Micro-electromechanical Systems (MEMS) Reliability Assessment Program for Department of Defense Activities

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ABSTRACT

As the United States (U.S.) Army transforms into a lighter, more lethal, and more agile force, the technologies embedded in both legacy and emerging weapon systems must decrease in size while increasing in intelligence. Micro-electromechanical systems (MEMS) are one such technology that the Army as well as entire Department of Defense (DOD). Even though the DOD plans to increase the usage of MEMS devices, there have been limited studies performed to determine their reliability and failure mechanisms. No standardized test protocols exist for assessing reliability. Accordingly, the U.S. Army Corrosion Office at Picatinny, NJ has initiated the MEMS Reliability Assessment Program to address this issue.

Keywords; Micro-electromechanical Systems, MEMS, Reliability Assessment, Reliability Testing, Safety and Arming Devices, IMU, Army, Department of Defense

INTRODUCTION

As the U.S. Army transforms into a more lethal, lighter, and agile force, the technologies embedded in military vehicles and weapon systems must be decreased in size and weight while providing improved reliability, capability, and intelligence. Recent conflicts abroad have underscored a need for the rapid response to varying missions, which often necessitate secure, accurate, and timely transmission of information. Attributes such as speed, network-centricity, and overall awareness are essential for the current and future force. Micro-electromechanical systems (MEMS) represent an enabling technology that the Department of Defense in general, and the Army in particular, may rely on heavily to meet these emerging requirements.

MEMS cannot be categorized as any one single application or device, nor can they be defined by a single fabrication process, or by a standardized set of construction materials. Rather, MEMS technology involves a complex, systematic fabrication approach that utilizes the advantages of miniaturization, multiple components, and microelectronics to design and construct integrated electromechanical systems. The U.S. Army Corrosion Office defines MEMS as Micro-electromechanical systems that employ an ever-expanding set of micro-fabrication methods to create and integrate micro-machined sensors, actuators, mechanical elements, and microelectronics on a single substrate. MEMS technology enables the manufacture of small systems with increased functionality that will lead to performance enhancement of current systems or to entirely new systems.

Current and future military applications of MEMS devices include safety and arming devices, fuzing devices, various guidance systems, sensors/detectors, inertial measurement units, tracking devices, radio frequency devices, wireless Radio Frequency Identification tags (RFIDs) and network systems, global positioning systems (GPSs), radar systems, mobile base systems, information technology, satellites, and missiles.

Incorporating MEMS technologies into the applications mentioned above will provide the military with new levels of speed, awareness, lethality, and information dissemination. The system capabilities enhanced by MEMS will translate directly into tactical and strategic military advantages. However, the application of MEMS to military systems is dependant upon their reliability within those systems. MEMS devices will be required to last the lifetime of the weapon system in which they are embedded, which may be decades. In addition, MEMS devices will be required to function properly after extended periods of inactivity while in storage, which poses a tremendous challenge as corrosion issues and device anomalies materialize.

While the reliance on MEMS devices has been increasing, there have been limited studies performed to assess their reliability and identify failure mechanisms. Accordingly, the US Army Corrosion Office at Picatinny, NJ has initiated the MEMS Reliability Assessment Program to address these issues.

DISCUSSION

The MEMS Industry

The MEMS manufacturing industry is one of the world's fastest growing industries, correlating to billions of dollars a year in design and fabrication. The industry is predicted to grow exponentially over the next few years (Figure 1). As more and more interest is placed on MEMS technology, numerous applications will emerge, resulting in a greater need for an accurate assessment of reliability. Thus, as the industry grows, MEMS devices will expand into numerous fields and applications including the military, automotive, medical, aviation, communication, and other industries.

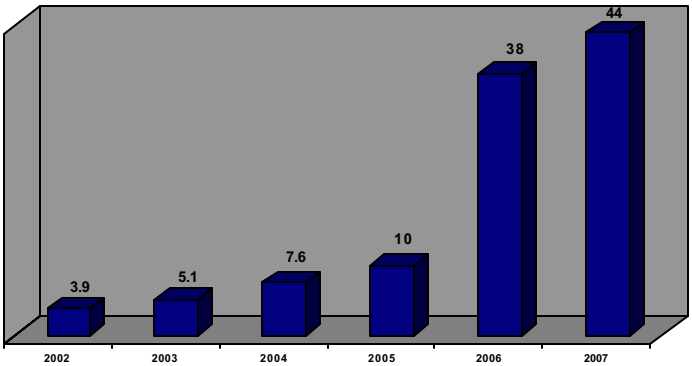

Figure 1: Worldwide Forecast of MEMS Market ($ Billions)[1]

Along with the world's increased reliance on MEMS, the DOD is developing and advancing MEMS (Figure 2). Applications of MEMS currently under development for DOD systems include inertial measurement units, remote & embedded sensors/detectors, fluidic systems, weapons safety & arming devices, fuzing technologies, guidance systems, wireless communications & network systems, logistics & tracking, radio frequency devices, soldier systems, radar systems, mobile base systems, satellites, missiles, information technology, and numerous other military areas and technologies.

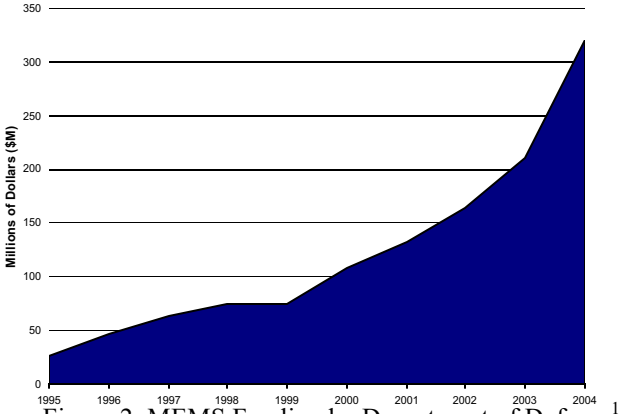

Figure 2: MEMS Funding by Department of Defense[1]

As DOD funding increases and more devices are developed and placed in weapon systems, there is a greater need for assessing the reliability of these devices in a standardized manner. In a report for the Department of Defense, it was stated that reliability was a major technology adoption issue. It stated, *"MEMS will have to be extensively tested and evaluated under all circumstances in order to provide highly reliable information on a particular system and components[2]".*

Program Drivers

There are several problems related to the reliance of MEMS in both military and commercial applications. One major problem is the lack of reliability data for MEMS and their related devices. There is very little documented reliability data for MEMS. The prime focus of MEMS to date has been on the development and implementation of vast arrays of devices; often, little consideration is paid to reliability. Furthermore, data from the commercial sector for MEMS reliability is nearly impossible to track, or is not easily accessible, due to its propriety nature. While many MEMS manufacturing organizations claim to have reliability test data on their devices, the majority keeps their data "in house" and is reluctant to disseminate the information. As a result, failure mechanisms and failure rates for many devices are not well characterized. In addition, accelerated test protocols for assessing the reliability of MEMS have not been standardized across the industry. Also, reliability models for these MEMs devices are not yet implemented.

It should be recognized that conditions for the utilization of MEMS by the military are unique. For example, operation and storage environments for the military are significantly different than those of the commercial sector. Issues unique to the military include high G-forces (from gun launch), extended periods of inactivity (20 years plus), and interaction with explosives and propellants. The military operational environments in which MEMS will be stored and/or required to function are extreme, far surpassing any commercial operating conditions. Furthermore, security and encryption are a must for all MEMS communication, tracking, or data reporting devices employed by the military.

Further complicating the assessment of MEMS reliability is the fact that most MEMS reliability data and testing to date are based on silicon ICs (integrated circuits). While silicon was the material of choice for MEMS manufacture some years ago, these devices make up only a portion of the total MEMS industry today. There are numerous other materials being implemented in MEMS devices; metallics, polymers, composites, and ceramics are all being incorporated into MEMS.

Along these lines, an important fact to remember is that MEMS devices are more than typical integrated circuits, as many believe. As recently reported, *"MEMS represent significant micro-electronic/molecular*

commercial and defense applications beyond those of I Cs[3]." MEMS devices have unique properties, materials, applications, etc. Therefore, current integrated circuit and silicon chip standards may not be applicable for the vast majority of MEMS devices. The structures of MEMS are primarily three-dimensional, as opposed to two dimensional ICs. Also, MEMS often contain moving parts with more complex interfaces than silicon based micro-electronics, further complicating the development of standards.

MEMS Reliability Assessment Program:

The U.S. Army's MEMS Reliability Assessment Program was established by the U.S. Army Corrosion Office at Picatinny Arsenal, NJ to address the limited availability of reliability data and develop a standardized methodology for the assessment of the reliability of MEMS devices. Under this activity, MEMS devices and components will be considered for testing, and issues such as the impact of transportation, storage environments, operating environments, packaging, interconnection issues, and other issues that directly and indirectly affect the reliability of MEMS will be assessed.

The U.S. Army Corrosion Office's objective is to establish a research program that will:

1) Identify those MEMS devices, types, and configurations under consideration for current and future weapon systems;
2) Identify the failure mechanisms and failure rates of these devices;
3) Identify and characterize the MEMS transport, storage, and operational environments;
4) Analyze the compatibility of MEMS devices with energetic and other hazardous materials found in military items such as ordnance;
5) Develop accelerated test protocols for assessing the reliability of MEMS;
6) Identify a standardizing body, standard terminology, definitions, and categories for MEMS devices and test protocols;
7) Develop reliability models for these devices.

As the field of MEMS is quite large, it was first necessary to derive a classification methodology for devices of interest. MEMS devices can be divided into several classes based on functional characteristics. Since each class may have unique failure mechanisms and reliability issues, each class must be addressed accordingly. The Army Corrosion Office has employed a system of four functionality classes based upon previous work[4], and has added a fifth class, Class V, to this system. The five device classes, their characteristics, and examples are presented in Figure 3. Devices that fall into Class V may be unique to the military in that the MEMS may be in contact with energetic materials or experience particularly aggressive environments inherent to military equipment.

Class of MEMS	Characteristics	Examples
Class I	No moving parts	Accelerometers Pressure sensors
Class II	Moving parts; no impacting surfaces	Gyros Resonators Filters
Class III	Moving parts; impacting surfaces	Relays Valves Pumps
Class IV	Moving parts; Impacting and rubbing surfaces	Optical switches Scanners Discriminators
Class V	Moving parts; interfaces with explosives, propellants, & Energetics	S&A Devices IMUs Fuzing

Figure 3: Generic MEMS Classifications[4]

Having established a classification system, it is then necessary to establish the usage and environments of MEMS devices for military materiel. Included within the program is the identification of those specific types of MEMS devices that will be employed in current and/or future vehicles and weapon systems. The program is also investigating potential failure mechanisms induced by design, materials, fabrication, assembly, packaging, and storage. This information will then be used to determine potential test methodologies.

The development of test guidelines for MEMS reliability testing is another objective of this activity. The small size and multifunctional nature of the devices makes many current electronics tests unpractical. To combat these issues, The Army Corrosion Office is investigating the use, adoption, and modification of those standards currently utilized by the electronics and semiconductor industries as required.

In addition, current military and industry standards will be analyzed and utilized when applicable. Various sections of the military microelectronic test method standard, MIL-STD-883 have been used for many MEMS test plans, but the applicability of this standard for MEMS has been questioned by numerous organizations. Many feel that this specification needs to be modified for use with MEMS. Most current MEMS devices will not survive such testing but perform the functions for which they are designed. The applicability of MIL-STD-810 for definition and testing for the effects of operating, transportation, and storage environments for MEMS devices will be investigated as well. This specification is particularly critical for military components, as all fielded military components must comply with this standard.

One of the most difficult tasks is identifying the various types of MEMS malfunctions, especially since the vast majority of MEMS devices are designed in a "packaged" state. Some failures are relatively easy to identify and track, while others are almost impossible to detect[3]. The failures and mechanis ms must be identified so they can be dealt with and designed out in a systematic manner.

Along with identifying failure types, the types of environments that these MEMS devices operate in are being explored. These operational environments need to also be categorized. As MEMS technology advances, new applications will arise and many of these applications will be in extreme environments. Numerous MEMS medical applications are being investigated; the human body is a unique environment unto itself. With aerospace and aviation advancements, even commercial MEMS will see extreme temperatures, G-forces, pressures, etc. The environments that MEMS are and will be exposed to in utilization, as well as storage, plays a critical role in determining reliability for these devices. Long-term storage is a major factor in which may affect MEMS reliability.

Factors which must be considered with regard to long-term storage include compatibility of materials (including corrosion), hermiticity of packaging, creep of materials, battery losses, and stresses on interfaces caused by cycling.

Compatibility is another factor in MEMS reliability. The MEMS Reliability Assessment program is not only looking at material compatibility of MEMS, but also the compatibility between devices themselves. The MEMS industry is using numerous new processes and material combinations with little know data on their compatibility issues. Potential for galvanic couples with these new materials will be investigated. Many MEMS devices will be interconnected together and required to function in situations never before explored or tested. As mentioned before, materials like metallics, polymers, composites, ceramics, and numerous fluidics are all being incorporated into MEMS and the compatibility of these materials have a direct affect on reliability.

MEMS failure is a growing concern. As MEMS devices are placed into more and more critical systems, these failures can become more catastrophic. Understanding the potential failure mechanisms will help reduce the number of failures. This information will assist in designing many of these failures out. MEMS are not inherently unreliable, but potential failures should not become a "show stopper" for the advancement of MEMS.

Based on the failure mechanisms identified and rates for these mechanisms, accelerated test protocols for assessing the reliability of the devices will be developed. Protocols may test devices at the packaged or unpackaged level. Included in these protocols will be the effects of storage and operating environments. Follow-on work will include the development of reliability models for these devices. As protocols are being developed, efforts will be made to standardize testing across the user/manufacturing community.

CONCLUSION

Previous investigations conducted by the Army Corrosion Office under the Corrosion Measurement and Control Program have demonstrated that reliability data and test protocols for MEMS devices are not readily available. To address this data gap, the Army Corrosion Office has initiated the MEMS Reliability Assessment Program. This program will benefit both the government and the commercial MEMS user communities by filling the information gap that currently exists for reliability. With the rapid growth of the MEMS market in both military and industry, it is imperative that we consider the reliability of these emerging technologies as well as their applications in the early stages of its development.

The goals of the MEMS Reliability Assessment Program include:

- Determine & Develop methods to preserve MEMS devices during long tern storage before they are designed into products
- Independent assessment of reliability that cannot be obtained from private industry
- Establishment of reliability data that will be fed back into development & design to improve MEMS devices

Production & design process can be vastly improved increasing yields that will drive costs down.

Short-term goals include identification of MEMS devices/designs that will be used in military systems, determination of the operating/storage environments and packaging requirements/interfaces of those devices. Interfaces include those between chips and boards, between parts, and with other MEMS devices. Also identifying failure mechanisms of potential MEMS devices both commercial and military MEMS and developing test methods for these devices will be instrumental in staging a focused approach to MEMS reliability, testing and standardization.

The long-term objective of this effort is to establish standards for reliability testing for both packed and unpackaged MEMS devices, establish test capability, and help provide direction and information for those who wish to enter the MEMS market place for DOD applications.

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