The role of standards in MEMS commercialization

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For many years, the development, creation and use of standards has played a valuable role in the successful commercialization of products, services and processes that address many industries and many applications. So it is with microelectromechanical systems (MEMS) [1]. In the annual MEMS Commercialization Report Card [1], standards were identified as one of the 14 critical success factors that have been monitored and assessed since 1998. Standards reporting began in 2002 and is shown in Figure 1. Creating standards is a long and deliberate process (Figure 2) with the volunteer efforts of many contributors who typically accomplish their goal after several years and many meetings.

Several industry experts who represent various organizations in the MEMS supply chain were interviewed for this article by the lead author. Soliciting the opinions of members of the supply chain is important because it is the suppliers that will adopt, use, and subsequently benefit from the establishment of these standards. They represent many of the entities that are intimately involved with the various functions of the MEMS commercialization process (Figure 3).

The consensus of the authors of this paper is that the lack of adequate standards in MEMS has far reaching consequences to MEMS commercialization. The impact of standards spans definitions, specification performance uniformity, testing methods, product time-to-market, device cost, and device interoperability. We found other examples of industry experts who have weighed in on the vital role that standards can play, as well as the difficulties in creating them. Examples are cited below.

S. Walsh, U. of New Mexico. R. Grace, in collaboration with Professor Steve Walsh of the University of New Mexico, has approximated that the median and mean time-to-market for a MEMS device from technology discovery to full commercialization to be approximately 30 years (Figure 4) [2]. The lack of creation of adequate MEMS standards has been one of the leading contributors to this prolonged commercialization process.

The need for standards H. Bennett, NIST. At the GaN Roundtable event [3], Herbert S. Bennett of NIST stated, “Knowledge of standards can help facilitate the transition from classroom to professional practice by aligning educational concepts with real world applications.”

R. O’Reilly, Analog Devices. Rob O’Reilly of Analog Devices – interviewed for this article – stated that, “With the involvement of MIG [MEMS Industry Group], a Data Sheet Performance...
Specification was created that helped level the playing field when it came for a potential customer to have an apples-to-apples comparison of our accelerometer’s performance. OEMs could now develop solutions using several sensor providers once the data sheet parameter definitions used across the industry were, by specification, the same.”

J. Wetzel, Novati Technologies. Finally, Jeff Wetzel of Novati Technologies (also interviewed for this article) has said, “Standards enable IDMs, OEMS and supplier communities to transact business efficiently since specifications, and the means to confirm specifications, are mutually agreed upon, documented and periodically updated. Standards provide manufacturers with the knowledge that their supplier base conforms to known specifications. Adherence to standards by the supplier and manufacturer communities defines a range of available solutions for lowest cost manufacturing.

The difficulty in establishing MEMS standards

D. Kirsch, EV Group. Dave Kirsch of EV Group (also interviewed for this article) noted that, “Semiconductor manufacturing processes are more established and tend to follow Moore’s Law, whereas in MEMS, the manufacturing process can be influenced by the application…and applications tend to be much more diverse than in the IC domain.”

M. Maher, SoftMEMS. Mary Ann Maher, SoftMEMS, (during her interview for this article) stated that, “Each company involved in manufacturing MEMS has found a way that works for them, and as such, has developed internal standards that they consider proprietary and may consider to be a competitive advantage. Another key point is that, because there are few standard processes in MEMS, we need to find a standard way to exchange information even though the information itself may not be standard. We will also find standards at the interface and connector level as more MEMS become integrated into other systems.”

Full speed ahead: the drive for MEMS standards

Besides the activities to drive standards development by those in both the supply chain and device fabrication space, major efforts have been made by a number of industry organizations. Some of those efforts are highlighted below.

Global Semiconductor Alliance. Recognizing the need to drive MEMS development processes along a path similar to fabless semiconductor development, the Global Semiconductor Alliance (GSA) undertook an effort to bring semiconductor expertise together with MEMS leaders to nurture a mutual understanding and forge a common development environment.

With the thrust towards a trillion sensors and the “Internet of Whatever,” it is critical to develop repeatable processes, minimize time-to-market, and drive toward first-pass success for MEMS sensors and products integrated with MEMS devices. Understanding this need, the GSA team meets quarterly to self-educate and develop tools that lead to this ideal. Our team has worked hand-in-hand with MEMS efforts in other organizations to contribute the collective knowledge of our semiconductor members.

In any design environment, it is critical that information exchange is comprehensive and clear. Foundry Process Design Kits are commonly used as guidelines for proven standardized processing platforms. These guidelines ensure that the design can be mass-
fabricated with predictable, high processing yields. The lack of standard processing MEMS platforms prompted the need for alternative methods to exchange design and processing information. The GSA MEMS team has generated a Process Design Documentation (PDD) Quality Checklist that aims to facilitate information exchange between designers and foundries.

The PDD contains a comprehensive list of information that is universal for designers and foundries alike. This list is not product specific, process specific, or foundry specific. The PDD is meant purely as a checklist to ensure that information exchange between MEMS designers and MEMS foundry is complete, accurate and comprehensive. For designers, the PDD helps understanding what information should be requested from a foundry. For the foundries, this checklist can be used to ensure that designers have covered all major processing aspects of the design. The ultimate goal is to make better quality products that are scalable for mass production and can get to the market faster.

Institute of Electrical and Electronic Engineers (IEEE). The IEEE Standards Association (IEEE-SA) was integral in developing IEEE Std 2700-2014 for Sensor Performance Parameter Definitions (http://bit.ly/175oQGX), and continues to play an important role in the Internet of Things (IoT), MEMS, and sensors spaces. Prior to the publishing of this standard, there was a void in the industry for defining sensor performance and a recognizable, industry-adopted terminology for describing the various performance parameters exhibited by sensors. An entity-based (one company, one vote) working group was formed to complete this effort. The sponsor for this effort was the MEMS Standards Development Committee, which operates under the IEEE Electron Devices Society. IEEE-SA has also developed many standards and guides for smart grid and personal health care devices that utilize sensors.

The standard from IEEE is an important and key step towards minimizing non-scalable integration challenges and accelerating time-to-market. Future efforts should look at standardized test methods for evaluating sensors, which would enable industry to have an unambiguous and systematic way to assess sensors. This kind of approach would then lead to the prospect of having interoperable products. Could we envision a future where sensors are certified prior to use? Numerous applications such as biometric screening and toy safety utilize conformity assessment with international consensus standards to ensure proper market rollout including removal of any trade barriers.

With industry adopted standards and a conformity assessment program, manufacturers will have the ability to implement standardized features within their products and compete on differentiating their offerings, which ultimately spurs innovation. From a systems integrator standpoint, they can require certified component that will then ensure proper operation and interoperability. This then brings about a seamless and enjoyable user-experience for all that will instill consumer confidence in the technology.

MEMS Industry Group (MIG). Based on discussions at its 2012 member meeting, MIG launched a standards working group. In 2013, MIG announced the first-ever Standardized Sensors Performance Parameter Definitions (SPD) document, authored by MIG members. In 2014, MIG led the creation of the first-ever IEEE standard for MEMS and sensors performance: IEEE 2700. To advance the adoption performance standards, MIG also has an accelerator performance testing subcommittee that meets regularly to solve the remaining issues affecting performance standards and testing/measurement for MEMS and sensors.

At its MEMS Executive Congress US 2014, MIG announced the open-source sensor fusion algorithm library, the Accelerated Innovation Community (AIC) to reduce time-to-market startup costs, risks and barriers to entry by encouraging inputs and collaboration across the MEMS/sensors supply chain. In three short months, there has been over 400 logins to the AIC website since its release in November 2014!

All of MIG’s working groups will meet in person at MIG’s MEMS Technical Congress, May 6-7 in Boston (memotechcongress.memsiindustrygroup.org/).

Standards, and in particular, standardization, are critical to the successful commercialization of MEMS and sensors as they create an open playing field for companies big and small. Performance standards, such as the ones authored by MIG, will enable reduction of overall costs and faster-time-to-market, enabling a true and smart Internet of Things/Everything (IoT/E). The MIG organization believes strongly that the IoT/E will not happen if the industry does not address the remaining challenges to MEMS and sensors commercialization, including standards/standardization.

National Institute of Standards and Technology (NIST). NIST has worked towards the advancement of MEMS standardization since the early 90s. At that time, the lack of standardization of test structures and test methods resulted in huge variation in important MEMS device design parameters, such as strain and elastic modulus, and their relationship to fabrication process conditions. This was most notable when researchers reported on values measured in a shared fabrication run, such as what was offered by the multi-user MEMS process (MUMPS). NIST brought together leaders in the field to participate in a round robin experiment that was crafted to develop agreement on how to standardize these tests. This consensus building effort was followed by the development and publication of the first MEMS standards, ASTM E2244, E2245, and E2246, which described procedures for the measurement of film thickness, strain, and strain gradient. The ASTM standards were followed by the development of the SEMI MEMS Standards described in another section of this article.

In 2009, NIST teamed with the MEMS Industry Group to develop the MEMS Technology Roadmap, which is now published yearly alternately by the International Electronics Manufacturing Initiative (iNEMI) and the ITRS. This roadmapping effort has served as a vehicle to develop consensus among the device manufacturers, test labs, equipment suppliers, and systems integrators on the need for standardizing the test methods for characterizing device performance that are published in device data sheets. It also tracks and reports on other gaps in the design and manufacturing process, including requirements for design tools, foundries, and assembly and packaging.

Our experience shows that technology roadmapping is an efficient way to bring manufacturers together to articulate their common challenges, and has led to important results. Responding to the device testing issue, NIST has teamed with the MEMS Industry Group and the IEEE to develop standard sensor parameter performance definitions. These standards are intended to drive harmonization in how
the sensor performance is reported in the device data sheets. So far, a terminology standard has been published (IEEE Std. 2700-2014). The sensors included in this terminology include accelerometers, gyroscopes, magnetometers, hydrometers, pressure sensors, and more. Now, the work is focused on the development of standard testing protocols for determining each of the parameters listed in the sensor performance specifications.

**Semiconductor Equipment and Materials International (SEMI).** In 2003, SEMI established a MEMS Standards Committee to address the need for standards in the MEMS industry. Ten standards have been published since inception:

- **MS1** – Guide to Specifying Wafer-Wafer Bonding Alignment Targets
- **MS2** – Test Method for Step-Height Measurements of Thin Films
- **MS3** – Terminology for MEMS Technology
- **MS4** – Standard Test Method for Young’s Modulus Measurements of Thin, Reflecting Films Based on the Frequency of Beams in Resonance
- **MS5** – Test Method for Wafer Bond Strength Measurements Using Micro-Chevron Test Structures
- **MS6** – Guide for Design and Materials for Interfacing Microfluidic Systems
- **MS7** – Specification for Microfluidic Interfaces to Electronic Device Packages
- **MS8** – Guide to Evaluating Hermeticity of MEMS Packages
- **MS9** – Specification for High Density Permanent Connections Between Microfluidic Devices
- **MS10** – Test Method to Measure Fluid Permeation Through MEMS Packaging Materials

Volunteer industry experts develop these consensus-based documents, motivated by the critical role SEMI Standards play in increasing manufacturing efficiency and producing faster time-to-market. Additionally, SEMI Standards increase market access and acceptance, promote communication within and across industries, enable faster commercialization and interoperability, accelerate product development, simplify installation and testing, reduce costs, and protect users and the environment.

Current SEMI Standards activity for MEMS is generally organized into six areas: microfluidics, wafer bonding, terminology, packaging, materials characterization, and reliability. Standardization discussions range from test methods for electro-osmotic mobility in microfluidic systems, to wafer bonding activities that align with related SEMI 3DS-IC initiatives, to hermeticity of MEMS packaging.

Looking toward the future, the Internet of Things (IoT) will rapidly increase the diversity and volume of MEMS sensors. Driven by industry, the SEMI Standards Program will continue to evolve to provide the important pre-competitive standards for this fertile area of innovation.

**Summary**

The recent Data Sheet Performance Specification (IEEE 2700-2014) championed by a MIG-formed committee and NIST is the first IEEE MEMS and Sensor standard. There are many more MEMS standards that need to be created to further successful MEMS commercialization. These need to address materials, processes, definitions, test methods and procedures, packaging and interoperability. To exploit low hanging fruit, the MEMS industry should assess the approximately 900 SEMI standards that were created for the IC industry, and, building on the 10 SEMI MEMS standards already in existence, create even more MEMS-specific standards that draw on the similar technology and processes of these standards. In this fashion, a broader range of MEMS standards can be created with the least degree of effort and time. The results of these proposed efforts should provide added value to all participants involved in MEMS commercialization eco-system, especially in light of the exploding creation of MEMS and sensor-based solutions for the Internet of Things (IoT) and wearable applications.

**References**

2. R. Grace, S. Walsh, MEMS Industry Roadmap, Micro and Nanotechnology Commercialization

**Acknowledgement**

Another source of information regarding MEMS and sensor standards can be found at the IEEE sponsored webinar that was held on February 19, 2015 (http://standards.ieee.org/events/multimedia/iot_mems_sensors.html).

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