The “NODAR”, by including both photonic and nano technologies, aims to implement multifunctional, multirole, multidomain sensors, as well as adaptive, flexible, knowledge-based sensors.

We identified the following highly innovative sectors of NODAR:

- Nanotechnology Vacuum Tube Amplifier: TX Reverse Nano Triode by means of million of Carbon NanoTubes. It should able to amplify with high efficiency TeraHz frequencies.
- Wide BandWidth Tx-Rx Optical Beam Forming Network by means of Optical Modulator, Combiner, Analog Optical Receiver, Programmable True Time Delay for Direct Time Beam Forming and Stearing.
- A Broadband Photonic Analog to Digital Converter.
- Nanotechnology Devices for Knowledge Based Signal Processing and for Grid Sensors Signal Fusion. These provide a feasible solution while waiting for the most promising Nano Quantum Processing.
- Carbon NanoTubes for Thermal Management and Interconnection.
- Optical - Nanotechnology Chemical state of art Sensors.
- Integrated “Multiscale” approach, by combining Materials Sciences, Photonics, Nanotechnologies and Production technologies with other technologies based on e.g. information technologies along the nano-micro-meso and macro length.

V. NANO VACUUM TUBE AMPLIFIER

High transmission efficiency is a key element in any Radar, Sensor and System. Actually, the radio frequency high power amplifiers use Gallium Arsenide (GaAs) or Gallium Nitride (GaN) solid state technologies. Unfortunately the recurrent costs are high. Moreover, for very high band applications such as TeraHz, there are gain and bandwidth limits due to the limited electron mobility in the solid state. TeraHz are of growing importance for health, space communication, defence and homeland protection applications,.

The “nano-vacuum tube” is an innovative device for TeraHz regime applications that aim to overcome all the problems related with the scarce miniaturization and the not negligible weight and volume of the standard vacuum electronic devices. As for the standard vacuum tubes, it consists of three main parts: the emitting cathode, the grid and the anode. The innovation is represented by the use of carbon nanotubes as a cold cathode for the emission of the electronic beam and by the introduction of an innovative layout that allows overcoming all the technological problems for the realization of such devices [1].

Carbon Nanotubes can be considered ideal field emitters due to their high aspect ratio, robustness, stability and lack of surface oxides [2]. It allows to obtain the miniaturization of the device and the improvement of the lifetimes when compared with the already existing Spindt type cold cathode devices. However, the critical growth conditions of those materials (high temperature and highly reactive plasma), leads to a difficult integration with standard technological processes. In this context we developed an innovative topology that is devised to limit the effects of the outlined problem. The device foresees the realization of two separate elements, the cathode and the integrated anode-grid structure, that are then packaged using by a vacuum bonding technique. The emitting cathode, made from aligned single wall carbon nanotubes, is realized on a patterned highly conductive silicon substrate that can stand the synthesis conditions (Fig. 1). The grid and the anode are realized on a single substrate separated by a thick silicon oxide layer that works as insulating layer. The grid is covered with an insulating layer in order to reduce the current losses of the device and thus to improve the transparency.

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This element is realized using standard lithographic processes. The cathode and the grid-anode plates are bonded together using proper spacers (Fig.2).

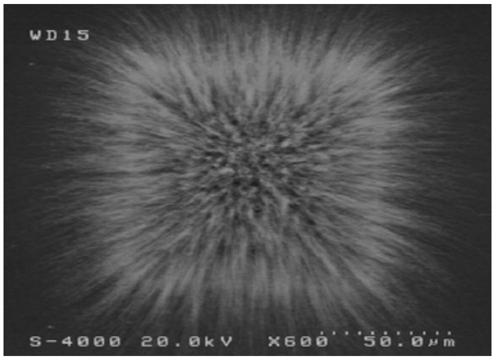

Fig.1: Patterned Cathode

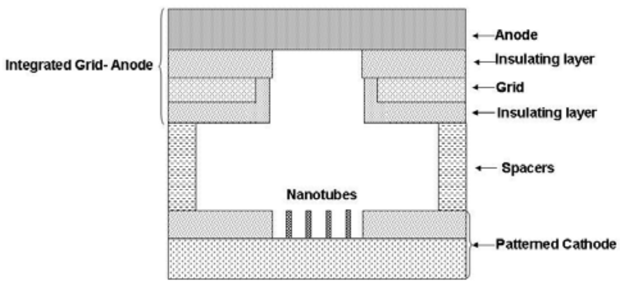

Fig. 2: Vacuum Reverse Triode

This structure has many benefits; as it relaxes many of the technological constraints for realization of conventional CNT base triodes, it allows building micro vacuum diodes with more favourable characteristics, while placing minimum restrictions to the gate structure and the materials used. In this geometry it is straightforward to use different kinds of emitting materials, grown on a variety of substrates, opening the way to new applications for scaled vacuum triodes. Furthermore, it is possible to efficiently tune the working frequency of the device by a proper design of the geometry of the electrodes.

VI. Photonic ADC

There are at least four classes of photonic Analog to Digital Converter (ADC).

In Nyquist-rate photonic ADCs, such as first proposed by Taylor [3] both sampling and quantization are performed optically and the system is analogous to the Nyquist-rate electronic ADC.

In demultiplexing photonic ADCs a high pulse repetition frequency (PRF) train of short optical pulses samples an RF waveform; the pulses are demultiplexed to multiple photodiodes and the current from the photodiodes is quantized electronically.

In oversampling photonic ADCs a high PRF train of short optical pulses and one or more feedback loops are used to yield behavior analogous to electronic oversampling ADCs such as delta sigma modulators.

The time-stretched photonic ADC uses fiber dispersion to lower the frequency of an electronic signal prior to digitization with an electronic ADC.

Other novel ADCs use ultra-stable, short-pulse lasers as part of the sampling process, but the term “photonics-assisted” ADC seems more appropriate for these systems.

Demultiplexing (or time-interleaved) photonic ADCs basically relies on using an optical architecture to:

- Generate a stream of sampling optical pulses
- Modulate the height of the optical pulses by the voltage signal to be sampled through an optical modulator
- Split along multiple (N) parallel channels the samples to be A/D converted
- Perform A/D conversion on each channel with 1/N sampling rate using standard electronic A/DCs
- Recombine the bit stream by digital processing

VII. Carbon NanoTubes for Thermal Management

Increasing attention is being paid to single-walled carbon nanotubes (SWCNT), characterized by very a thermal conductivity that can reach values up to 6000 W m-1 K-1. The good thermal and electrical conductivity make the SWCNTs an excellent candidate material to be used as a heat sink medium to increase thermal dissipation from the chip toward the package and also to build bumps interconnecting the heat sink with the chip (Flip Chip configuration).

In this context SELEX-SI in collaboration with MINASlab is carrying out a research focused on the preparation of SWCNT-based systems for thermal management applications in high power electronic devices.

The performances of the SWCNT as TIM material are measured using the nanotubes in the same configuration foreseen for the working device, i.e. as interface between the microprocessor chip and the heat spreader or between the heat spreader and the heat sink. The activity of material preparation pivots along the following main lines:

i) Setting up of protocols for the preparation of epoxy/SWCNT or polymer/SWCNT nanocomposite layers.

Some investigations of polymer-based nanocomposites have indicated significant increases in the thermal conductivity of the CNT-loaded samples [4]. The controversial values obtained in different experiments can be certainly ascribed to the different capabilities of the testing apparatuses, but the scattering of data can be rationalized by considering, beyond the variations in nanotube characteristics, the homogeneity and reliability of the SWCNT dispersions in the various matrices.

In order to evaluate the efficiency of the nanotubes as TIM in different chemical environments, SWCNT are chemically treated following protocols settled in our laboratory and are incorporated into a variety of polymer or epoxy matrices. Nanocomposites with various amounts of nanotubes and different levels of dispersions are prepared and tested using a test bed for thermal resistance measurements.

Preliminary measurements performed on nanocomposite silicon samples containing SWCNT showed an increase of thermal dissipation up to ~ 30% with respect to the unloaded paste.

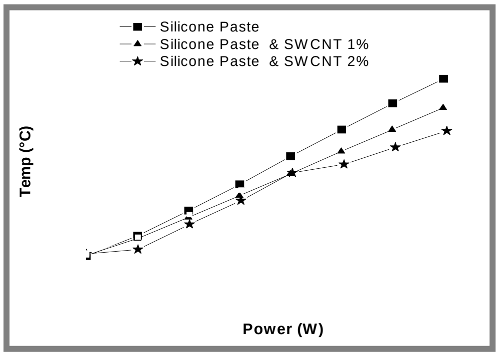

Fig.3: Nano Thermal Conductivity

ii) The growing by CVD techniques of aligned/oriented bundles of SWCNT on areas patterned by lithography and fabrication of bumps for flip-chip interconnections. This research line relies on the expertise reached by MINASlab on the synthesis and manipulation of nanotubes. The employed CVD techniques enable to deposit bundles with specific geometries and arrangements, and to design nanotube-based architectures for assembling network of bumps for flip-chips interconnects.

It is possible to integrate SWCNT bundles with selected orientation on semiconductors and to obtain a direct bonding device-substrate characterized by good thermal and electrical conductivity.

Thermal measurements of the assembled systems can be carried out by means of an innovative electro-optical technique [5] designed for precise measurements of channel temperature in power devices. The main advantages of using this non invasive method are the better spatial resolution and the feasibility to measure the effective temperature of the device due only to the photocurrent.

VIII. MULTISCALE APPROACH

New design tools and methodologies are needed to develop more and more complex and multifunctional nanostructured devices and integrate them into systems that are organized according to hierarchical architectures.

The multiscale approach integrates, inside a coherent framework, different layers of scientific and engineering mathematical representations and models, data structures, information and knowledge. The development of complex nanostructured systems like NODAR will benefit from new advanced concurrent and adaptive multiscale methods. Multiscale concurrent and adaptive methods make it possible for the first time to integrate inside a single model the following domains: quantum mechanics, quantum chemistry, multi-particle simulation, molecular simulation, and continuum-based techniques and address, in a unified way, nanoelectronics, nanophotonics, and nanomechanics issues.

A key step for nano electronics and photonics engineering is the development of Integrated Multiscale Multiphysics Science – Engineering Environments. Several civil and military organizations in Italy (NMP), Europe, US and Japan have launched important projects and initiatives along this direction. The strategic objective is to close the gap between classical engineering CAD/CAE systems and specialized atomistic analysis and design environments. New Integrated Frameworks allow for a systematic applications inside nano electronics and photonics design processes of integrated multiscale performance – properties – structures - processing analyses. They represent an important step to overcome classical barriers between engineering and manufacturing design. In this contest, the impact on devices and systems performance of even very small structural and chemical composition variations can be reliably evaluated.

Multiscale sensitivity analyses are an important challenge for nano engineering. New developments are putting the bases for a transition from “multiscale analyses” to a “multiscale design” strategy; this opens the way to a wealth of new nano-based architectural solutions. Multiscale design implies the integration of the classical bottom up approach with the newly developed top down strategy.

IX. CONCLUSION

Photonics and NanoTechnologies are emerging, innovative, and highly promising; they would enable new solutions and approaches.

Therefore, it is reasonable to predict that the impact of these technologies in the future, particularly as they converge with others inside an Integrated Multiscale Multi-Science – Engineering Environments, will become more and more important as we are entering this “nano-photon century”. In order to remain and consolidate our position as a leader, in the field of radar, sensors and systems, we want to take advantage of such technologies through proactive studies and developments in collaboration with many Universities and Research Centres.

The outcome of this complex process will be a new “Quantum Engineering” era.

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