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# INNOVATION ON NANOMATERIALS ACROSS COUNTRIES IN A TRIPLE HELIX FRAMEWORK: THE CASE OXIDE OF HAFNIUM

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## Resumen

El objetivo de este artículo es identificar las capacidades de innovación y los flujos de conocimiento de firmas, universidades e institutos de investigación en el campo de nanomateriales en diversos países, particularmente de nanomateriales basados en hafnium. Mediante del análisis de las patentes concedidas en la Oficina de Patentes y Marcas de los Estados Unidos (USPTO) en el campo de hafnium, se busca conocer la contribución de los empresarios, gobierno e instituciones universitarias y de investigación a la innovación y cómo los flujos de conocimiento se expresan en el ámbito de los inventores. Asimismo, nos proponemos explorar cómo en México, las firmas, universidades y gobierno contribuyen a desarrollar capacidades científicas y tecnológicas para desplegar este nuevo paradigma tecnológico y, por tanto, a favorecer el alcance tecnológico en el campo de los nanomateriales.

*Palabras clave:* Hafnium nanomateriales, I&D, patentes USPTO, inventores, papel de firmas-universidad-gobierno de México en innovación y alcance tecnológico
*Clasificación JEL:* O31, O34

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## Abstract

The aim of this paper is to identify the innovation capabilities and knowledge flows of firms, universities and research institutes in the nanomaterials field across countries, particularly in the "hafnium" nanomaterial. Through the analysis of patents granted at the United States Patent and Trademark Office (USPTO) in hafnium field we want to know how the entrepreneurs, government and academic and research institutions are concern to innovate and how the knowledge flows are manifested at the inventors level. As same, we want to explore how in Mexico the firms, universities and government are contributing to build scientific and technological capabilities in this new scientific and technological paradigm. Taking into account the international innovation gaps in hafnium nanomaterial, we discus about the main institutional policies that Mexico could foster to build scientific and technological capabilities, to spread the new technological paradigm and, therefore, to favor the technological catch up in nanomaterials field.

*Keywords:* Hafnium nanomaterial, R&D, patents, Mexican firms-university-government role on innovation and technological catching up
*JEL Classification:* O31, O34

## 1. Introduction

The remarkable scientific progress on 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.

Nanotechnology innovation has been particularly dynamic in the information and communication technologies (ICT). "Since the invention of silicon based transistors, … hafnium (HfO2) emerges from all likely candidates to become the new gold standard in the microelectronics industry. HfO2 based materials have emerged as the designated dielectrics for future generation of nano-electronics with a gate length less than 45nm" (Choi, Mao and Chang, 2011). The progress of this hafnium nanomaterials could be entail the end of the silicon age and to pass towards an efficient and competitive new technological paradigm by: i) improving the control of logical nanocircuits; ii) reducing radically the size and increasing the capacity of computer processors and, iii) improving the performance and speed of nanochips for data transmission and communications.

The aim of this paper is to identify which countries are moving to the frontier nanotechnologies, and specifically in nanomaterials. By analyzing patents granted at USPTO in hafnium field (a new nanomaterial) we want to know how the entrepreneurs, government and institutions are concern to innovate in this field and how the knowledge flows are manifested at the inventors level. Likewise we want to know if Mexico is building capabilities to develop frontier nanotechnologies, such as in hafnium or other nanomaterials, by considering universities, government and entrepreneurial scopes. Particularly, we want to analyze the nature of the innovation of this emerging sector 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. We set out the next questions: How the universities, research institutes and entrepreneurs across countries are concern to develop innovation in the nanosciences and nanotechnology? In the case of Mexico is the government fostering 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? What are the challenges for Mexico to be capable of appropriating the new knowledge generated regarding the new nanomaterials, as the hafnium, to boost the industrial activity? In this sense, we state the following hypothesis: the path of innovation in nanotechnologies, specially in hafnium nanomaterial, suggest that universities and research institutions, firms and government are key actors to develop scientific and technological knowledge, to create new process and new products impacting the industrial and market scopes and to foster R&D and innovation policies to assure to be at technological frontier. In this sense, in Mexico, as other developing countries, characterized by a lack of financial resources, the new knowledge generated in nanotechnologies 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 issues concerning the debate of the institutional innovations or innovation policies to promote the closer links between academia and entrepreneurial sectors by considering mainly the National System of Innovation approach and the Triple Helix framework. Next, in the second section we analyze the emergence of the hafnium (new nanomaterial) replacing the silicon oxide. In the third section we identify the technological gap in nanomaterials across countries, including the efforts on R&D, the innovation capabilities (patents and scientific production), and research networks. Finally, in the last section we identify the nature of the university-firm-government linkage building capabilities in the sector of nanosciences and nanotechnology in Mexico. We point out some elements and strategies, which might contribute to the design of public policies in Mexico.

## 2. Theoretical framework

The increasing importance achieved by the knowledge economy has focused the necessity to discus about the role of universities in the economic development and the institutional policies to generate an adequate environment that favors the closer relations between university and firms. As producer of the scientific and technological knowledge, the universities play a catalytic role in the innovation process (Etzkowitz and Leydesdorff, 2000). Nevertheless firms are recognized to have the leading role on innovation, according to National System of Innovation (Lundvall, 1992; Nelson, 1993) and the statal policies could have a promoter leadership role, following Triangle of Sabato Model (Sábato and Mackenzi, 1982), the interaction between universities, firms and governmental agencies through institutionals arrangements are essential to foster and to increase the knowledge-based societes, from the Triple Helix point of view (Etzkowitz and Leydesdorff, 2000).

Although the networks between science and technology are the key element for knowledge production in fields such as biotechnology and nanotechnology (Freeman, 1974; Gibbons *et al.*, 1994; Foray, 2000) and consequently, to the national and regional developments, there has been a strong debate concerning the academic technology transfer (Mowery, Nelson, Sampat and Ziedonis, 2004). The several obstacles to develop successfully the industry and sience links are associated to different kind of arguments, mainly those focused to institutional changes, and more precisely to the new mission of university and the appropriaton of benefits generated derived from the new knowledge and technological change.[1]

Firstly, it is important to identify the nature of collaboration of universities and firms with regard to the market. While firms which are collaborating compete in the output market, the universites-firms collaboration are not characterized by a logic of competition, specially because "…the universities are not being able to apppropiate exclusively the benefits from the new know how… unless the know how would leak out the competitors indirectly through common partners" (Veugelers and Cassiman, 2005: 359).

Secondly, the joint R&D projects between universities and industry are arranged with a "...high uncertainty, high information asymmetries between partners, high transaction cost for knowledge exchange requiring the presence of absorptive capacity, high spillovers to other market actors and, restrictions for financing knowledge production and exchange activities due to risk-averse and short-term oriented financial markets"[2] (Veugelers and Cassiman, 2005: 359). The uncertaintity in this kind of cooperation could be explained by the nature of scientific knowledge. But regarding the transaction costs derived from academic technology-transfer, they are seen by Swedish academics as unnnecesary because once the knowledge is patented, it cannot go freely to industry (Etzkowitz and Leydesdorff, 2000). Otherwise, the regulation of intellectual property rigths (IPR) and tecnological transfer regulation at universites, specially those referring the new organizational mechanisms, is appreciated as necessary to incentive scientific and technological innovation and assure the knowledge flows and the innovation returns.[3]

Thirdly, in a university-industry-governement relation framework aiming an alternative strategy for an innovative path, economic growth and

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[1] The establishment of links between university and firm has been the outcome of a process in which, on the one hand, the university has transformed the environment of its mission and, on the other, firms have internalized the need for cooperation in order to strengthen R&D with the idea of developing new products and processes in the context of the innovation economy.

[2] The uncertainty is present in this kind of cooperation because the nature of scientific knowledge and therefore the demand of the universities scientific know how will be localized in some particular firms associated to specific technologies as biotecnology and nanotechnology.

[3] The Act Bayh Dole has been a reference for developed countries as same of developing countries as a statal policy to endorse academic institutions to be involved in patenting and transferring technology. The evidence about the impact of the Bayh Dole Act in the growth of patenting activity in the universities is not conclusive. If it is true that patents from universities have grown during the 80s and 90s, also is true that other factors could have influenced in this tendency (Mowery *et al.* 2004).

social transformation, the analysis must be focused on the factors explaining the universities R&D collaborations, as the firm size, the government support, the patenting and scientific industry, the strategies to choose the complementarity between the internal and external technological sources (Arora and Gambardella, 1990). Hence, the firm builds absorption of external knowledge as it increases the internal R&D effort (Cohen and Levin, 1989; Kamien and Zang, 2000), meanwhile the fortress of internal R&D facilitates the adoption of imported technologies.[4] At the same time, the acquisition of external technologies favors the optimization of a firm's R&D efforts and consequently contributes to improve its technological capabilities to undertake an endogenous innovation path (Kamien and Zang, 2000; Kaiser, 2002). Concerning the links university-firms, Veugelers and Cassiman (2005: 361) state that "firms being engaged in other innovation strategies will have a larger incentive to engage in industry-science cooperation". The hypothesis expecting firms having more R&D activities, both basic and applied, will benefit more from the basic capabilities developed through R&D cooperation with universities is confirmed in specific science industries. They founded that "firms impeded by cost to innovate are more likely to cooperate with universities, attracted by the often government subsidized cost-sharing in public-private partnerships." (Veugelers and Cassiman, 2005: 373). Another finding is that the fact of firms protecting their properties rights does not affect the decision to cooperate with universities.

The literature regarding innovative activity in developing countries has identified different factors that block the R&D investment and stop the innovative efforts of the companies; among them are: unlikely access to financing and macroeconomic instability, low level of human capital, lack of policies promoting the interactions between the different institutional scopes, necessity to make regulatory and institutional reforms. The developed countries firms and universities are internalizing the need to undertake R&D collaboration, promote university spin-off firms, transferring specialized knowledge. The joint R&D and innovation efforts from developing countries must be higher to develop absorption capabilities that allow profiting from foreign technologies and further developing endogenous scientific and technological knowledge. Specially, in these countries, these two helices

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[4] For the case of developing countries see: Caves and Ukesa, 1976; Katrak, 1997; and Arora, 1997.

need of a third one: the government support and institutional policies leading the interaction of knowledge networks (even in a global context) and incentive the industrial activity, therefore improving the economic and social development.

## 3. The emergence of hafnium oxide as nanomaterial in semiconductor field

There are four nanotechnologies that converge with scientific and technological disciplines and they have several application sectors: i) nanometrology/nanoanalysis; ii) nanobiotechnology/nanomedicine; iii) nanomaterials/nano chemical/nanoelectronic and iv) nano-optic (Abricht *et al.*, 2004: 17).

In electronic field, nanotechnology augur a big fertility to the semiconductors devices, spurring economically from 10 to 15 years more than 300 thousands of millions of dollars by year for each area (Doering, 2001: 74).

The silicon dioxide, SiO2, and the silicon oxynitride were essential materials for semiconductor devices development, key of technological revolution in the ICT, more the three decades ago. As semiconductors have gotten smaller, the limiting factor in further size reduction has been the ability of the silicon oxide gate to perform below 10 angstroms where leakage occurs (Keita, Keisuke, Yasuhito and Hiroshi, 2011). Therefore, these materials risk to be replaced by gate dielectric materials with significantly higher dielectric constant (Sparks, Lysaght and Rhoad, 2005). The future generation semiconductor devices, as CMOS architectures and Metal-Insulator-Metal architectures for DRAM applications, need new materials such as having high dielectric constant oxides. In that sense, SiO2 reaches its physical limits, by the fact it has equivalent thickness of about 1nm. Among various metal compositions having the materials requirements as *k*, (leakage current, crystallization temperature, charge trapping) and the integration requirements (thermal stability on interface, dry etching feasibility), Hafnium based oxides is one of the most promising candidates (Stéphane, 2008). The effort to introduce a high-*k* gate dielectric thin film with equivalent electrical silicon oxide thickness (EOT) less than 1nm that meets required performance characteristics including low leakage current and high electron mobility, while demonstrating the capability of continued scaling, has evolved with the realization that the combination of many specific chemical treatments in conjunction with variations in Hf silicate (HfSiO) composition may be necessary (Sparks, Lysaght and Rhoad, 2005)

Hafnium could replace polysilicon as the principal gate or electrode material in metal oxide semiconductor field effect transistors (MOSFETs), because they have become essential for all modern semiconductors. “Using hafnium based alloys, as this di-electric gate has allowed for the development of MOSFET gates smaller than 10 angstroms. This allows for further size reduction, reduced switching power requirements and improved performance”.[5]

Therefore, Hafnium based materials seems to be the designated dielectrics for the new paradigm of nano-electronics, passing from thermal processes to atomic layer deposition processes. These new materials provide a physically thicker layer to suppress the quantum mechanical tunneling through the dielectric layer. They have a thin gate length less than 45nm. (Choi, Mao and Chang, 2011).

Hafnium is obtained by refining various zirconic mineral deposits and was discovered by Dirk Coster in 1923. “Hafnium is available as metal and compounds with purities from 99% to 99.999% (ACS grade to ultra-high purity); metals in the form of foil, sputtering target, and rod, and compounds as submicron and nanopowder. It’s primary uses are due to its ability as a nuclear ‘getter’ or absorber of neutrons. It is a primary component in nuclear control rods for this purpose. It also finds uses as a dopant in the alloy of steel and titanium. It is also used in the production of mantles for high intensity incandescent lamps”.[6]

The progress of nanoparticles and nanopowders allows to hafnium oxides other properties and benefits with clear advantages linked to the fact that Hafnium is available in soluble forms including chloride, nitrates and acetates. These compounds are also manufactured as solutions at specified stoichiometries.[7]

Given the importance of the emergence of nanotechnologies, governments and multinationals are making gross investments on R&D in this field.

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[5] <http://www.americanelements.co.uk/hf.htm>.

[6] Hafnium is a Block D, Group 4, Period 6 element. The electronic configuration is [Xe] $4f^{14}\ 5d^{2}\ 6s^{2}$. In its elemental form hafnium’s CAS number is 7440-58-6. The hafnium atom has a radius of 156.4.pm and it’s Van der Waals radius is 200.pm. (*Ibídem*).

[7] *Ibídem*.

By 2005 their R&D spending on nanotechnologies reached 9 billion dollars and 0.5 billion came from venture capital firms. Specially in the nanomaterials, where the market has registered an enormous growth,[8] multinationals, such as IBM, Texas Instruments and Intel are hugely financing on HfO2 research and development of systems and also have start 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.

## 4. Technological gaps between developed and developing countries in nanomaterials

The public R&D investment in nanotechnologies is relatively recent. Since the second half of the 90s, the United States, countries of European Union and Japan started to support R&D activities focused on nanotechnologies and increased even more from the beginning of the XXI century. Between 1997 to 2006 we observe three facts in the evolution of R&D expenditure: i) the R&D has growth 30.3 per cent in annual average rate ii) the leadership of United States, who has cumulated one quarter of total R&D and iii) the notable increasing participation of Asian countries as China, Korea and Taiwan on global R&D, with a contribution of 660 millions of dollars in 2004, which means two thirds of that invested as whole by the group of other countries including Australia, Canada, Singapore, Israel and East European.

According to the nature of the different National Systems of Innovation of the countries, in the US the private support to R&D in nanotech is slightly higher (54.4%) than the public; in Japan is even higher (63.2%). In contrast, in the European countries the importance of public funding is bigger than the private.

In accordance to the bigger R&D efforts of US, this country maintains an extensive leadership in nanotechnology inventive activity over the other

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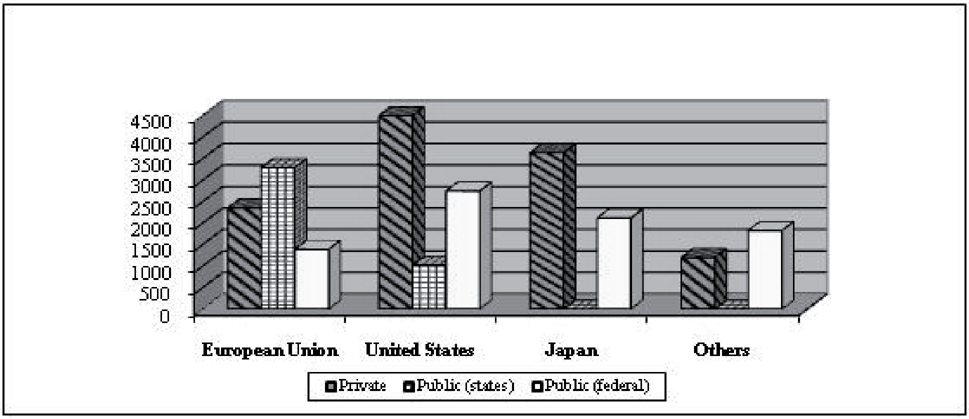
[8] In 2006 was predicted for two year later a total demand for nanoscale materials, device and tools more than 28 billion of dollars. Meanwhile, the US nanotech market is predicted to reach 3.3 billion by 2008 and cross 19.8 billion by 2013 (The World Nanotechnology Market, 2006).

industrialized countries and some Emerging countries from 1980 to 2009 in nonomaterials patents. Patents are an expression of the capacity of creating new knowledge. Following the increased tendency of R&D spending in nanotechnologies the number of applications and patents granted by the USPTO to residents and no residents have raised. Between 1980 and 2009 we have found 5 830 patents granted in the class 977 of USPTO, referring to nanotechnologies. From these patents 952 belong to patents in seminconductor field of the nanomaterial sector.

**Graphic 1**
**R&D spending in nanotechnology sector by sector funding, 2004-2006**
**(Millions US dls)**



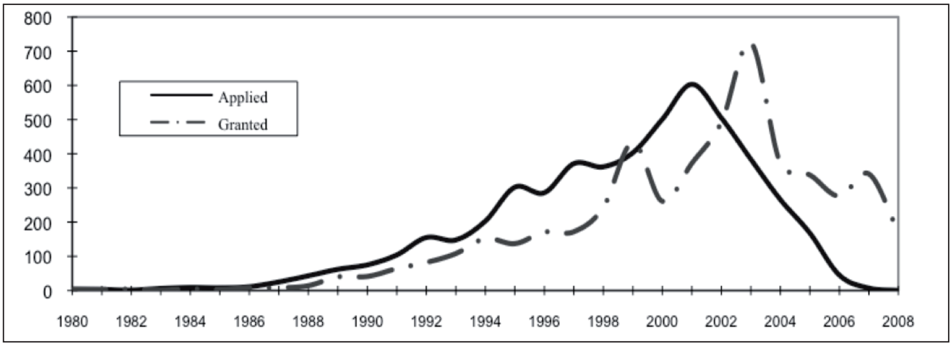
Source: Plamberg *et al.* (2009: p.33).

The patents granted by USPTO to residents and non residents in nanomaterial field concerning hafnium are 153 since 1982 to July 2010. Of these patentes, 83% belong to the United States and only four countries have applied and granted patents in this emerging technology. Japan is a follower with 10.2% of the total patents. The contribution of Germany (3.3%), Korea (3.3%) and France (2.0%) is marginal. Mexico doesn't have any USPTO patent in hafnium nanomaterials until now.

From the middle of the 90s, the inventive in hafnium field has increased remarkably in the United States, stressing the technological gaps respect to other developed countries. In the United States, the main locations of hafnium innovative firms or institutions are located in California and New York, with 30 and 21 patents respectively; Texas and Missouri with less patents (9 each one).

### GRAPHIC 2

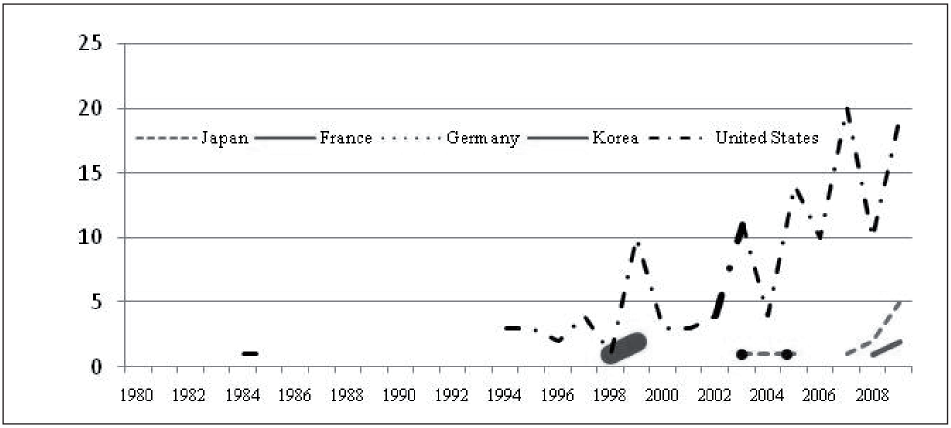
### Patents granted to residents and non residents in nanotechnology field by USPTO, 1980-2008



Source: USPTO, patents data base, class 977.

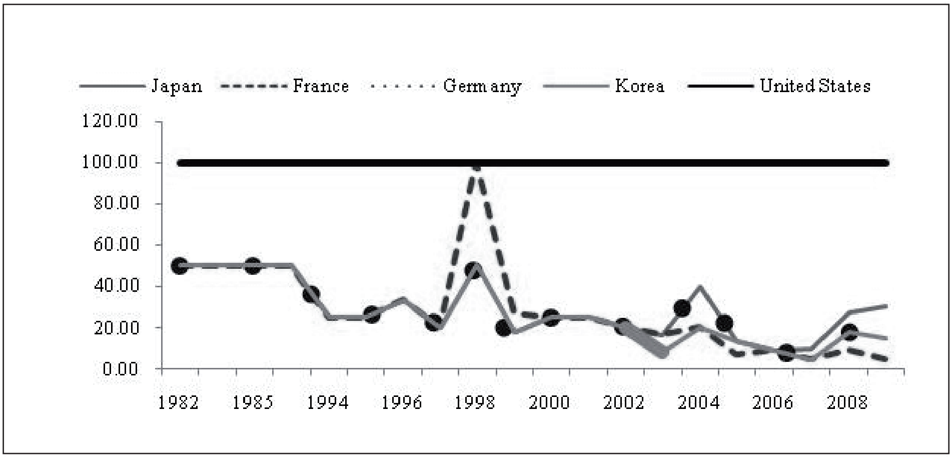
### GRAPHIC 3

### Patents in nanomaterial field, hafnium applied for USPTO countries, 1982-2009



Source: USPTO, patents data base, class 977.

### GRAPHIC 4
### Technological gaps of countries based in the number of patents granted in USPTO, 1980-2009



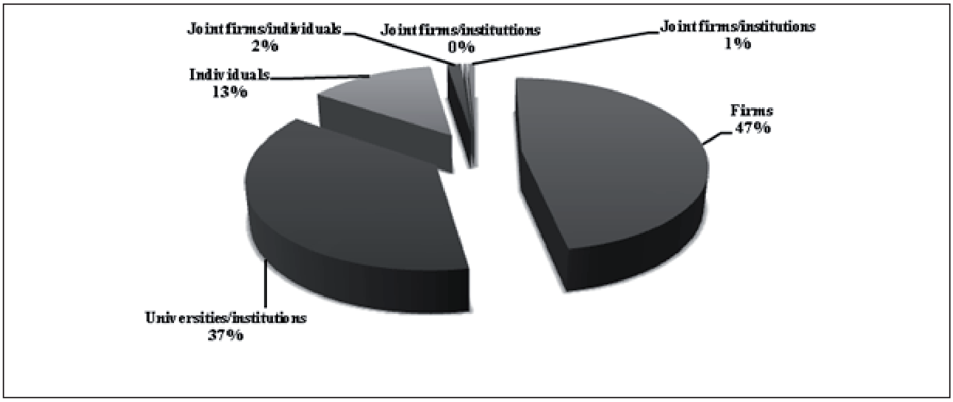
Source: USPTO patents data base class 977/hafnium.

Near to the half of the total patents in hafnium are assigned to firms. The universities or research institutes have contributed near to two thirds and individuals have 13% of the patents granted. The joint patents assigny are marginal; only 2% of patents belong jointly to firms and individuals and 1% to firms and institutions.

We identify, only firms among those that have more patents and mainly Americans. Those who have one patent are either firms of the other countries or institutions/universities.

We have build a symmetrical matrix associating the total number of the inventors of hafnium nanomaterials patents granted to residents and non residents of the United States with the origin of the inventor, either country or region (US state), with USPTO patents data base class 977/hafnium nanomaterials. We identify from where are coming the inventors that take part of the research teams of the novelty in hafnium field. We take into account not only countries but also we include the different American states in order to notice researcher mobility not only across countries but also across the Unites States. The number of countries in the matrix is bigger than those that have patents granted in hafnium because they are only indicating the origin of the researchers that have contributed to the creation of the patent that is the case of Netherlands, Norway, India and China.

### GRAPHIC 5
### Patents granted by USPTO in hafnium nanomaterials field by assigny type, 1988-2009



Source: USPTO patents data base, class 977/hafnium.

This research mobility could be explained by the individual migration of researchers highly skilled to regions of the United States or other countries, but also could be on account of collaborating research networks. Most of the total patents of each country or American states have inventors from the place, but also have inventors coming from other regions or countries. We identify that researcher mobility is higher to California, New York, Illinois, Ohio and Texas. The inventors of patents assigned to California come from six different regions of the US (Delaware, Illinois, Minnesota, Oregon and from other countries as Korea and Norway), but the researchers are mainly residents from California (80.1%). Meanwhile, to New York are coming researchers from seven US regions (California, Connecticut, Delaware, Vermont) and from India, but almost four fifths parties of the inventors are residents of New York. Even if Japan has a contribution to the knowledge progress of hafnium, his innovative activity is made almost without having foreign inventors; among the 34 inventors only there is an American from Ohio. France has similar phenomenon. In the total patents where Korea is the first assignee, there 12 are Korean inventors and 2 are Americans from New York; Samsung, a Korean firm, shares with General

Electric, an American firm, a patent. Although India does not have any patent in hafnium technology, for Indian researchers are inventors in American patents. Although is wider the mobility of the inventors across the Unites States, taking into account the residence of the inventor, we notice that an important number of inventors are native of the Asian countries (mostly from China and India).

### TABLE 1
### The top ten firms with more patents granted by USPTO to residents and non residents in hafnium nanomaterials field, 1980-2009

| | **Firms** | **Number of patents** |
|---|---|---|
| 1 | International Business Machines Corporation | 11 |
| 2 | Mallinckrodt Medical, Inc./ Micron Technology, Inc. | 7 |
| 3 | Micron Technology, Inc. | 7 |
| 4 | Motorola, Inc. | 6 |
| 5 | Intel Corporation | 5 |
| 6 | NanoProducts Corporation | 4 |
| 7 | Hewlett-Packard Development Company, L.P./ NanoProducts Corporation | 4 |
| 8 | Samsung Electronics Co., Ltd. | 3 |
| 9 | General Electric Company / Samsung Electronics Co., Ltd. | 3 |
| 10 | Allied-Signal Inc. | 2 |
| 10 | APS Laboratory | 2 |
| 10 | E. I. du Pont de Nemours and Company | 2 |
| 10 | Everspin Technologies, Inc. | 2 |
| 10 | Honeywell International Inc. | 2 |
| 10 | Hyperion Catalysis International, Inc. | 2 |
| 10 | Kabushiki Kaisha Toshiba | 2 |
| 10 | Keesmann; Till | 2 |
| 10 | Kennametal Inc. | 2 |
| 10 | Mecagis | 2 |
| 10 | Qimonda AG | 2 |
| 10 | Shin-Etsu Chemical Co., Ltd. | 2 |
| 10 | U.S. Philips Corporation | 2 |

Source: own elaboration based on USPTO.

### TABLE 2

### Matrix of origin of the inventors in the total inventors of hafnium nanomaterials patents by country or US State, 1980-2009

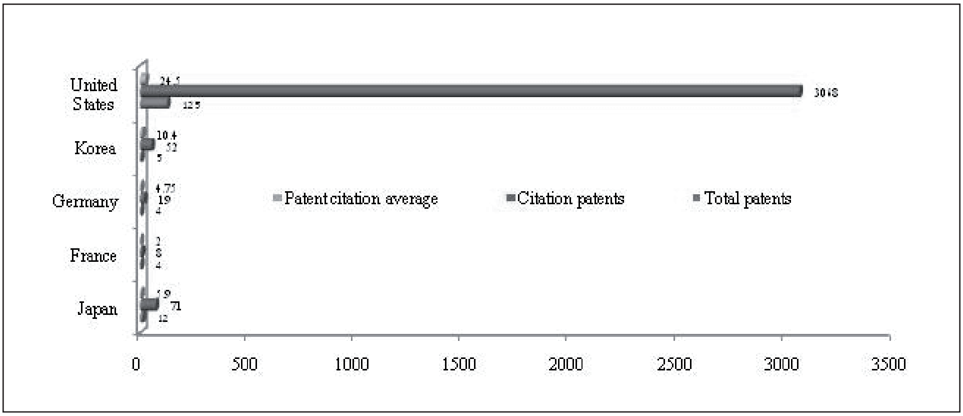
| Patent inv/orig in | AK | AL | AZ | CA | CN | CO | CT | DC | DE | DE/US | FR | GA | ID | IL | IN | JP | KR | MA | MD | MI | MN | MO | NC | NH | NJ | NL | NM | NO | NY | OH | OR | PA | TN | TX | UT | VA | VT | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AK |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 1 |  |  |  |  |  |  | 1 |
| AL |  | 2 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 2 |
| AZ |  |  | 4 |  |  | 4 |  |  |  |  |  |  |  | 11 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 19 |
| CA |  |  |  | 38 |  | 1 | 6 | 1 |  |  |  |  |  |  | 1 |  |  |  |  | 1 |  |  |  |  | 4 |  |  | 1 | 1 |  |  |  |  | 12 |  |  |  | 66 |
| CN |  |  |  |  |  | 1 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| CO |  |  |  |  |  | 3 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 3 |  |  |  |  |  |  |  | 2 |  |  |  |  |  |  |  | 8 |
| CT |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 1 |  |  |  |  |  |  |  |  | 1 |
| DC |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| DE |  |  |  | 1 |  |  |  |  | 4 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 3 |  |  |  |  |  |  |  |  | 8 |
| DE/US |  |  |  |  |  |  |  |  |  | 4 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 2 |  | 3 |  |  |  |  |  |  |
| FR |  |  |  |  |  |  |  |  |  |  | 6 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 6 |
| GA |  |  |  |  |  |  |  |  |  |  |  | 2 |  |  |  |  |  |  |  |  |  |  |  |  | 1 |  |  |  |  |  |  |  |  |  |  |  |  | 3 |
| ID |  |  |  |  |  |  |  |  |  |  |  |  | 8 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 8 |
| IL |  |  |  | 1 |  |  |  |  |  |  |  |  |  | 2 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 3 |
| IN |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 2 |  |  |  |  |  |  |  |  | 2 |
| JP |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 33 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 33 |
| KR |  |  |  | 1 |  |  |  |  |  |  |  |  |  |  |  |  | 12 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 13 |
| MA |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 10 | 2 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 12 |
| MD |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 2 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 2 |
| MI |  |  |  | 1 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 5 |  |  |  |  |  |  |  |  |  | 2 |  |  |  |  |  |  |  | 8 |
| MN |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 8 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 8 |
| MO |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 11 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 11 |
| NC |  |  |  |  |  | 1 |  |  |  |  |  |  |  |  | 1 |  |  |  |  |  |  |  | 15 |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 17 |
| NH |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 1 |  |  | 1 |
| NJ |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 1 |  |  |  |  |  |  |  |  |  |  |  |  | 1 |
| NL |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 3 |  |  |  |  |  | 1 |  |  |  |  |  |  |  |  |  |  |  | 4 |
| NM |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 4 |  |  |  |  |  |  |  |  |  |  | 4 |
| NO |  |  |  | 2 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 2 |
| NY | 1 |  |  |  |  |  |  |  | 1 |  |  |  | 1 |  | 1 |  | 2 |  |  |  |  |  |  |  |  |  |  |  | 38 |  | 1 |  |  |  |  |  | 2 | 47 |
| OH |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 1 |  |  |  |  |  |  |  |  |  |  |  |  |  | 1 |  |  |  |  |  |  |  | 2 |
| OR | 1 |  |  | * |  |  |  |  |  |  |  |  | 4 |  | 1 |  |  |  |  |  |  |  | 1 |  |  |  |  |  |  |  | 3 |  |  | 3 |  |  |  | 13 |
| PA |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 2 |  |  |  |  |  |  |  |  |  |  |  |  |  | 8 |  |  |  |  |  | 10 |
| TN |  |  |  |  |  |  |  | 2 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 1 |  |  |  |  | 3 |
| TX |  |  |  |  |  |  |  |  |  |  |  |  |  | 2 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 10 |  |  |  | 12 |
| UT |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 1 |  |  |  |  |  |  |  |  |  |  | 5 |  |  | 6 |
| VA |  |  |  |  |  |  |  | 2 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 3 |  | 5 |
| VT |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 3 |  |  |  |  |  |  |  |  | 3 |
| Total | 2 | 2 | 4 | 44 |  | 10 | 6 | 5 | 5 | 4 | 6 | 2 | 13 | 15 | 4 | 34 | 14 | 14 | 2 | 9 | 8 | 14 | 16 | 1 | 6 | 1 | 4 | 1 | 48 | 7 | 5 | 11 | 1 | 25 | 6 | 3 | 2 | 344 |

Source: own elaboration based on USPTO patents data base.

Either by individual decision or in the context of institutional collaboration networks, the mobility of the researcher, using patent indicator is still weak. This is probably because the research in hafnium is emerging. Probably, the collaboration networks could be identified through current projects or scientific publication.

Patent citations reveal the sources of technological knowledge. A greater number of consulted citations show the ability of inventors to accede to a vast field of technological knowledge. Given the leadership of US in patenting in hafnium, this country has the biggest number of patent citations. Therefore, the Unites States also register the largest patent citation average, in contrast to other countries; the 121 US patents granted in hafnium since 1982 to July 2010, have cited 3 068 patents, that means 24.5 citation patents per patent. By its side, Korea, only having 5 patents, has 10.4 citation patents per patent in average, more than Japan, even if this country has more patents.

**GRAPHIC 6**
**Patents, citation patents and patent citation average**

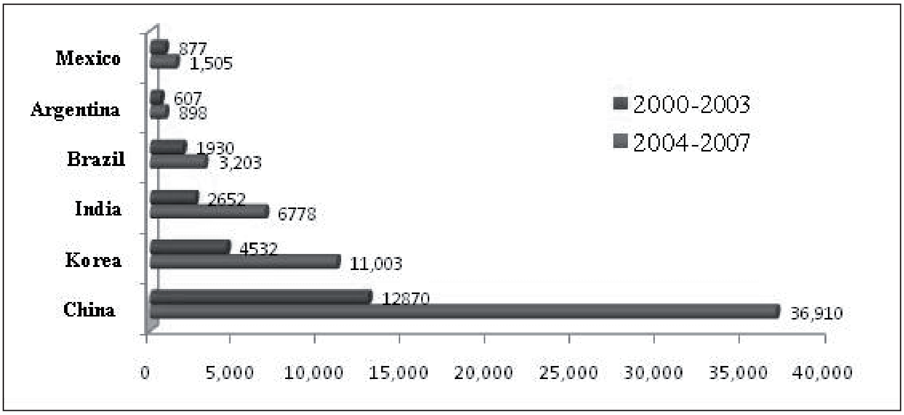


Source: own elaboration with USPTO patents data base class 977/hafnium.

Developing countries have a small research base, and do 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. Mexico has the second place, after

Brazil, in Latin America on the number of articles published in nanosciences and nanotechnology field, according to the Science Citation Index data base, but is far away from the Emerging Asian countries as India Korea and China. Even if Mexico has doubled the scientific articles from the period 2000-2003 to the period 2004-2007, still remains low in comparison to other Emerging countries.

**GRAPHIC 7**
**ISI articles in nanosciences and nanotechnology field of Emerging countries, by periods**



Source: Science Citation Index.

## 5. Nanotechnology sector in Mexico and the NAFTA region scope. The case of nanomaterials/hafnium

Nevertheless the Mexican government has expressed its interest to develop nanotechnologies in Mexico through the Science and Technology Special Program (PECYT-Programa Especial de Ciencia y Tecnología) 2001-2006 and 2008-2012 and has supported several projects, until now there has not been any Nanotechnology National Plan (Záyago-Lau and Foladori, 2010). Indeed, Mexican government has admitted the potential benefits of nanotechnologies development to improve the technologies in the energy sector and mainly in the petroleum industry, and consequently contributing to increase their competitiveness.

Although the Science and Technology National Council (conacyt-Consejo Nacional de Ciencia y Tecnología) has given financial funds to create research centers on nanotechnology and research projects, there has been absence of an articulated and strategic policy assuring a high R&D investment, giving priority to the most urgent technological needs of the country and the opportunities niches, fostering the research networks in nanotech and supporting the creation of education programs to diffuse nanotech knowledge and develop skills in this scientific and technological field. conacyt has supported 152 project on nanotechnologies, spending 14.4 millions of US dollars between 1998 and 2004 (Secretaría de Economía, 2008); this amount is far away from the expenditure destinated to R&D in nanotech in industrialized countries and even some Emerging countries, as China and India, that have spend 510 and 50 million of dollars in 2008, respectively. So, if Mexico has registered a relative technological backwardness in the new Information and Communication Technologies paradigm with respect to industrialized countries and Emerging Asian countries, Mexico must undertake a wide R&D efforts but building an active policy creating the network of actors and institutions in the public and the private sectors in order to develop and to diffuse the new nanotechnology paradigm.

## Role of universities

In Mexico there are around 56 institutions and 159 laboratories, where 449 researchers are involved in 340 issues of nanotech research (Secretaría de Economía, 2008). Among the institutions the more relevant, by taking into account their articles of the International Scientific Index, are the National Autonomous University of Mexico (unam-Universidad Nacional Autónoma de México) and the Research and Advanced Studies Center of the National Polythecnic Institute (cinvestav-Centro de Investigaciones y de Estudios Avanzados del Instituto Politécnico Nacional), which concentrate the 40 and 16.4% of the total articles on nanotech in 1995-2007, respectively. From these articles, the nanomaterials is the most field tackled, surely it is associated to the fact that nanomaterials includes a wide scope of scientific issues. Among them we identify more than 380 frontier research articles about nanomaterials/hafnium field in the science citation index, where stands up the contribution of the Condensed Matter and Nanoparticles Laboratory of Physics Department at cinvestav.

Nevertheless the relative active article's production of the Mexican institutions, concerning patents, the institutional inventive activity is still weak. According to World Intellectual Property Office (WIPO), the number of patents granted at the Patent Cooperation Treat (PCT) by Mexican is 28, where IPN has 4 and UNAM has 2. But regarding the hafnium there is not any patent granted nor at the PCT, USPTO or even at the Industrial Property Mexican Institute (IMPI-Instituto Mexicano de la Propiedad Industrial).

### TABLA 3
### Main universities and research centers involved in nanosciences and nanotechnologies in Mexico

| Institutiton | Number of laboratories |
|---|---|
| CPI-CONACYT<br>(Public Research Centers-Science and Technology National Council; not including CIMAV and IPICYT) | 45 |
| UNAM<br>(National Autonomous University of Mexico, including faculties and institutes) | 23 |
| CIMAV<br>(Advanced Materials Research Center) | 18 |
| IMP<br>(Petroleum Mexican Institute) | 16 |
| IPN<br>(National Polytechnic Institute, including CINVESTAV) | 7 |
| IPICYT<br>(Scientific and Technological Research Institute of Potosi) | 6 |
| University of Sonora | 6 |
| University of Guadalajara | 6 |
| UAM<br>(Autonomous Metropolitan University) | 5 |
| UACH<br>(Autonomous University of Chihuahua) | 3 |
|  | 135 |

Source: Záyago-Lau and Foladori, 2010.

The laboratories identified as having capabilities to study frontier knowledge in nanotechnology and nanosciences are mainly those of the UNAM, the National Center of Metrology (CENAM-Centro Nacional de Metrología), some research public institutes of CONACYT as the Chemical Applied Research Center (CIQA-Centro de Investigación en Química Aplicada), also the Advanced Materials Research Center (CIMAV-Centro de Investigación en Materiales Avanzados), the first national laboratory funded by conacyt in nanotech and is located in Chihuahua, the National Laboratory in Nanosciences and Nanotechnology Research (linan-Laboratorio Nacional de Investigaciones en Nanociencias y Nanotecnología), was the second laboratory supported by conacyt located too in the Scientific and Technological Research Institute of Potosi (ipicyt-Instituto Potosino de Investigación Científica y Tecnológica) headquarter in San Luis Potosi.

The different universities or research centers in Mexico have created 6 bachelor's degree programs, 33 master programs and 33 PhD programs on nanotechnologies or linked to them. The unam is most active institution worried to bring up graduates in nanosciences and nanotechnologies fields through 10 masters and 10 PhD programs. The second one is the ipn, having 6 masters and 5 PhD programs. The University of San Luis Potosi, the city where are placed the ipicyt/linan, has 3 bachelor's degree, 4 master and 5 PhD programs. Also the University of Sonora stands up with 5 master and 3 PhD programs. Other institutions have academic programs but still are few extended in their university campus as uam, uanl, udla and the ug. Given the role of the universities and research centers as source of knowledge in this scientific technological paradigm, the academic programs are relevant to spread a new culture of nanotech in the entrepreneurial scope through professionals or research highly skilled.

As we have seen, the research in nanosciences and nanotechnology Mexico takes part of the scientific and technological goals of several universities and research centers. Many of them have undertaken projects on nanotech field under the support of the conacyt, states financial funds or even of international institutions. Some of them have internalized the necessity of building research networks with national and foreign institutes. The model of technological collaboration has been important to joint efforts between institutions with similar purposes.

Because the geographical and commercial closeness to the United States, the main international connections of Mexican institutions are with the similar American ones. The Mexico-Unites States Foundation for Science (fumec-Fundación México-Estados Unidos para la Ciencia), which promotes the scientific linkages between these two countries of North American region, has contributed the create a network of universities and superior institutes called *Design Centers Network*. Through this network, the institutions are engaged to develop industrial projects and

## TABLE 4

## Research projects in nanosciencies and nanotechnology in Mexico by institution/laboratory

| Institution | Localization | Main purposes and research projects |
|---|---|---|
| CIMAV/NANOTECH (National Laboratory of Nanotechnology) | Chihuahua | To develop nanotech specific application for industrial products enhancing the collaboration with national and international institutions and firms and improving industrial competitiveness. Nanotech aims to become the main center of linkage of all the Mexican nanotechnology activities with the foreign ones. They have established research networks with North American region institutions as Arizona State University, Texas University, UAlbany College of Nanoscale Science and Engineering of Albano Nanotech, aiming to create a regional cluster. Also there is a project with the collaboration of Brazil and Argentina to create Tri-National Center of Nanotechnology (CNT). The focus research of Nanotech will be on materials synthesis, materials characteristics, development of new materials, consultancy and training to firms and institutes. |
| IPICYT/LINAN | San Luis Potosi | Research focused to bring up and to train human resources highly skilled and to contribute with the firms development to become international competitive. Master and PhD programs in nanosciences and nanotechnology focusing on issues such as: nanostructures synthesis, biomimetrics, magnetic nanomaterials and applications, nanobiotechnology, biomaterials nanostructures characteristics, nanocompounds, electronics estimations of nanosystems. The collaboration with international institutions (NASA, MIT, USDC-Unites States Department of Commerce, the Shin Shu University of Japan) and national institutions (UNAM, IMP, ITESM-Monterrey Superior Studies Technological Institute, Phisycs Institute of IPN, among others). |
| UNAM | Mainly in Mexico City | University Environmental Nanotechnology Project (PUNTA-Proyecto Universitario de Nanotecnología Ambiental) to foster multidisciplinary research aiming to solve national problems with the participation of 30 experts. Network of Research Groups in Nanosciences (REGINA- Red de Grupos de Investigación en Nanociencias) with more than 50 researchers, searching on issues such as: nanoparticles synthesis using colloidal methods, nanobiotechnology, nanostructured systems with application to catalysis, nanomaterials computer physics, nanomachines, among others. Nanoscience and Nanotechnology Center located in Ensenada, Baja California. |
| IMP | Mexico City | Institution focused on energy sector, mainly on petroleum industry through Pemex linkage. Aims to develop nanotechnology research in order to find out more efficient use of petroleum derivates and look for new sources of energy. The main research issues are new materials and nanostructures. |

Source: Záyago-Lau and Foladori, 2010.

## TABLE 4

## Research projects in nanosciencies and nanotechnology in Mexico by institution/laboratory (Continued)

| | | |
|---|---|---|
| CINVESTAV | Mexico City | Advanced Laboratory for the study of semiconductors nanostructures, department of Physics. Master and PhD in Nanosciences and Nanotechnologies focusing in nanomaterials, nanodevices, nanosystems and nanobiotechnology. This laboratory has undertaken the R&D in nanomaterials/hafnium. |
| CENAM (National Center of Metrology) | Queretaro | Aims to foster knowledge and to use of metrology to strengthen industrial competitiveness, equity in market transactions, health environment protection and scientific research. Therefore, CENAM establishes the measure standards, including norms for nanotechnology. Collaborates jointly with the National Institute of Measurement Standards (NIMS) from Canada and the National Institute of Standards and Technology (NIST) from the US in a Tri-National Workshop discussing about the risks of the use of nanotechnologies for the environment, health, and consumers and for the whole society. |
| BUAP (Meritorious Autonomous University of Puebla) | Puebla | Research stressing on semiconductors. Headquarter of the International Nanosciences and Nanotechnology, with researcher of the IPN (Mechanical and Electrical Engineering Superior School, Posgrade Studies Section, UAM Iztapalapa, CINVESTAV, Nuclear Research National Institute (ININ-Instituto Nacional de Investigaciones Nucleares), Neurology and Neurosurgery National Institute (INNN-Instituto Nacional de Neurología y Neurocirugía). |
| INAOE/LNN (Electronical, Optic and Astrophisycs National Institute/ Nanoelectronic National Laboratory) | Puebla | Aims to become the linkage between high technological research and the industrial sector to promote the electronics industry development, in favoring a university-industry-government model. They started since the donation of Motorola Inc company of a production line of devices and circuits |

Source: Záyago-Lau and Foladori, 2010.

academic programs specialized in Micro and Nano electromechanical systems (MEMS/NEMS). Also with the intervention of FUMEC was created de *Productive Articulation Center* to influence industry-academia policy maker collaboration to undertake the development of new projects and business. In the FUMEC framework was creating Bi-national Sustainability Laboratory (BNSL) aiming to boost the sustainable development in the frontier territory enhancing local capabilities and favoring successful entrepreneurial environment of the Paso del Norte Packaging Cluster. Through the collaboration of Mexican and American institutions, BNSL looks for having complementarities in R&D of products and their commercialization, energy and advanced materials, packaging MEMS. Collaboration is that made by Texas University-Austin and the CIMAV; both have made an agreement and therefore creating the International Center for Nanotechnology and Advance Materials (ICNAM). Likewise the Center for Nano and Molecular Science and Technology in the Texas University search for the stay academic exchange with the R&D purposes, specially the researcher coming from the Hispanic community.

## Universities and firms linkage

Although the Mexican firms have been characterized by having scarce R&D efforts and innovation capabilities, their specialization is not identified by the high technology and register important gaps with respect to industrialized and some Emerging countries, few of them have started to incorporate to their production process and products the nanotechnology knowledge. Near of three fifths of the 30 firms are using nanoparticles in the chemical and electrical industries. Comex, a Mexican firm with a larger business of paint and coating products is using nano clay and the firms Prolec GE/Xignux Group and General Electric are working with nanomaterials in Nuevo Leon. One third of firms using nanotech have the headquarter at Mexico City, less than one third are located at Nuevo Leon state, three in Coahuila, Jalisco and State of Mexico and finally, 5 companies (21.7%) are multinationals coming from Minnesota, South Carolina and Texas (United States), Tokio (Japan) and Glucksburg (Germany) (Záyago-Lau and Foladori, 2010).

Following the initiative to develop research networks and foster industrial clusters in nanotech undertaken by Mexican research centers and universities, there have been the linkage with foreign and national firms as Cementos de Chihuahua, Peñoles, Delphi, Lexmark, Mabe and Cydsa and other firms belonging to industrial parks or clusters. Several of these cases are launched under the joint agreements, mostly, with American institutions and in some cases with the public funds.

Among the projects to build industrial parks or clusters profiting of the nanotechnology knowledge generated at the universities or research centers are:

i) The Silicon Border Development Science Park (SBDSP) located in Mexicali, Baja California, specialized in nanocomponents in order to supply the semiconductors industry chain and other industry of high technology. The financial support is coming from federal Mexican government, state of Baja California and California US State.
ii) High technology park of Huejotzingo, located in Puebla. The measures planned by government include profiting of the nanotech knowledge produce by the INAOE and INN for the medical and automotive industries (García, 2007).
iii) Innovation and Transfer Center, project to be placed in Puebla with the support of ITESM of Puebla looking for fostering innovation to improve the regional industrial competitiveness (CIT-ITEMS, cited by Záyago-Lau and Foladori, 2010).
iv) Technological Research and Innovation Park (PIIT-Parque de Investigación e Innovación Tecnológica), knowledge city project in course since 2005 in Nuevo Leon state with the collaboration of the UANL and the laboratory of nanotechnology and nanosciences of the Engineering and Technology R&D and Innovation Center, likewise other CONACYT research centers (CIMAV), the ITESM, the UAEM and the IPN. The PIIT aims to create a high technology firms incubator, including a software cluster and firms as Sigma, Pepsico and Motorola.
v) The Paso el Norte MEMS/NEMS Packaging Cluster aims to build an industrial park between Alburqueque, Nuevo Mexico and Chihuahua city. The R&D activities on nanotech are focused to military activities with the support of Sandia military laboratories and FUMEC and the activities are those contributing to the development and competitiveness of the frontier business.

## 6. Conclusions

Nanotechnologies will have a huge impact on production process and therefore on economic and social development. They have became a scientific and technological paradigm and it is predicted to become the next technological revolution. Its difussion is noticed by the growing nano products and nano components diversity. The most industrialized countries have been involved in funding R&D nanotechnologies without precedent. Therefore nanotechnologies are rapidly making progress on new scientifi and technological knowledge, registered in articles and patents.

Nanomaterials linked to on chemical and nano electronic are one of the four fields of nanotechnology that has been dynamic. It is predicted that in electronics and specially in semiconductors, the progress in nanotechnology will give enormous benefits to corporates by increasing the efficiency and quality of this sector.

In nanomaterials field, the research on hafnium oxide as a new material for semiconductor and electronic sector has been placed at the frontier state of art. We have found that only few countries have developed innovation capabilities in this emerging technology associated to an important effort of government, firms and research institutions, including universities on R&D spending. United States stands out as an innovation leader in hafnium nanomaterials field, with their firms and research institutions at the head of patenting. France, Germany and Korea are distant followers. Nevertheless, among the community of inventors in the United States there is an interesting mobility and even if the inventors nationality is mostly American, several of them come from other countries by identifying their names. It is remarkable the number of inventors of Chinese origin. The flows of knowledge are significant in the United States taking into account patent citation.

Mexico is characterized by a disarticulated national innovation in the nanotech system with still low 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 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 to 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.

## Policy implications

By identifying the relative scientific strength of some university research teams on the innovation of nanomaterials field applied to the ICT 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 ($HfO_2$) stands out as an important technological opportunity, which could improve efficiency, stability and manufacturing costs in the ICT sector.

## References

Abricht, L., H. Freikamp and U. Schumann (2006), "Identification for skill needs in nanotechnology", *Cedrofop Panorama Series: 120*, Luxemburgo, Office for Official Publications of the European Communities.

Alvarez, Fregoso O., J. G. Mendoza Alvarez and F. Sanchez Sinencio (2009), "The growth and structure of Cd0.95Fe0.05Te thin films grown by radio frequency sputtering", *Journal of Applied Physics*, vol. 64, no. 8.

Aguirre-Tostado, F. S., D. Layton, A. Herrera (2007), "X-ray photoelectron spectroscopy study of the oxidation of Hf Se passivated Si (001)", *Journal of Applied Physics*, no. 102.

Arora, A. and A. Gambardella (1990), "Complementarity and External Linkages: The Strategies of the Large Firms in Biotechnology", *Journal of Industrial Economics*, vol. 38, no. 4, 361-379.

Choi, J.H., Y. Mao and J. P. Chang (2011), "Development of hafnium based high-k materials-A review" Materials Science and Engineering: R: Reports, vol. 72, no. 6. Publisher: Elsevier, 97-136.

Cohen, W. M. and D. A. Levinthal (1990), "Absorptive Capacity: A New Perspective on Learning and Innovation". *Administrative Science Quarterly*, vol. 34, no. 1, 128-152.

EOPUS (2009), Executive Office of the President of United States, "National Nanotechnology Initiative FY 2009 & Highlights", <http://www.nano.gov/NNI_FY09_budget_summary.pdf>.

ETC Group (2005), *Potenciales repercusiones de las nanotecnologías en los mercados de productos básicos: consecuencias para los países en desarrollo dependientes de productos básicos*. <http://www.etcgroup.org>, 75 pp.

Etzkowitz H. and L. Leydesdorff (2000), "The Dynamics of Innovation: From National Systems and 'Mode 2' to a Triple Helix of University-Industry-Government Relations", *Research Policy*, vol. 29, no. 2, 109-123.

Etzkowitz, H. (2002), "The Triple Helix of University-Industry-Government, Implications for Policy and Evaluation", *Science Policy Institute*, Working paper, 17 pp.

Foray, D. (2006), *The Economics of Knowledge*, Cambridge: MIT Press, 287 pp.

Freeman, C. (1987), *Technology Policy and Economic Performance: Lessons from Japan*, London: Pinter Publishers.

Gibbons, M., C. Limoges, H. Nowotny, S. Schwartzman, P. Scott, and M. Trow (1994), *The new production of knowledge: the dynamics of science and research in contemporary societies*, London: Sage.

Kaiser, U. (2002), An Empirical Test of Models Explaining Research Expenditures and Research Cooperation, *International Journal of Industrial Organization*, vol. 20, no. 6, 747-774.

Kamien, M. and I., Zang (2000), "Meet me halfway: research joint ventures and absorptive capacity", *International Journal of Industrial Organization*, vol. 18, no. 7, 995-1012.

Keita, I., O. Wataru, E. Keisuke, G. Yasuhito and T. Hiroshi (2011), "Development of a vacuum transistor using hafnium nitride field emitter arrays", *Journal of Vacuum Science and Technology B: Microelectronics and Nanometer Structures*, vol. 29, no. 2, March. <http://ieeexplore.ieee.org/xpl/RecentIssue.jsp?punumber=4915583>.

Juma, C. and L. Yee-Cheong (Coords.) (2005), *Innovation: Applying Knowledge in Development*, United Nations Millennium Project <http://www.unmillenniumproject.org/reports/index.htm>.

Intel, Corp. (2010), "Hafnium-based Intel® 45nm Process Technology", <www.intel.com/technology/45nm/index.htm>.

Lundvall, B.A. (Ed.) (1992), *National Systems of Innovation*, London, Pinter Publishers.

Miyasaki, K. and N. Islam (2007), "Nanotechnology systems of innovation- An analysis of industrial and academia research activities", *Technovation*, vol. 27, no. 11, Publisher: Elsevier, 661-675

Mowery, D., R. Nelson, B. Sampat and A. Ziedonis (2004), *Ivory Tower and Industrial Innovation. University-Industry Technology Transfer Before and After the Bayh-Dole*, Stanford California, Stanford University Press.

Nelson, Richard (Ed.) (1993), *National Innovation Systems: A Comparative Study*, New York: Oxford University Press, New York.

Palmberg, C., H. Dernis and C. Miguet (2009), *Nanotechnology: an overview based on indicators and statistics*, Paris, OCDE.

Sábato, J. (1975), *El pensamiento latinoamericano en la problemática ciencia-tecnología-desarrollo-dependencia*, Buenos Aires: Ed. Paidós.

Silberglitt, R. S., P. S. Anton (2006), "The Global Technology Revolution 2020", RAND Corporation, Security Research Division, U.S.A.

Sparks, C. M., P. Lysaght and T. Rhoad (2005), "Measurement of the silicon dioxide concentration in hafnium silicate gate dielectrics with a TXRF", *International Centre for Diffraction Data, Advances in X-ray Analysis*, vol. 48 (290).

Stéphane, D. (2011), "New Hafnium Precursors for High-K Dialectrics Molecular Hafnium Precursors for Metal Oxide Thin Fils in CMOS Architectures", FRINNOV Technologies Portafolio, CNRS Ref. 01947-01 <http://www.fist.fr/index.php?option=com_content&task=view&lang=&id=453>.

Veugelers, R. and B. Cassiman (2005), "R&D cooperation between firms and universities. Some empirical evidence from Belgian manufacturing", *International Journal of Industrial Organization*, vol. 23, no. 5-6, 355-379.

The World Nanotechnology Market (2006), www.nanoinf.jo/whitepaper/wp143.pdf.

Záyago-Lau, E. and G. Foladori (2010), "La nanotecnología en México: un desarrollo incierto", *Economía, Sociedad y Territorio*, vol. 10, no. 32, Jan-April: 143-178.