

# The 2007 Report Card on the Barriers to the Commercialization of Microelectromechanical Systems (MEMS) and Nanotechnology

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## INTRODUCTION

The barriers to the commercialization of technology exist for MEMS as well as they do for most other technologies. There are many reasons for the commercialization process to be hindered. The article will present a number of critical success factors for successful MEMS commercialization and will use a “commercialization report card” to define the issues. The first commercialization report card was issued in 1998 and has been updated yearly to reflect the changes in the MEMS industry that affect its performance.

It is interesting to note that the first manifestation of MEMS was in 1954 with the discovery of the Piezoresistive effect (the basis of many MEMS sensors especially pressure sensors) by Charles Smith of Bell Lab. Thus we can say that the MEMS industry is over 50 years old. When compared to the semiconductor industry which had its founding less than 10 years earlier by scientists from the same lab, why has MEMS underperformed its semiconductor “cousin”. Considering that there is at least a 20:1 ratio of yearly sales volume between semiconductors and MEMS...we must ask ourselves...“what are the problems”. The commercialization report card attempts to answer this question.

## COMMERCIALIZATION TIMETABLE

A number of MEMS devices have been commercialized since the pressure sensor achieved this hallowed status in 1990. We have conducted a study to determine the commercialization timetable of some of the more significant MEMS products that have been developed in the last 50 years (Figure 1). As one can see, it takes approximately 20 years from discovery to full commercialization. We expect as people will look to lessons learned from other commercialization efforts to help reduce the timeline necessary to achieve full commercialization.

## RESEARCH METHODOLOGY

I have used a “Delphi” method to create the information to be provided. The Delphi method uses interviews with a small number (in this case 55) experts in the field of MEMS taken from a broad range of applications and companies in the US, Asia and Europe. It is important to note that the interview universe represents MEMS suppliers, MEMS users and providers of MEMS infrastructure. As such I attempted to closely represent the broad MEMS universe. The study was conducted in the April 2007 time frame.

## RESULTS

The results of the study are provided in a report card format and given in Figure 2. Grades were assigned from “D” to “A” and rationale for the grading is explained. A number of the most significant of the 14 barriers to MEMS commercialization are given below.

**R&D (Grade = A-):** R&D spending for MEMS has remained relatively constant at a favorable grade since 1998 never dropping below A-. In earlier times, the Defense Advanced Research Projects Agency’s (DARPA) funding activities were focused on MEMS device development activities. Recent DARPA funding has included reliability of RF MEMS and packaging. The National Science Foundation (NSF) continues to provide support to MEMS R&D in the form of Small Business Innovation Research (SBIR) grants for early phase design and development activities. A good indicator of funding is the number of graduate students graduating from MEMS rich academic programs. This number appears to be holding constant. There has been a great deal of “small R” and “large D” in the commercial sector. Funds appear to be directed to fine tuning processes to increase yield. This is especially true in areas where large volume MEMS products are being produced e.g. automotive and consumer applications that use accelerometers, gyros and displays. There has been a significant increase in the R&D funding levels in emerging technology countries including India and China. The popularity and explosion of Nanotechnology and diminished the funding levels of MEMS. Areas of expanded MEMS funding on the rise include energy harvesting.

**MARKETING (Grade = C+):** Marketing grades have languished at the “C” level from the inception of the report in 1998. Efforts to date have been a technology push versus a market pull. Only recently with the recent introduction of MEMS into consumer applications e.g. Texas Instruments Digital Light Projector, Nintendo Wii accelerometers by Analog Devices and ST Microelectronics, has MEMS been exposed to the mass market. There still exist several serious voids on the part of MEMS suppliers to understand customer needs. Most companies attempt to sell their products on specifications and fall far behind semiconductor companies on marketing expertise. Marketing of MEMS is quite challenging and expensive since application sectors are diverse and fragmented and require application engineers that are well informed on the customers’ needs and requirements. Another major problem is that there is a serious lack of product differentiation between suppliers. Marketing communications resources tend to be inadequate. In my opinion, the best marketing efforts have been turned in by companies including Analog Devices and Freescale who are major MEMS players. It is interesting to note that these companies are also veterans of the semiconductor industry and perhaps MEMS has benefited from the cross-pollination.

**MARKET RESEARCH (Grade = B):** Market research for MEMS continues to be provided by a number of organizations worldwide (including ours). Total markets by device types e.g. accelerometers, gyros and market sector e.g. automotive, military are provided. In addition, specific market reports on “hot” application topics including inertial rate sensors are made available by multiple research groups. Conducting accurate

market research in the MEMS market is quite difficult since there are so many suppliers (most of them private companies) and as such, sales volumes are not public information and typically held in high confidentiality. As a result, market numbers from different organizations are prone to vary from report to report. As MEMS has become a larger business opportunity, traditional large semiconductor research firms are entering the field. While published reports by established organizations appear adequate to serve the industry's need, the use of in-depth custom research is woefully inadequate. Before one enters a market, one needs to know and understand the size of the market, the competition, their firm's unique differentiated advantage and most importantly...the unfulfilled customer need. Until MEMS companies acknowledge and embrace this valuable tool i.e. "Marketing:101", they cannot expect to truly be successful in the marketplace.

**DESIGN FOR MANUFACTURING AND TEST (Grade = B):** As the Beatles sang..."It's getting better"...this characterizes the MEMS sector for DfM&T. The major consideration here is the "S" in MEMS i.e. SYSTEMS. Acknowledging this concept by MEMS players has been slow to mature since 1998 when this topic received a "C+". DfM&T is one of the most important and critical success factors for MEMS commercialization. It is at the heart of determining the cost of manufacturing and the reliability of the produced part. Unlike the semiconductor industry where the device package plays a minor role in the overall product solution, MEMS packages are often more important and most always more expensive than the devices a.k.a. MEMS die. A commonly accepted rule of thumb establishes MEMS packaging, assembly and test to be between 60% and 80% of the total solution cost. The reason for this is that many MEMS devices are subject to the rigors of harsh chemical media in which they must make their measurement e.g. pressure sensors for automotive oil pressure. As such, the Silicon die often needs protection and a mechanical packaging solution must be used. In addition, since most MEMS are electro-mechanical in nature, their performance is effected in changes in temperature especially when they are made of Silicon and are mounted on a substrate that has a different thermal coefficient of expansion which results in inducing stress into the chip. As one can see, the system and its mounting method must be considered as a system and properly modeled as such. In addition, many MEMS devices are interconnected with semiconductor devices, typically application specific integrated circuits (ASICs). To achieve an optimum design, device connectivity strategies must be considered. Finally, testing is a major contributor to the cost. Testing strategies need to be considered and addressed in the early stage of the design process. In summary, for a MEMS design to be optimized for cost and reliability, DfM&T must happen early in the design process and follow the "concurrent engineering" principles that were popular in the past. Unfortunately not many of the MEMS manufacturers have seen the light. However, large volume suppliers have typically accepted this approach to meet the price demands of the consumer marketplace. Companies including Bennington Microtechnology Center and Infotonics are resources available for MEMS developers to use to assist in the development of packaging and DfM&T process development.

**ESTABLISHED INFRASTRUCTURE (Grade = A-):** The most dramatic improvement of any grade from a "C+" in 1998 to an "A-" in 2007 has been achieved with the MEMS

established infrastructure area. We define “infrastructure” as the resources needed to support the design, development and manufacture of MEMS. The main infrastructure elements are: software tools, manufacturing and test equipment, and manufacturing facilities a.k.a. foundries.

Software Support- Numerous companies have a solid history of providing excellent design, analysis and simulation tools to MEMS designers. Included in this are Coventor, Intellisense and SoftMEMS. All of these providers have their own specialties.

Manufacturing and Test Equipment has come a long way from the retrofit days of semiconductor processing equipment. Today, a broad spectrum of equipment made specifically for MEMS is being offered by companies including EVG, Suss Microtec and Jenoptic. These companies have done an excellent job in their Marketing 101 and have developed equipment well suited to the requirements of the industry. The major area of interest in infrastructure is in MEMS foundries...these organizations produce MEMS wafers from designs provided by its customers. Our research shows that there are over 60 of these foundries worldwide and have thus created an oversupply of these services. Major players include Micralyne, Asia Pacific Microsystems, Colibrys and IMT. The newly adopted “fabless” or “fablite” MEMS business model was taken from the semiconductor industry. Most VC’s prefer to fund companies using this model since their investment is in ideas and people versus brick and mortar. The major drawback here is that each foundry has its unique set of processes and tools. If the development of the early design is conducted at a university, there stands a good chance that there will be a need to undertake process modifications or device design changes to effect a smooth transition. Also of note is the need to convert 4-inch and 6-inch wafer sizes to 8-inch in order to take advantage of the new technologies associated with 8-inch production equipment as well as the lower cost per device resulting in using the larger format wafer. SVTC is an organization focused on providing this service. Here again, process and design changes may be necessary which could lead to additional cost and a time to market delay. In summary, there is more infrastructure in place than is presently required for the successful commercialization of MEMS. It is critical that MEMS organizations fully understand their short term and long term manufacturing requirements early on in order to judiciously select the right manufacturing partners.

#### INDUSTRY ASSOCIATIONS (Grade = B+)

A number of industry associations currently exist worldwide to support the commercialization. Chief amongst these are the Micro and Nanotechnology Commercialization Education Foundation (MANCEF), the MEMS Industry Group (MIG) in the US and IVAM in Germany and Nexus in the EU. All of these organizations conduct numerous meetings yearly and provide a valuable forum for their members.

#### STANDARDS (Grade = C)

The progress on standards for MEMS has been less that exciting. Less than 10 standards currently exist for MEMS whereas in the semiconductor industry, over 700 have been published by the Semiconductor Equipment and Materials International (SEMI) organization. The reason for the lack of standards is the lack of standard processing for

MEMS as well as many companies using their processing as product differentiators. I believe that many, and not all, items associated with MEMS packaging, processing and test can have standards and I believe that the creation of standards will have the effect of reducing part cost in the industry.

#### VENTURE CAPITAL ATTRACTION (Grade = C)

Venture Capital attraction continues to focus on MEMS companies that promise to be successful in the large volume consumer and medical markets. The grade has migrated to “C” from its highpoint grade of “A” at the height of the high tech bubble in 2001. Recent startups including SiTime (system timing products) Invensense (gyros for digital cameras) have received advanced Round B and C funding in 2007. VCs are always looking for good investment opportunities characterized by good management, a large and growing market and a great idea with defensible intellectual property. However, not many MEMS companies are able to prove that they can deliver a 10X return on invested capital in five years (the mantra of the VC industry). Recently, VCs are focusing their interest in energy, “green” and Web 2.0 opportunities and have moved away from Nanotechnology. New MEMS investments are taking the back burner while earlier funded companies continue to be funded.

#### CLUSTER DEVELOPMENT (Grade = B-)

Cluster Development was added to the report card in 2003. The creation of clusters has proven to be a major catalyst in creating new MEMS companies. Clusters were created to increase the competitiveness of the organizations within the cluster (Reference 1). The first MEMS cluster was created in 1986 in Dortmund Germany (Reference2). Since then, more than 35 MEMS-specific clusters have been created worldwide.. Successful clusters include Washington State, Hinshu Taiwan, Edmonton Canada and Minatec in Grenoble France. MEMS clusters currently in the ramp-up stage include Manaus Brazil and Paseo del Norte Mexico. While existing clusters are tending to grow, and achieve their financial objectives, MEMS cluster funding activity has given way to the funding of Nanotechnology clusters. Here, federal and local governments are making significant investments. Hopefully, some of the R&D undertaken in these nanotechnology clusters will have MEMS content and/or applicability.

#### LESSONS TO BE LEARNED BY NANOTECHNOLOGY

As MEMS has learned a great deal from the semiconductor industry, I submit that nanotechnology should learn from its bigger brother i.e. MEMS...1) not to create technology for technology sake...understand the market unfulfilled need by undertaking formal and well planned market research 2) take care to understand competitive offerings and to create a product that is defensibly different...3) not fall prey and oversell the ability of nanotechnology to uniquely solve problems...4) properly promote the product especially its ability to uniquely solve the customers’ application problems.

It is fortunate that nanotechnology manufacturing has been an area of significant funding from organizations including NSF. MEMS were not so fortunate in its early days what has led to the slowdown of its commercialization timetable.

At this point in time, it appears that nanotechnology has been a good student in many of the critical success factors given above. The challenge will be to continue to fund research especially in manufacturing area, to continue to support development in the infrastructure area including the providing of excellent manufacturing and metrology tools, the continuation of attracting venture capital money especially in the current financial market conditions and to create standards and roadmaps to help guide the industry participants.

### SUMMARY

The MEMS commercialization report card has demonstrated the significant advances of the industry in addressing by the 14 critical success factors that are important in achieving successful commercialization of MEMS. While a number of the grades have changed for the better or worse, the overall grade remained at “B-“ as it was in 2006. Many of grades still need major improvement including marketing, standards, venture capital attraction wealth creation, profitability and employment. The author encourages the individuals interested in the commercialization of nanotechnology become students of the evolution of both the semiconductor and MEMS industry. To quote the popular author, George Santayana in his book, *The Age of Reason* (1908-1910)...”those who forget the past are condemned to relive it”. For an expanded version of the report card please visit...[www.rgarce.com/MEMS\\_reportcard2007](http://www.rgarce.com/MEMS_reportcard2007).

<b>Product</b>	<b>Discovery</b>	<b>Product Evolution</b>	<b>Cost Reduction</b>	<b>Full Commerc.</b>
Pressure Sensors	1954-1960	1960-1975	1975-1990	1990
Accelerometers	1974-1985	1985-1990	1990-1998	1998
Gas Sensors	1986-1994	1994-1998	1998-2005	2005
Valves	1980-1988	1988-1996	1996-2002	2002
Nozzles	1972-1984	1984-1990	1990-2002	2002
Photonics/Displays	1980-1986	1986-1998	1998-2005	2005
Bio/Chemical Sensors	1980-1994	1994-2000	2000-2010	2010
Radio Frequency (R.F.)	1994-1998	1998-2001	2001-2009	2009
Rate Sensors	1982-1990	1990-1996	1996-2006	2006
Micro Relays	1977-1993	1993-1998	1998-2010	2010
Oscillators	1965-1980	1980-1995	1995-2010	2010

Figure 1: MEMS Commercialization Timetable

SUBJECT	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
R&D	A	A	A	A	A	A-	A-	A-	A-	A-
Marketing	C-	C	C+	C+	C+	C	C	C+	C+	C+
Market Research	C	B-	B-	B-	B	B	B+	B-	B-	B
Design For Manufacturing	C+	B-	B	B	B	B	B	C+	B-	B
Established Infrastructure	C+	B	B+	A	A	A	A	A-	A	A-
Industry Association	INC	INC	INC	B	B+	B+	B+	B	B	B+
Standards	INC	INC	INC	INC	C	B-	B-	B-	C+	C
Management Expertise	C	C	C+	C+	C+	C+	C+	B-	B-	B
Venture Capital Attraction	C	B-	B+	A	C	C-	C	C+	C+	C
Creation Of Wealth	C	B-	B+	A	C	C-	C-	C-	C-	C
Industry Roadmap	N/A	B-	B	B+	A-	A	A	B	B-	C+
Profitability	C-	C-	C-	C-	C-	C-	C-	C	C+	C
Employment	INC	INC	INC	INC	INC	C	C	C+	C+	C+
Cluster Development	INC	INC	INC	INC	INC	B	B+	B+	B	B-
<b>Overall Grade</b>							<b>B</b>	<b>B</b>	<b>B-</b>	<b>B-</b>

Figure 2: 2007 MEMS Industry Report Card

## REFERENCES

- (1) M. Porter, On Competition, Harvard Business School Press, 1998, 481 pp.
- (2) R. Grace, Technology Clusters and their Role in the Development of the Microsystems Industry, Proceedings of the Commercialization of Micro and Nanotechnology Conference (COMS) 2003, Amsterdam, The Netherlands, September 8-11, 2003. [www.rgrace.com](http://www.rgrace.com)