CLEAN ROOMS AND THE PRODUCTIVE SECTORS THAT USE THEM IN MEXICO

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ABSTRACT

This paper introduces the basic concepts about cleanrooms (sometimes spelled as clean rooms); it encompasses its definition, classification according to (NOM) national and (ISO) international regulation, which regulates anything from classification of air quality, all the way to the classification by nanoparticle concentration, among others; besides identifying the existing kinds of cleanrooms, and the application in the various industries that use them throughout the world, with special emphasis on the micro electromechanical system (MEMS) labs, that exist in Mexico.

The main aim is to understand the current landscape in Mexico about the use of cleanrooms in the different industries; to achieve this, a review of international documentary information was carried out from government and academic instances, regulatory agencies; companies that develop cleanrooms; as well as scientific magazines. The research method used on this paper was the descriptive research method, with the purpose of answering the question about the benefits from the manufacture of MEMS in Mexico that make use of cleanrooms.

The literature review allowed for greater knowledge about the use of cleanrooms in Mexico for the manufacture of MEMS; This in turn, allows for the reflection of the current technological breakthroughs, the national and international norms and standards that govern their design and operation, as well as future research with regards to cleanrooms for the manufacture of MEMS.

KEYWORDS: *Cleanrooms, MEMS, ISO14644-1, Industries, Mexico*

INTRODUCTION

The advancement of science in different sectors such as health, engineering, systems and technology, have been important for scientific development, but on this occasion, the focus is on advances in micro and nanotechnology. To this end, the topic of clean rooms is presented, which have played an important role for more than half a century, because they have encouraged study, research and development at a micro and nano level in all these areas.

Being one of the most important instruments in laboratories, hearing about the existence of a clean room becomes increasingly common, it is considered one of the essential

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tools in scientific research, because it contains many benefits in the development and evolution of results.

According to(Naughton, 2019), the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), mentions that "the application of clean rooms has become a common method to control pollution and improve the environment for people, equipment and materials" On the other hand, the International Organization for Standardization(ISO, 2015), states that "contamination control can be beneficial for protecting the integrity of products or processes in applications in industries such as aerospace, microelectronics, pharmaceuticals, medical devices, healthcare, and food."

This topic is addressed in a deeper way, focusing on the application and techniques applied in their use, the advancement of these instruments for the development of projects of any kind, thus highlighting their benefits within some research centers. and laboratories in country.

MATERIAL AND METHODS

The main reason why the descriptive method was chosen is to answer the question about the benefits of MEMS manufacturing in Mexico with the use of clean rooms, which is why several international and national standardization standards were compiled, as well as as background and relevant data provided by clean room development companies.

Likewise, use is made of the descriptive powers of the information, some uses of similes and cause-effect explanations, which allow explaining the phenomena of the objective of this document. It is supported by techniques such as observation, opinions, records and sociometry.

Finally, the tools of inductive explanation are used, starting from the particular to the general, based on the collection of data to create new theories and give way to future research.

RESULTS

1. DEFINITION OF CLEAN ROOMS

The US federal standard (now obsolete) defines them as a room in which the concentration of particles in the air is controlled to specific limits.(IEST, 2001).

The British standard BS 5295 defines them as a room with particle contamination control, designed and used in such a way as to minimize the introduction, generation and retention of particles inside the room, and in which the temperature, humidity, patterns Airflow, air movement and pressure are controlled(Airplan, 2021).

Although the two previous definitions were the most accepted, they were local application standards (the US FS 209E and the UK standard 5295), which is why the ISO 14644-1 clean room protocol was introduced. the International Organization for Standardization, which is the globally accepted classification to designate levels of cleanliness in these areas.

Therefore, the(ISO, 2015)defines clean rooms as a room in which the concentration of particles in the air is controlled, and which is prepared and used in a way that minimizes the introduction, generation and retention of particles inside the room and in which other particles and relevant parameters, such as temperature, humidity and pressure are controlled as necessary.

2. MAIN CHARACTERISTICS OF CLEAN ROOMS

According to the magazine(Cleanroom Industry, 2019), a clean room limits the risk of contaminants. These include dust, chemical vapors, microbes, and other airborne impurities; Temperature and humidity are also controlled. Clean rooms protect equipment that is susceptible to airborne particles. Contaminants could even destroy equipment such as nanotechnologies, pharmaceuticals, semiconductors, electrical and medical equipment, among others. When clean rooms implement appropriate standards, an effective and safe work environment is created.

The clean room development company(Airplan, 2021), summarizes some of the characteristics of clean rooms in the following points:

- The air that enters the laboratory is filtered to eliminate suspended particles and microorganisms, and is completely renewed so as not to accumulate dust.
- Clean rooms keep the air free of particles through high-efficiency particulate air (HEPA) filters that trap particles 0.3 microns and larger. All air entering clean rooms passes through HEPA filters, and when strict cleaning performance is necessary, ultra-low particulate air (ULPA) filters are used.
- The pressure in the clean rooms is slightly higher than that outside, to prevent outside air (contaminated with microorganisms) from entering when the doors are opened.
- The airlocks maintain pressure differences between the rooms and isolate them from the outside.
- The goal is always for filtered air to flow from the cleanest spaces to the least clean ones. In multi-chamber clean room, the cleanest room will have the highest pressure. Pressure levels between rooms are set so that cleaner air flows into spaces with less clean air.
- Two controlled environment rooms with the same classification may require development with totally different technologies and construction materials, depending on their dimensions, scope of application, flows, workload, etc.

3. BACKGROUND OF CLEAN ROOMS
    a. BACKGROUND

Although the foundations of clean rooms date back more than 150 years to the beginnings of bacteria control in hospitals, the clean room itself is a relatively modern development. The need for a clean environment for industrial production during the 1950s was what led to today's clean rooms.

As the magazine puts it(Cleanroom Industry, 2013), Louis Pasteur, a French chemist, discovered the importance of the relationship between the smallest particles, known as microorganisms, and the effects they had on people, food, and disease. He discovered that bacteria were responsible for souring beverages such as milk, wine and beer. Pasteur discovered that boiling water and excluding air stopped decomposition in meat.

The first instances of clean rooms can be found in operating rooms within hospitals. British surgeon Joseph Lister, a pioneer of antiseptic surgery, was the first to support the idea of sterile surgery. After studying Pasteur's work, Lister discovered that using carbolic acid on wounds produced antiseptic results and in 1867, he began using it in surgery. Lister saw the positive results and began using carbolic acid to clean his surgical instruments and to wash his hands. He found that taking these measures reduced infection and eliminated bacteria. This was the first time a conscious effort was made to control an environment. Lister later incorporated antiseptic sprays into his surgical practices, but this did not control airborne contaminants.

(Fernandez, 2020)comments that the turning point in the history of clean rooms was the invention of the first “laminar flow” or true unidirectional ventilation concept in 1960-

1961 by physicist Willis Whitfield at Sandía Laboratories in Albuquerque, New Mexico, while working for the US Atomic Energy Commission (AEC). This was thanks to the fact that the three main problems presented by the clean rooms of the time were attacked: first, that they did not have the self-cleaning capacity to counteract the contamination that the staff brought to the room; second, that the airflow patterns were not uniform or directed in a way to remove particles from critical work areas; and third, that because personnel in a conventional clean room contributed largely to room contamination, strict personnel controls were required. The success of the laminar flow cleanroom quickly spread to other military and space agencies and contractors.

(Naughton, 2019)concludes about clean rooms today, that HVAC designs have undergone changes since Whitfield's first "laminar flow" clean room, but its main idea of self-cleaning clean rooms has remained the same. One-way cleanrooms still rely on vertical or horizontal air movement. Industries such as semiconductors and microelectronics created multi-level vertical one-way clean rooms to accommodate their complex process requirements. The spread of cleanroom applications led to the creation of industries focused on the design and manufacturing of cleanrooms and their components.

In this figure (Bouie, 2011) you can roughly see the different scientific and technological advances of the last decades at the end of the millennium.

b. TIMELINE OF INTERNATIONAL STANDARDS

Year	International Standard
1960s	• US Air Force T0 00-25-203 • US-MIL-STD-1246 • US Federal Standard 2019 • US Federal Standard 209A
1970s	• Federal Standard 209B • Australian Standard AS 1386 • British Standard BS 5295 • Japanese Standard JIS B 9920 • French Standard AFNOR 44101 • German VDI Standard 2083:3 • Dutch Standard VCCN 1
1980s	• US Federal Standard 209C • US Federal Standard 209D
1990s	• US Federal Standard 209E • ISO 14644-1 (1999) • ISO 14644-2 (1999)
2000s	• ISO 14644-3 • ISO 14644-4 • ISO 14644-5 • ISO 14644-6 • ISO 14644-7 • ISO 14644-8 • ISO 14644-9
2010s	• ISO 14644-1 (2015) • ISO 14644-2 (2015) • ISO 14644-10 • ISO 14644-11 • ISO 14644-12 • ISO 14644-13 • ISO 14644-14 • ISO 14644-15 • ISO 14644-16 • ISO 14644-17

(Naughton, 2019)

c. ISO 14644

As mentioned above, ISO 14644 is the most accepted international standard worldwide; Furthermore, this standard not only defines clean rooms, but also regulates other important aspects of them through several parts into which it is divided.

Part 1: Classification of air cleanliness; part 2: Specifications for testing; part 3: Test methods; part 4: Design, construction and commissioning; part 5: Operation; part 6: Terminology; part 7: Separation devices; part 8: Molecular air pollution; part 9: Classification of surface cleaning; part 10: Chemical contamination (surfaces); and part 12: Classification by concentration of nano particles(ISO, 2015).

d. NATIONAL STANDARDS (NOM)

In Mexico there are three national regulations that regulate certain aspects regarding clean rooms:

NOM-059-SSA1-2015 published in the(DOF, 2016), is the Official Mexican Standard, responsible for regulating good manufacturing practices (GMP) of medicines. Its objective is to establish the minimum requirements and specifications such as temperature, humidity and air quality among others, which must be met for the manufacture of medicines in our country. Its field of application is mandatory compliance for all establishments dedicated to the manufacture and/or import of medicines for human use marketed in the country and/or for research purposes, as well as quality control laboratories, packaging warehouses, storage and distribution of medicines and raw materials for their production.

Appendix A of NOM-059-SSA1-2015 indicates the minimum required degree of air quality that is needed according to the type of product to be manufactured. The type of clothing required to enter each type of area, which is another important factor that can affect the quality of the product that NOM-059-SSA1-2015 describes and regulates in subindexes 7.6.4 to 7.6.7.

NOM-241-SSA1-2012, published in the(DOF, 2012), is the Official Mexican Standard in charge of good manufacturing practices for establishments dedicated to the manufacture of medical devices. This standard establishes the requirements that the processes must meet, from the design of the facility, development, obtaining, preparation, mixing, production, assembly, handling, packaging, conditioning, stability, analysis, control, storage and distribution of commercialized medical devices. in the country, by the type of input in question; and its objective is to ensure that they consistently meet the quality and functionality requirements to be used by the final consumer or patient.

It also regulates the design and construction of an establishment dedicated to the production, packaging, and storage of medical devices. For example, it mentions that the area where aseptic filling and/or sterility tests are carried out must be classified as ISO-Class 5; Areas adjacent to areas where aseptic filling and/or sterility testing are performed must comply at least with ISO-Class 7; Medical device production, assembly and/or packaging processes in which environmental conditions may have an adverse effect on product quality must comply at least with ISO-Class 9.

Finally, NOM-249-SSA1-2010 published in the(DOF, 2010)It is the Official Mexican Standard in charge of sterile mixtures: nutritional and medicinal, and facilities for their preparation. This standard establishes the minimum requirements necessary for the preparation and dispensing of sterile mixtures: nutritional and medicinal, by medical prescription to use or administer quality mixtures to patients, as well as the minimum necessary requirements that must be met by all establishments dedicated to their preparation. and dispensing, for example, the air quality in clean rooms and dressing rooms must be evaluated by qualified personnel so that they meet quality requirements every 6 months and whenever there are modifications.

4. CLASSIFICATION OF CLEAN ROOMS

a. FOR AIR QUALITY (INTERNATIONAL STANDARDS)

The Center for Nanoscale Science and Engineering(CENSE, 2021)of the College of Engineering of the United Kingdom shows in the following table, the classification of clean rooms according to the maximum particles in the air per cubic meter; In addition, it shows a comparison between the ISO 14644 standards and the American federal standard 209E, and with this you can see the differences that exist between the previous standards and the current ones, since today the demands on air cleanliness are greater.

ISO 14644-1 Cuartos Limpios Estándar							
Clasificación	Máximo de partículas / m^3						Equivalente FED STD 209E
	≥0.1µm	≥0.2µm	≥0.3µm	≥0.5µm	≥1µm	≥5µm	
ISO 1	10	2.37	1.02	0.35	0.083	0.0029	
ISO 2	100	23.7	10.2	3.5	0.83	0.029	
ISO 3	1,000	237	102	35	8.3	0.029	**Clase 1**
ISO 4	10,000	2,370	1,020	352	83	2.9	**Clase 10**
ISO 5	100,000	23,700	10,200	3,520	832	29	**Clase 100**
ISO 6	1.0×10^6	237,000	102,000	35,200	8,320	293	**Clase 1,000**
ISO 7	1.0×10^7	2.37×10^6	1,020,000	352,000	83,200	2,930	**Clase 10,000**
ISO 8	1.0×10^8	2.37×10^7	1.02×10^7	3,520,000	832,000	29,300	**Clase 100,000**
ISO 9	1.0×10^9	2.37×10^8	1.02×10^8	35,200,000	8,320,000	293,000	**Aire de la habitación**

(CENSE, 2021)

i. BY THE TYPE OF AIR FLOW USED

The air flow determines the direction in which the air moves within an enclosure. Depending on the application, this flow can be configured as unidirectional or laminar air flow or non-directional or turbulent air flow.(ABACO, 2021).

Clean rooms must meet certain parameters that ensure the control of particles within them. To do this, elements such as temperature, humidity, pressure, outside air, lighting, microbiological control and filters are considered. Within these, there are four types of clean rooms(AEN, 2021):

Conventional

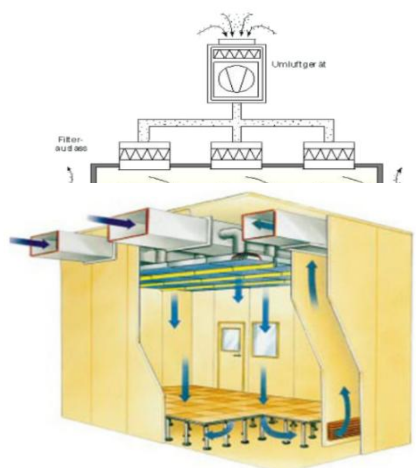
This type of clean room is also known as turbulently ventilated and is characterized by the way the supply air enters through diffusers or filters installed in the suspended ceiling.

Unidirectional Flow

Also known as laminar flow, where clean supply air passes through a bank of high-efficiency filters, unidirectionally through the room.

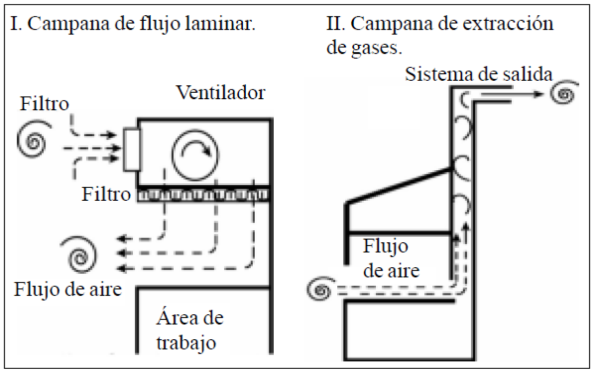
Mixed Flow

This type of clean room is ventilated in a conventional way with the exception of areas where the product is exposed to contamination; In this case, booths with unidirectional flow are used.



Microenvironment

They are used within a clean room to ensure maximum protection against contamination through turbulent airflow (non-unidirectional) and laminar airflow (unidirectional).



In critical work areas for the manufacture of microcircuits, there must be laminar flow hoods within the clean room to give it even greater care than the room itself where it is located and prevent the performance of the device from being affected.(Pedroza, 2012).

b. BY THE INDUSTRIES THAT USE THEM

The Mexican company that develops clean rooms(AEN, 2021), classifies them according to the international standard ISO 14644 and the American federal standard 209E as follows:

- Integrated circuits and sub-micron geometries (ISO 3 = FED STD 209E = 1).
- Semiconductor producers that create integrated circuits with line widths less than 2 microns (ISO 4 = FED STD 209E = 10).
- Manufacture of injectable medicines produced aseptically (ISO 5 = FED STD 209E = 100).
- Manufacture of high quality optical equipment, precision assembly and testing of gyroscopes and miniature bearing assembly (ISO 6 = FED STD 209E = 1,000).
- Assembly of hydraulic or pneumatic equipment, servo-control valves, timing devices and high-grade gears (ISO 7 = FED STD 209E = 10,000).
- General optics work, electronic component assembly and hydraulic and pneumatic assembly (ISO 8 = FED STD 209E = 100,000).

5. CLEAN ROOMS IN INDUSTRIES AT THE INTERNATIONAL LEVEL

According to the clean room development company(Airplan, 2021), clean rooms are used in virtually all industries where small particles can negatively affect the manufacturing process. We find clean or controlled environment rooms in the following industries:

- Electronic industry: Computers, televisions, etc.
- Semiconductor industry: Production of integrated circuits, etc.
- Micromechanical industry: Gyroscopes, etc.
- Optical industry: Laser equipment, lenses, etc.
- Chemical industry: Production of raw materials for the pharmaceutical industry, etc.
- Pharmaceutical industry: Research and development, production, etc.
- Medical equipment industry: Heart valves, by-pass systems, etc.
- Food industry: Processed food and drink, beverage production, etc.
- Hospitals and clinics: Therapies for immunocompromised patients, operating rooms, etc.

Likewise, the company that develops clean rooms(LWS, 2021), mentions the following categories: The automotive industry, aerospace, military, research, solar energy, cosmetics and perfumes, life sciences, among others.

Finally, the Italian company that develops clean rooms(Delta-2000, 2021), concludes that, in all these industries, clean rooms pursue high air purity, the difference between one application or another lies in whether you want to protect the product, the operator, the environment or combinations of them. For example, in the electronics, semiconductor and optical industries, protection of the product against interfering particles is usually sought, while in the pharmaceutical and chemical industries, the product, but also the operator and the environment must be protected.

6. CURRENT PANORAMA OF CLEAN ROOMS IN MEXICO

With data taken from the latest report of(360iResearch, 2021), in 2020 the size of the clean room technologies market in Mexico was valued at $164.66 million dollars, and is forecast to reach $172.34 million dollars in 2021, with an annual growth of 7.18% and thus reach $249.69 million by 2026 .

In terms of market segmentation and coverage, the clean room technologies market study was studied by rigid structure clean rooms, dry closets, soft structure clean rooms, and standard clean rooms. This last segment had the largest market size in 2020, followed by the soft structure segment. On the other hand, soft-structured clean rooms are expected to have the highest annual growth rate over the next 5 years, followed by dry closets.

Based on product type, the market is divided into consumer goods, controls, and equipment. Within consumer goods are cleaning and safety goods. Within the equipment segment are air diffusers and showers, fan filter units, HEPA filters, HVAC systems, and laminar air flow systems and biosafety cabinets. The largest market size was occupied by the consumer goods segment in 2020, followed by equipment. Likewise, the consumer goods segment is expected to have the highest annual growth for the next 5 years, followed by controls.

Finally, based on the end user, the market study was carried out through the biotechnology industry, hospitals, medical equipment manufacturers, and the pharmaceutical industry. Hospitals had the largest market segment in 2020, followed by the pharmaceutical industry. Likewise, hospitals are expected to have the highest annual growth over the next 5 years, followed by medical equipment manufacturers.

7. MICRO ELECTROMECHANICAL DEVICES (MEMS)

a. DEFINITION

MEMS are better known as micrometric-scale mechanical elements that interact with physical or chemical phenomena that, through the transduction of electrical signals, relate the behavior of the device with the phenomena to which it is exposed.(Ramos, 2016)

Other authors also define it as miniature embedded and specialized systems that involve one or more components or micro-machined structures that act as sensors or actuators to enable functions at a higher level within the structure of a more complex system.

b. CHARACTERISTICS

It is understood as a system made up of microstructures, microsensors, microelectronics and micro actuators that work together. In particular, MEMS design and technology fundamentally offer the benefits of scaling across physical domains beyond the electrical domain, to include the mechanical, chemical, and biological domains.

Within which different categories emerge, such as: Sensors, Actuators, Radiofrequency, Optical, micro fluids and bio. The nature of the microsystem can be electrical, magnetic, optical, thermal, mechanical or fluidic. The microsystem architecture incorporates electronic and/or optical circuits, signal generators and receivers, microsensors, micro actuators and micro generators.(Marquez, 2006).

The following benefits stand out:

- Faster speed.
- Less energy consumption.
- Greater functional complexity, through integrated circuits through links.

Likewise, the most basic functions of MEMS are shared:

- Detection of parameters that include inertial variables.
- Control of physical variables.
- Generation and/or delivery of useful physical quantities.

c. CLEAN ROOMS IN MEMS LABORATORIES IN MEXICO

The Mexico Clean Rooms Network(RCLM, 2021), is a group of research centers and universities in Mexico with clean room capabilities for the manufacturing of Micro devices. They define clean rooms as laboratories specialized in the manufacturing of "micrometric and nanometric" devices and systems normally used in the semiconductor industry for the creation of integrated circuits. Its objective is to make the scientific and technological community aware of the clean room capabilities that exist in Mexico for the use of infrastructure and development of high technological impact projects. The Network is made up of Institutions that include 4 CONACYT centers (CIDESI, INAOE, CIO and CIDETEQ), 4 of the largest Public Universities in Mexico (IPN, UNAM, BUAP and UACJ) and 3 National Laboratories (SEDEAM, LaNNaFab and LABMyN) .

i. CONACYT CENTERS

1. CIDESI

The Center for Engineering and Industrial Development(CIDESI, 2021), was founded on March 9, 1984; It belongs to the System of Centers of the National Council of Science and Technology, CONACYT; contributes to the development of the country's productive sector, through Research and Innovation projects, as well as high-level specialized technological services, in its facilities located in the States of Querétaro, Nuevo León, within the Research and Technological Innovation Park and in the state of Mexico.

The Microtechnologies Directorate is made up of a body of technologists leading the research, development and operation of its laboratories. Likewise, the Directorate relies on the extensive network of scientific collaboration that includes the main universities, research centers and national laboratories in Mexico and abroad. Its development areas are: development of base sensors, emerging sensors and application sensors; development of MEMS microelectromechanical devices; integrated circuits based on crystalline silicon and polysilicon MOS technology; physical layout design for standard semiconductor technologies; materials deposition and characterization services for the semiconductor industry.

2. CIO

The Optical Research Center(CIO, 2021), develops basic and applied research that contributes to the generation of knowledge and innovation in the field of optics and photonics, strengthening the country's technological leadership and promoting the formation of new knowledge-based companies. It offers the best postgraduate program in optics and photonics and contributes to the development of a scientific and technological culture.

The CIO has 41 laboratories: optical sensors and microdevices; of biophotonic devices; photonic device manufacturing; perception and robotics; nonlinear optics and photophysics; non-destructive optical testing; materials characterization; biophotonics; photonic conversion into optical fibers; quantum photonics; UV grating engraving station; optical and mechanical tests; of lasers; spectroscopy; holography; to name a few.

3. INAOE

The National Institute of Astrophysics, Optics and Electronics(INAOE, 2021), was created by presidential decree on November 11, 1971 as a decentralized organization, of public interest, with legal personality and its own assets, located in Tonantzintla, Puebla, to prepare researchers, specialized professors, experts and technicians in astrophysics, optics and electronics ; seek the solution of scientific and technological problems related to the aforementioned disciplines; and direct its research and teaching activities towards overcoming the conditions and solving the country's problems.

The electronics coordination has several high-tech laboratories, such as high-frequency laboratories, optical communications, cryoelectronics, integrated circuit design, MEMS design, instrumentation, microelectronics, electron microscopy, digital signal processing, and testing and characterization of integrated circuits. In these laboratories, both research projects and student training in the use of specialized software and equipment are developed.

4. CIDETEQ

The Center for Research and Technological Development in Electrochemistry(CIDETEQ, 2021), was created as a public research center in September 1991, with the fundamental purpose of linking researchers with the challenge of responding to the need to link industry with academia and research. The axes of development of CIDETEQ are the training of human resources, promoting collaboration of the industry with the country's productive area and scientific institutions and providing technological services in the automotive, aerospace, water and materials sectors; offering projects, services and solutions based on national and international standards.

The areas they focus on are: water and environment, energy and health; for which they have a chemical analysis laboratory; an automated manufacturing room for reflective surfaces; an electrochemical energy systems laboratory; pilot plants for the production of biofuels; and study areas for reactivity of biological systems; assembly of architectures for the generation of sensors and biosensors; and construction of microfluidic devices for online detection.

5. CIMAV

The Advanced Materials Research Center(CIMAV, 2021), is one of the 27 institutions coordinated by the National Council of Science and Technology, CONACYT. It was created on October 25, 1994 in the city of Chihuahua, Chihuahua, where its headquarters are also located. The institution has two academic units located in Monterrey, Nuevo León, and in Durango, Durango, in addition to a representative office established in Ciudad Juárez, Chihuahua.

It has the following laboratories: mechanical analysis of materials, metallographic analysis and optical microscopy, chemical analysis, thermal analysis, characterization of polymeric materials, RAMAN spectroscopy, spectroscopy and particle size laboratory, atomic force microscopy, scanning electron microscopy, microscopy transmission electronics, polymer processing, x-rays, spray coatings, thin film synthesis, xps, auger and ups; among others.

6. CINVESTAV

The Research and Advanced Studies Center of the IPN Querétaro unit(CINVESTAV, 2021), has the mission of developing multidisciplinary and cutting-edge research and technology in the area of materials science and engineering, which guarantees the training of high-quality human resources and which, with a clear vocation for linking with the productive and social sectors, contributes outstanding way to the development of the country.

It has 28 laboratories: Electrical properties, x-ray diffraction, RAMAN spectroscopy and hall effect, materials and devices for environment and energy, materials chemistry, growth of thin semiconductor films, alternating energies, processing of organic materials, optical properties of films thin films, nanostructured materials and electrochemical characterization, composite materials, polymers and biomaterials, chemical film processing, process simulation and analysis, metallographic sample preparation, metal powders, multifunctional ceramics, LIDTRA (microscopy), nanometric multifunctional properties, thermal transport properties , alternative energies, thin films and coatings, rheology, physicochemical properties, thermal analysis by DSC and elemental analysis by ICP-OES, processing and characterization of nanofilms (LPCN), terahertz optoelectronics, quantum technologies for advanced communications, among others.

ii. UNIVERSITIES

1. Center for Nanosciences and Micro and Nanotechnologies of the National Polytechnic Institute (IPN)

The Center for Nanosciences and Micro and Nanotechnologies(CNMN, 2021), opened its doors to users starting in 2009, providing support services for research, the academic, public, government and industrial sectors; Its objective is to promote research in the areas of nanosciences and micro- and nanotechnologies, supporting the generation of new high-impact scientific knowledge and the transfer of technology to the productive sector and offering to the public, social and private sectors in Mexico and abroad, high-tech instrumentation services for the development of scientific research and technological development projects in the areas of competence of the CNMN.

The micro and nanotechnologies laboratory is designed to house equipment focused on the manufacturing of micro and nano devices, the integration of micro/nano electromechanical (MEMS and NEMS) and biomicro/nano electromechanical devices (bioMEMS and bioNEMS), as well as lab-on -chips, in specialized areas: 3 class 1000 rooms, and 220 m^2 of class 100 clean rooms divided into two areas, which house the equipment for manufacturing micro devices, MEMS, bioMEMS, systems for microfluidics, material storage and flexible electronics .

2. Center for Nanosciences and Nanotechnology of the National Autonomous University of Mexico (UNAM)

The background of the current Center for Nanosciences and Nanotechnology(CNyN, 2021), date back to the creation of the Ensenada Laboratory of the Institute of Physics (LEIF) in 1983 from which the Condensed Matter Sciences Center was created. In August 1998, an extension to the building was inaugurated, adding vital spaces for its development: 23 cubicles, 8 laboratories, library, workshop and dark room.

The CNyN of the UNAM has laboratories for: laser ablation, catalysis, surface spectroscopy, luminescence, atomic force microscopy, nanocharacterization, and high resolution XPS. In addition, it has the following lines of research: multiferroic materials, materials and plasma optics, transition metal sulfides as hydrotreatment catalysts, metal nanoparticles supported in nanostructured matrices for the development of nanocatalytic materials, stabilization of clusters inside zeolites , luminescent materials, chemical analysis of surfaces, and spintronics and electronic transport of nanostructures.

3. Research Center in Applied Science and Technology of the Autonomous University of Ciudad Juárez

The Autonomous University of Ciudad Juárez(UACJ, 2021), was officially established on October 10, 1973, as a result of the integration of the Center for Research in Applied Science and Technology Universidad Femenina, the University of Ciudad de Juárez and the Autonomous University of Ciudad Juárez. In addition, it has a Research Center for Applied Science and Technology (CICTA), which belongs to the consortium called Red MEMS-Mexico. This Network has the general objective of jointly developing technological innovation and transfer projects in this type of technology. Several members of the institutions that make up the Network have been trained in the area of microtechnology during 2003. This training has consisted of participating in several specialization courses on MEMS technologies.

The conception of CICTA was to contribute to the development of science and technology in the region and the country through research activities and development of multidisciplinary projects in micro and nanotechnology; and promote the technological development of the industry through projects associated with the generation of new products, prototypes, and process optimization.

The equipment that CICTA currently uses is special equipment for the encapsulation and characterization of microsystems and equipment for the advanced characterization of materials (scanning electron microscope.)

4. Benemérita Autonomous University of Puebla (BUAP)

The Institute of Physics of the Benemérita Universidad Autónoma de Puebla(IFUAP, 2021), is an academic unit dedicated to conducting research in physics and materials science; to train human resources through teaching and postgraduate courses, preparing high-level researchers and specialists; to promote collaboration with other departments of the university itself, as well as in the country and abroad; and to promote the national and international dissemination of the knowledge generated by the institute. The institute has an important infrastructure of research laboratories and service units for scientific work.

It has the following laboratories: X-ray diffraction; granular materials (GrainsLab); photoelectric and photoluminescent properties of materials; atomic force microscopy; superconductivity and magnetism; surface analysis; physical deposition of thin films; acoustics and optics in structured systems; semiconductor materials for photovoltaic applications; nanomaterials and photovoltaic devices; nanostructures; electrets and semiconductors; nonlinear optics; growth of ferrous materials; crystallographic studies; general chemistry; nanostructures, nanoparticles and nanocomposites; among others.

5. University of Sciences and Arts of Chiapas (UNICACH)

The University of Sciences and Arts of Chiapas(UNICACH, 2021), is an institution recognized nationally and internationally for its commitment to the training of highly competitive professionals and for its contributions to the development of science, technological innovation, art and culture. It has the following laboratories:

Geomatics laboratory, laboratory for the conservation and sustainable management of the plant genetic resources of Chiapas, laboratory of evolutionary ecology and spatial analysis of biodiversity, academic research and environmental services laboratory, plant tissue culture laboratory, multidisciplinary experimental laboratory and vivarium , germplasm bank, environmental education and sustainability laboratory-workshop, aquaculture and fisheries evaluation laboratory, genetics and molecular biology laboratory, plant physiology and chemistry laboratory, evolutionary ecology laboratory, culture and biological conservation laboratory, among others.

6. Autonomous University of the State of Mexico (UAEM)

Formalized as a university under the name of the Autonomous University of the State of Mexico(UAEM, 2021)In 1956, the institution found its beginnings in 1828 with the creation of the Literary Institute of the State of Mexico, in the former state capital of Tlalpan. In 1943, the institution was expanded to become the Scientific and Literary Institute of Toluca (ICLA), and thirteen years later it obtained its current name and institutional status.

The university has a biochemical-clinical analysis laboratory. Providing its services since 1982, it has focused on managing high quality standards that cover current national and international standards, which entails the academic and certification preparation of staff, guaranteeing a reliable and avant-garde service.

7. Veracruzana University (UV)

The Veracruz University(UV, 2021), was founded in 1944 and acquired its autonomy in 1996. It is located in the state of Veracruz located in the Gulf of Mexico. It has five regional headquarters: Xalapa, Veracruz, Orizaba-Córdoba, Poza Rica-Tuxpan and Coatzacoalcos-Minatitlán, with a presence in 27 municipalities. Due to its enrollment, it is among the five largest state public universities of higher education in Mexico.

It has a Micro and Nanotechnology Research Center (MICRONA). It previously began its activities in 2003 as a MEMS Technology Design Center (Microelectromechanical Systems); as a result of a national development strategy headed by the Ministry of Economy. In 2005, the MEMS Design Center expanded its development portfolio towards the design and characterization, not only of MEMS structures, but also of micro and nanotechnology. One of the main objectives pursued by MICRONA is related to the development of Micro and Nanosystems, as well as the provision of services to clients, both regional and national, in the areas of instrumentation, sensing and automation of industrial manufacturing processes; through the design, manufacturing and implementation of Micro and Nanosystems.

iii. NATIONAL LABORATORIES

1. SEDEAM

The Laboratory in Embedded Systems, Advanced Electronic Design and Microsystems(SEDEAM, 2021), is a CONACYT national laboratory focused on advanced electronics, a strategic transversal area for the scientific and technological development of various industrial and academic sectors in the country. It also promotes the generation of technology-based companies (EBT) in Mexico, in addition to meeting the demand of strategic industrial sectors such as: Agroindustry, metalworking, textiles, mining, alternative and renewable energies, automotive, tourism, health and medical devices, food and beverages, and information and communication technologies.

As a national laboratory in embedded systems, advanced electronic design and microsystems, its mission is to drive the economic growth of society.

2. LABMYN

The National Micro and Nano Fluidics Laboratory(LABMYN, 2021), based at the Center for Research and Technological Development in Electrochemistry (CIDETEQ), in conjunction with the Autonomous University of Querétaro (UAQ), the Center for Research in Advanced Materials (CIMAV) and the Center for Research in Applied Chemistry (CIQA) , has been created to form a laboratory with the infrastructure and human capital that allows the development of this line of research at a level of international competitiveness and that promotes the industrial development of this emerging technology.

This laboratory offers services such as: Prospective evaluation, design and simulation of microfluidic chips; manufacturing of SU-8 molds on silicon for soft lithography; deposition of thin metallic layers on the entire surface or with specific designs; deposition of metals by cathodic sputtering (sputtering) and by electron beam evaporation (e-beam); manufacturing microfluidic chips in acrylic (PMMA), PDMS or PDMS/glass; characterization of microfluidic chips by optical and electrochemical techniques; among others.

3. LANNAFAB

The National Nanofabrication Laboratory(LaNNaFab, 2021), based in the Nanofabrication Unit (UNaFab) of the Center for Nanosciences and Nanotechnology (CNyN) of the National Autonomous University of Mexico (UNAM), aims to generate knowledge through scientific research related to the design, manufacturing, characterization and applications of micro and nano devices, as well as training high-level human resources and offering cutting-edge services, in order to satisfy the needs of the public and private sectors.

The main services offered at LaNNaFab are: Training courses in basic device manufacturing processes; advice on the manufacture of devices through photolithography processes; manufacturing of masks for photolithography processes; transfer of micrometric patterns through masks, to materials that allow etching with plasma or some type of acid; manufacturing of micro devices (prototypes) for electronics, optoelectronics and/or integrated optics; among others.

DISCUSSION AND CONCLUSIONS

In Mexico, there are few laboratories that use clean rooms for the manufacture of MEMS; The network of clean rooms is made up of the CONACYT centers, the main universities in the country, as well as the three national laboratories; and although it could be observed that there is a great connection on the part of these agents with academic institutions, government agencies, the productive sector, and other international agents, this is not entirely sufficient to have a greater presence in technological advances and scientific developments; Therefore, more exhaustive research is required to know the scope of each of the laboratories with capacity for MEMS manufacturing in Mexico.

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