

THE 2021 MEMS INDUSTRY COMMERCIALIZATION REPORT CARD: CONTINUING IMPLICATIONS OF COVID

FINAL REPORT

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Roger H. Grace
President, Roger Grace Associates
rgrace@rgrace.com
www.rgrace.com



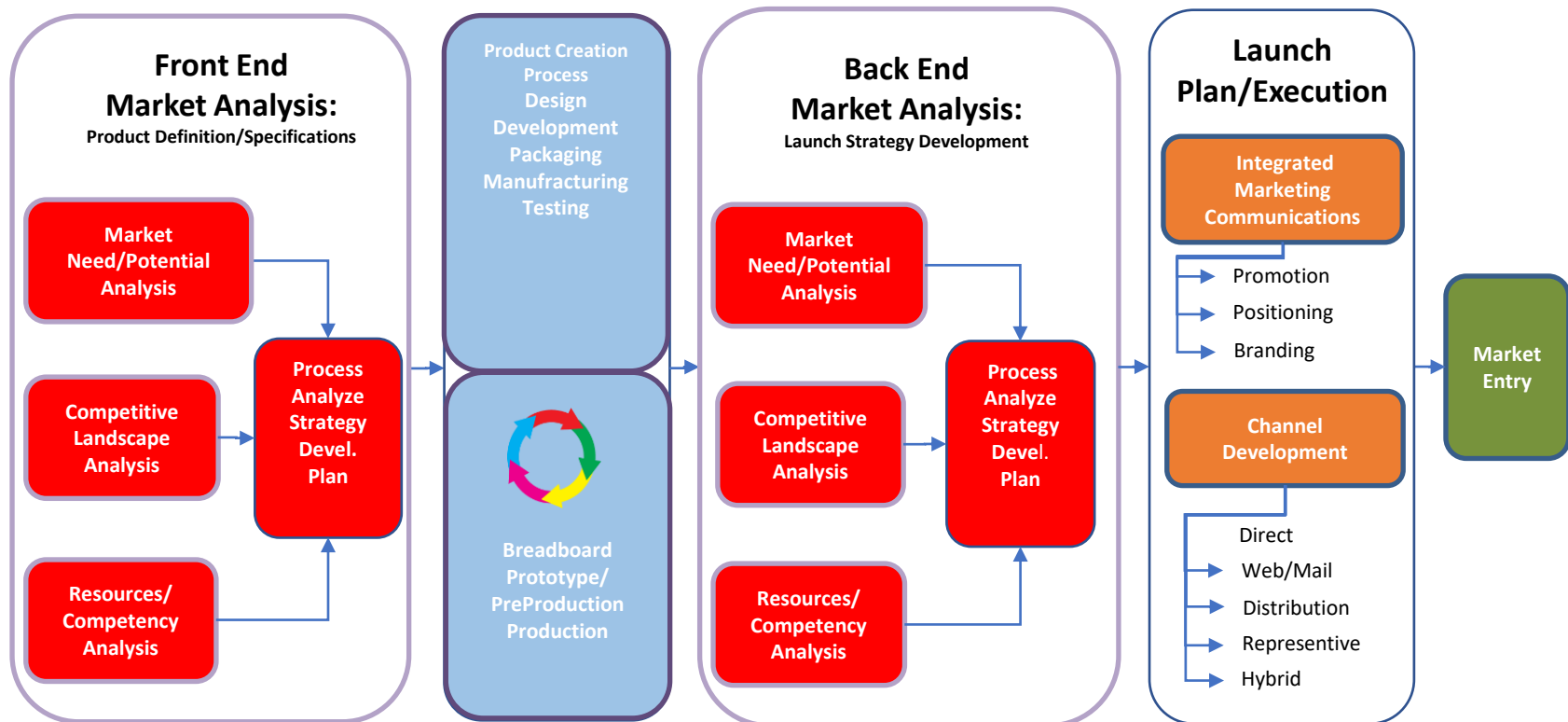
ROGER GRACE ASSOCIATES

- Founded in 1982
- Offices in Bonita Springs, Florida and San Francisco, California
- Over 40 Years of experience in the MEMS/Nano industry...an industry pioneer
- International clientele of companies, laboratories and governments
- Specializing in sensors, semiconductors, MEMS/MST, Nanotechnology, capital equipment
- Focus on:
 - custom market research
 - strategic marketing
 - due diligence analysis / merger and acquisition support
 - strategic marketing communications
 - company and product positioning
 - new product introduction
 - Branding
 - promotion
 - business development
 - distribution channel development
- For more information...www.rgrace.com; rgrace@rgrace.com

ROGER GRACE BACKGROUND

- Education: BSEE, MSEE (Raytheon Graduate Fellow) Northeastern University, Boston, MA; MBA Program, University of California Berkeley
- Design Engineer / Project Engineer with specialty in microwave and RF, 13 years...Raytheon, Avco, Ford Aerospace
- Applications Engineer, RF semiconductors, 3 years, Avantek/HP
- Marketing Manager, MEMS, 3 years ,Foxboro ICT
- Marketing Consultant, MEMS, Sensors and Semiconductors, 32 years
- Guest Lecturer, University of California Berkeley, 1990-2003
- Engineering Alumni Engineer of the Year, 2004, Northeastern University
- Co-Founder, Past President and VP Americas of Micro and Nanotechnology Commercialization Education Foundation (MANCEF)
- Published over 50 papers and articles on MEMS/Sensors
- Organized and Chaired over 40 technical sessions worldwide on MEMS/Sensors
- Board membership...Florida MEP, University of Michigan WIMSS, Northeastern University High Rate Nanomanufacturing Center, Sensors Converge
- Organizing committee includes Transducers 2009,COMS, Smart Systems Integration (EU), Advanced Microsystems for Automotive Applications (EU), IRISS(EU), IWLPAC
- Citizenship...US / Portugal

TECHNOLOGY COMMERCIALIZATION* PROCESS MODEL



*Def: Process or cycle of introducing a new product or production method to the market

Roger Grace Associates supports its clients in front and back-end market analysis as well as in the product launch plan and execution

OUTLINE

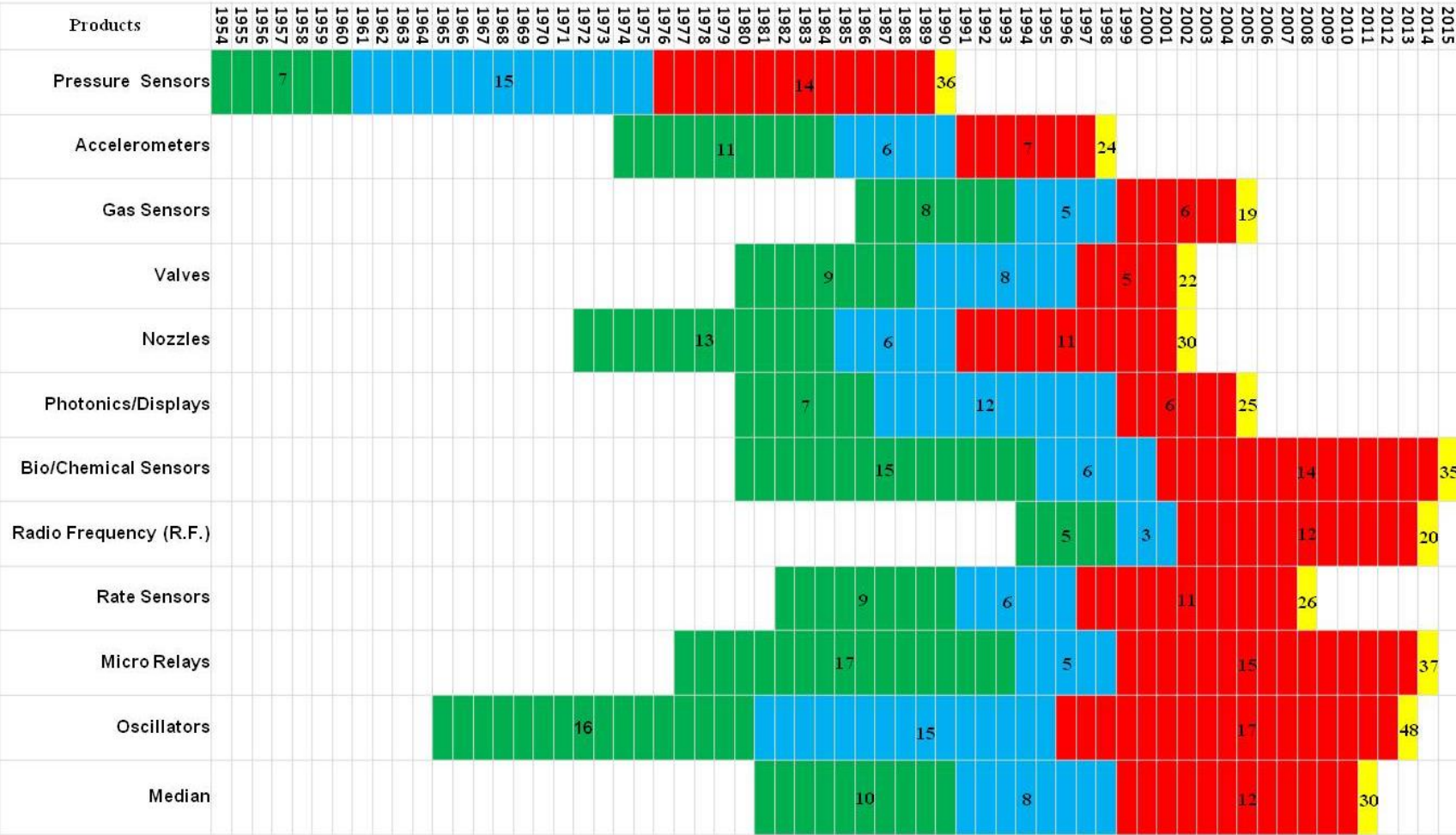
- Situational Analysis
- Market Research Background
- Market Research Mythology
- Results
- Implications of COVID on Grades
- Summary/Call to Action/Recommendations
- References
- For more information

BARRIERS TO COMMERCIALIZATION

SITUATIONAL ANALYSIS

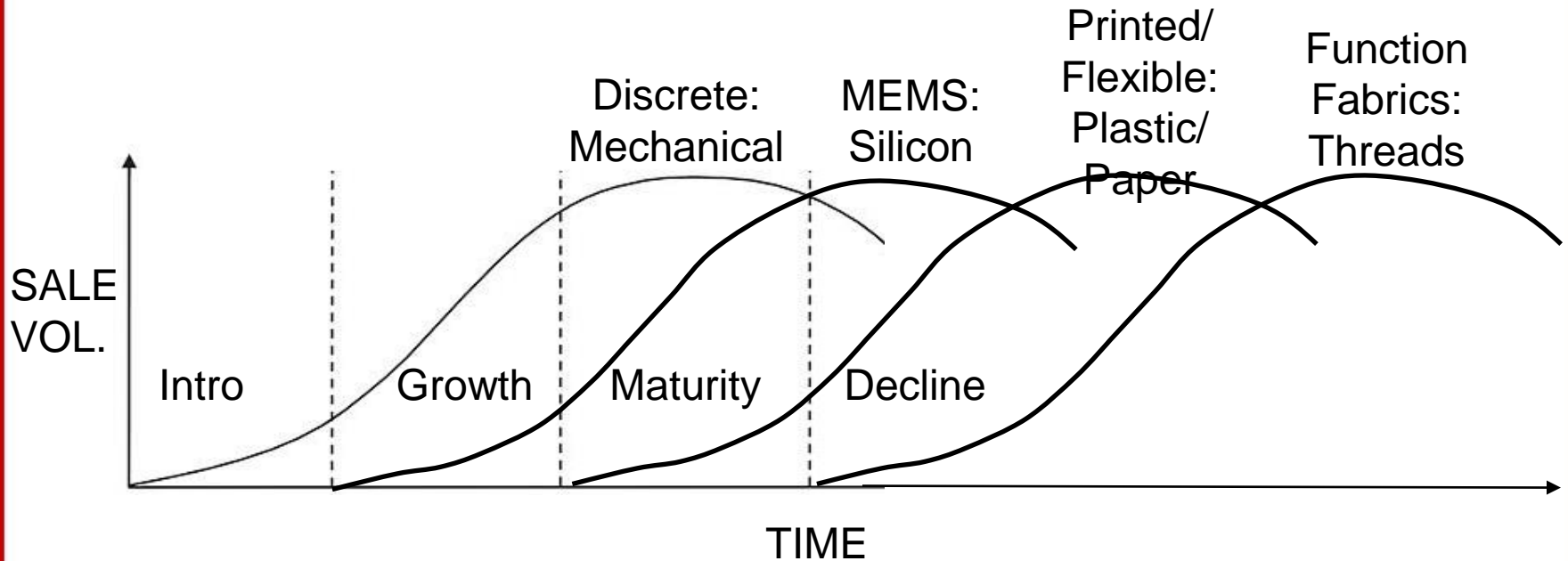
- Lack of well defined direction from roadmaps, industry standards, industry associations
- Multidisciplinary knowledge is required...materials, electronic design, mechanical design
- Packaging and testing costs typically at 70% of total value...however focus has been (and continues to be) on devices not systems solutions
- Lack of focus on customer needs...technology-centric suppliers...technology push versus market / applications pull strategy
- Lack of capital formation opportunities, risk averse investors; low IPO opportunity because of small sales volume levels of companies
- Successive “bubble busts” i.e. biomems, optical telecom...wary investors
- Very fragmented market, many small companies, few large players
- Limited “success stories” of MEMS/MST companies e.g. Invensense, SiTime (IPOs)
- However...new market opportunities for large volume applications have emerged in Automotive; Consumer e.g. mobile phones; Point-of-Care Diagnostics; Wearables; Environmental/Infrastructure Monitoring; Internet of Things (IoT)

MEMS COMMERCIALIZATION TIMETABLE



Legend ■ Discovery ■ Product Evolution ■ Cost Reduction ■ Full Commercialization Elapsed Time in Years

SENSOR PRODUCT LIFE CYCLES



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DOES THE MEMS INDUSTRY COMMERCIALIZATION REPORT CARD MATTER?

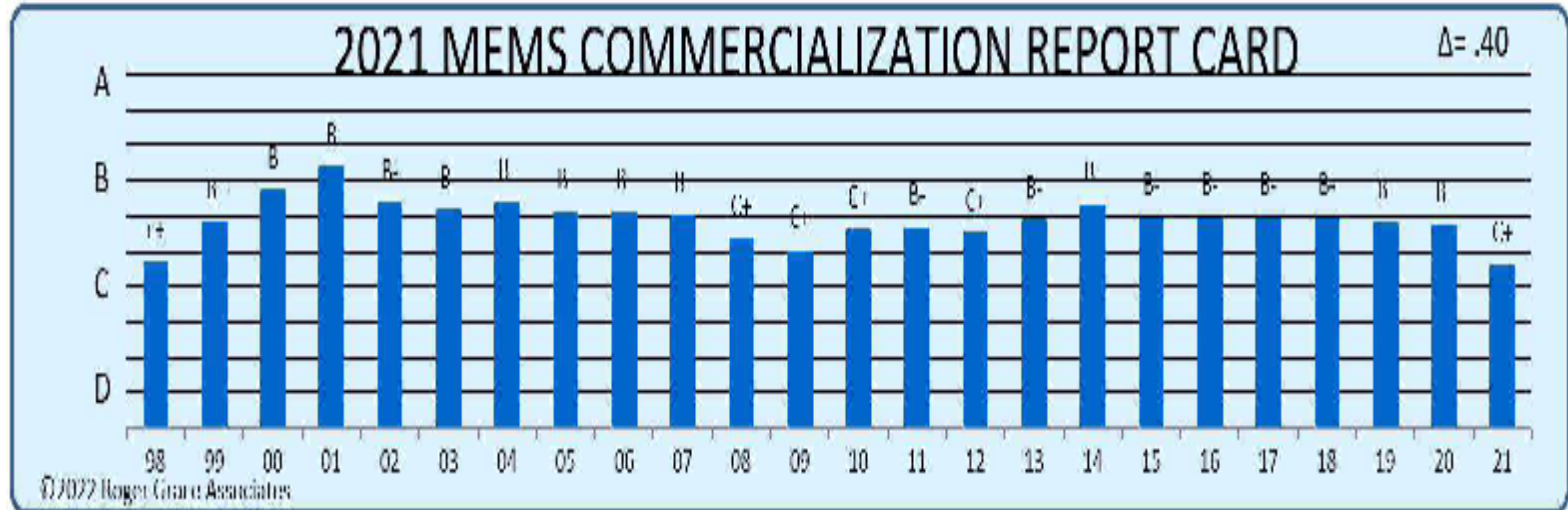
- Initiated in 1998 during Hilton Head Conference
- 24th. continuous year in its reporting
- Determination of 14 critical success factors established after investigation of various other industries (9 initial and 5 added over time)
- Everyone likes grades...people can easily relate...e.g. NY Department of Health grades restaurants regarding their cleanliness, Zagat Restaurant Guides, Michelin Restaurant Stars, AAA Diamonds
- Study Objective: monitor and report on the “health” of the MEMS industry in hopes of creating and influencing positive change...not only by conducting the research but by “evangelizing” via presentations and articles
- Added motivation was to determine the possible continuing effects of COVID on the grades

MARKET RESEARCH METHODOLOGY

- “Delphi”/“Mass Observation” hybrid approach used...not statistically significant i.e. non-projectable...however constitutes the opinions and rationale (via verbatim comments) of MEMS industry thought leaders (average experience 25 plus years) amounting to over 1000 person-years of experience
- Personal Emails sent to over 111 personally known and highly respected MEMS industry leaders
- Individuals had an average of 25 years of MEMS experiences equating to over 1000 years of cumulative experience
- Three follow- up mailings. (I did not vote)
- 42 completed questionnaires received with over 125 verbatims
- Follow up telecons with numerous respondents
- International in scope with majority of respondents from US and Europe
- Broad selection of interviewees...suppliers, users, infrastructure providers (little-to-no academics)
- Incentive of \$100 Amazon gift card (random drawing from submissions)

2021 MEMS INDUSTRY COMMERCIALIZATION REPORT CARD

SUBJECT / YEAR	98	99	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	Δ
R&D	A	A	A	A	A	A-	A-	A-	A-	A-	B+	B	B	B+	B	B	B	B	B+	A-	A-	B+	B	B-	-1
Marketing	C-	C	C+	C+	C+	C	C	C+	C+	C+	C+	C	C	C+	C+	B-	B-	B	B	B	B	B-	B-	C+	-1
Market Research	C	B-	B-	B-	B	B	B+	B-	B	B	B	B+	A-	B	B-	B-	B-	C+	C+	B-	B-	B-	C+	C	-1
Design For Manufacturing	C+	B-	B	B	B	B	B	C+	B-	B	B+	A-	A-	B+	B-	B	B+	A-	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-	A-	A-	A-	A-	A-	B+	B-	-2
Management Expertise	C	C	C+	C+	C+	C+	C+	B-	B-	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B-	-1
Venture Capital Attraction	C	B-	B+	A	C	C-	C	C+	C+	C	C-	D	D+	D+	D+	D+	D+	D	D	D+	C-	C-	C	C-	-1
Creation Of Wealth	C	B-	B+	A	C	C-	C-	C-	C-	C	C-	D+	C-	C+	C+	C+	B-	C+	C+	C+	C+	C+	C+	C	-1
Profitability	C-	C-	C-	C-	C-	C-	C-	C	C+	C	C-	D+	D	C-	C	C+	C+	C	C-	C-	C	C	C+	C	-1
Industry Roadmap	INC	B-	B	B+	A-	A	A	B	B-	C+	C-	C-	C	C	C	C+	B-	C+	C	C-	C	C	C	C	0
Industry Association	INC	INC	INC	B	B+	B+	B+	B	B	B+	B	B	A-	B+	B+	B+	B+	B+	A-	B+	B-	B-	B-	C+	-1
Standards	INC	INC	INC	INC	C	B-	B-	B-	C+	C	C	C	C+	C	C	C+	B-	C+	C-	C-	C-	C	C	C-	-1
Employment	INC	INC	INC	INC	INC	C	C	C+	C+	C+	C	C-	C	C+	C+	C+	B-	B-	B	B	B	B	B	B-	-1
Cluster Development	INC	INC	INC	INC	INC	B	B+	B+	B	B-	C+	C+	C+	C	C+	C+	B-	C+	B-	C+	C+	C+	C+	C	-1
Overall Grade	C+	B-	B	B	B-	B-	B	B	B-	B-	C+	C+	B-	B-	B-	B-	B	B-	B-	B-	B-	B-	B-	C+	-1



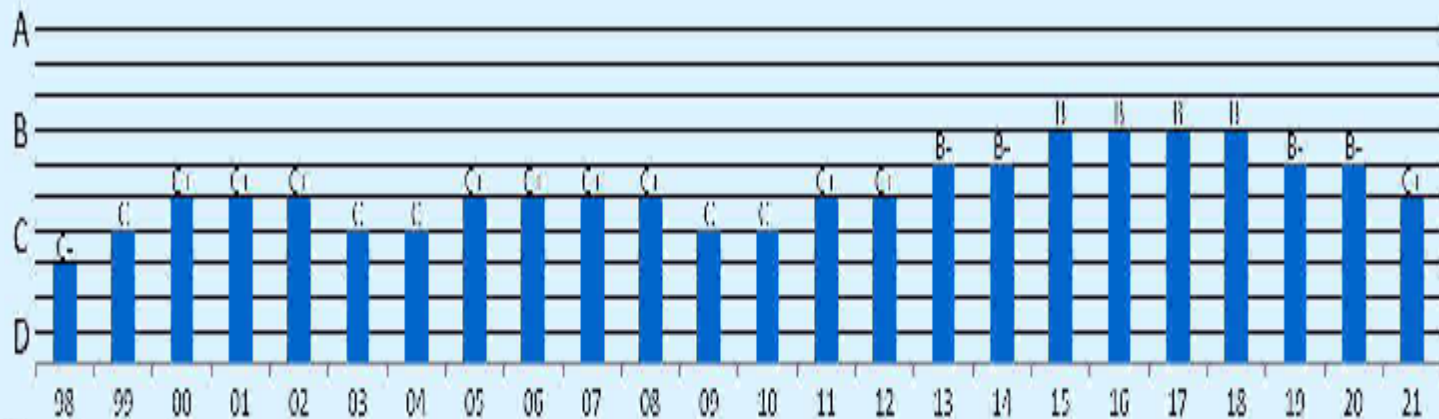
- 2021 grade declined to C+ from at B-...after six years at the B-level
- Over 125 verbatims provided especially in VC attraction and Established Infrastructure with over 65 in Final Report
- Virtually all grades affected by Covid based on verbatims
- Standard deviation of 0.40. Lowest overall grade was C+ in 1998, 2008, 2009.
- Changes from 2020 to 2021:
 - With the exception of Industry Roadmap, all grades decline at least one level
 - Established infrastructure declined two grades...supply chain issues dominated
 - Industry Roadmap remained at C

VERBATIMS...GENERAL

- System level applications like 5G, electric/battery- operated systems (like automotive) are driving the new “killer applications” that are based on MEMS and sensor technology.
- I just feel like we as an industry should have gotten further.
- It is hard to say really (regarding my grade assessment). I do this grading pretty based on general feeling and I guess Covid and also current general world situation has me in a slightly more negative mood today.
- In my opinion, the broad classification of “MEMS” is less valid than it used to be. The field of MEMS is victim to its own success in many ways, in that there are now multiple sub-fields (power MEMS, bioMEMS,etc.), each of which can lay claim to its own mantle. This is not a bad thing, just a change from past perceptions.
- People do not want to buy a MEMS...customers want to buy a device that (does a specific function) like redirecting light. They don't care if it's a MEMS mirror, an acousto-optic modulator or an electro-optic modulator. They want to know speed, wavelength dependence of the device and how many resolvable spots (diffraction limit).
- The “novelty” of MEMS is gone. MEMS is now a tool available to solve more than small sized sensor and actuator needs. MEMS is part of a general system solution just as ICs are not just a tube replacement. Like ICs, MEMS is now more than just silicon based. MEMS techniques (three-dimensional stacking, vertical feedthroughs, bonding of wafers) are being widely used to manufacture system solutions.
- In many ways, MEMS is still suffering from a problem of perception. It is viewed as a component or technology and not truly an enabler of the system or application. Thus, MEMS is not appropriately valued.
- The continued low grades for most of the grades is now mostly due to economic and government leadership issues rather than from Covid. There are lingering Covid issues such as working from home (not as productive) and government disincentives to work. The most destructive issues for commercialization are now supply chain, energy, rampant inflation due to unparallel spending, increased interest rates and general societal issues such as social media, crime and immigration.
- Integration of MEMS devices are on the rise in new applications.
- The technologies are slowly but surely becoming pervasive in our daily lives but not many realize. Companies/laboratories do not necessarily call them MEMS but with multiple other name variations, and politicians refer to “chips”....so I believe that the lines are getting more blurred and this is not helping in tracking the technology to make an argument for more support and to make it a desirable career for the new graduates.

2021 MEMS REPORT CARD ... Marketing

$\Delta = 1.10$



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2020 Grade=B

2021 Grade=B-

Grade Change=-1

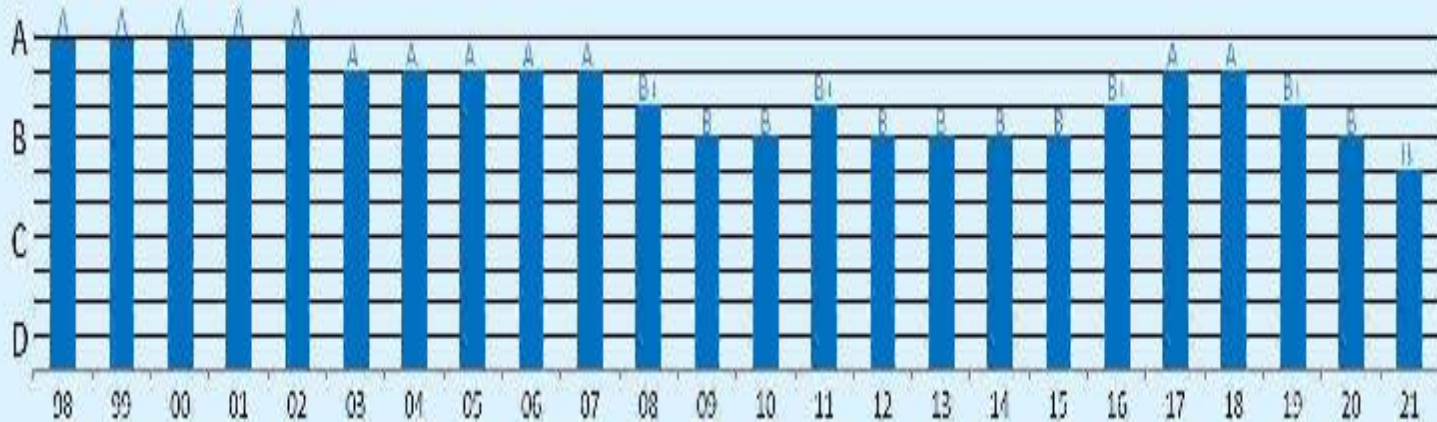
Standard Deviation=1.10

VERBATIMS...MARKETING

- Competition in MEMS is increasing. I have noticed more companies are now offering MEMS devices, but don't market the "MEMS" aspect of the semiconductor product.
- Across the value chain...design, modelling, packaging, assembly, test, foundry and OSAT there has been a significant uptick in social media marketing in LinkedIn and Facebook. This is due to broad market applications where MEMS are connecting everything from the physical world to the digital world.
- Restrictions in travelling, more web-based communication, less visits in fairs and exhibitions and smaller marketing budgets.
- Dealing with Covid has been a mess. Online conferences are not very efficient.
- Not much of a grade change but I do see continued efforts along the lines of MEMS market awareness between your efforts and those in other consortia-oriented areas.
- I do see quite a bit being promoted from an end uses perspective. I believe that we really still try to drive applications and ideas using technologies in place, which is of course good.
- The more we investigate the need and use for such devices, I believe that design and enhancements of the product itself will certainly follow.
- The return of face-to-face meetings has enabled showcasing R & D, marketing, market research and new employment in the MEMS industry again. This is demonstrating that we have a wealth of innovation still within our field (e.g. Hilton Head 2022 registration and sponsorships (in June) is up beyond 2018 pre-pandemic

2021 MEMS REPORT CARD ... R&D

$\Delta = 1.24$



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2020 Grade=B

2021 Grade=B-

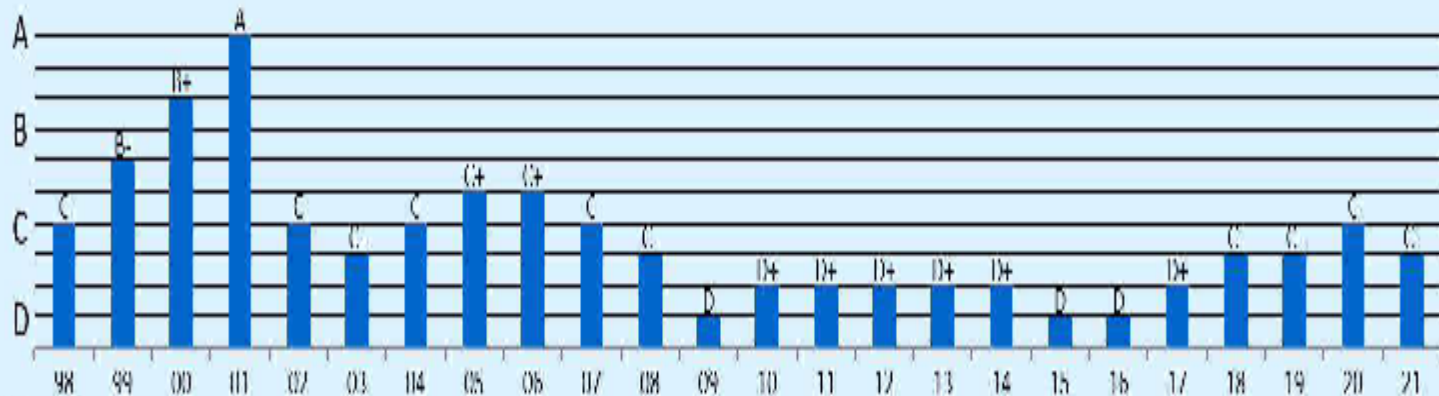
Grade Change=-1

Standard Deviation=1.24

VERBATIMS...R & D

- R & D improving due to expanded commercial capabilities in thin film piezoelectrics and glass processing.
- Covid-based work at home makes R & D discussions problematic, lower numbers of start-ups
- There is an ever-increasing number of activities in combination of MEMS with digital data processing, communications and AI.
- Even with Covid in the last two years we have seen very significant interest from several customers on new product developments in diversified fields. We have seen it both of our fabs and customers are willing to fund the required R & D. Life science has been one of the biggest drivers, stimulated by rapid testing needs.
- R & D grade dropped because increasing amount of research does not take manufacturability into account
- R & D was tough indeed, effects of Covid linger on but are getting better.
- I downgraded the R & D grade just because companies don't emphasize R & D enough and while some are increasing R & D as a percentage of total spend, it doesn't feel like this is shared industrywide as companies wrestle with supply chain shortages still.
- While it appears that there are many innovation examples of MEMS technologies published in journals and trade publications, most appear to be academic in nature.
- The impact of Covid in 2021 continued to plague R & D and most companies were focused in manufacturing, operational efficiencies and supply chains. All three of these focus areas were impacted significantly from the Covid pandemic (from starting wafers to materials, chemicals, gases and equipment were all negatively impacted from disruptions in the global economy).
- Companies including SiTime and TDK Invensense are conducting R & D, which is evident by publicly acknowledged awards associated with SEMI and US Government funding.
- Many companies reduced R & D budgets in preparation for ongoing uncertainty from the pandemic, shattered supply chains and declining economic conditions.

2021 MEMS REPORT CARD ... VENTURE CAPITAL ATTRACTION $\Delta=2.17$



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2020 Grade=C

2021 Grade=C-

Grade Change=-1

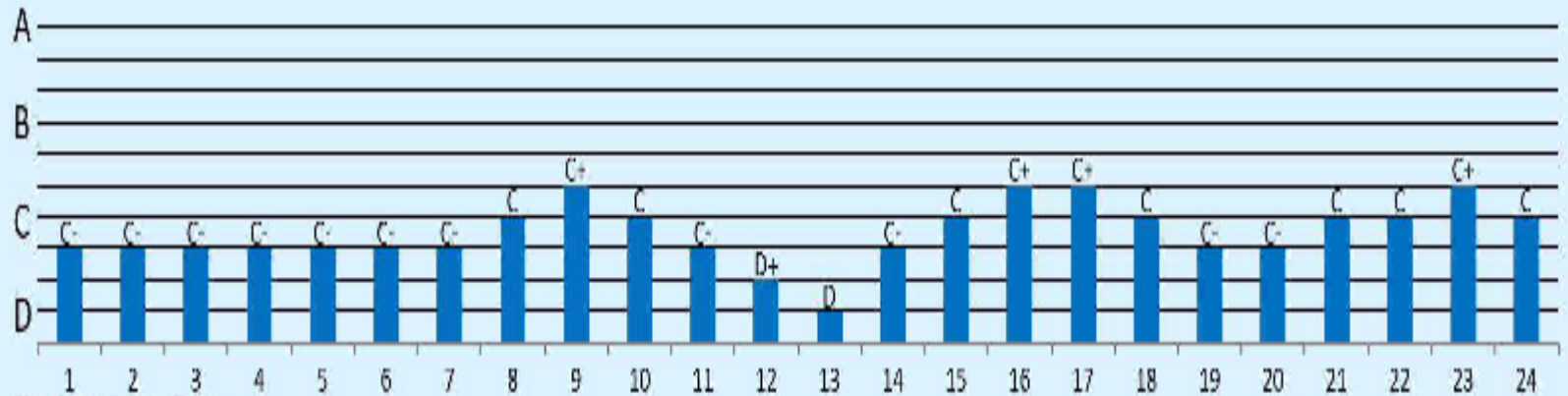
Standard Deviation=2.17

VERBATIMS...VC ATTRACTION

- Our company, Exo Imaging raised \$220M in a Series C for our pMUT-based ultrasound imager. At least another 20 companies raised significant amounts for Series A, B, C and D Series. Most notable were wearables companies which is one of the most active sectors for investors.
- I see MEMS management expertise and industry credibility (and wealth creation) greatly improving in recent years. A big part of this is due to the success of Menlo Micro, Exo Imaging, Butterfly Networks, InjectSense and others such as AdHawk and USound. I also believe that this is a factor in VCs becoming more interested in MEMS and for this year's score to be the highest of my involvement with this study.
- There appears to be some renewed investment interest in the bio space, in particular in DNA analysis, enzyme development and lower-cost diagnostic devices.
- The complexity and diversity of MEMS products and technologies does not help MEMS. In general, this causes return on investment to be long and growth rates to be low (and thus reducing interest from VC's).
- MEMS companies are being attracted by new hardware-oriented incubators and accelerators.
- Interest increased partly because of increased medical interests, Covid, e-automotive and battery applications, slowly interest in agriculture and food processing applications.
- Most VC's don't see the unicorn potential, which is understandable. I would like to change this by establishing a new IDM semiconductor manufacturing company in the US with full MEMS and CMOS capabilities.
- VC's are very active given the shortage of supply band demand for future growth.
- There is a real uptick worldwide in startup funding where I would classify MEMS again as a "software startup enabler".

2021 MEMS REPORT CARD ... PROFITABILITY

$\Delta = 0.98$



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2020 Grade=C+

2021 Grade=C

Grade Change=-1

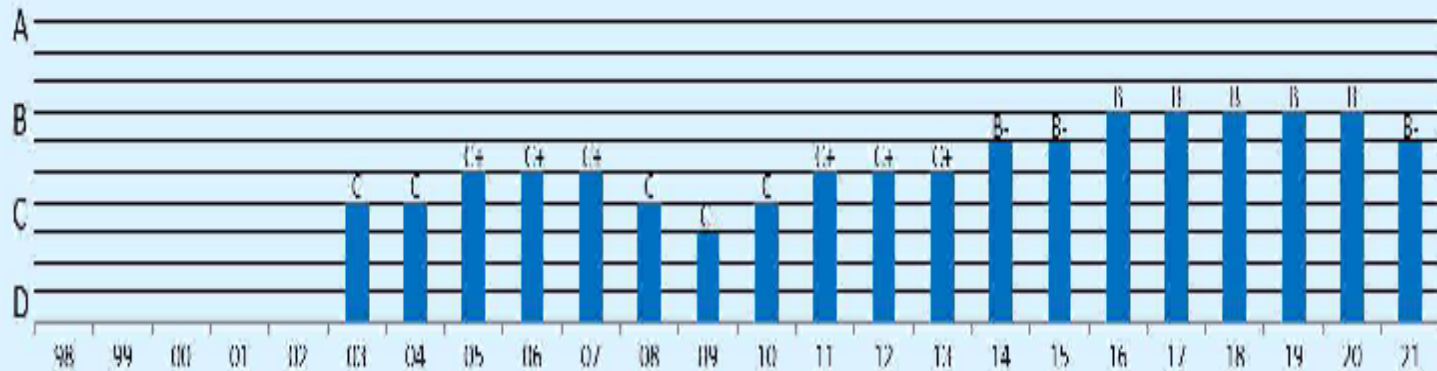
Standard Deviation=0.98

VERBATIMS...PROFITABILITY

- Profitability has improved due to price increases caused and in spite of reduced wafer capacity.
- Growth in product revenues at the top line and bottom line.
- 2021 was a good year for MEMS profitability and focus towards new product development.
- Covid reduced working force costs and marketing travels...and as such...increased profits.
- Profitability has been affected by Covid. Need to pay premium to get supply of raw materials, equipment parts, etc...wages cost increasing with resources shortages.
- Disruption in supply chain along with increased lead times for most semiconductors are the primary reason for my lowering the profitability grade. However, unit prices have increased 8-10% for most semiconductors including commodity memory (just an example). However, it is unclear if profitability is increasing.
- MEMS products, especially sensors, are embedded and enable successful smart phone, automotive, medical, wearable and military aerospace products achieving the best type of profitability: stable, predictable, long-lived with solid cash flow. The substantial up-front development costs are soon amortized creating a solid future stream of cash flow.
- The MEMS industry has bifurcated into a high-volume lower profit mass production segment and the lower volume high profit margin segments...and they have different grades.
- It is difficult to determine if pricing increases are a result of the economic uncertainty, availability of wafers, chemicals, materials, equipment or the global supply chain disruptions that are affecting every industry.

2021 MEMS REPORT CARD ... EMPLOYMENT

$\Delta = 1.26$



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2020 Grade=B

2021 Grade=B-

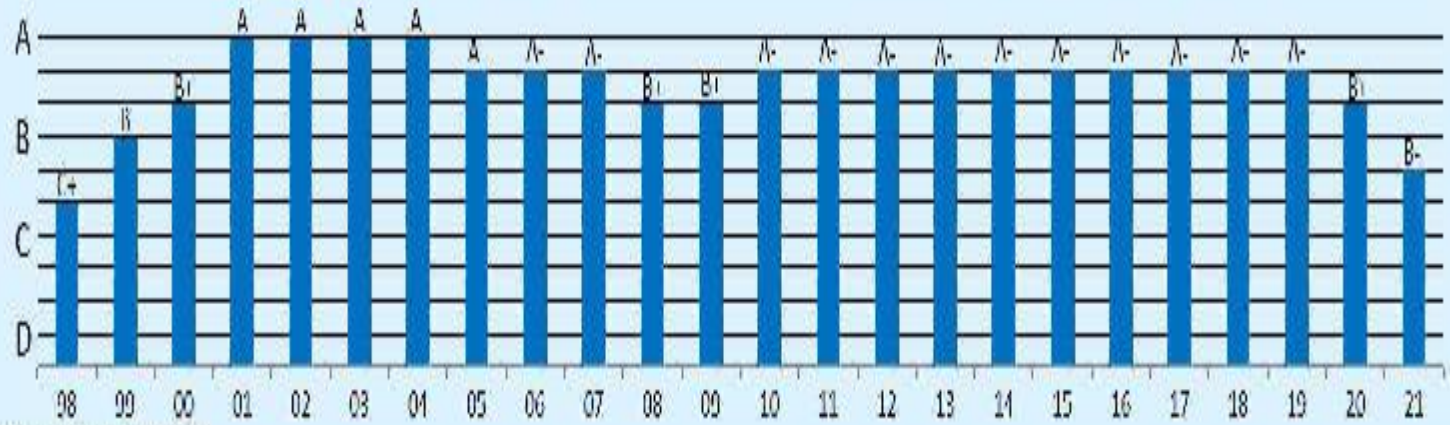
Grade Change=-1

Standard Deviation=1.26

VERBATIMS...EMPLOYMENT

- Engineering salaries are up due to competition from Apple, Google, Meta etc. for engineering talent.
- Employment changes have been realized in most companies as a result of strategic alignment to the growth in healthcare, AI, EV's, electrification of other industries, ADAS, autonomous systems, edge sensing/edge computing, cloud automation data centers. Companies are aligning to the future of sensing everything.
- It is unclear if employment numbers have increased or if the changes represent shifts in skill sets, leadership and SME's for current and future markets
- Employment in R & D could be significantly and positively impacted if IC/MEMS manufacturing gets stronger in the US.
- There is a nearly desperate need for well-trained employees. The job market is perfect for job seekers but difficult for the industry.
- Strong MEMS engineers are finally getting their due. Due to strong competition and limited talent, compensation packages are going up with the strongest individual contributors being compensated similar to executives in most cases.
- We are seeing MEMS engineers get promoted more. This is due to growth in the business, with more leadership spots available, combined with the need to retain strong employees by showing them positive career progression.
- Very tight labor market. Companies are hiring, people are leaving jobs for other fields results in lots of jobs for qualified MEMS professionals.

2021 MEMS REPORT CARD ... ESTABLISHED INFRASTRUCTURE $\Delta=1.21$



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2020 Grade=B+
 2021 Grade=B-
 Grade Change=-2
 Standard Deviation=1.21

VERBATIMS...ESTABLISHED INFRASTRUCTURE

- In our case, we are well-served with a reasonably well-equipped infrastructure. Due to our business model, our customers are contributing to our capex when product specific equipment are required. Customers seem to understand this model much better now than in the past. And we have access to a very good development center.
- Like many other industries, the MEMS industry is currently plagued by supply chain problems and cost explosions in raw materials and logistics.
- Supply chain changes due to Corona have a major effect. Companies tend to move to local producers. But the required infrastructure still has to be built.
- Established infrastructure has become relatively stable, with multiple options available for new programs. In addition, there are now decent foundries in nearly every region. One continuing trouble spot however is the challenge associated with finding a stable foundry who can also (or is willing to) do advanced development (proof-of-principle and post proof-of-principle to early beta stage).
- Not surprisingly the biggest issue this year is supply. And MEMS appears to have taken this about the hardest among all componentry including comm and SoC chips...hence my low grades.
- There is a substantial supply chain issue.
- The infrastructure that I am referring to is the value chain and manufacturing. There has been little increase in MEMS production capacity or in new MEMS fabs coming on line. Most companies in the value chain are now offering design, modeling, packaging, test and OSAT with certifications coming very soon. We are all aware of the spend increase announcements by major semiconductor and IDM manufacturers, but increase is for future expansion (2023 and beyond) and future new facilities.
- The established infrastructure is taking a hit as smaller companies in particular areas get purchased by larger enteritis. This removes the expertise and capability from the supply base. This seems to be happening at a much faster rate and with more negative consequences.
- Supply chain problems, delivery from China is problematic. Problems with supply of exotic / special materials.
- One of the biggest negatives in the last year is the lack of MEMS production fab capacity, the difficulty in purchasing new fab tools. This has hit smaller foundry customers hard, driving up commercialization timelines.
- With more emerging technologies as required by new systems and applications, more process design, materials and fabrication capabilities have matured.

SUMMARY IMPLICATIONS OF COVID ON GRADES

- INTRODUCTION
 - As seen in the previous verbatim slides, virtually all of the grades have been negatively affected by COVID
 - The many insightful verbatims provided by the respondents addressed several of these issues from their personal perspectives
 - Especially affected negatively was Marketing and Infrastructure...but not surprisingly
- GRADE SUMMARY EFFECTS
 - R & D...work at home negatively affected progress
 - Marketing/Market Research...elimination of travel affected in-person meetings and conferences...however compensated for by virtual events
 - Infrastructure...supply chains were severely challenged and under-performed
 - VC Attraction...COVID accelerated new investments in biomed and supported later stage commitments
 - Profitability...reduction of work force, overhead and reduced R & D and marketing budgets increased profitability
 - With the recent surge in COVID cases in Q-1/2, 2022, we believe that the Report Card for 2022 will be similarly affected

SUMMARY / ANALYSIS / CALL TO ACTION / RECOMMENDATIONS

- Final overall grade for 2021 was C+ which declined from B- which it held for the past six years and was recently reported in Fierce Electronics [1].
 - Standard deviation was 0.40
 - 12 of the 14 subjects decline one grade
 - Established infrastructure declined two grades from B+ to B-
 - Industry Roadmap held at C.
 - Worst final numerical grade in the history of the reporting which began in 1998
 - Grades track closely with socio-economic conditions...e.g. 2008/2009 worldwide economic meltdown saw a significant decrease in grades to the C+ level which represents the very bottom of grade levels
- 42 respondents provided over 125 verbatims with 65 appearing in the Final Report
- Due to the continuation of Covid Omicron BA.4.0 and BA. 5.0 into Q-3 2022 and beyond, it is expected that 2022 grades will also be adversely affected as documented in my Fierce Electronics Forecast 2022 [2] and NASA Tech Briefs Forecast 2022 [3] articles.
- Continue to create significant awareness as to the unique solution benefits of MEMS based system solutions (MBSS)...add value
- Understand customer / market needs vis-à-vis rigorous market research
- Define and establish defensible product differentiation

SUMMARY / ANALYSIS / CALL TO ACTION / RECOMMENDATIONS

- Adoption of a marketing / applications pull vs. technology push strategy
- Adopt new media strategies including social media, webinars, email to keep/develop new customers...lessons learned from Covid [4].
- Continue to develop manufacturing / packaging solutions that can help differentiate the product from a price/feature/performance perspective...packaging and testing will continue to be “king”
- Embrace system solutions/integrated products vs. component approach to maximize value and encourage investments e.g. Exo Imaging which recently obtained its Series C funding of \$220M US.
- Accept the fact that obtaining VC funding for MEMS will continue to be a big struggle. Better routes include angels, industrial partnering and buy- outs.
- Those who forget the past are condemned to relive it [5]. Embrace the lessons to be learned from the results of the Report Card and especially the verbatims.

REFERENCES

- [1] R. Grace; 2020 MEMS Industry Commercialization Report Card; Fierce Electronics; August 2, 2022; www.rgrace.com.
- [2] R. Grace; Industry Insiders Share Their Sensors/MEMS Industry Forecasts for 2022, Including the Impact of Covid ;Fierce Electronics; January 18, 2022; www.rgrace.com.
- [3] R. Grace; Forecast 2022 for Sensors/MEMS: Focus on the Impact of Covid-19 on the Commercialization Process Global Supply Chain; NASA Tech Briefs; June 2022; www.rgrace.com.
- [4] R. Grace; Marketing in a Recession: How to Survive; Sensors Daily; April 8, 2020; www.rgrace.com.
- G. Santayana, Reason in the Common Sense, 1905.

FOR MORE INFORMATION

- A copy of the article on the 2021 MEMS Industry Commercialization Report Card Study which was published in the August 2, 2022 issue of Fierce Sensors/Fierce Electronics is available on the Roger Grace Associates website www.rgrace.com
- A complimentary copy of this final report also appears on the Roger Grace Associates website...www.rgrace.com