



A. M. Fitzgerald & Associates, LLC

655 Skyway Rd., Suite 118 San Carlos, CA 94070
650.592.6100 tel/fax
www.amfitzgerald.com

No Rest for the Weary: MEMS Manufacturing Must Press On, With Big Markets Ahead

Alissa M. Fitzgerald, Ph.D.

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The MEMS industry is not for the faint of heart. It is an industry based on a large collection of manufacturing techniques and materials that resists standardization and the resulting economic benefits. Despite their heritage in the semiconductor industry, MEMS devices are inherently mechanical, and so can not fully leverage the standards and infrastructure of that industry. The MEMS industry must strive towards some level of standardization, and foundries should lead the way to enable truly fabless service. Only then will the industry be better able to reach many huge, untapped markets that can surely benefit from the capabilities of MEMS.

MEMS and semiconductor industries diverge at point of production

The MEMS industry is not like the semiconductor industry, despite using silicon wafers and many of the same tools. Investors and entrepreneurs in the MEMS industry need to recognize these important differences and adjust their expectations and capitalization accordingly.

The exuberant claims that MEMS would automatically enjoy the manufacturing benefits of its semiconductor heritage had intoxicated investors with fantasies of rapid commercialization, and then left them with a post-telecom-bubble hangover that is only now starting to fade. By some accounts, tens of billions of dollars were invested during 1997-2002 in new MEMS companies, few of which survive today.¹

The semiconductor industry is based on a standardized building-block technology, the transistor, which can be incorporated into many products and functionalities using well-established design rules. A correlation between transistor size versus time, known as Moore's law, unified this global business behind the goal of implementing standard lithography linewidths (130nm, 90nm, etc.) by certain dates. As a result, the entire semiconductor industry has been able to make huge investments in infrastructure with reasonable certainty of future outcome.

In contrast, the MEMS industry has no one standardized building-block like the transistor. It does not have a Moore's law to set the pace or direction for equipment and R&D investments. MEMS as an industry is not really a technology at all, but rather a loose collection of manufacturing techniques, some borrowed from the semi industry,

¹ Joseph E. Ford, “Optical MEMS: Legacy of the Telecom Boom,” 2004 Solid State Sensor, Actuator and Microsystems Workshop Proceedings, Hilton Head, SC.



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which are used to make micron-scale 3D structures with electro-mechanical functions. It employs a variety of techniques such as: surface micromachining; bulk micromachining; electroplating; micro-molding with soft polymers; silicon-glass bonding, glass etching, and the list goes on.

Lack of truly fabless MEMS service hurts time to market

There is a giant chasm between the two definitions of *fabless* used by the semiconductor and MEMS industries. Semiconductor companies can be truly *fabless*, which means: all their design work is done entirely on a computer, and their chips are fabricated by a remote facility and can be expected to work as designed. MEMS companies that call themselves *fabless* simply do not have their own in-house fabrication facility.

The semiconductor industry has collectively invested decades to develop standard processes, design rules, and sophisticated software tools, in order to allow the entire design cycle to take place on a computer. This is the very reason new integrated circuit (IC) chips can be on the market in 18 months.

The MEMS industry does not currently have such luxury. The mechanical properties of thin films are sensitive to deposition conditions, so simulations of mechanical designs will not be accurate unless the working materials are characterized and monitored. Some MEMS device physics, such as the phenomenon of stiction, are not well understood and beyond the capabilities of current commercial simulation tools.

MEMS designers do as much simulation as possible, and then must process, test, re-design, and repeat, to empirically converge on a final design. This iterative design process takes enormous time and money, and requires highly skilled engineers with access to sophisticated and customized test equipment. As a result, most MEMS devices take a minimum of five years to commercialize.

MEMS supply chain is still fragmented

The manufacturing supply chain for MEMS development and fabrication is still weak and fragmented. Due to a lack of standardization in manufacturing processes and design methods, a company developing a new MEMS device must assemble their own process flow, and consequently, their supply chain, from scratch. Custom processes require extensive engineering interaction with foundries and vendors and so will tend to bias a company towards selecting local sources. Exotic processes also leave companies vulnerable to sole source specialty providers. The time and resources expended to create a manufacturing supply chain significantly contribute to the long time to market for most MEMS devices.



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Until some amount of process standardization occurs, only MEMS devices that are close in process and morphology to IC chips can dodge this problem, by piggybacking onto the large and strong semiconductor supply chain.

Growing market for MEMS is expanding manufacturing options

The premier semiconductor foundry - Taiwan Semiconductor Manufacturing Company (TSMC) - has been slowly opening their door to MEMS devices, and quietly enhancing their MEMS-specific capabilities. Their offerings herald the expansion of the MEMS industry and markets, which is being driven by demand for high-volume MEMS devices for automobiles, displays, and cell phones. The big IC foundries had previously discounted the manufacture of MEMS as being too exotic for their main production lines, and too low-volume to be economically viable. Smaller companies with MEMS devices that are mostly semiconductor process-compatible can now enter large markets with the backing of the IC foundries. In the past, only large companies with in-house fabrication facilities, e.g. Bosch, Texas Instruments, Freescale, Analog Devices, had been able to successfully operate in truly high volume markets (i.e., one million devices per month).

Another bellwether for the rise of MEMS commercialization is the increasing availability of MEMS-specific fabrication equipment. For over twenty years, engineers have been using and modifying semiconductor-specific tools (often depreciated, older equipment cast off from mainstream production) to fabricate MEMS devices. However, the 3D geometry of MEMS and the desire to use non-standard materials and processes, have created a need for MEMS-specific tools not offered by the traditional semi equipment makers. Deep silicon etch, wafer bonding, and sacrificial layer release are processes that have been pioneered by smaller equipment companies, specifically for MEMS fabrication. The MEMS industry has grown to a point where the established large equipment makers, such as Applied Materials and Lam Research, have taken notice and have finally started to develop tools specifically for MEMS production work.

Standardization will reduce time to market

It is unlikely that the MEMS industry will ever be able to be as fully standardized as the semiconductor industry. In order to mature, however, the MEMS industry must find ways to strive in that direction: to establish standards, design kits, and simulation capabilities, where it makes sense.

Initial efforts in standardization should focus on the current weakest link in the design-fabricate-test cycle of MEMS development: materials properties. The industry needs to develop best practices for characterizing MEMS materials, methods to employ those practices to stabilize and monitor material quality, and to define design rules for working with the materials. Given the variety of MEMS devices and the different ways they employ materials, standards should be tailored to device type, such as pressure sensor, accelerometers, gyroscopes, etc.



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Standardized materials, and design rules for working with them, will fully enable simulation-driven design, which as discussed earlier, is the key to a truly fabless industry. Streamlining the MEMS development cycle is essential to reducing time to market and the capitalization needed by MEMS companies.

Foundries should drive materials standardization efforts

The premier IC foundries enjoy their status because they provide detailed, *foundry-specific* design information and rules to IC chip designers. The enormous effort to characterize processes and keep them stable is part of the IC foundry's intellectual property, and their key value offering to the customer.

MEMS foundries should strive to emulate this model. They should drive material characterization efforts because it is in their best competitive interest. Mechanical properties of MEMS materials are highly dependent on deposition conditions, and the recipes to produce those materials constitute valuable trade secrets. The MEMS foundries that can stabilize and fully characterize their materials, and then package that information to be used with design and simulation software, will enjoy a huge competitive advantage. They will also put the burden of design success back onto the designer.

Tapping into new multi-billion dollar markets

MEMS is a manufacturing technology that can provide devices and sensors to virtually any product market where there is a need for miniaturization. There are global, multi-billion dollar manufacturing businesses, such as agriculture and food processing, that surely have technical problems that could be solved with MEMS devices. The opportunity for the MEMS industry is to find and connect with those potential customers, and to educate them on the possibilities offered by MEMS devices.

To provide the most attractive solution to these new customers, the MEMS industry must continue to streamline its manufacturing infrastructure and supply chain to reduce time to market. Truly fabless service will better enable emerging MEMS companies to pioneer these new markets. There is much work to be done, but the good news is that there is still much, much more money to be made.