BARRIERS TO THE SUCCESSFUL COMMERCIALISATION OF MEMS:

The 2014 MEMS Industry Commercialization Report Card

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Preface

I consider myself to be quite fortunate to be given the opportunity (again) to write about the findings of my most recent MEMS Commercialization Report Card research project for the readers of Commercial Micro Manufacturing International (CMM). The first publishing of my Report Card in CMM was the 2012 version which appeared in the 2013, Vol. 6, No. 3 issue [1]. The results of this unique market study, begun in 1998 and conducted annually, have tracked the development of what I consider to be the critical success factors for the commercialisation of MEMS. I must apologise at this time if some of the readers of previous Report Cards have seen some of these background materials, however, I am compelled to briefly state them again in order to provide our new readers with the valuable background and methodology of the study process and its important role and contribution to the MEMS community. For those who have been following previous Report Cards, you have my permission to 'fast forward' to the results of this year's Report Card.

Introduction

This article provides the results of the recently completed Roger Grace Associates (RGA) 2014 MEMS Industry Commercialization Report Card Study (Report Card). Most recently, the MEMS Commercialization Report Card for the year 2013 was published in the Volume 7, Number 4 edition of Commercial Micromanufacturing in 2014 [2]. The article appearing here serves as an update. The Report Card has been published annually beginning in 1998 [3]. For the establishment of the specific topics of the Report Card, market research was conducted on the general topic of technology commercialisation and resulted in the selection of a number of critical success factors (a.k.a. topics) that were considered necessary for successful commercialisation specific to MEMS and to the MEMS industry. The Report Card began with nine topics in 1998 and by 2003 it had expanded to 14 based on continuous reassessment of the ever-changing dynamics of the MEMS industry.

The purpose of the Report Card is to provide MEMS industry participants with an objective assessment of these critical success factors over time and to act as a tool to help them better understand, respond to and exploit the ever changing dynamics of the MEMS industry. The MEMS Industry Commercialization Report Card has been developed not only to help assess the progress of the commercialisation of this technology but more importantly to serve as a vehicle to help guide industry participants to overcome the barriers to the successful commercialisation of MEMS.

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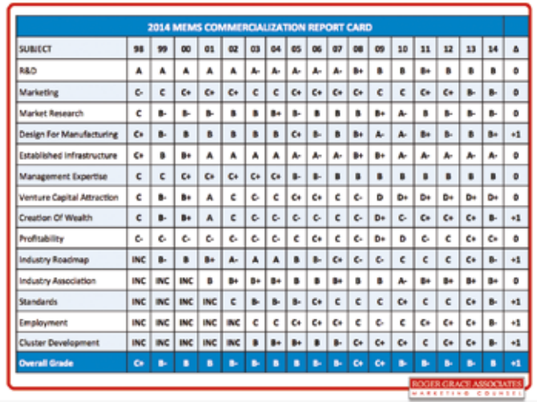
The Report Card is unique in the technology commercialisation strategy sector and also to the MEMS industry. It has been widely published and presented worldwide since its introduction in 1998 and is widely accepted as a valuable tool for MEMS industry participants to create winning business strategies for their organisations.

It is interesting to note that MEMS technology established vis-à-vis the discovery of the piezoresistive effect at Bell Laboratories in 1955 by Charles Smith is approximately the same 'age' as Integrated Circuit (IC) technology established vis-à-vis the semiconductor effect that was discovered at the same laboratory by Bardeen et al. only a few years earlier. More importantly however, the total sales of MEMS as reported by numerous groups in 1998 was approximately 1/25th of the sales of ICs at the time of the publishing of the first Report Card. The MEMS market for 2014 has been reported by several organisations to be approximately $11 Billion (US) whereas Gartner Research has reported that that total IC market for 2014 was $339.8 Billion (US), approximately a 33:1 ratio. The positive news here is that the MEMS market has been reported to be steadily growing over the past several years at a compounded annual revenue growth rate (CAGR) in the 12-15 % range (primarily fueled by mobile phones/tablets and consumer products) whereas the IC market has recently fluctuated $307.8 Billion (US) in 2011, $299.9 Billion (US) in 2012 and $312.9 Billion (US) in 2013 with a CAGR from 2013 to 2014 of 7.9% (per Gartner Research). However, the question still remains: why is there still such a disparity in the market sizes? The Report Card's raison d'être is an attempt to help address this seeming paradox.



2014 MEMS COMMERCIALIZATION REPORT CARD

SUBJECT	98	99	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	Δ
R&D	A	A	A	A	A	A-	A-	A-	A-	A-	B+	B	B	B+	B	B	B	0
Marketing	C-	C	C+	C+	C+	C	C	C+	C+	C+	C+	C	C	C+	C+	B-	B-	0
Market Research	C	B-	B-	B-	B	B	B+	B-	B	B	B	B+	A-	B	B-	B-	B-	0
Design For Manufacturing	C+	B-	B	B	B	B	B	C+	B-	B	B+	A-	A-	B+	B-	B	B+	+1
Established Infrastructure	C+	B	B+	A	A	A	A	A-	A-	A-	B+	B+	A-	A-	A-	A-	A-	0
Management Expertise	C	C	C+	C+	C+	C+	C+	B-	B-	B	B	B	B	B	B	B	B	0
Venture Capital Attraction	C	B-	B+	A	C	C-	C	C+	C+	C	C-	D	D+	D+	D+	D+	D+	0
Creation Of Wealth	C	B-	B+	A	C	C-	C-	C-	C-	C	C-	D+	C-	C+	C+	C+	B-	+1
Profitability	C-	C-	C-	C-	C-	C-	C-	C	C+	C	C-	D+	D	C-	C	C+	C+	0
Industry Roadmap	INC	B-	B	B+	A-	A	A	B	B-	C+	C-	C-	C	C	C	C+	B-	+1
Industry Association	INC	INC	INC	B	B+	B+	B+	B	B	B+	B	B	A-	B+	B+	B+	B+	0
Standards	INC	INC	INC	INC	C	B-	B-	B-	C+	C	C	C	C+	C	C	C+	B-	+1
Employment	INC	INC	INC	INC	INC	C	C	C+	C+	C+	C	C-	C	C+	C+	C+	B-	+1
Cluster Development	INC	INC	INC	INC	INC	B	B+	B+	B	B-	C+	C+	C+	C	C+	C+	B-	+1
Overall Grade	C+	B-	B	B	B-	B-	B	B	B-	B-	C+	C+	B-	B-	B-	B-	B	+1

ROGER GRACE ASSOCIATES MARKETING COUNSEL

<< Figure 1: MEMS Commercialization Report Card research project was launched in 1998 and has yearly provided an objective assessment of the progress of the MEMS industry in its efforts to achieve successful commercialisation success. 2014 grade was B, an improvement from its prior three years' level of B- and the highest grade to be attained since 2005. Courtesy: Roger Grace Associates. >>

Research Methodology

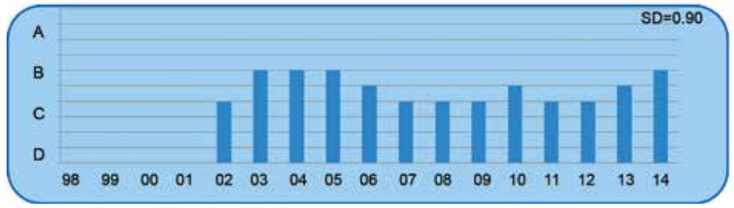
Questionnaires were emailed to selected individuals in the RGA database who have and continue to play major roles in the MEMS commercialisation process. These 'expert' participants represented a broad range of MEMS manufacturers, users of MEMS as well as individuals who represent companies engaged in MEMS infrastructure e.g. foundries, design software and equipment providers. Academics were not included in the research universe. The participants represented a worldwide universe with the majority of the respondents coming from the US and Europe. The members of the research universe were asked to rate the 14 critical success factors/topics using grades 'A' through 'D' using plusses and minuses where applicable. Additionally, they were asked to provide specific comments a.k.a. 'verbatims' as to the rationale of their assigned grades. The 78 respondents had a collective experience of over 1700 years averaging out to approximately 20 years per respondent. Certainly this was an exceptionally well-experienced and well-qualified group of participants a.k.a. 'experts'. This research approach, known as "Delphi" was developed by Project Rand during the 1950's and 60's by Olaf Helmer, Norman Dalkey and Nicholas Rescher. It provides the best possible insight into a research topic where a statistically significant/projectionable approach is not feasible.

Results

Figure 1 provides the letter grade results of the 2014 MEMS Commercialization Report Card on a yearly basis from 1998 to 2014. It also provides the change in grade from 2013 to 2014. The 2014 MEMS Commercialization Report Card established an overall grade of B to the 14 critical success factors for MEMS commercialisation. The overall grade improved from the B- grades of 2010 to 2013. More important, however, were the changes in the individual grades. Out of the 14 topics, Established Infrastructure had the highest grade of A- and Venture Capital Attraction had the lowest grade of D+. Six topics improved one grade level, no topics decreased in their grade level and the remaining eight topics remained constant.

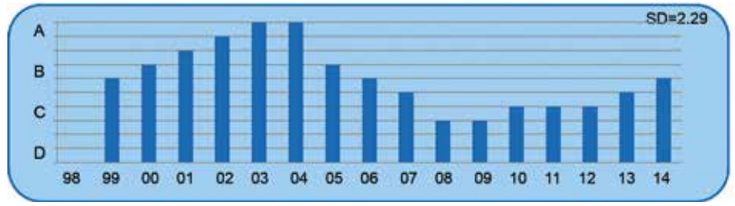
Increasing one grade level from 2013 were Roadmaps (C+ to B-), Standards (C+ to B-), Cluster Development (C+ to B-), Design for Manufacturing (B to B+), Employment (C+ to B-) and Creation of Wealth (C+ to B-). The grades established that Venture Capital Attraction continues to need major improvement and may be critical items in restraining the industry from realising its true potential. Venture Capital Attraction has been in the D category since 2009 when the worldwide crisis hit our economy and regrettable venture capital monies have been targeted to software and social media startups.

In the following paragraphs, I will attempt to summarise the 'verbatims' of the responses to three topics that experienced a change in grade from 2013 to 2014 and to provide some of my personal opinions as to the rationale for these changes. These topics are: Standards, Roadmaps and Cluster Development. The other three topics will not be addressed at this time because of limited editorial space available.



<< Figure 2: MEMS Standards 2014 grade of B- has been positively influenced by the recent success of the MIG/ NIST/IEEE team in creating the "Data Sheet Performance Specification" (IEEE-2700-2014). This level was last achieved in the 2003-2005 period. Standard Deviation (S.D.) was 0.9. Courtesy: Roger Grace Associates. >>

<< Figure 3: MEMS Industry Roadmap grades have been bolstered to their current B- level, having been significantly positively influenced by the recent introduction of the Trillion Sensors Roadmap Initiative and the Trillion Sensors Summits. Standard Deviation (S.D.) was 2.29. Courtesy: Roger Grace Associates. >>



Roadmaps

Technology Roadmaps were reported to have started in the 70's. In the early 2000's, the Micro and Nanotechnology Commercialization Education Foundation (MANCEF) produced the first MEMS and top-down nanotechnology roadmap which continues to be upgraded to this day and is currently in its fourth edition. Most recently, EPoSS (2013), iNemi (2013) and ITRS (2014) have dedicated chapters of their roadmaps to address MEMS. The Trillion Sensors (TSensors) Roadmap, initiated in 2013 has gained immediate and significant attention in the industry and is in the process of quickly ramping up.

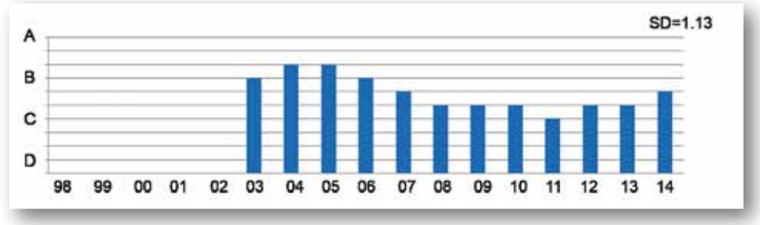
As reported in the previous MEMS Commercialization Report Cards, the MEMS Roadmap grades have been less than stellar since they first appeared in 1999, however, the recent improvement in grade level from C to B- from 2012 to 2014 holds promise shown in figure 2. Verbatims establish that a very high level of awareness currently exists for the Trillion Sensors Roadmap (TSensors Roadmap) effort and widespread support and hope in the success of Janusz Bryzek, TSensors Roadmap founder and chairman, and his collaborators' activities to accomplish its lofty goals and objectives abound [4]. With the recent involvement of the MEMS Industry Group (MIG) in its adoption the Trillion Sensors Initiative under a MIG divisional status, we believe that the organisational efforts by MIG that produced a successful MEMS and Sensors Standard will be utilised to create the same successful and timely outcome for the TSensors Roadmap. Janusz and his collaborators welcome interested parties to join in this effort. Please contact him at www.tsensorssummit.org.

Standards

Since the first appearance of a MEMS device over 50 years ago, only 10 MEMS standards have been created through the efforts of the Semiconductor Equipment and Materials International (SEMI). This is in comparison with their approximately 900 IC standards SEMI created for a technology that has approximately the same time frame of commercialisation. MEMS standards grades improved from C+ in 2013 to B- in 2014 (figure 3) significantly based on the level of success achieved by the MEMS Industry Group (MIG) and the US National Institute of Standards and Technology (NIST) -organised MEMS and Sensors Standards Committee. Their recent Data Sheet Performance Specification (IEEE 2700-2014) is the first IEEE MEMS and Sensors performance standard. I believe that effort should be considered a poster child for future MEMS standard developments. It was a result of the professionally planned and thorough manner in which the standard was created including polling the industry as to what items needed to be included and the quick turn-around of approximately 12 months to complete creation process from inception to issuance.

There are many more MEMS standards that need to be created to further successful MEMS commercialisation. These need to address materials, processes, definitions, test methods and procedures, packaging and interoperability. To exploit 'low hanging fruit', I believe that the MEMS industry should judiciously address the approximately 900 SEMI standards and create MEMS –specific standards that draw on similar technology and process of these standards that were created specifically for ICs. 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 the MEMS commercialisation eco-system especially in light of the exploding creation of MEMS and sensor-based solutions for Internet of Things (IoT) and wearable applications.

<< Figure 4: MEMS Cluster Development grades have improved over the past three years from C in 2011 to B- in 2014. The recent announcement of Florida's iCAMR is the first new cluster in over a decade and is expected to continue to positively influence this grade in the near future. Standard Deviation (S.D.) was 1.13. Courtesy: Roger Grace Associates. >>



Cluster Development

Micro and nanosystems clusters have proven themselves to be effective facilitators to the successful commercialisation of these technologies [5]. They literally have created hundreds of companies worldwide and thousands of high -skilled and high -paying jobs. Their economic development growth and enhanced competitive advantage objectives have more than been met. I foresee the continuation of support for both existing micro and nanosystems clusters in the future and the creation of yet additional clusters to help facilitate the successful commercialisation of these technologies worldwide. Furthermore, based on the many of the verbatims, I believe that the concept of clusters is not well known as well as thoroughly understood by the MEMS community, a verbatim stated: "not sure what this means" and to use a verbatim on the topic which sums up the situation: "this is a topic that is beyond the vast majority of management and decision makers, yet the power is unmistakable" — now give that person a cigar!

Since I began tracking this topic starting with the 2003 Report Card, which was facilitated as a result of a strategic marketing research study that I conducted on technology clusters for the State of Michigan's Economic Development Corporation, the grades have varied between C+ to B+ with the 2014 grade improving from C+ in 2013 to B- in 2014 and a standard deviation of 1.38 over the 12 years of its tracking of the grades shown in figure 4. I believe that these mediocre grades provided by the market research participants have recently existed due to the

<< Figure 5: Scheduled to be opened by Q-1, 2017 in Osceola County/Orlando Florida, iCAMR's 109,000 sq. ft. laboratory/ office building will provide proof-of-concept to production capabilities for novel material developments to support advanced smart sensor and integrated device technologies. (Site Rendering). Courtesy: iCAMR. >>

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lack of newly formed clusters in the past couple of years and also based on the lack of continuing level of support of existing clusters, especially in the US. Additionally, based on the 78 verbatim inputs that I received as part of this study, it is quite apparent to me that the concept of clusters and their inherent benefits are not well known, and especially in the US. Micro and Nano clusters are a significant entity in the European Community to the point where they have initiated a "Cluster of Clusters" meaning that they have brought together several technology clusters from various parts of the EU and have formed this 'cluster of clusters'.

Several MEMS/microsystems technology clusters exist in the US. In my opinion, two of the most significant are the Albany, New York Nanotech Cluster and the State of Florida Photonics Cluster. The State of Florida, driven by the ambitions of its current Governor, Rick Scott, is guiding Florida in a major transformational process with high technology playing a major role in workforce development. Enterprise Florida, Florida's Economic Development arm (www.enterpriseflorida.com), has been tasked to support this goal. "Hosting the TSensors Summit here on December 9/10, 2015 (www.tsensorssummit.org) —which will attract visionaries, technologists and investors — is yet another step we're taking to promote Florida's technology advancements as means of creating new high-wage, high-value jobs" stated John Krug, Enterprise Florida Vice President of Business Development. Who thought that Florida was only about Disneyworld, beaches, citrus, golf and retirement?

For technology clusters to be successful, they need several requirements as a foundation: financing, infrastructure, including a manufacturing development facility, and intellectual property/human capital [5]. A primary expected outcome of a successful cluster is its role in the economic development growth of the community in which the cluster resides. Recent developments in Florida demonstrate the solid support of these requisites. Most noteworthy for its role, the Florida Photonics Cluster (FPC) trade association (www.floridaphotonicscluster.org) was established in 1986 to serve the Florida photonics industry cluster, which has a total of over 271 companies. These companies employ over 5,700 professionals and create $7.2 Billion (US) in Florida economic output. In my recent interview with Dr. Jim Pearson, Executive Director of the Florida Photonics Cluster and Special Consultant to CREOL, on the barriers to the future success of the Florida Photonics Cluster, he said, "The biggest barrier to the Florida photonics industry is a lack of recognition by some government and economic development organisations of photonics as a distinct industry with tremendous growth opportunities. Photonics is too often buried within one of the key industries it enables such as communications, manufacturing, defense, or biomedical."

A major player in the cluster is the College of Optics and Photonics at the University of Central Florida (UCF), known to many as CREOL (Center for Research in Electro-Optics and Lasers), one of the three centers that are part of the College, with a focus on microphotonics (www.creol.ucf.edu). Its 83,000 square foot lab and office building was initially constructed in 1994. A new building of 21,000 square feet was opened in 2006, which includes a photonics incubator. CREOL currently has 34 faculty members, 65 research scientists, 155 graduate students, 51 undergraduate students, and has produced over 250 patents and spun-out a remarkable number of 32 companies to date, this is quite impressive! Approximately 33% of its funding comes from industrial sources.

Currently, the big news in Florida is the International Consortium for Advanced Manufacturing Research (iCAMR) www.icamr.net, which broke ground for its Osceola County/ Orlando Florida 109,000 square foot laboratory/office facility in August 2014 and is expected to open its doors to business in Q-1, 2017

Currently, the big news in Florida is the International Consortium for Advanced Manufacturing Research (iCAMR) www.icamr.net, which broke ground for its Osceola County/ Orlando Florida 109,000 square foot laboratory/ office facility in August 2014 and is expected to open its doors to business in Q-1, 2017. $168 Million (US) has been invested in the building (figure 5) and associated infrastructure. A recent study determined that within 10 years, the iCAMR will create 19, 344 new high tech jobs, generate $2.1 Billion (US) per year in wages, generate $482 Million (US) in tax revenues and support more than 80,000 total jobs related to the project. To quote Dan Holladay, iCAMR's Executive Director: "iCAMR has been created to provide a mechanism for organisations to scale up their emerging technologies, from proof-of-concept to full scale production in areas of compound semiconductors e. g. III-V, and other novel advanced base materials to support next generation advanced sensors and other Silicon-based devices and all at our facility. It is a public/private partnership supported by our regional government, universities and industrial partners. Some of our early activities include the sponsoring of technical workshops and to bring together device manufactures, materials and equipment suppliers, national labs and end users to serve as a first step to create standards and a technology roadmap that will address the challenges and provide solutions to these next generation technology. We expect to publish the results of these workshops by mid-2016." He concluded: "using an improved SEMATECH model, we expect iCAMR to successfully provide an 'inverse valley of death' scenario that can overcome the historically plagued process of organisations attempting to scale up technology to production levels. I believe that with the creation and success of iCAMR will begin a new chapter in the creation of establishing Florida as a major competitor in the international community of technology players." This is great news for the Florida's future economic development and for its citizens who will reap the benefits resulting from the workforce development creation.

Summary

I believe that the objective of the 2014 annual MEMS Industry Commercialization Report Card of providing a valuable tool for MEMS industry participants to objectively monitor the 'health' of the MEMS industry has been realised once again. It is encouraging to note that six subjects: Roadmaps, Standards, Clusters, Creation of Wealth, Employment and Design for Manufacturing have improved in their grades and with no topics decreasing in grade. The final Report Card grade increased from B- in 2013 to B in 2014. This marks the first improvement in final grade since 2010. I would like to propose that this performance demonstrates a maturing of the industry to acknowledge and invest in several of these important 'infrastructure' topics. Especially to be noted here is the creation of the iCAMR in Florida, the first major investment to establish a new technology cluster in the US for over a decade. I strongly recommend that MEMS industry participants should embrace the famous George Santayana quotation: "Those who cannot remember the past are condemned to repeat it" [6]. The results of the 2014 Report Card should provide industry participants with valuable information to effectively help craft their business strategies moving forward.

Want to Learn More?

For a more comprehensive look at the 2014 MEMS Industry Report Card, I recommend that you visit my website, ***www.rgrace.com***, to see much more information on each of the 14 topics.

The upcoming Trillion Sensors Summit will take place in Celebration (Orlando) Florida on December 9/10, 2015. Topics relating to the Trillion Sensors Roadmap are scheduled to be presented.
www.tsensorssummit.org

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[1] *R. Grace, Barriers to the Successful Commercialization of MEMS: The 2012 MEMS Industry Report Card, Commercial Micromanufacturing International, Volume 6, Number 3, pp. 43-46*

[2] *R. Grace, Barriers to the Successful Commercialization of MEMS: The 2013 MEMS Industry Report Card, Commercial Micromanufacturing International, Volume 7, Number 4, pp. 43-46*

[3] *R. Grace, S. Walsh; MEMS Industry Roadmap; Micro and Nanotechnology Commercialization Education Foundation Roadmap; Chapter 2; 1990; www.mancef.org*

[4] *J. Bryzek, R. Grace; The Trillion Sensors Initiative, Commercial MicroManufacturing International; Volume 7, Number 2; pp. 42-46*

[5] *R. Grace, Technology Clusters and Their Role in the Commercialization of Micro and Nanosystems, Commercial MicroManufacturing International, Volume 5, Number 2.*

[6] *G. Santayana, Reason in the Common Sense, Volume 1 of the Life of Reason, 1905.*

Roger Grace is President of Roger Grace Associates of Naples Florida, a marketing consulting firm that he founded in 1982, specialising in the commercialisation of MEMS. His firm provides business development, custom market research, market strategy and integrated marketing communications services to high tech clients worldwide. He has published over 20 articles in industry publications, organised and chaired over 50 MEMS technical sessions and conferences and is frequently quoted in the technical and business press as a MEMS industry guru. He was a visiting lecturer in the School of Engineering at the University of California Berkeley from 1990 to 2003. He holds BSEE and MSEE (as a Raytheon Company Fellow) degrees from Northeastern University where he was awarded the "Engineering Alumni Engineer of the Year Award" in 2004.