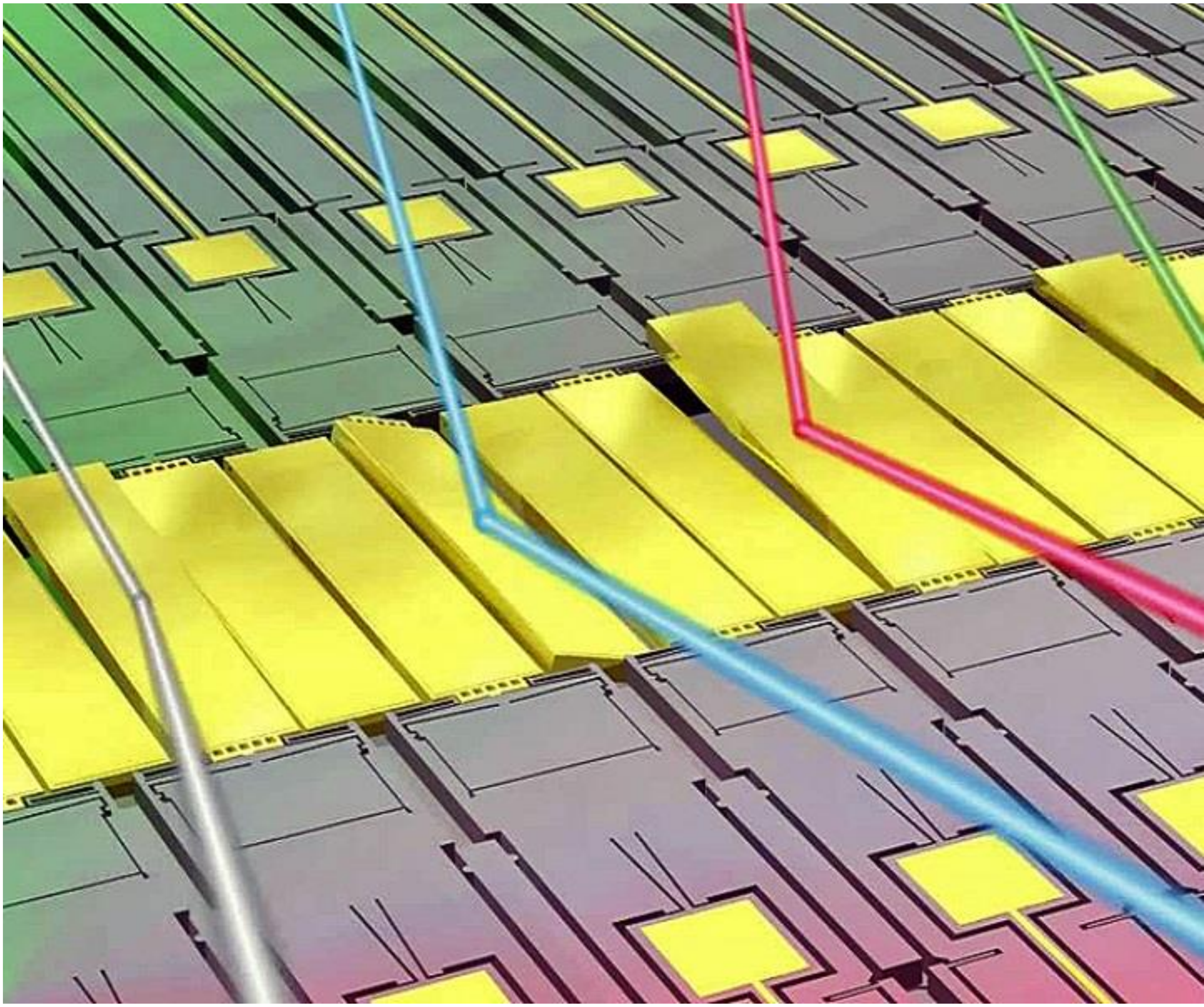


Expert Contributors

MEMS Commercialization Report Card – Part 3: Infrastructure

By Roger H. Grace & Douglas Sparks, Ph.D.

Introduction

This is the third episode in a bi-weekly series that will address the 2018 MEMS Industry Commercialization Report Card. As the 2018 Report Card shows, MEMS infrastructure grades have remained quite good for several years at the A- level (see fig. 1). The only reason that the 2018 grade fell one level to B+ was due to round-off errors in the computational process of the grade. Essentially, it almost remained the same.

Having a strong infrastructure means that companies, especially startups who are usually cash-starved, can invest their money in people and ideas rather than in brick and mortar. Also, some MEMS designs require very special and expensive process equipment for device creation and manufacture…and it is more judicious to rent than to own. Finally, investors very much favor the highly adopted fabless approach.

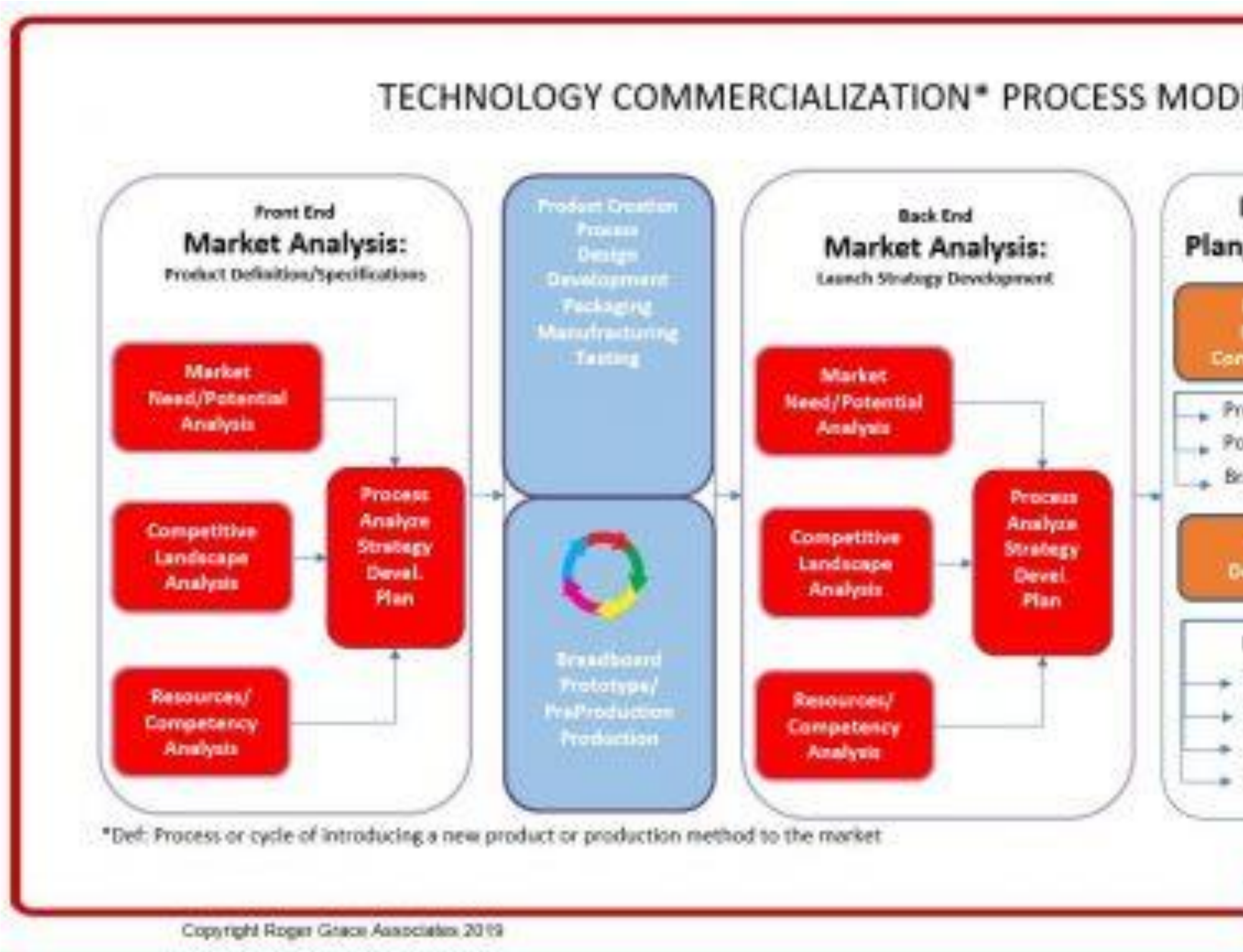


Fig. 1: The grade for Infrastructure for 2018 was B+ following the grade of A- for 2015, 2016, 2017.   Standard deviation was 1.14 placing it in the middle of standard deviations of the 14 Report Card subjects.   Infrastructure grades remain high in the Report Card topics from its inception in 1998. The maturity of the MEMS industry is a key element of the current ongoing high grades. Additionally, the commonality of processes and equipment from the semiconductor industry supports this.   Copyright 2019 Roger Grace Associates

For companies who are fabless, which are virtually most of the MEMS companies worldwide, a large selection of silicon-wafer foundries, i.e. facilities that manufacture MEMS from silicon wafers, exist worldwide. And there are many with special processes using specialized and

expensive process equipment.   Additionally, other elements in the design and manufacturing process are necessary to commercialize MEMS designs into a product.

Most MEMS-based products and systems are designed in-house with many of the processes supplied via fab infrastructure. However, several organizations provide a soup-to-nuts capability by additionally creating a design for the customer while incorporating design for manufacturing and test strategies for scaling up for future large volume production requirements, selecting a foundry to manufacture the silicon MEMS, and selecting an organization to package and test the device.

DiPaola Consulting is one such organization and its founder, David DiPaola will co-author Episode 4 of this Report Card series on the topic of design for manufacturing and test.   Additionally, several organizations exist that can provide application specific integrated circuits (ASICS) that are critical for MEMS sensor interfacing and integration into MEMS-based systems [1]. Figure 2 shows the role of the design and manufacturing elements in the overall MEMS commercialization process that rely heavily on the availability of infrastructure

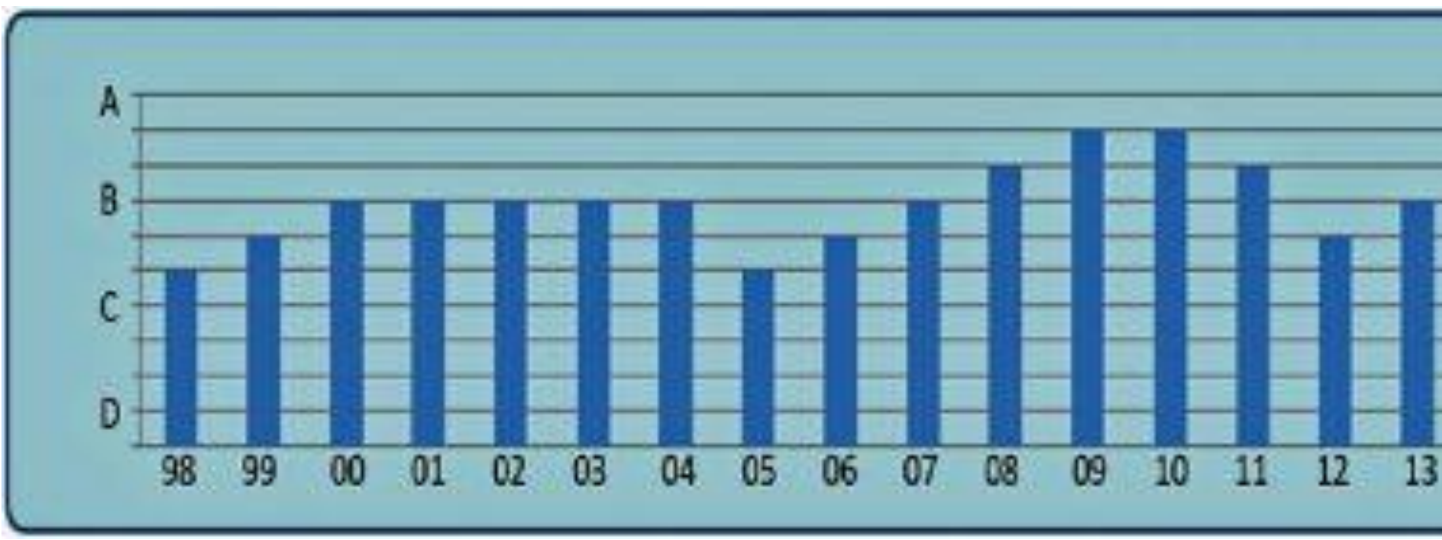


Fig. 2: The MEMS Industry Infrastructure plays a significant part in the product design and manufacturing process of MEMS.   Through a broad spectrum of suppliers, MEMS developers can conveniently adopt a fabless strategy that focuses their resources on product design and development and not "brick and mortar" issues which are costly and time consuming to bring on line. Copyright 2019 Roger Grace Associates

Infrastructure Engagement Examples

An excellent example of the effective use of this broad-based robust infrastructure is Exo-Systems, a company planning on coming to the market shortly with its MEMS piezoelectric ultrasonic medical imaging system.   Janusz Bryzek, Exo-Systems Co-Founder and Executive Chairman said, "We undertook all of the system design in-house and have selected the world's best suppliers for all of the necessary elements to create our product, from the Silicon wafer supplier that deposits the piezo materials on the Silicon and a supplier who assembles, packages and tests our system.   We decided to take the ASIC design in-house because we could not find anyone in the industry that could meet our very demanding performance

requirements for this most critical component of our system. The real challenge is to thoroughly vet all of these suppliers and know up-front if they can be used throughout the early R&D cycle to full-scale production. In several instances, we needed to add suppliers to accommodate our expected high-volume requirements versus smaller prototyping manufacturing requirements that they were able to provide."

Invoneering, a recent startup, is developing a plethora of MEMS-based products, many of which address operation in extreme environments. One such application is their MEMS micro heat flux sensor which provides environmental monitoring of hypersonic aerospace vehicles. Nick Tiliakos, Principal and CTO reports, "We looked at development partners from a broad field of infrastructure providers to help us manufacture and test our design. We decided on the team at the University of Maryland since they had the proven competencies to provide the processes needed and the staff who complimented ours and understood our application. It truly was a marriage made in heaven."

Infrastructure Constituants

Wafer Foundries

Wafer fabs play a significant role in the development and production of MEMS. In 2018, the largest growth in wafer fab infrastructure, both for ICs and MEMS, was in China. This has been driven by the government mandate to reduce the imports of ICs and MEMS chips. To overcome this local manufacturing barrier, the government has supplied capital to build fabs and buy fab equipment.

While the new multi-billion dollar 12" memory fabs get the headlines in China, 8" MEMS fabs have been springing up there as well to enhance the scaling of consumer MEMS manufacturing. New 8" MEMS fabs in China under construction or starting up in 2018 include the development lab at SITRI (Shanghai Industrial Technology Research Institute), Hanking Electronics' 8" fab in Shenyang, (see fig.3), and Silex 8" MEMS foundry under construction in Beijing.

SMIC in Shanghai has focused on 8" CMOS compatible surface MEMS devices and CMOS Imaging Sensors (CIS) and in Taiwan, TSMC has likewise used older 8" fabs for high volume MEMS processing and manufactured CIS wafers at both 8" and 12" fabs. In 2020, Hanking Electronics will be holding a MANCEF sponsored COMETS conference for those who want to tour a 200-mm MEMS fab in China and explore this.

A local MEMS manufacturing cluster has sprung up in China comprised of fabs, wafer, and tooling suppliers. Technology clusters were previously addressed in Part 2 of this series[2]. In China, the MEMS fab expansion must compete for infrastructure resources like experienced fab construction teams, materials, engineers and fab equipment with the new IC fabs. Other changes in China that moderated MEMS growth in 2018 were new regulations to slow capital flight from China and in the US through CFIUS, to slow intellectual property loss and technology to China.

Fig. 3: The recently completed 8″ Silicon wafer fabrication facility of Hanking Electronics in Shenyang, China in one of many such facilities recently development in China to create a technology cluster in that region to support the burgeoning MEMS business in that region and worldwide. Courtesy: Hanking Electronics

In the EU, Bosch began construction of a new 12″ CMOS wafer fab in Dresden, Germany in 2018. This will allow Bosch to make more CMOS and power ICs, potentially freeing up MEMS floorspace in their 8″ fab in Reutlingen, Germany. A number of MEMS fabs in the EU and US,

like IMS in California, Silex in Sweden, and Sandia National Labs in the USA, recently added 8" floorspace or converted 6" capacity to 8" wafer capacity. Some fab and MEMS company consolidation is going on in Canada where Teledyne Dalsa recently acquired Micralyne.

Manufacturing Tools/Capital Equipment

New materials and larger diameter wafers spur growth in MEMS fab and test equipment. Just like the cleanroom facilities, the fab MEMS tools have leveraged infrastructure developed for ICs. MEMS fabs have often drawn from refurbished IC fab tools to lower capital costs. Used 8" fab equipment was plentiful 5 years ago, but in 2018 were in tight supply due to fab expansions in Asia.

Traditional MEMS fab tools like wafer bonders and deep reactive ion etchers that were initially developed just for MEMS wafers are now being employed in high volume products like CIS, 3D stacked memory wafers which can also impact lead times and prices for new fab tools. Dave Kirsch, VP at EVG, states, "New bonders are now out in the field with higher bond force, 100KN and high vacuum chambers for improved vacuum bonding and eutectic sealing (see fig. 4). The new processes and tools can eliminate the physical barrier at the wafer surfaces, the native oxide on metals like aluminum and copper, to offer a superior bond between wafers. 300-mm wafer bonding is common with Silicon on Insulator (SOI), CIS wafers and starting to grow in numbers with MEMS wafers. Additionally, newly introduced nano-spray resist coaters are enabling photoresist patterning into deep cavities and through wafer vias with high aspect ratios."

Fig. 4: Gemini Cluster Process tool for wafer-to-wafer bonding. Silicon wafer bonders and

aligners are two of the key process tools necessary for the manufacture of MEMS devices. Equipment suppliers that serve the MEMS industry with these tools simultaneously can serve the semiconductor industry. Thus, R and D costs for these key process tools can be amortized over these two industry sectors whose market values are a combined yearly $500 billion dollars. Courtesy: EVG

Materials

New materials are finding their way into high-volume MEMS applications. As previously stated in Episode 1[3], silicon has achieved maturity as the platform of choice for MEMS with variations on this being adopted. In 2018, Broadcom (formerly Avago) and their piezoelectric aluminum nitride (AlN) RF filter products replaced Bosch and STMicroelectronic's capacitive inertial and pressure product lines as the MEMS sales leader.

Vesper has successfully launched an AlN MEMS microphone product line that is gaining market share. ExoSystems has adopted piezoelectric technology as the platform for their ultrasonic medical imaging platform. U-Sound has also adopted Silicon piezoelectric technology for their miniature MEMS speakers.

In Asia, A*Star in Singapore has been a research leader in piezoelectric MEMS to reduce the barrier to start-ups associated with material R&D in the region. Silterra, in Malaysia, converted significant CMOS fab floor space over to backend AlN processes in 2018 and is offering high volume CMOS integrated piezoelectric AlN MEMS foundry services.

AlScN and PZT films are also being used to develop piezoelectric MEMS devices. Using these films in CMOS and bipolar fabs is frowned upon due to potential silicon wafer contamination from the transition metals in the layers. Transition metal contamination can lead to high junction leakage and gate oxide defects. These materials must be processed in a separate backend fab or isolated in a pure-MEMS wafer fab where BiCMOS and bipolar devices are not manufactured.

Design and Analysis Software

Mary Ann Maher, CEO of SoftMEMS, says, "Software infrastructure used to design and fabricate MEMS devices is also changing. The new MEMS design software trends include the move to the cloud, incorporating AI algorithms into the sensor/system model and generating digital twins for products. One barrier to improving MEMS Finite Element Modeling (FEM) was the memory required to perform the millions of individual simulations on a device. This barrier was overcome in the 2018 timeframe by using the cloud to store all this modeling data."

She continues, "The move to the cloud has started to enable finite element modeling to move from simulations with just a million degrees of freedom to billions of degrees of freedom in order to model all the possible variations that a device may encounter during manufacturing, packaging and use. Simulations encompass more than just the MEMS chip, and include material variations, packaging, system algorithm, AI and now the ability to look at variations in all of these which has required the cloud to handle all the simulation iterations. This same

cloud and AI enhanced software trend is also found in wafer fab software, modeling and data analysis to enhance yield, equipment uptime and quality control."

SUMMARY

The Report Card grade of B+, mentioned earlier as almost A-. for 2018 with A- grades in 2015-2017 demonstrates the robustness of the MEMS industry infrastructure. As the MEMS industry continues to mature, companies that support the design and manufacture of MEMS are constantly fine tuning their offerings to provide MEMS designers and producers with the highest performance, lowest cost and highest throughput.

It is interesting to note that MEMS infrastructure had a head -start since much of the equipment and the base silicon material upon which virtually all MEMS are made originated directly from the semiconductor industry. These tools and equipment are either identical as those used for semiconductor fabrication or are have been modified to accommodate the requirements specific to MEMS fabrication. We believe that infrastructure will continue to garner excellent grades and thus provide developers of MEMS devices with excellent product at aggressive pricing to meet the requirements of the market, especially those of the consumer and automotive where price is a major factor.

Learn More

MEMS Infrastructure will be one of the tracks scheduled for the upcoming MANCEF Commercialization of Emerging Technologies Conference (COMS) to be held from October 19-22, 2020 in Rockville, MD. For more information, visit MANCEF.

REFERENCES

[1] R. Grace, Thinking Outside the Chip for MEMS Design Success, Electronic Products, February 2010, www.rgrace.com

[2] R. Grace; Barriers to the Successful Commercialization of MEMS Devices, Part 2, Technology Clusters; Sensors Daily; January 8, 2020

[3] R. Grace; Barriers to the Successful Commercialization of MEMS Devices, Part 1, Introduction; Sensors Daily; December 3, 2019

About the Authors & Their Companies

**Doug Sparks**

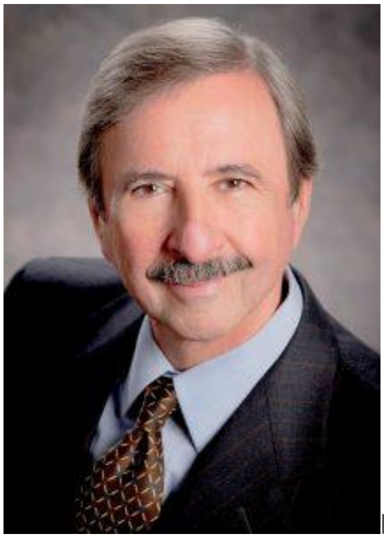
Doug Sparks Ph.D.

Doug Sparks is the CTO at Hanking Electronics and a board member of MANCEF. He also founded a microsensor packaging company called NanoGetters, was the EVP at Integrated Sensing Systems and worked in automotive sensors with Delphi. Doug holds a PhD in materials engineering from Purdue University has published more than 120 technical papers and has 56 issued patents.

Hanking Electronics Company Profile

Hanking Electronics Ltd. was founded in 2011 by Hanking Group. It is headquartered in Shenyang, China, with offices in Milan and Pisa Italy and Solon, Ohio. It built China's first 200mm pure MEMS wafer fab and in 2016 acquired the Maxim Integrated inertial MEMS business. It's Shenyang campus occupies 1.2 km2 and contains both a frontend and backend fab. Hanking Electronics offers MEMS foundry services and a variety of MEMS-based products to those who need better access to the Chinese market. Learn more, visit Hanking Electronics.

Roger H.Grace

**Roger H. Grace**

Roger H. Grace is president of Roger Grace Associates, a Naples Florida based strategic marketing consulting firm specializing in high technology. His educational background includes a BSEE and MSEE (as a Raytheon Company fellow) from Northeastern University, and the MBA program at Haas Graduate School of Business at U.C. Berkeley. He has specialized in sensors and ICs for over 35 years with a focus on micro electromechanical systems (MEMS). He has authored over 75 technical papers and articles, organized, chaired, and spoken at over 50 international technical conferences.

Roger is frequently quoted as an industry expert in major international technical and business publications on the topic of technology commercialization. He was the co-founder, past president, and currently is the Vice President of the Americas of the Micro, Nano and Emerging Technologies Commercialization Education Foundation (MANCEF), and has served on the Board of Directors of the Florida Manufacturing Extension Partnership from 2008 to 2014. For more details, contact Roger via email at rgrace@rgrace.com.

Roger Grace Associates Company Profile

Roger Grace Associates; founded in 1982 and headquartered in Naples, Florida; is a technology marketing consultancy specializing in sensors and microelectromechanical systems (MEMS). Its founder, Roger H. Grace held positions in design engineering, project management, manufacturing engineering, applications engineering and sales and marketing for major electronics manufacturers. Roger Grace Associates' clients include the international "who's who" in the electronics, sensors and MEMS industry from startups to Fortune 50 organizations, regional and national governments and agencies. Roger Grace Associates provides custom market research, strategic marketing communications, M&A due diligence, business development and strategy consulting to domestic and international clients. Learn more, visit Roger Grace Associates