# The 2006 Report Card on the Barriers to the Commercialization of MEMS and Nanotechnology

Roger H. Grace
President, Roger Grace Associates
Past President, Co-Founder, Micro and Nanotechnology
Commercialization Education Foundation (MANCEF)
rgrace@rgrace.com

www.rgrace.com

## INTRODUCTION

Barriers to the commercialization of every technology exist. Nanotechnology and Microelectromechanical Systems (MEMS)/Microsystems Technologies (MST) are not exceptions. We are currently at a half-century of MEMS research, design, and development. Many people ask, "Why has it taken so long for the MEMS/MST market and technology to realize it's potential or reach the expected volumes?" Will Nanotechnology face the same barriers?

Here, I will address 14 major barriers to the commercialization of MEMS/MST and the progress made to overcome these barriers through the introduction of a "MEMS Industry Report Card " given in Figure2. The report card has been updated yearly since 1998 [1], where it was first presented at the seminal Hilton Head (South Carolina US) Conference. The changes in grades from 1998 to 2006 will be addressed here with some rationale for the actual grade as well as recommendations for improvement and lessons to be learned from the Semiconductor industry. For the successful commercialization of Nanotechnology, lessons learned from the MEMS/MST ( as well as from the semiconductor industry) areas must be heeded.

## COMMERCIALIZATION TIMETABLE

Figure 1 provides as assessment of the commercialization timetable for a number of popular MEMS/MST products ( the11$^{th}$. Edition of the Mirriam Webster's Collegiate Dictionary defines commercialization as…" to manage on a business basis for profit").The dates of the phases of development were created using research into technical papers and having discussions with many of the pioneers of the MEMS industry. It is interesting to note that the first MEMS/MST product to be fully commercialized was the pressure sensor. It took approximately 36 years for this product to be fully commercialized. This is not good news. However, as more products became developed to meet the need of the market, MEMS/MST entrepreneurs began the difficult task of learning from their experience with pressure sensors and applied these lessons learned to accelerate the commercialization of new products. As one can see, accelerometers rate sensors (a.k.a. gyroscopes) were commercialized in 24 years and displays in 25 years. Certainly, lessons are being learned by many industry participants to bring these products/technologies to market quicker. The results of the table demonstrate that it takes a great deal of commitment of time, people and money to commercialize a product/technology and unless one takes advantages of past developments success/failures, they are doomed to be on the slow lane for commercialization.

| Product | Discovery | Product Evolution | Cost Reduction | Full Commerc. |
|---|---|---|---|---|
| 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 | 2001-2008 | 2008 |
| Rate Sensors | 1982-1990 | 1990-1996 | 1996-2006 | 2006 |
| Micro Relays | 1977-1993 | 1993-1998 | 1998-2008 | 2008 |
| Oscillators | 1965-1980 | 1980-1995 | 1995-2009 | 2009 |

Figure 1: MEMS/MST Commercialization Timetable

## RESEARCH METHOLOGY

The methodology used to develop the grades and the rationale was to employ a "Delphi" market research technique where a select number of MEMS/MST industry experts representing the Americas, Europe and Asia/Pacific were personally interviewed for their opinions. These interviewees represented the broad MEMS/MST industry and included people from infrastructure (testing, foundries, capital equipment, consultants and software providers); manufacturers of MEMS/MST components and end users of MEMS/MST products. In this fashion, a truly representative but not statistically significant sample was realized. The period of interest for the 2006 grades encompassed July 2005 to June 2006.

## RESULTS

**R&D (Grade = A-):** Spending on MEMS R&D has been robust even before 1998 with DARPA/ARPA making major investments early in the game. Private funding also has historically supported this R&D activity in a robust fashion. The research showed that funding from MEMS/MST has been shifting over to Nanotechnology. The Small Business Innovtive Research (SBIR) program has been very supportive for MEMS/MST companies especially in their Phase 2 and Phase 3 programs where commercialization is the primary objective. The European Community has been funding MST through its Framework programs 1 through 4. Framework 5 will be funded shortly. Finally, the EC has funded the EPoSS program in 2004 with the focus not being on device research but the integration of MST-based smart systems value chain as they apply to aerospace, automotive, telecom, medical technology and logistics/RFID sectors. The research will be conducted in institues ans small-medium enterprises (SMEs). This truly is a victory for commercialization advocates. The year 2006 saw a small upturn in the high-tech economy and in corporate R&D budgets (including personnel) but not enough to affect its grade. Total worldwide funding of R&D efforts grew from $884.8 billion US to $925.5 billion US in 2006 constituting a 4.6% increase (1). The 2005 grade continued from its "A-"value in 2003, 2004 and 2005 (2).

**Marketing (Grade = C+)/Market Research (Grade = B-):** Marketing grades have moved slowly from the 1998 C- value to C+. MEMS/MST companies, by and large have been created by strong technically-oriented people who tend to believe in the "build it and they shall come" mantra. Not much formal market research historically has been conducted to determine customer needs and price points. This lack of marketing, market research, and marketing expertise still exists today in direct comparison to the excellent and significant marketing/promotion activities demonstrated by the semiconductor industry. For MEMS/MST to be truly successful, a major effort must be undertaken by solution providers to understand customers needs/wants, to provide unique solutions, and to provide adequate resources to promote each company's market position, brand, and approach to solving these issues as well as to differentiate its products against its competition. The best way for this to be accomplished is through rigorous market research programs. Faster, better, cheaper is the mantra of the semiconductor industry in direct response to customers' needs. MEMS/MST producers need to adopt a similar customer-centric attitude. From a formal market study perspective, a number of organizations have made significant contributions to provide market studies on MEMS/MST. The NEXUS "Market Analysis for Microsystems III 2005-2009" was published in December 2005. Numerous other reports from other suppliers are available.

**Established Infrastructure (Grade = A-):** Since its C+ 1998 grade, this area has improved significantly and has remained in the A/A- region since 2001. In early days, most MEMS processing equipment, packaging, and test were “hand-me-downs” from the semiconductor industry. Most MEMS/MST fabs today use 6” diameter wafers for high-volume production; many still use 4” wafers. A handful use 8”. For MEMS/MST fabrication, in-house process engineers typically accomplished modifications to the existing semiconductor process design driven tools. Today things have dramatically improved with many companies, e.g., EV Group, Jenoptik, STS, and Suss MicroTec, providing custom MEMS/MST specific equipment solutions, replicating the semiconductor industry. In addition, MEMS/MST specific design automation tools are being made available by a number of suppliers, including Coventor, Intellisense and MEMScap. In the case of the increasingly more popular fabless semiconductor model, most newly created MEMS companies are fabless since there is a selection of over 60 worldwide sources of MEMS/MST foundries in business today including Dalsa (Canada), Micralyne (Canada), Sony (Japan), Asia Pacific Microsystems (Taiwan), IMT (US), and Colibrys (Switzerland). Our research has determined that the capacity of the MEMS/MST industry is approximately 40%-50% in excess of its current needs. Value is one of the most significant barriers to the commercialization of MEMS/MST. Packaging and testing are most costly for MEMS/MST today while market applications drive prices to the bottom. A number of organizations including Amkor (Korea) and Bennington Microsystems (US) provide packaging foundries and MST Microsystems Technology is a merchant market provider of MEMS/MST paging solutions. These are conflicting and one must give in. When MEMS/MST provides value such as Pentium processors or if packaging and testing can be brought to the level of a few pennies the cost / value hurdle will be removed and the floodgates open for MEMS/MST. A number of organizations provide packaging solutions including Amkor (Korea) and Bennington Microsystems (US) while MST Technology Systems (US) provided merchant market MEMS/MST testing solutions.

**Industry Association (Grade = B):** In 1998, no association existed to promote the MEMS industry and its commercialization. Today the Micro and Nanotechnology Commercialization Education Foundation (MANCEF) (www.mancef.org) and MEMS Industry Group (MIG) (www.memsindustrygroup.org) are growing not-for-profits supporting this industry. MANCEF, founded in 1999, boasts over 1000 members worldwide and has as its primary goal the education of the micro and nanosystems industry through the creation and dissemination of information to the people, organizations, and governments who are in the position to influence the commercialization process. Its annual Commercialization of Micro and Nanosystems Conference (COMS) is a unique forum which addresses the major issues of commercialization over a three and one-half day period with typically over 100 world-recognized experts making presentations. MIG, founded in 2001 has 61 member companies and hosts two annual meetings, their METRIX meeting in Pittsburg and their Executive Meeting in

Scottsdale Arizona….both in the Fall timeframe. Nexus (www.nexus-mems.com) was created in the early 90's by the European Commission and has been extremely valuable in developing the commercialization activity in Europe. Currently there are 1350 members representing 480 organizations.

In addition, the Semiconductor Equipment and Materials International (SEMI) (www.semi.org) organization has formed the International MEMS Steering Group (IMSG) which recently has been disbanded. The semiconductor industry owes a great deal of its success to the SEMI and SEMATECH organizations and their efforts to organize, inform, and standardize the semiconductor industry. The MEMS/MST industry needs to similarly embrace organizations whose role is to help facilitate the commercialization of this technology. Various regional "small tech" associations have either recently formed e.g. Michigan and New Jersey or are in the early stages of formation. The IVAM organization in Germany (www.ivam..de) founded in 1995 was the first such organization currently representing over 180 primarily German and other EC companies and institutes.

**Standards (Grade = C+):** This grade was reduced from B- in 2005. SEMI has been the major proponent of helping facilitate the creation of standards for MEMS as they have historically been for the semiconductor industry. The last three years have seen increased interest by the MEMS/MST industry to support standards. This is evident by the initiation of the first two MEMS/MST process standards recently issued and the many meetings over the past five years of the SEMI MEMS Standards Committee. The good news is that the first SEMI MEMS standard , "Guide for Standard Fluidic I/O Design, Fabrication, and Assembly in Microscale Fluidic Systems" was available on July 1, 2005. The maturity of an industry can be directly related to the development and issuance of standards. Lesson to be learned from the Semiconductor Industry: Over 700 SEMI standards have been published to date and are available. The adoption of these standards brings a number of benefits to the users – both equipment suppliers and device manufacturers including lower product cost and faster time to market of the end product. For MEMS/MST to accelerate its commercialization timetable, it will be necessary for it to create and adopt many process, packaging, and testing standards.

**Profitability (Grade = C+), Creation of Wealth (Grade = C-), and Venture Capital Attraction (Grade = C+)**: The downturn in worldwide economic conditions severely punished most high technology companies in the 2001-2003 time frame, including companies with MEMS/MST programs. Corresponding to the height of the NASDAQ in 1999 and early 2000, many new MEMS/MST companies, especially those participating in the booming optical telecom market, were founded…only two exist today. Today, it is quite a different story. Little activity exists in new startups. Sensor Platforms (interface ICs), Invensense (gyros), LV Sensors(networked sensors) and SiTime (oscillators) are for new promising startups in Silicon Valley that have been venture capitalist funded over the past two years. Microfabrica (microstructures-Los Angeles),IMT (foundry-Santa Barbara), Akustica (microphones-Pittsburg) and Colibrys (accelerometers and foundry-Switzerland) have also received second/third round funding. From 1990 through 2000, about 200 venture-backed IPOs were launched per year. The yearly average since then is under 50 according to Thomson Financial. In 2005, the market value of venture-backed companies rose just 1.5% from the previous year. In Q-1 2006, the value was up 1% over the previous quarter according to Sand Hill Index. In Q-2, 2006 there were 19 venture –backed IPOs versus 10 in Q-1 [3]. While these are overall industry figures, they should provide an indication as to the health of the IPO business…and that it that all is not well. The French company, MEMSCap went public a few years ago and as such was one of the very few MEMS companies that has done so over the past five years. Its stock is down substantially from its offering price. Finally, VCs tend to want to fund companies that have the ability to grow to very large companies quickly. This is typically what does not exist in the MEMS/MST industry. VCs consider a $50 Million (US) annual sales volume the lowest that is required to produce a successful IPO. While most privately MEMS/MST companies do not currently have this sales volume, we expect that some of the new startups mentioned above to be good candidates for IPOs since they are targeting the high volume consumer market.

Mergers and acquisitions have been on the upturn. The early wealth created in the MEMS/MST industry by a small number of entrepreneurs was vis-à-vis acquisition by large optical telecom companies. Due to the demise of this industry, these acquired MEMS/MST companies also were adversely affected, sold, or written off by their previous owners. A positive note here was the recent acquisition of BEI Systems by Schneider in a stock trade valued at $562 Million US and the acquisition of the Texas Instruments Sensors and Controls unit by Bain Capital for over $3.0 billion US. A number of biomems companies have gone public in the 1996-1998 timeframe. However, these companies have not been as successful as hoped for with their sales volumes less than projected and stock prices currently not much higher than their original offering price and certainly significant less than their historical high. Profitable MEMS/MST companies are few and far between (e.g. Micralyne, Sillicon Microstructures, and NovaSensor). This is due to many factors including the commoditization of solutions (automotive sensors), small number of killer applications, and lack of product differentiation and adequate marketing.

In summary, these grades continues to pull the overall commercialization report card grade down and the "Creation of Wealth" grade received the lowest grade of any of the other 13 subjects. Regrettably, the research does not see any great improvement soon. Perhaps the huge success of some of the high volume startups mentioned above will help turn around this situation and breathe new life into the investment business.

**Industry Roadmap (Grade B-):** This grade fell from "B" in the 2005 report card. Two MEMS/MST industry roadmaps currently exist. The MANCEF International Commercialization Roadmap, which was published in February, 2003 is a 16-chapter, 614-page classical technology-driven roadmap, addressing many of the issues in this article including standards and infrastructure (www.mancef.org). The early work on this publication was funded by SEMI. A September 2004 update to this document included chapters on patents and RF MEMS. The Nexus roadmap (www.nexus-mems.com), which was formally introduced to the market in September 2003, is a product-market roadmap created to a large degree from inputs of the numerous Nexus User-Supplier Clubs. Together, these roadmaps provide readers with a wealth of information to aid in the commercialization of MEMS. However, all this being said, a large number of the respondents either never have heard of the report, consider the reports to be out of date or feel that the reports do not adequately their informational needs.

**Technology Cluster Development (Grade = B-):** This subject was added in 2003 to reflect the ever-increasing value that regional and federal governments place on micro and nanotechnology as a viable business. The grade was reduced from "B" in the 2005 report card. It appears as a result of the location the results differed greatly. European respondents gave this subject higher grades than their US counterparts. In our opinion this is due to the higher level of participation of the many EC individual governments believing strongly in the financial support of their national technology initiatives. No less than 35 MEMS/MST/NANO clusters have been formed since the first one in Dortmund Germany in 1986 [4]. Currently, clusters exist or are in the process of being formed in Europe, Asia/Pacific, North and South America. Of considerable interest is the level of commitment of the regional governments of Edmonton Canada, Manaus (Amazon) Brazil [5] and in Mexico especially in Paseo De Norte in their rapid expansion of programs to support MEMS technology development. To date, thousands of highly trained and high paying jobs and scores of companies owe their existence to their creation. Lesson to be learned from the Semiconductor Industry: Clusters certainly have existed in the semiconductor industry since the early 60's. Silicon Valley, Route 128, and Austin, Texas are most noteworthy. The intellectual property, source of capital funding and establishment of in-depth infrastructure associated with these semiconductor clusters are prerequisites for future success.

## LESSONS TO BE LEARNED

So, what commercialization lessons have been learned to date by the Nanotechnology industry and what are the key lessons to be learned from the semiconductor and MEMS/MST industries? 1) do not create technology for technology sake…the raison d'etre should be a well defined market need for a specific solution that is uniquely enabled by a nanotechnology-based solution. 2) care must be taken to understand competitive offerings and to communicate/promote to the market the unique customer benefit of the nanotechnology-based approach. 3) do not fall prey and participate in the great "hype" of nanotechnology in the popular press.

It is gratifying that nanotechnology research has received a great deal of support from governments worldwide with 2005 funding levels exceeding $3.0 Billion US. MEMS/MST has never achieved this level of support from federal governments and is more than likely not to ever achieve such. In addition, a great deal of private investment through venture capital has made itself available…more so than has ever been available for MEMS/MST. A number of the companies that are being funded are in the equipment and metrology area…the creation of a solid manufacturing infrastructure to insure large throughput and low cost nanotechnology-based solutions was a major deficiency of the MEMS/MST industry as can be seen from the report card. Most noteworthy is the National Science Foundation in the US and their major support through numerous grants to support Nanomanufacturing research.

At this point in time, it appears that nanotechnology has been a good student of its bigger brother i.e. MEMS/MST in a number of areas noted above. The challenge will be to continue to fund research; attract venture capital money; continue to support infrastructure development including design for manufacturing, metrology and manufacturing equipment; and to create roadmaps and standards to help guide the direction of these efforts.

## SUMMARY

As one can see, the MEMS/MST industry has made significant advances in overcoming commercialization barriers since the first report card was published in 1998. While a number of grades have changed over the past 12 months, the 2006 overall grade was reduced to B-. Many lessons have and still need to be learned from the semiconductor industry (as well as other industries). It is interesting to note that education continues generation after generation, today education opportunities abound in the nanotechnology industry from its big brother, the MEMS/MST industries. The author strongly recommends that people interested in the commercialization of nanotechnology become students of the progress of both the semiconductor and MEMS. To quote a 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 2006 Report Card, please reference www.rgrace.com .