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# **Microscopy and Spectroscopy Analysis of MemS Corrosion Used in the Electronics Industry of the Baja California Region, Mexico**

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Additional information is available at the end of the chapter

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## **1. Introduction**

MEMS are very important devices used in the electronic industry of the northwest of Mexico where are located Mexicali as arid zone and Tijuana as marine region. In boths enviroments the humidity and temperature are factors which have influence in the operation of these microcomponents. MEMS are utilized principally in electronic systems as acoustic, audio and video, communication, industrial and medical, as a control and operation activities. In the industrial plants are primordial in the manufacturing process to improve the production yielding, with automatized systems (B.G. Lopez et al, 2007). These microdevices have advantages as a lot operation and, need small spaces in the electronic boards, but microcorrosion appears very easy and quickly in short spaces between electrical connections. At RH levels higher than 80%, an electrochemical process occur in the metallic surfaces of connectors of MEMS, and its arevery difficult detect it, to the naked eye. For this reason MEMS presents deterioration in the electrical connections, and originates electrical failures, and it is not detected until are checked in the last steps of the manufacturing process or when buyers are used, causing economic losses. In base of this, an analyss was made to know the behaviour of corrosion phenomena in the MEMS used in the development of new technologies in the electronics, mechanical and electromechanical systems (Tanner et al, 2000).

## **2. History of MEMS**

MEMS technologies have evolved to develop miniaturize complex systems integrating multiple functions in small or simple packages. In Europe these microsystems are known as MST or "Micro Technology Systems", however the term of MEMS has become increasingly prevalent. Helvajian (Helvajian, 1999) and Vittorio (Vittorio, 2001) are agree that MEMS

manufacturing, emerged with the development of novel semiconductors in the late of XXI century. The first was manufactured semiconductor transistor at Bell Laboratories by Shockley, Bardeen and Brattain in 1947 (Lopez B. G. et al, 2011). This led to an unparalleled development in the technology semiconductors, which subsequently creation of electronic systems increasingly faster, smaller and less expensive manufacturing. However, this same manufacturing process created a vacuum so fast in knowledge of their operations (Hindrichsen t al, 2010). This was because more and smaller circuits were manufactured with process information faster, and the interfaces of these circuits, sensors and actuators, could not easily attached to their functions in their applications. Moreover, in a principle of the manufacture of MEMS not take into account their protection against corrosion. The efficiency of MEMS is a major motivation after development, because these micro devices proved to be more rapid, inexpensive and efficient their macroscopic devices. However the development of such solutions has been envelope by the technological limitations (Plass etal, 2003). The first research in the area of MEMS was oriented to the micro sensors obtained as a result of these investigations: the discovery of piezoelectricity. This feature present in the silicon and germanium, allows the development of micro silicon pressure sensor. According to Vittorio, the sensor silicon pressure was the first of the sensors and micro more successful. Additionally the availability of silicon as the material raw encouraged the development of micro techniques semiconductor whose range has grown to include measurements physical, chemical and biomedical. Table 1 shows a list of some of the most significant findings in the evolution of the MEMS. Among them is in the development of solid state transducers and micro sensors with micro machining techniques, producing micro actuators that can lead to the appearance of the first mechanisms and engines microscopic level (Zawada et al, 2010, Jin, 2002).

<b>Historial development of MEMS</b>	<b>Period, Year</b>
Anisotropic silicon device with attack	Season of 1940
Piezoresistive silicon component	1953
Semiconductor extensometers	1957
Silicon pressure sensors	Season of 1960
Solid state transducers	Season of 1970
Microactuators	Season of 1980
Micro mechanisms and micro motors	From 1987 to 1989
Micro Electromechanical Systems	After 1988

**Table 1.** History of manufacturing process of MEMS

The term MEMS emerged in 1987 as part of a series of workshops held in Salt Lake City, Utah, Hyannis, Massachusetts and in 1988 in Princeton, New Jersey (Pedersen et al, 2007). These workshops were the forerunners in the development and adoption of this technology. MEMS are currently considered as an interdisciplinary field of knowledge that makes use of many areas of science and engineering to solve problems. Helvajian, considers some advantages of MEMS technology on macroscopic aspects that determine its development

today: definition of small geometries, precise dimensional control, design flexibility and low cost and interface The term MEMS emerged in 1987 as part of a series of workshops held in Salt Lake City, Utah, Hyannis, Massachusetts and in 1988 in Princeton, New Jersey (Olson III et al, 2007). These workshops were the forerunners in the development and adoption of this technology. MEMS are currently considered as an interdisciplinary field of knowledge that makes use of many areas of science and engineering to solve problems. Helvajian (1999) considers some advantages of MEMS technology on macroscopic aspects that determine its development today: definition of small geometries, precise dimensional control, design flexibility and low cost, interface with control electronics and easy manufacturing processes (Christian C et al, 2010, Kihira, 2005).

### 3. MEMS in the industry in the northwest of Mexico

Actually the industries need more efficiency in their manufacturing processes using MEMS for the diversity of activities and the small spaces in the electronic boards. In the northwest of Mexico, the majority of the industrial plants manufacture electronic equipments and have a lot electronic systems with MEMS in their production operations (Lopez-Badilla Gustavo et al, 2011). This study has relevance today because it is a developing topic that improves the efficiency of the products. It is important in the society to be applied in various daily activities to ensure the reliability of the products manufactured.

### 4. Fabrication of MEMS

The evolution of MEMS is closely related to advances of semiconductor industry, in many process steps are similar, or identical, and adapted to the requirements (Roger, 2010). The principal features of the MEMS manufacturing processes are:

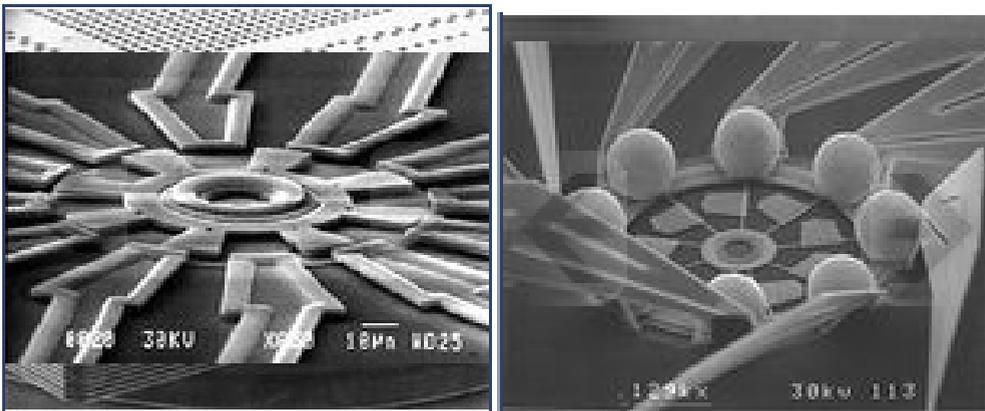
- *Miniaturization.* The reduction in the size to be smaller and lighter with shorter response times.
- *Multiplicity.* The capacity to produce tens, hundreds or even thousands of products in parallel, being inherited characteristic of the semiconductor production processes.
- *Microelectronics.* The intelligence of MEMS which allows control implemented as closed systems with integrated microsensors and microactuators.

These advantages shows the great influence of the manufacturing processes of the electronics integrated circuits. However, it is important to note that not all microdevices have a benefit of miniaturization (Baldwin, 2009). One of the major limitations of the techniques inherit from semiconductor processes, is the works in planar scale, difficult the design of devices in three dimensions (Figure 1).

### 5. MEMS in automatized control systems

An automatized control system (ACS) is equipment which operates with a lot functions to control industrial machines. An ACS is an interconnection of elements related to

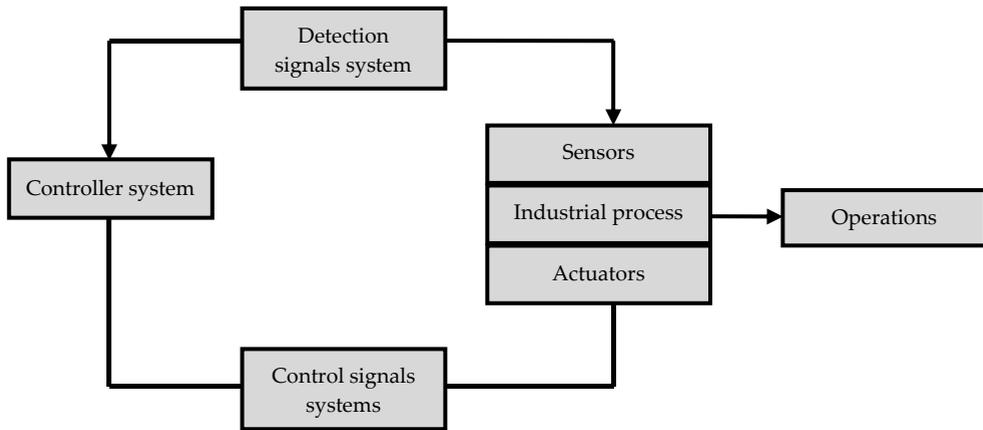
manipulate activities and control the behaviour of other devices which not has control as devices of high power to work for a purpose to control the inputs and outputs of manufacturing processes (Lopez B. G., 2008, Cai, 2005). In ACS are used MEMS to a lot functions to check, adjust and operate with the industrial regulations of each products, with a feedback equipments to regulate the variations of the output which are signal of the inputs of the activities. An ACS may be open or closed depending on if it makes a feedback system, using the same system output as input to make decisions based on past states of the system. For example, an open system may be one that receives the amount of light of the environment and this intensity can be controlled in any object, but uncontrolled of the source (Bateson, 1999). By other way, the closed systems can control which works regulating the effect in the object and the source. It makes the automation as group of technologies that are used in different areas of knowledge as electronic, mechanical and electromechanical machines, controlled by computer systems, for a more autonomous or independent functions. The benefits of this are flexibility, lower cost, higher capacity and quality. An ACS with MEMS is an elemental sensor that performs the function of measuring the manufacturing process, while active an actuator which implements the control action on the industrial operations, and change the behavior of the system according the adequate regulations (Beeby, 2004, Chongchen, 2003). An ACS performs the actions of process control, manipulates the actuators and bases its decision on information received by the sensors. In addition MEMS are used in real life control systems to perform tasks that require powerful output, meaning that it is easier for robust systems. A diagram of control system, below showed that express the importance of sensors and actuators in a control system (Figure 2).



**Figure 1.** Microdiagram of MEMS utilized in industrial operations

The minimized ACS with MEMS in the last twenty years revolutionated the technologies, by the diminute spaces and the great quantity of functions in the microelectronic boards, but its necessary a specific and adequate design to avoid the accumulation of visible and invisible water by the condensation of humidity and the variations of temperature. It originates the corrosion phenomena and deteriorates rapidly the metallic surfaces

principally of copper. This generates electrical failures in the industrial equipments and products manufactured and reduce the productive yielding (Yao, 2000). MEMS for their mechanical properties can receive physical and chemical agents from the environment, which deteriorate thier electrical pins and are complicated, analyze it. Based on this, a study was made to determine the principal physicochemical agents which react with the metals, determine the types of corrosion and propose methods to reduce or avoid the corrosion process (Tuite, 2009).



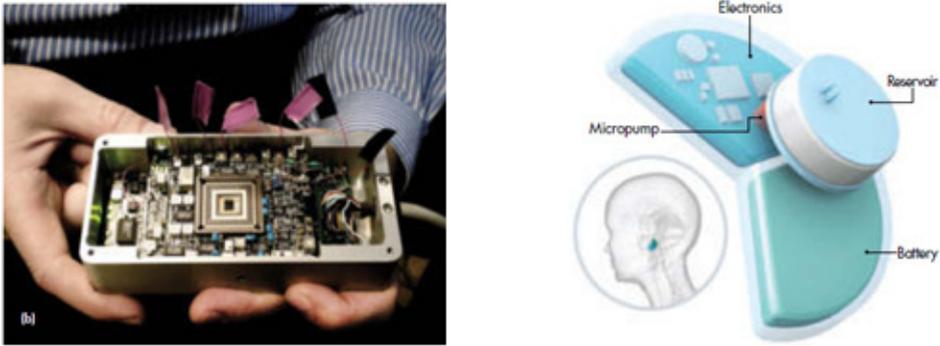
**Figure 2.** Diagram of a control system used in industrial plants in the Baja California, Mexico

## 6. Innovative applications

Many people dont know about MEMS technology that occupe a place in our lives, such as the use of cellular phones, which has a microsystem with MEMS. Other examples is the airbag of cars that have a MEMS equipment, which determine the exact time that a collision occurs and triggers the air bag states (Nise et al, 2004, Stanley, 2006). MEMS are micromachines that will change the world, and are currently used in different activities or areas such as industrial, medical, automotive and related technologies including in the electronics systems. Below is explained a brief description of MEMS in each of the areas being developed (Wojciechowski, 2007, Virmani, 2006).

### 6.1. Medicine

In the medical field, MEMS are implanted in body parts such as the heart, brain and other parts that are difficult to diagnose or study (Roger, 2010), and their implementation are used to prevent diseases like cancer,cardiovascular diseases, lupus and others. Today many companies are developing devices with this technology, for monitoring patients with heart and cancerigen conditions, and also utilized as a prototype chip to test for the presence of substances such as viruses or diseases like flu. Actually are used as microdevices to screen blood, inject drugs or doses of medicine to improve the heath of people (Figure 3).

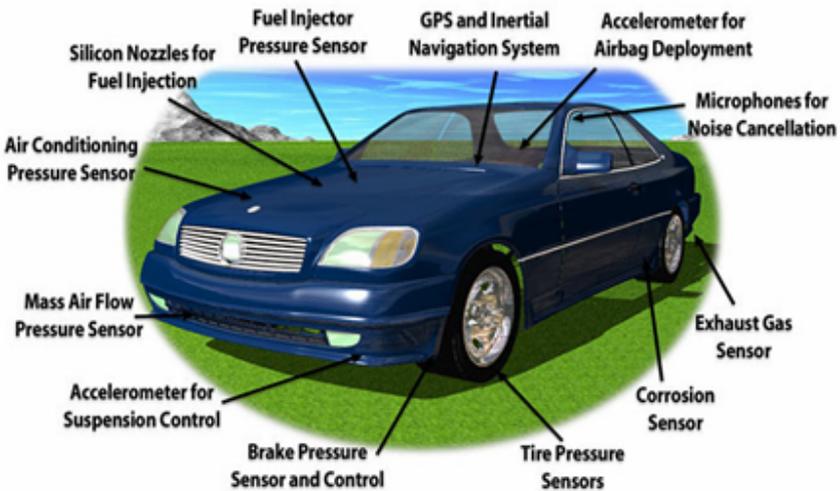


**Figure 3.** MEMS used in the medical applications: (a) microelectronic circuit and (b) micromedical equipment.

### 6.2. Automotive

In the automotive area, the electronic systems with MEMS are an important key to the smart cars with microsensors, with different functions for security in the operations of cars (Figure 4). In the automotive applications, MEMS are used to analyze and respond to a variety of mechanical and electrical actuators (Smart et al, 2007). Successful applications of MEMS are presented in the automotive market as accelerometers bags air and micro-lenses to projectors light of cars and the future applications in tihs area will reduce costs and improve the performance of the devices.

### *Automotive Applications of Microelectromechanical Systems (MEMS)*



**Figure 4.** MEMS used in the automotive applications with lot applications

### 6.3. Industrial

In the industrial area, MEMS generates more efficient heating systems, air conditioners, refrigerators, freezers, principally, to integrate these equipments, being an intelligent system, to monitoring their functions of climatic parameters as humidity, temperature levels, and pollution agents that react with metallic surfaces of systems in the robust industrial machines (Figure 5). The MEMS are used to a great variety of industries, as military (principally to embed in the body to prevent diseases) and aerospace industries (principally to monitore air pressure and vibration process in the fligths (Laurent, 2008).



Figure 5. MEMS used in the industrial operations.

### 6.4. Acoustic

MEMS promises revolutionize products allowing complete systems on a chip, and be an integration of mechanical elements, sensors, actuators, and electronics on a common silicon substrate through microfabrication technology. Using MEMS cell phones have less power consumption, greater flexibility, lower costs and better features. Other application of MEMS is the replacement of electromagnetic condenser microphone for silicon microphones. Motion capture is a vital application for accelerometers (utilized as acceleration sensors for machine interface / human) and gyroscopes (used for image stabilization by the image sensor), applied in air bagas of cars (Tuite, 2009). A more recent use of these systems are applied in the Iphone and Ipod Touch from Apple and game consoles like the Wii (Figure 6).

## 7. MEMS in micro and nano electronic systems

MEMS is the branch of micro electronic systems that operates at low level of electrical signals in any type of activities, where scientifics of this area are working every day to improve thier functions. At this level of scale analyzes with MEMS are very important for

the amount of information that can be obtained, as the eye can not observe. Due to the large surface to volume ratio of the MEMS, surface effects such as electrostatic and viscosity effects dominate such as volume or mass thermal inertia (Van Spengen, 2003, Cole, 2004). The finite element analysis is an important part of the MEMS design. Sensor technology has made significant progress due to MEMS. The complexity and advanced performance of MEMS sensors has evolved with the different generations of MEMS sensors. The potential of very small machines was appreciated long before there was technology that could develop with experiments of scientifics in the electronics area, which were presented as electronic devices with a very little space. MEMS became practical once they could be manufactured using modification of semiconductor manufacturing technologies, normally used in electronics (Maluf et al, 2004). These include molding and plating, wet and dry etching, electro discharge machining and other technologies capable of manufacturing very small devices (Gerhardus, 2006). There are different sizes of companies with strong MEMS programs. Larger companies specialized in the manufacture of components or high volume at low cost, manufacture MEMS to principally of automotive, biomedical, aerospace, communications, and industrial operations. The success of small businesses is to provide value in innovative solutions and absorb the cost of manufacture with high margins of sales. One of biggest problems is the absence of autonomous MEMS with micro power sources of high current density, power and electricity. Advances in the field of semiconductors are resulting three-dimensional integrated circuits with features and even moving parts (Ohring, 2003) (Ohring, 2003) (Ohring, 2003).



**Figure 6.** MEMS used in acoustic systems as cellular phones.

MEMS can solve many problems that a microprocessor with software or configuration as ASIC (Application Specific Integrated Chip) can't develop. MEMS technology can be applied using a number of different materials and manufacturing techniques, depending of the type of device that is being created and the commercial sector which has to operate (Zawada, 2010). Researchers in MEMS use various software engineering tools to their design

with simulation, prototyping and testing operations. The finite element analysis is an important part in the design of MEMS. Dynamic simulation of heat and electricity, mechanical properties can be performed by specialized softwares as ANSYS and COMSOL. Other software, such as MEMS-PRO, is used to produce a composition suitable design for be easy processes of manufacturing of electronic devices with MEMS (Figure 7) used in industrial plants. After the process of software activities, the prototypes are ready to be tested by the researchers using various tools, as scanning laser Doppler vibrometers, microscopes, and strobes (Tuite, 2009).

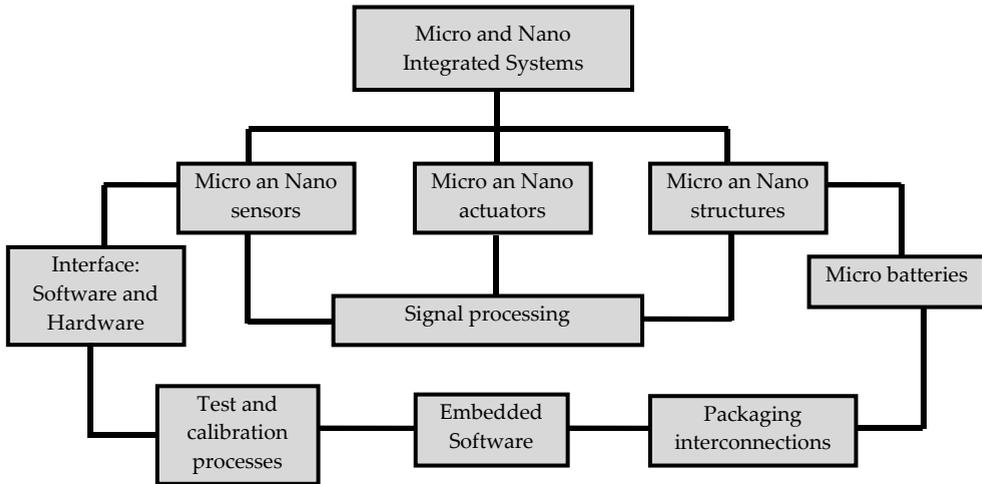


Figure 7. MEMS used in acoustic systems as cellular phones.

## 8. Operations of MEMS

The miniaturization of electromechanical machines or MEMS is a reality today. Indeed, these microdevices are already used for the performance of accelerometers, found in airbags in cars to determine the right time when a collision occurs and shoot like the inflation mechanism of the bags. This same type of MEMS is used as navigation elements, particularly in the aerospace industry, but also provides applications such as pressure, temperature and humidity (Lope-Badilla Gustavo et al, 2011). They have been incorporated into pacemaker to sense the patient's physical activity and change your heart rhythm. To prevent forgery of signatures has been designed to incorporate these accelerometers in pens. Thus, not only be registered owners of the firm stroke but also the velocities and accelerations imparted to the hand to the pen while signing, which would make it much more difficult to counterfeit. Also MEMS are used in heads of ink jet printers, producing the controlled evaporation of the ink at the right moment, thanks to the localized delivery of heat. Besides the advantage of size of these devices is the fact that they can be manufactured by the thousands lowering manufacturing cost significantly (Madou, 2002). MEMS, like any new technology, have had a major impact when it comes to promoting access to new scientific knowledge. This is the case called adaptive optics. The light from astronomical objects coming to ground-based

telescopes necessarily passes through the atmosphere, changing its optical path by changes in air density and temperature. The result is a blurred image with poor angular resolution. To avoid this problem, an expensive solution is to place telescopes in space (such as Hubble). Another interesting and least expensive solution for its ability to use large telescopes, not limited by the dimensions that can be handled in space transport, is what brought the development of mirrors whose surface is deformed by MEMS, correcting distortions produced by the atmosphere land (Tanner et al, 2000). Another scientific application of MEMS was the realization of instruments for measuring forces between two objects whose surfaces are at submicron distances ( $<1\mu\text{m}$ ). One objective was to highlight possible deviations from the law of universal gravitation on the law established by Newton, as predicted by some theoretical models. According to these models, these deviations could be made more evident the smaller the distance between the objects (Vittorio, 2001). The problem is that at short distances are also other interactions, such as that arising from the so-called Casimir effect. This effect, linked to the appearance of an attractive force between conducting objects, whose origin is related to a quantum property (zero-point oscillations), is mainly manifested nanometric distances and depends on the geometry of the objects in question. MEMS have provided the tools to evaluate these forces and corroborate laws and deviations in the range of distances explored so far (Olson III et al, 2007, Lewis, 2004).

## 9. Corrosion in MEMS

From its beginnings MEMS was an emerging technology and is very used actually. The use of MEMS in the electronics industry has contributed to the development of new technologies to improve the microelectronic devices (MED) (Schoedrer A. et al, 2003). In the last decade, has increased its use in MED in any operations. Exposure of MEMS to aggressive environments, decrease its operating yielding (Lopez-Badilla Gustavo et al, 2011) for the presence of corrosion, for the chemical and electrochemical processes. For this reason, scientifics were analyzed new designs and materials to avoid the generation of corrosion. Is necessary the use of specialized packaging in the manufacturing processes for maintain optimal functions (Yao, 2000, L. Veleva, 2008). To technical and manager people, corrosion in MEMS is very concerned factor because its working in harsh or corrosive environments in the packaging processes of MEMS and its functionality in a lot operations (Ashrae, 1999). There are some parameters as variations of humidity and temperature, bad design with small and curve spaces and at the exposition of air pollutants in indoor of industrial plants accelerates the kinetics of the chemical reactions of corrosion process. Sometimes hermetically sealed packages contain drops of water vapour or any aggressive acids, which increase the corrosion rate (CR) and deteriorate very fast the electrical connections of MEMS. The most common packages of MEMS are plastic, and when these are not well sealed, water penetrates very slowly to the internal parts of these microdevices (Wojciechowski, 2007, Abdulaziz, 2003).

## 10. Methods and materials

In the northwest of the Mexico country, in the state of Baja California, are located around 400 electronics industries in Mexicali (AMM, 2011) as arid zone where predominate sulfurs

(ASTM, 2004) as air pollutants and Tijuana (AMT, 2011) and Ensenada (AME, 2011) as marine regions with sulfurs and chlorides (ASTM G140, 2008) corrosive agents. This research makes an evaluation of the operation of MEMS which are of importance for the scientific techniques used for analysis, manufacturing and electrical tests. The industrial plants interested in this study required specialized techniques and methods analysis of MEMS (Robertson et al, 2005). This study is of great importance for the electronics industry of the northwest of Mexico and other environments similar of this region, where the influence of climatic factors as relative humidity (RH) and air pollutants as sulfurs and chlorides are present for long periods of time and at concentrations higher than the air quality standards (ASTM G 4, 2008). This is important because MEMS are very efficient systems that generate a lower cost in production and more reliability (Lopez, 2008). The application of MEMS is an important issue in the electronics industry of the northwest of Mexico, which is available for use in the improvement and optimization of systems (Lopez et al, 2010). The study focuses on analyzing the factors that generate corrosion in MEMS with the Scanning Electron Microscopy (SEM) method and the Auger Electron Scanning (AES) technique. These techniques were applied to determine the agents which react with the copper surfaces of the electrical connections and connectors and propose the design of new methods of manufacture of micro devices with MEMS and the use of new materials, to avoid or reduce the generation of corrosion (Lopez et al, 2010, Leidecker, 2006). This study was made in three steps:

1. Evaluation of electrical failures of MEMS in industrial plants of video games in Mexicali, cellular phones in Tijuana and portable computers in Ensenada.
2. Micro and nano analysis of surfaces with the SEM and AES techniques.
3. Developed of an electronic system to control humidity and temperature and make periodic monitorings to detect very fast principally the high concentration levels of sulfurs and chlorides.

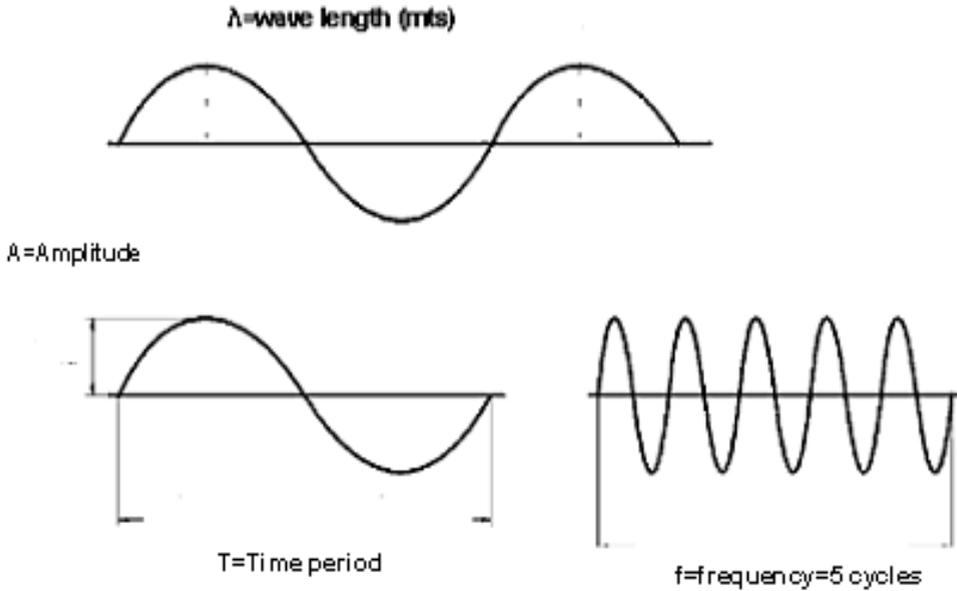
## 11. Evaluation of electrical failures

The measuring of electrical signals is important in the evaluation of productive yielding of MEMS, and its process consists in the analysis of the period of oscillation, which is the time for one complete oscillation and its unit is second. The frequency is the number of cycles, oscillations or vibrations in the unit time and its unit is the Hertz or cycles / sec. The amplitude of oscillation is the maximum elongation or detachment of the particles with respect to its middle position and due to the oscillation introduced. The wavelength is space for the propagation speed  $v$  for a time corresponding to the period  $T$ , using measurements of length. The propagation velocity is that which reaches the oscillatory state at various points on the source of the disturbance. The amplitude of the oscillations depends on the power used to produce the initial disturbance (Figure 8).

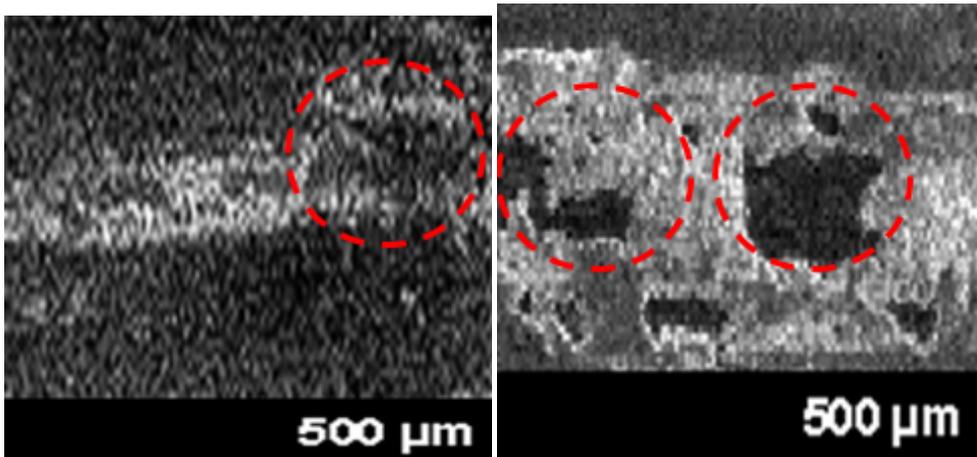
## 12. Micro and nano analysis of surfaces

SEM analysis represents the evaluation of surfaces with microphotographies at surface level indicating the grade of deterioration of the internal and external electrical connections and

connectors of MEMS. This shows the pathways damaged and the agents that react with the metallic surfaces added and blocked the electrical conductivity (ISO 9223, 1992, ISO 11844-1, 2006, ISO 1844-2, 2005). AES technique analyze at surface level and in of this, representing the chemical agents that reacted with the copper surfaces and the dimension of thin layers formed in different areas of the electrical conexions of connectors of MEMS (Figure 9).



**Figure 8.** Electrical signal of MEMS with wave length and different periods of time.



**Figure 9.** Electrical conexions and connectors deteriorated in the electronics industry of the northwest of Mexico.

### 13. Electronic system to detect and control the atmospheric corrosion

The design, fabrication and use of an electronic system to maintain the humidity and temperature at 70% and 35°C, which are the standard levels to reduce the corrosion process, was made. This equipment is very cheap and easy to apply in any place of the industrial plants evaluated. Its system detects small variations of values of RH and temperature and when any aggressive agent reacts with the metallic surfaces of conexions and connectos of MEMS (Figure 10). The first step is the power supply that gets electrical energy to the system (Lopez B. Gustavo, 2011). Next are the electronic devices which detect the variations of humidity, temperaure and the electrical current to determine if any chemical agent was reacting with the copper surfaces. Also is the indication step to shows the good or bad function of the control system and in the last step is the operation that active a power electrical actuator as electrical fan or other mechanism to maintain the values of climati and electrical current factors (Lopez B. Gustavo, 2010).

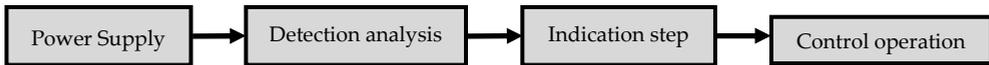


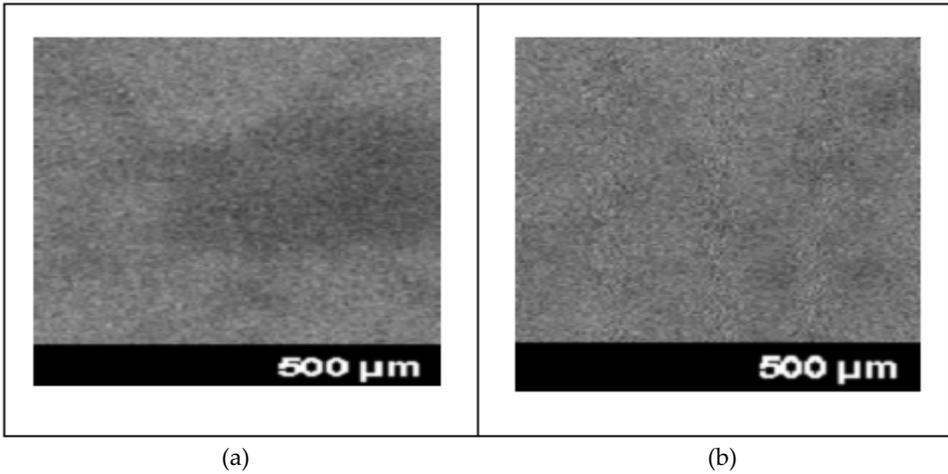
Figure 10. Steps of electronic and automatic control system.

### 14. Results

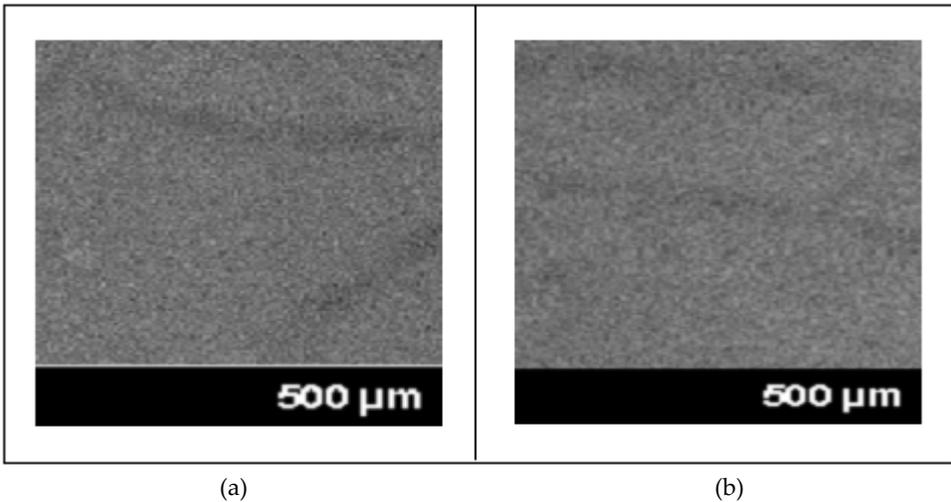
The deterioration of MEMS used in the electronics industry was affeting to their operatibility and increasing the electrical failures at around 35%, representing the major factor in the download of manufacturing areas of the electronic industry. The electrochemical process was accelerated in winter very fast than in summer by the condesantion of humidity and low temperatures. There were presented differen types and proceses of deterioration: uniform, piiting and crevice corrosion. A small and big tarishings were presented in the electrical conexions and conectors of the industrial electronics equipments that were represented in the figures 11 to 13 at 500 X of the SEM evaluation and figures 14 to 16 at 5 X in the same technique (Van Ingelgem, 2007). The Auger analysis showed in combination with the SEM technique (G. L. Badilla et al, 2011), the interested zones of the metallic surfarces to determine the chemical agents which reacted with the copper surfaces (figures 17 to 19). As the theory considerations mention, the sulfurs in Mexicali as arid zone was the higher air pollutant that affected increase the corrosion rate and the chlorides in Tijuana and Ensenada as marine regions. Also the traffice vehicles and chemical agents to verted in water of cities were other pollutants to contribue to the air pollution and deterioration of metals. Figures 11 to 13 in both pictures showed tarnishings that are an obstruction to the electrical pathways of MEMS. In Mexicali was represented the bigger tarnishing, in Tijuana some pathwys affected and in Ensenada less intensity.

At 5X level of microscopy the same analysis as figures 11 to 13, were presented the figures 14 to 16 with better view as its is showed and with a better description of the deterioration. In figure 14 that shows the ocurred in Mexicali, an electrical pathway was deteriored and braked. The same deterioration process was in Tijuana and Ensenada but without the brake

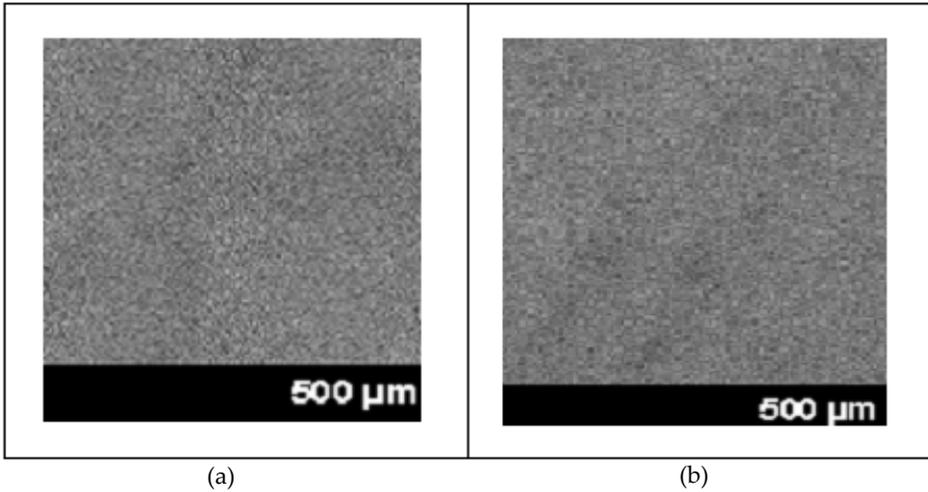
of the pathways. With this microanalysis the description of the negative effect of the air pollutants mentioned above and the drastic variations of humidity and temperature were the principal parameters involved in the corrosion processes in each type of corrosion to determine the methods of control to avoid and reduce this phenomenon.



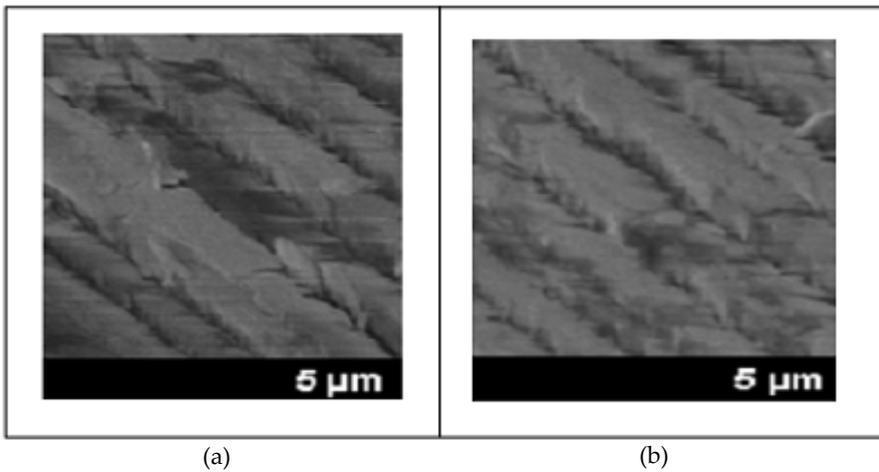
**Figure 11.** SEM 500X microphotographies of pathways damaged by the atmospheric corrosion in (a) summer, and (b) winter in Mexicali (2010).



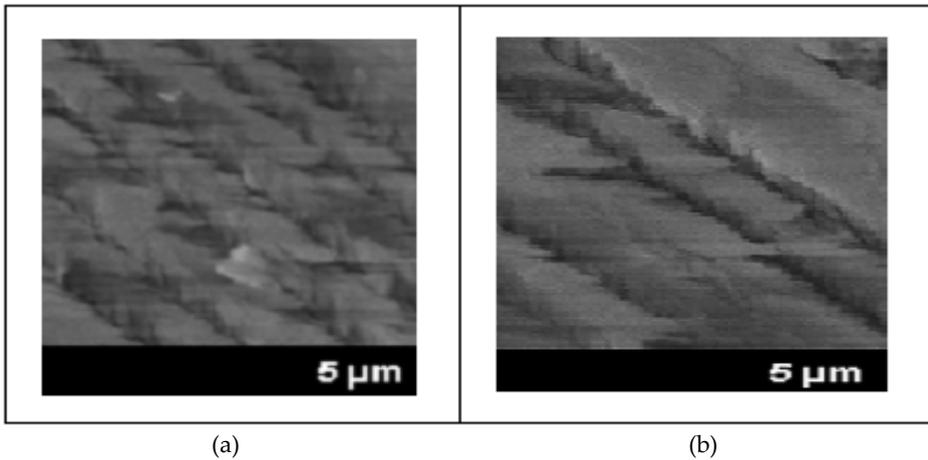
**Figure 12.** SEM 500X microphotographies of pathways damaged by the atmospheric corrosion in (a) summer, and (b) winter in Tijuana (2010).



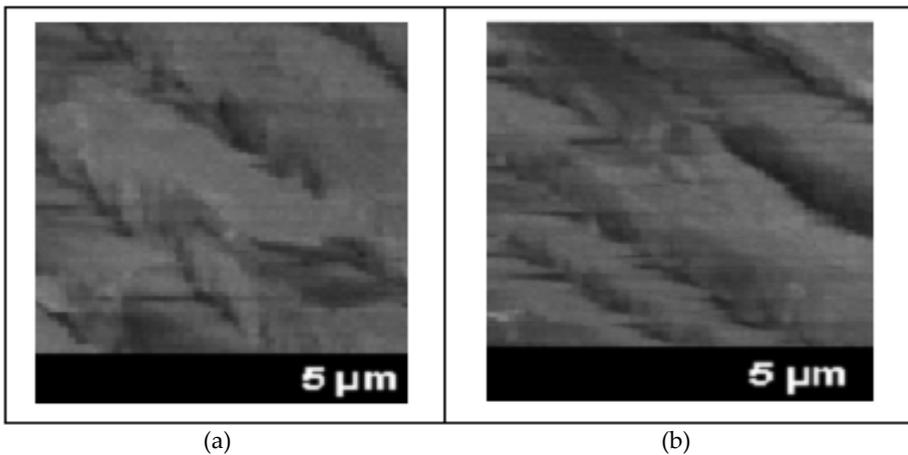
**Figure 13.** SEM 500X microphotographies of pathways damaged by the atmospheric corrosion in (a) summer, and (b) winter in Ensenada (2010).



**Figure 14.** SEM 5X microphotographies of pathways damaged by the atmospheric corrosion in (a) summer, and (b) winter in Mexicali (2010).

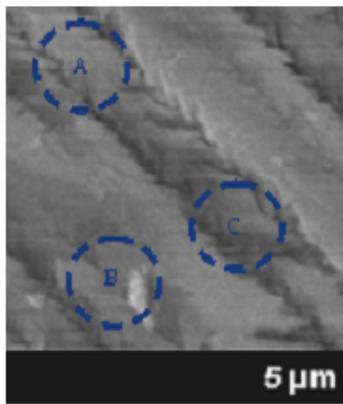


**Figure 15.** SEM 5X microphotographies of pathways damaged by the atmospheric corrosion in (a) summer and (b) winter in Tijuana (2010).

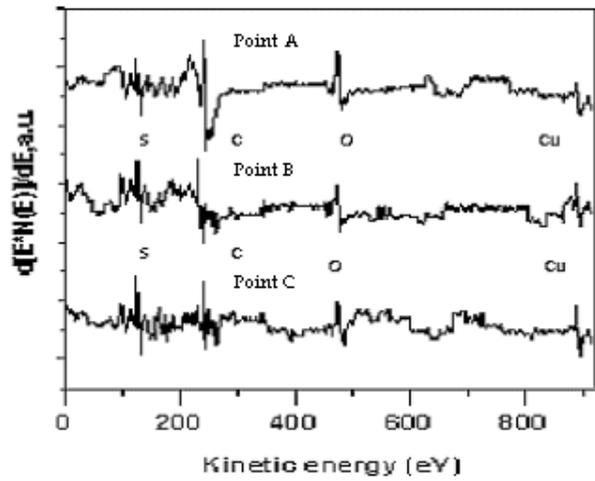


**Figure 16.** SEM 5X microphotographies of pathways damaged by the atmospheric corrosion in (a) summer and (b) winter in Ensenada (2010).

The Auger analysis determined the principal chemical agents that reacted with the copper surfaces and the percentages of these air pollutants combined with the carbon dioxide of the environment and the description of the level of copper. The evaluation shows with spectra the intensity at different kinetic energy to each chemical element in the three regions of the interest. As mentioned carbon is from the atmosphere and oxygen can be from the environment or of the oxidation process. SEM evaluation represents a microscopy analysis and Auger technique at nanoscale penetrating the surface and has an operation to clean individual surfaces to a specific analysis.

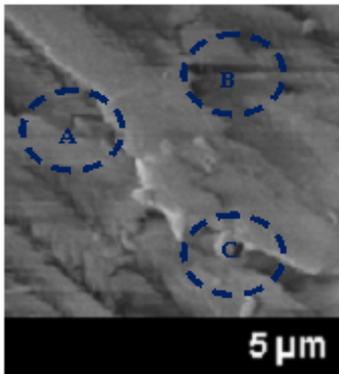


(a)

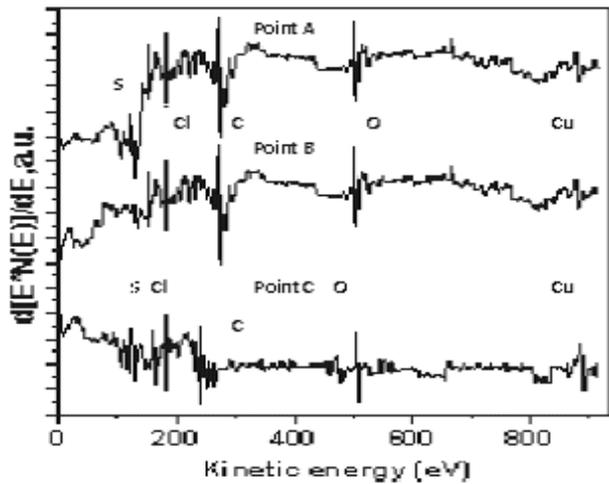


(b)

**Figure 17.** AES analysis: (a) Auger map and (b) spectrum evaluation of pathway damaged by the atmospheric corrosion in Mexicali.

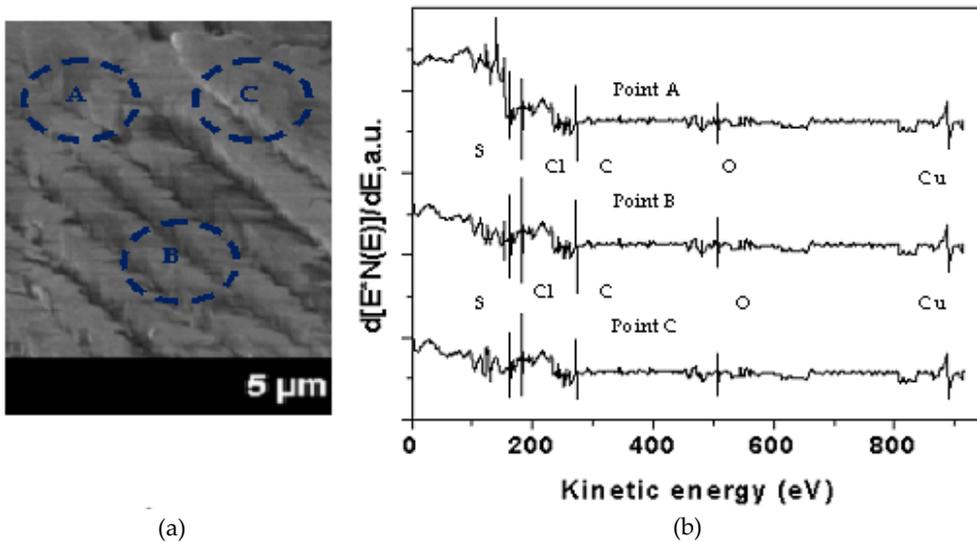


(a)



(b)

**Figure 18.** AES analysis: (a) Auger map and (b) spectrum evaluation of pathway damaged by the atmospheric corrosion in Tijuana.



**Figure 19.** AES analysis: (a) Auger map and (b) spectrum evaluation of pathway damaged by the atmospheric corrosion in Tijuana.

## 15. Conclusions

The use of MEMS in the electronics industry is an important technology applied to improve the manufacturing processes and their commercial products. This microdevices support to diverse operations in the industrial plants increasing the productive yielding. With climatic factors and pollution parameters controlled is possible avoid the presence of aggressive environments and the generation of corrosion in the electrical conexions and conectors of MEMS used in indoor of the electronics industry. This contribute to mantain in good conditions the indusrial equipments and machines of companies. In Mexical considered as arid zone, the principal air pollutants that react with the metallic surfces are sulphurs and in Tijuana and Ensenada, that are marine regions, the chlorides are the principal chemical agents that deteriorate the copper surfaces of electrical conexions and connectors. This study represents an analysis of the presence of corrosion in MEMS of industrial electronic systems, evaluated by the SEM and Auger techniques, and describe the percentage of each chemical agent that react to estimate the type of corrosion occurred and know the grade of deterioration that origiante the electrical failures. Also was designed, fabricated and tested an electronic system to detect drastic variations of humidity and temperature and low concentrations of air pollutants with a filter that determine a bad operation of electronic equipment, detecting and indicating the begin of the corrosion process that can occur. At levels 80% to 90% of RH and 30 °C to 35 °C of temperature, the corrosion was uniform and was presented in winter and some periods of summer especially in some days of July and August. At levels around 60% to 80% of RH and 35 °C to 45 °C in Mexicali principally; the deterioration was as a pitting corrosion. In the ranges of RH and temperature mentioned

above, the concentration levels of sulphurs in Mexicali and chlorides and Tijuana and Ensenada overpass the air quality standards and the corrosion rate was higher. The thin films formed in the metallic surfaces of electrical conexions and conectors acelerate the electrochemical process and increase the CR very fast. Mexicali was the city where the CR was higher followe of Tijuana and at the final case was Ensenada. A factor important is the traffic vehicle that emmit sulfurs, nitrogen oxides and CO, and Mexicali being the city where the corrosion process affect with a major intensity, is smaller in population around 3 times less than Tijuana and have less automoviles, but the emission of sulfhidric acid of the geothemoelectrical plant that generate electricty to Mexicali and other small cities in this region, is an important factor, which cause the deterioration of metallic surfaces as copper used in MEMS. With electronic system controller (ESC) of climatic and enviromental parameters in indoor of the electronics industry, the corrosion decrease and the electrical failures was reducing, obtained a good productive yielding, and this manitained less concerned to the manager and technical people. The indusrial plants of this region principally in Mexicali make new rules and proceddings to avoid the corrosion process, as control of microclima in indoor of the electronics industry, install filtes with better quality to detect finite particles and the use of this ECS to detect gases with a special filter of air pollution. Also were developed courses to managers and technical people to avoid the corrosion pehnomena and if this appears, was suggesting some methods to control. With these resources the corrosion decreasing in the last six months and the manufacturing processes were in good conditons with efficient productive yielding.

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