Learning about Perspectives in Nanomaterials

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The aim of this research map is to exhibit the relationships among concepts and key issues regarding the scientific and technological capabilities of the universities and research institutes in the segment of nanomaterials and, particularly, the case of the ‘hafnium’ in Mexico. As same, to look for the entrepreneurial activity in this field, and finally, to know the existence of governmental policies encouraging the diffusion, R&D investments and cooperation networks between the three sectors in this new scientific and technological paradigm. Once analyzed the nature of the R&D and innovation of hafnium in Mexico by considering the international technological gaps, we discuss about the main institutional policies which could favor to build scientific and technological capabilities, to spread new knowledge and, therefore, to strength the country’s industrial specialization and competitiveness.

The remarkable scientific progress on the knowledge of the atomic and molecular material properties has driven to the convergence of a wide scope of scientific disciplines. Since the development of the nanosciences field and the emergence of nanotechnologies as a new technological paradigm, the role of the governmental policies has became of crucial importance to foster a virtuous circle where universities, firms and government institutions could interact to innovate. The aim of this research map is to identify, in the case of Mexico, the universities and research institutes scientific and technological capabilities in the nanosciences and nanotechnology; likewise, to know how the entrepreneurs are concern to develop capabilities in this field, and finally, to recognize if the government is building policies to encourage this new scientific and technological paradigm by supporting research projects and education programs, incentive the entrepreneurial investment and promoting the links and cooperation between universities and firms. Particularly, we want to analyze the nature of the innovation of this emerging sector, particularly in the case of hafnium in Mexico, identifying the R&D and innovation
efforts, the communicating vessels between the universities, firms and governmental agencies in a national, regional and international context.

The main questions we set out are: Is it possible to develop frontier nanotechnologies in Mexico? What are the challenges for Mexico to be capable of appropriating the new knowledge generated regarding the new nano-materials, as the hafnium, to boost the industrial activity? In this sense, we endorse the following hypothesis: in Mexico, as other developing countries, characterized by a lack of financial resources, the new knowledge generated by the research teams could be appropriated by the multinational firms (without having benefits for the country) if there is no financial support, alongside institutional policies to develop a new local industry based on the nanotechnology paradigm. Firstly, we discuss the main questions by considering the debate of the Triple Helix framework. Secondly we analyze the current state of nanomaterials and nanotechnology. Next, in the third section we analyze the challenges of the hafnium (new nanomaterial) in comparison to the silicon oxide. In the fourth section we identify the technological gap in nanomaterials in Mexico, compared with some industrialized and developing (emerging) countries, including the efforts on R&D, the innovation capabilities (patents & scientific production), the research networks. Finally, in the last section we analyze which are the prospects of nanomaterials in Mexico, particularly the hafnium, identifying the dynamics of sectoral innovation systems.

Among the fields of knowledge where technological change is more intensively manifested is nanotechnology, applied to information processing. Over the last few decades, nanostructures have been present in the manufacturing materials of the electronic devices sector. In particular, systems based on the chemical element Silicon (symbol Si) have already dominated the world of information technology for more than forty years. However, not until a few years ago were those
nanostructures, composed of ultra thin films of silicon oxide (SiO$_2$), clearly characterized, as was its real scope and limitations.

The scientific community now warns of the decadence of the silicon era so as to make way for new technologies and materials to improve the control of logical nanocircuits, to continue reducing the size and increasing the capacity of computer processors and improving the performance and speed of nanochips for data transmission and communications. Among the new systems proposed to boost the technological leap towards a new era for information and communication technologies (ITC), hafnium oxide (HfO$_2$) stands out among other alternatives, by virtue of it advantages in terms of efficiency, stability and manufacturing costs.

Nowadays, global firms such as IBM and Texas Instruments are betting on multimillion investments for the research and development of systems based on HfO2 and have even begun to launch the first innovative hafnium based products into the market. The speed at which the new era of hafnium could displace older technology based on silicon will depend largely on the accuracy and precision with which ultrathin films can be elaborated and used for manufacturing the computer processors, hard drives and the other MOS devices. The only way to predict the stability of hafnium oxide systems is through a high-precision analysis of the composition of the nanostructures that form them.

In Mexico, such an analysis (called stoichiometric analysis of nanostructures) has been located at the forefront of science and technology through the application of methods of angular photoelectron emission spectroscopy (ARXPS) and new probabilistic models for the determination of the accuracy of the spectra parameters.
The benefits of such developments are only being used by global companies and research centers in the developed countries. There is no regional innovation system for extending the benefits of local achievements to the rest of the developing countries of the region.

In this research map we show how, despite the importance of patents in the field of nanotechnology and because of their impact on the development of a wide range of scientific and technological disciplines, Mexico, as most of the developing countries, are likely to extend their technology gap in the field of nanotechnology after the imminent arrival of the new era of hafnium.

I. THEORETICAL FRAMEWORK

In order to analyze the possibility of Mexico of being able to carry out the necessary technological catching up in the nanomaterials field, we adopt the national (Freeman, 1991; Lundvall, 1992; Nelson, 1993; Metcalfe) and sectoral (Edquist, 1997; Breschi y Malerba, 1997) innovation systems focus, the technological gap (Posner, 1961; Gomulka, 1971; Cornwall, 1977; Abramovitz, 1986; Fagerberg, 1987) approach and the Triple Helix framework (Etzkowitz, 2008; Etzkowitz et al 2005)

2. CURRENT STATE OF NANOMATERIALS AND NANOTECHNOLOGY

In recent decades, advances in the scientific study of matter at the atomic scale have made it possible to consolidate a new knowledge: nanotechnology. Social implications of nanotechnology are more profound than any other new technology in the last two centuries of industrial
revolution. Indeed, there is no shortage of foresight studies and technological trends scenarios that agree that this knowledge could change the global geopolitical balance as well as our way of thinking and acting.

Nanotechnology defines the skill accumulated by man on the characterization, design, production and control of matter, living or not, at the atomic or molecular level. From a practical standpoint, this technology is a set of different techniques, but they have in common the size to which they operate, the nanoscale (scale a thousand times lower than microtechnology allowed to operate). This ability to manipulate materials at the atomic level (called nanomaterials) explains the interest aroused cross this technology in other converging technologies, and its integrating role in several fields of knowledge, where the key elements are nanoscaled. Examples of these are the genes for biotechnology, new electronic devices for information technology, or nanocomposites based on new materials for Materials Technology, among many others.

Similar to biotechnology or information technology, nanotechnology is a merger of many sub-disciplines (engineering, physics and modern chemistry, vgr.), introducing new qualitative developments. Hence its transdisciplinary nature and its potential to converge with other knowledge fields introducing new ways in the processes of production of goods and services. The advantages of involving the convergence of these new technologies can be illustrated with the innovations achieved by the semiconductors industry towards fusing nanotechnology and information technology. This industry has been able to adapt gradually to the new nano manufacturing processes, making it accessible to a large part of society to powerful electronic devices. Multifunctional mobiles proliferation, flat screens, powerful satellite dishes, new computer processors and memory readers, demonstrates this.

But what the foresight studies point out for the technological trend is that a process of unification of multiple technologies articulated in nanotechnology could go in a ten year horizon. Therefore, it
is expected that the impact of this convergence of multiple technologies at the nanoscale will be much broader than what we have seen in the field of communication, allowing innovative developments on a wide range of topics covering education, health, food, water, housing, textiles, transport, energy, environment, defense, among many others. The interest raised by the convergence of new technologies in these areas lies in its pledge to introduce a new technological paradigm in the global society.

Conceptually, the revolutionary of any convergent or transdisciplinary knowledge lies in the potential solutions they provide to the complex and multidimensional problems of society, precisely where divergent knowledge fields have failed. Examples of these problems are the energy crisis, health, water, climate change, as well as the food crisis and the problem of social disconnection (democratization of knowledge), where the fusion of nanotechnology with biotechnology and new information technologies, respectively, are helping to solve.

Already available on the market are the innovative diagnosis devices called nanoliter (lab-on-a-chip) used for personalized disease in situ diagnosis from a blood sample. Equally important may be the nanotechnology for new medical therapies (cancer treatments cheaper and less invasive to the human body) for genetically modified crops, the efficient production of clean energy as well as environmental water remediation. Also highlights from the UN Millennium Project report that the new applications of nanotechnology could contribute not only to achieve five of the eight Millennium Development Goals, but also represents an opportunity for developing countries wishing to achieve technological independence as the use of nanotechnology “involves little labor, land or maintenance, is highly productive and cheap, their use requires only a modest amount of materials and energy”

This research map attempts, on the one hand, to remark the worldwide economic and social importance nanotechnology is becoming, the relevance which its use may have on regional
innovation systems intending to emphasize the absence of public policies on the subject in Latin American countries, the dearth of national plans with regard to scientific and technological development of countries as well as security issues that entails. On the other hand, the document presents moreover a brief analysis of regional capabilities organized around networks in nanotechnology research and development. We point out some elements and strategies which might contribute to the design of public policies. We also suggest advantages of the design and implementation of developments based on partnerships involving government-industry-research centers, with common objectives seeking to strengthen endogenous social development, and building a sustainable future. In this regard, with adequate support, the systems must undertake to direct their efforts to cohesion, empowerment and guidance of national actors to R & D which aim to reduce technological gaps, with a high ethical commitment enabling capitalize the opportunities and minimize the risks posed to use the new knowledge.

At present the total turnover involving the use of nanotechnology is comparable to the worldwide oil bill, and it is estimated that in five years could double. Similarly, a report from the Executive Office of the President of United States indicates that by 2015 the countries that control the new developments related to nanotechnology shall be in charge of the economy in the world. Regardless of the credibility that can be attributed to the size of potential markets associated with nanotechnology applications, there are sufficient grounds to believe that they will achieve significant magnitudes over the next decade (EOPUS, 2009).

Nanomaterials

In the latter sense, since a decade ago, many countries seek to position themselves in emerging markets that are generated by nanomaterials. Indeed, industrialized countries are rethinking their
policies on science, strategies and instruments of financing, in order to better organize and advance the global technology race. The United States of América launched almost a decade ago the National Nanotechnology U. S. Initiative. Other initiatives has been intraregional, as the sixth and seventh Framework Programme for Nanotechnology at the European Union or the newly created Iberian Nanotechnology Laboratory like efforts of Portugal and Spain pointing to this direction. Similarly is happening with science policies of China, Korea and Japan, countries that are taking rapid steps in the matter. Other emerging countries are promoting R & D activities in nanotechnology from their governments. This is the case of India, Israel and South Africa with their respective plans, programs, networks and centers of ID, or Iran with an aggressive initiative implemented five years ago, which aims to position the country for 2015 among the ten world powers nanotechnology developments (INIC, 2009). Countries of Latin America, including Argentina, Brazil and Mexico, have tried bi-national initiatives such as the creation three years ago the Argentine-Brazilian Center for Nanoscience and Nanotechnology. Other countries in the region still lack public policies, but have emerged from the communities of researchers in networks and activities about nanotechnology. This is the case of Chile, Colombia, Peru and Venezuela.

Similarly, the relevance of nanotechnology to the plans of economic and social development of countries can rally round to create new sources of alternative energy to help restore soils and degraded bodies of water, prevention and control of diseases, food safety, the widespread distribution of ICT in the country, among others. Furthermore, the design and implementation of nanotechnology development plans to solve the problems of regional interest may allow, from the beginning, the promotion of a new industrial development scheme for the use of nanotechnology based on criteria that establish new production model, and the interest of developing countries to position itself as world energy powers, and foster a new geopolitics in the world.
Similarly happens with new nanomaterials developed to the strengthening of national science, technology and innovation systems. These developments could help to increase production of science, technology and innovation products to potential of Latin-American countries. However, these materials poses several challenges: Developing countries have a small research base, and does not have any program that can substantially increase the training of qualified personnel in nanomaterials. Most of the Latin Americans researchers working in nanomaterials make it so dispersed maintaining only weak contacts among themselves and with international peers. Nanotechnologists in developing countries are not covered by public policies and instruments such as those that exist in Brazil, India and China. The production of projects, technical reports and applications are emerging and the research initiatives are due fundamentally to the researchers, with lines of work are not necessarily linked to the needs of their regions. In terms of infrastructure and equipment, there is a minimum basis. There are no appropriation of knowledge policies that raise awareness of the opportunities and challenges for proper utilization of nanomaterials. There is no specific intellectual protection regime for converging this innovative technology (Vessuri, 2006; Aguirre-Tostado, 2007).

- The necessary regulations for the use of nanomaterials
- Incentive programs and instruments for industrial activities derived from innovative nanomaterials.
- Alternative scenarios of R&D in nanomaterials and impacts escalation plans.
2. Silicon oxide versus hafnium: arising and new era

After four decades of remarkable advances in semiconductor manufacturing, many scientists believe that the scope of the silicon has reached its limit. However, the pressure to increase the speed of data transmission, storage capacity and a reduction in the size of the devices has forced the industry to innovate materials with radically new materials, such as hafnium-based nanocircuits. Hafnium (Hf) is a chemical element in the periodic table of gray-silver color, highly ductile, corrosion resistant and chemically similar to zirconium. The Intel® firm engineers found that the introduction of hafnium in the nanochips helps reduce the leakage of electrons, which in turn allows processors to develop smaller, more efficient energy consumption and high performance. The new Intel® metal gate helps to significantly increase the performance and efficiency in processor, power consumption as well as enhance the design flexibility.
Through this innovative technology of transistors, nanomaterials industry features an incredible advantage in the hafnium-based nanochips. These revolutionary new processors boost computer processing power, storage and transmission capacities for images, voice and data. According to Gordon Moore, author of Moore’s Law which relates the evolutionary change of the size decreasing of chips, hafnium dielectrics represent the largest semiconductor innovation for 40 years. The new 45nm hafnium technology has broken the existing performance barriers pose the greatest technological leap of the new century.

(INTEL CORP., 2010)
WITH ROUGHLY TWICE THE DENSITY OF INTEL® 65NM TECHNOLOGY, THE INTEL HAFNIUM 45NM PACKS ABOUT DOUBLE THE NUMBER OF TRANSISTORS INTO THE SAME SILICON SPACE. THAT’S MORE THAN 400 MILLION TRANSISTORS FOR DUAL-CORE PROCESSORS AND MORE THAN 800 MILLION FOR QUAD-CORE.

INTEL® HAFNIUM 45NM NANOTECHNOLOGY ENABLES GREAT PERFORMANCE LEAPS, UP TO 50-PERCENT LARGER THAN L2 CACHE, AND NEW LEVELS OF BREAKTHROUGH ENERGY EFFICIENCY. SMALLER TRANSISTORS PACK THE PERFORMANCE PUNCH

ACCORDING TO THIS NEW TECHNOLOGICAL PARADIGM, INDUSTRY OF NANOMATERIALS HAS DEVELOPED THE WORLD’S FIRST VIABLE 45NM PROCESSORS IN-HOUSE. THIS HAFNIUM BASED PROCESSOR IS THE FIRST OF FIFTEEN 45NM PROCESSOR PRODUCTS IN DEVELOPMENT. THE BIGGEST ADVANCEMENTS IN FUNDAMENTAL TRANSISTOR DESIGN. HAFNIUM TECHNOLOGY CAN DELIVER MORE THAN A 30 PERCENT IMPROVEMENT IN TRANSISTOR SWITCHING SPEED, AND REDUCE TRANSISTOR GATE LEAKAGE BY OVER 10 FOLD.

USING A COMBINATION OF NEW NANOMATERIALS INCLUDING HAFNIUM-BASED HIGH-K GATE DIELECTRICS AND METAL GATES, 45NM TECHNOLOGY REPRESENTS A MAJOR MILESTONE AS THE INDUSTRY AS A WHOLE
RACES TO REDUCE ELECTRICAL CURRENT LEAKAGE IN TRANSISTORS (A GROWING PROBLEM FOR CHIP MANUFACTURERS AS TRANSISTORS GET EVEN SMALLER).

This new transistor breakthrough allows to continue delivering record-breaking computers and server processor. It also ensures that Moore’s Law thrives well into the next decade (INTEL CORP., 2010).

3. TECHNOLOGICAL GAPS BETWEEN DEVELOPED AND DEVELOPING COUNTRIES IN NANOMATERIALS

MAIN LOCATIONS OF HAFNIUM INNOVATIVE CENTERS

HF PATENTS

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WORLDWIDE HAFNIUM INNOVATIVE NETWORK
WEAK LINK

• THE MOST ACTIVE REGIONS ARE LOCATED IN CALIFORNIA, NEW YORK, GERMANY AND JAPAN

• CALIFORNIA MAINTAINS AN INTERNATIONAL AND DIVERSIFIED COLLABORATION ACROSS EIGHT DIFFERENT REGIONS OF THE WORLD

• NEW YORK IS COLLABORATING WITH SEVEN REGIONS THROUGHOUT THE WORLD

• GERMANY IS ACTIVELY INVOLVED WITH CANADA AND UNITED STATES

• JAPAN HAS A MAJOR PRESENCE IN THE WORLDWIDE INNOVATIVE NETWORK OF HAFNIUM, ALTHOUGH IN ISOLATED CONDITIONS, HAVING NO PATENT REGISTRATIONS OF INTERNATIONAL COLLABORATION

• CHINA AND KOREA DO NOT APPEAR AMONG THE COUNTRIES WITH HAFNIUM PATENTS

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2.1.1.24 Performance and speed of nanochips

2.1.1.25 Capacity of computer processors

2.1.1.26 New era for information and communication technologies

2.1.1.27 Efforts on R&D and innovation capabilities

2.1.1.28 Fields of knowledge

2.1.1.29 Silicon Oxide Era

2.1.1.30 Size reducing and capacity increasing
3.1.1 PROCESS ELEMENTS

3.1.1.1 Manufacturing costs

3.1.1.2 High-precision analysis

Gates
Ways to predict the stability of hafnium oxide systems
Accuracy and precision of films manufacturing
Systems based on HfO2

3.1.1.3 Displacing older silicon technology

3.1.1.4 Ways to predict the stability of hafnium oxide systems

3.1.1.5 Accuracy and precision of films manufacturing

3.1.1.6 Forefront of science and technology

3.1.1.7 Research centers
3.1.1.8 New probabilistic models

3.1.1.9 Global companies

3.1.1.10 Composition of nanostructures

3.1.1.11 Accuracy of spectra parameters

Gates
Angular photoelectron emission spectroscopy

3.1.1.12 Angular photoelectron emission spectroscopy

3.1.1.13 Importance of patents in the field of nanotechnology

3.1.1.14 Impact on the development of scientific and technological disciplines

3.1.1.15 Other converging technologies

3.1.1.16 Technological trends scenarios

3.1.1.17 Global geopolitical balance

3.1.1.18 Integrating role

3.1.1.19 Transdisciplinary nature
3.1.1.20  Semiconductors industry

3.1.1.21  Nanotechnology as a merger of many sub-disciplines

3.1.1.22  Potential to converge with other knowledge fields

3.1.1.23  New qualitative developments

3.1.1.24  Systems based on HfO2

3.1.1.25  Advantages in terms of efficiency

3.1.1.26  Benefits of developments

3.1.1.27  Regional innovation systems

3.1.1.28  Technological catching up
4.1.1 PROCESS ELEMENTS

4.1.1.1 Accessibility to society

4.1.1.2 Failure of divergent knowledge fields

4.1.1.3 Unification of multiple technologies articulated in nanotechnology

4.1.1.4 Foresight studies

4.1.1.5 Transdisciplinary knowledge

4.1.1.6 Complex and multidimensional problems

4.1.1.7 Energy crisis, health, water, climate change, food crisis

4.1.1.8 Clean energy

4.1.1.9 Cancer treatments

Gates

Technological independence
4.1.1.10  Absence of public policies

4.1.1.11  Scientific and technological development of countries

4.1.1.12  Technological independence

4.1.1.13  Partnerships involving government, industry and research centers

4.1.1.14  Empowerment and guidance of actors

4.1.1.15  Ethical commitment

4.1.1.16  Total turnover

4.1.1.17  Sustainable development

4.1.1.18  Economic and social development of countries

Gates
New sources of alternative energy

4.1.1.19  New sources of alternative energy

Gates
Promotion of a new industrial development scheme
4.1.1.20 Promotion of a new industrial development scheme

Gates

Emerging markets

4.1.1.21 Emerging markets

4.1.1.22 Policies on science, strategies and instruments of financing

4.1.1.23 Potential markets associated with nanotechnology applications

4.1.1.24 Fusing of Information Technology and nanotechnology

4.1.1.25 Worldwide economic and social importance nanotechnology

4.1.1.26 Regional capabilities organized around networks in nanotechnology research and development
Any scientific progress that is exploding exponentially predicts a technological leap. However, it cannot grow without coming across certain limit. Stephen Hawkin said recently when asked about the limits of nanoelectronics "The speed of light and the atomic nature of matter (nanoscale)." We are not far from that point in reality. Until recently, before science and industry entered the Hafnium, nanomaterials had the limit of five molecular layers. Films cannot be reduced to less than one layer. In fact, it is virtually impossible to reduce to less than three layers without major problems, so that fundamental limits are present already. Such fundamental limits can escape from the imagination. It was thought that science would take two or three generations to reach them, and now, we witness.

Mexico is characterized by a disarticulated NIS with minimal efforts in R&D and patents fields. In the nano material sector, the poor performance of these two innovation indicators provides evidence of the important technological gap that Mexico has vis a vis the industrialized countries, and even with some other developing (emerging) countries. Nevertheless, there is some strength in the frontier scientific research of the universities. Even if the international scientific leadership of some research teams is atypical, it provides a technological opportunity to develop a local industry that could be the beginning of a converging path. In the absence of active, institutional and supportive government policies, multinational firms could appropriate the innovative efforts of the research teams without having any local benefits, or the rest forgotten.

The role of government policies is crucial to fostering the development of the entrepreneurial activity in nanomaterials applied to information processing. The government’s policies will be addressed to build technological capabilities so as to
assure the linkages between firms and universities as well as assure financial support. All this, in order to make profits, from the technological opportunities resulting from the scientific progress of the research teams, leaders in this kind of knowledge. By considering the important amounts of R&D investment, the Mexican government has to consider the possibility of promoting some technological cooperation agreements with international firms, but, at the same time, making sure that Mexico can be a beneficiary of the innovation activity carried out by university researchers.

By identifying the relative scientific strength of some university research teams on the innovation of nano materials field applied to the ITC in the context of a weak NIS and a sector few developed, the government must facilitate the communicating vessels between universities and local enterprises in order to foster the local firms investment (demand factors), the technological collaboration, the absorption of knowledge spillovers and probably the strategic alliances with foreign firms, leaders in this field. The government has to play a crucial role in this process of technological innovation, where the R&D of the raw material hafnium oxide (HfO2) stands out as an important technological opportunity, which could improve efficiency, stability and manufacturing costs in the ITC sector.