A HISTORY OF CONSUMER MICROPHONES: THE ELECTRET CONDENSER MICROPHONE MEETS MICRO-ELECTRO-MECHANICAL-SYSTEMS

Gary W. Elko
mh acoustics
Summit, New Jersey 07901

and

Kieran P. Harney
Analog Devices, Micromachined Products Division
Cambridge, Massachusetts, 02139

Introduction

On a bright fall morning last October there was a historic meeting among three industry stalwarts that was of particular interest to the acoustics community. Gerhard Sessler and James West returned to New Jersey, the home state of Bell Labs where they both started their professional careers, to be inducted into the "New Jersey Inventors' Hall of Fame." Ray Stata, founder of Analog Devices and a pioneer of Micro-Elecro-Mechanical-Systems (MEMS) devices, was passing through on business. The three got together at the beautiful Reeves-Reed arboretum in Summit, New Jersey for a discussion on the evolution of consumer microphones towards MEMS (see Fig.1).

> *"Sessler and West were on the trail when they metalized charged Teflon with a thin layer of aluminum and created the modern electret microphone."*

Drs. Sessler and West invented the Electret Condenser Microphone (ECM) at Bell Labs in the early 1960's.[1] The low cost and small size of the ECM has enabled the production of modern consumer devices such as cell phones, headsets, and video cameras. As a result, in excess of 2 billion ECM microphones shipped in 2008. In 1965, Ray Stata founded Analog Devices, a world leader in semiconductor converter and amplifier microchips today. In the early 1990's Ray Stata played a key role in evangelizing MEMS technology, enabling the manufacture of small, low cost accelerometers and gyroscopes for automotive and consumer markets. More recently, he, with his company, developed world-leading MEMS microphone technology. In the 1980's Dr. Sessler did much of the early academic research in MEMS microphones at the University of Darmstadt, Germany. Dr. Sessler is recognized as one of the earliest advocates for research in the field of silicon microphones.

Fig. 1. Kieran Harney, Gary Elko, Jim West, Gerhard Sessler, Ray Stata. (Source: Analog Devices)

Amid the beauty of the autumnal foliage of the Reeves-Reed Arboretum, Sessler, West, and Stata sat down to discuss the evolution of microphones and consider what the future might hold.

Sessler, West and electret condenser microphones (ECMs)

Gerhard Sessler and Jim West both started their professional careers at AT&T Bell Laboratories in the 1950's. Jim arrived first in 1955 as a summer intern from Temple University. Gerhard arrived soon after in 1959 as a fresh Ph.D. from the famous University of Göttingen Laboratory of Professor Erwin Meyer. Both began working in the already well-known Acoustics Research Department, a department that had a deep and rich history in contributions to the field of acoustics and to the founding of the Acoustical Society of America. This historical link is so important that we felt that some of the highlights should be mentioned.

A brief history of the evolution of ECMs

Although the word microphone can be found in references back to the late 1600's, it was not until the 1870's that Alexander Graham Bell realized that time varying electrical signals were a direct analog of acoustic pressure variations that could be used to transmit speech on electrical wires.[2] With this novel insight, Bell began working on the transducers that would be required for telephony. A moving-armature microphone and receiver were constructed (albeit with some help from Joseph Henry) and these transducers formed the basis of Bell's patent of the telephone in 1876. Figure 2 shows the now famous "Fig. 7" from Bell's 1876 patent entitled "Improvement in Telephony,"[2] where the moving armature

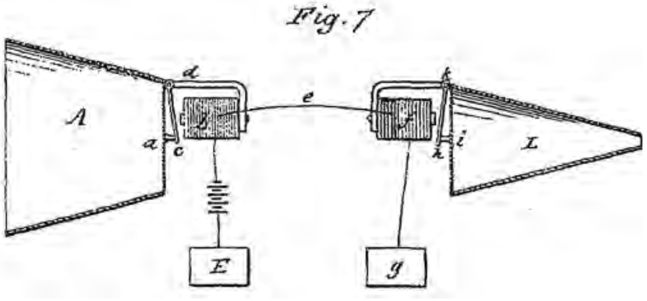


Fig 2. Figure 7 from Alexander Graham Bell's 1876 patent of the telephone. [2]

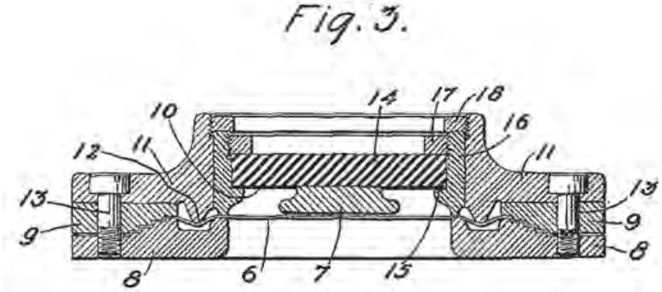


Fig 3. Image from Edward Wente's 1917 patent of the condenser microphone.[6]

transducers drive membranes (a) and (i) at input (A) and output (I) horns. Thus, Bell's work (and his competitors in the race to invent the telephone) can be considered as the beginning of microphone development. Although Bell's patent described moving armature transmitters (telephone terminology for microphones) and receivers (telephone terminology for loudspeakers), the device that transmitted the now famous phrase "Mr. Watson, come here, I want to see you" was obtained using a microphone that consisted of a membrane containing a conducting needle in a slightly acidic water bath. The modulation of the membrane by Bell's voice caused a time varying resistance in the circuit which drove a corresponding modulation of a moving armature receiver. That Bell used a liquid transmitter device that was the basis of Elisha Gray's work, has led to claims that Bell stole Gray's invention. However, Bell's patent was submitted to the patent office in advance of when he could have known about the details of Gray's work. Bell's use of the liquid transmitter was part of the normal process of "reducing an invention to practice." Bell was also accused of fraud and misrepresentation by the government of the United States who moved to annul his patent in favor of Antonio Meucci, an inventor from Staten Island, New York who had filed a caveat (a one year renewable notice of an impending patent) in 1871, about 5 years before Bell's patent. The case was remanded to the Supreme Court for trial but due to Meucci's death and Bell's patent expiring, the true inventor of the telephone (who was entitled to the patent) was never determined.[3]

Bell successfully demonstrated his invention all over the world and widely became known as the inventor of the telephone. It was not until the invention and refinement of the carbon microphone by Edison[4] that adequate speech levels could be obtained over reasonable distances that telephony became practical. Microphone design continued at a rapid pace with the further development of the moving coil, or dynamic microphone invented by Siemens[5] in 1874.

With the invention of the Audion vacuum tube by Lee DeForest and refinements by Western Electric in 1916, E.C. Wente of Bell Labs invented the first stable commercially viable condenser microphone based on a tensioned diaphragm.[6] Figure 3 shows a drawing contained in Wente's 1917 patent clearly showing the main features of a condenser microphone. Wente's condenser microphone established the basic design rules that form the foundation of condenser microphones still used and built today. An interesting historical fact is that Wente extensively used equivalent circuit analysis to model the basic frequency response on the condenser microphone. He was clearly one of the first practitioners to use "lumped parameter models" to design and understand electroacoustic transducers.

Further progress was made with the commercialization of the ribbon microphone invented by Gerlach[7] as a loudspeaker in 1924. The ribbon microphone inherently offered dipole directionality and improvements and variations of the ribbon element to obtain cardioid and hypercardioid patterns were developed by Olson at RCA.[8] Microphone directivity was desired in radio broadcasting for more spatial attenuation between the separate sources and for increased robustness against acoustic feedback in public address systems. Ben Bauer[9] of Shure Brothers made a significant contribution in the late 1940's by using a passive acoustic filter to control the sound propagation to the rear of a dynamic microphone. The acoustic filter he proposed formed an acoustic delay that allowed the formation of a directional microphone with only a single microphone diaphragm. Bauer's design and variants of the principle is still widely used today to build directional microphones.

In 1956, in a consent decree with the U.S. Department of Justice, AT&T was forced to sell its audio transducer business. Most of the professional audio business was handed over to Altec. Coincidentally, this business divestiture occurred at the same time that Jim West, a summer student intern at Bell Labs, was experimenting on how to increase the sensitivity of high quality condenser headphones made from Western Electric 604AA condenser microphones. Jim had some quick success by following the work of Kuhl, Schodder, and Schroeder[10] who had experimented with a dielectric made from a Mylar® membrane known at the time as the Sell[11] transducer. The new large headphone transducer that Jim constructed produced much higher sound pressure levels than the earlier 640AA headphones. Unfortunately, this success was short lived when the transducer sensitivity fell off quite a bit within a few months. Kuhl, Schodder, and Schroeder had observed that the Sell transducer had to be reverse-biased periodically if one desired to use the transducer over a long period of time.

This "problem" became an opportunity, as is so common in scientific breakthroughs. By 1959 Gerhard Sessler had joined Bell Labs and Jim had returned from the university to investigate the sensitivity problem with the headphone transducer on which he had worked as an intern. In another of those strange coincidences that seems to play important roles

Fig 4. Photograph of Gerhard Sessler and Jim West in their lab holding Teflon foil with a production Western Electric EL2 electret microphone in the foreground at Bell Labs around 1977. (Source: Bell Labs Archive)

in scientific history, Sessler had also worked with the Sell transducer. Gerhard used the reciprocal Sell transducer in his Ph.D. work on sound propagation and absorption of gasses at high and low pressures and temperatures. When Jim began experimenting with the problem transducer, he accidentally (but fortuitously) left the DC bias to the Sell receiver disconnected. To his surprise, the receiver started playing loudly again with its original sensitivity—it had been restored by removing the bias voltage! Kuhl, Schodder, and Schroeder had observed this behavior as well but did not pursue this phenomenon in their research. By this time Sessler and West were on the trail and realized the sensitivity problem was due to the fact that the Mylar® polymer had become slowly charge-compensated. Charge compensation was causing the slow loss of sensitivity in the Sell transducer. With this understanding of the problem they went to the CRC Handbook of Chemistry and Physics[12] that was an encyclopedia of materials at the time, and found that Teflon® had the highest volume resistivity of any material they could find (greater than 10^{18} ohm-cm). With this discovery, they managed to procure some sheets of Teflon® from Dupont, the creator of Teflon®. They metalized the Teflon® with a thin layer of aluminum and created the modern electret microphone by tensioning a charged Teflon® membrane over a metalized backplate. Like the condenser microphone, the principle of the electret was well known before a practical working system had been built. In fact, the name electret is credited to Heaviside in 1892.

It is interesting to note that AT&T decided that the electret invention was not commercially important. Apparently the folks producing telephones believed that the carbon microphone, whose invention was in the 1800's, had been perfected and cost reduced to the point that no other technology could displace it. Thus it took almost 7 years after the first publication of the electret before Sony in Japan produced an electret microphone for portable tape recorders. The low mass of the electret microphone diaphragm offered Sony a microphone that was much less sensitive to motor structure-borne noise. Once Sony started producing the electret microphone the growth in production was exponential. Conservative estimates place the total production of electrets to more than 2 billion annually. AT&T eventually produced their own electret microphones for their consumer and business telephones, but this production ended around 1986 when relatively high-quality low-cost electrets became available on the market. A photograph of Jim and Gerhard in their laboratory (circa 1970) is shown in Fig. 4. Both are holding a sheet of metalized Teflon® that was used for testing charge storage with different charging mechanisms, the modified JEOL U-3 electron microscope behind them was one of the preferred ways for precision space charging of electrets. In the foreground of the photograph can be seen a hand holding an EL2 electret microphone manufactured by AT&T Consumer products in Indianapolis.

Figure 5 shows a photograph of Jim and Gerhard in the anechoic chamber at Murray Hill (the world's oldest existing anechoic chamber) holding a research prototype of a second-order unidirectional microphone made from a single electret diaphragm.[13]

Finally, a photograph of Jim, Gerhard, and Jim Flanagan at the launch of Apollo 17 can be seen in Fig. 6. Jim and Gerhard had successfully measured extremely low frequency acoustic signals from a previous launch of a Saturn V rocket from Cape Canaveral. The distance between Murray Hill, NJ and Cape

Fig 5. Photo of Jim West and Gerhard Sessler examining a second-order differential electret microphone in 1973. (Source: Bell Labs Archive)

Fig 6. Photograph of Jim West, Jim Flanagan, and Gerhard Sessler at the launch of Apollo 17 on December 7, 1972. They were recording the acoustic signal from the launch using a large electret sensor (approximately 3 inches in diameter) that was capable of recording to very low frequencies. (Source: Bell Labs Archive)

Canaveral, Florida is about 950 miles (nearly 1800 km), and the acoustic signal from the Saturn V was detectable at low frequencies where the excess absorption was apparently low enough. The time delay between the launch and the signals at Murray Hill was just over 1.2 hours. An interesting historical note here is that Jim and Gerhard were asked not to publish this finding since a similar method was used to confirm atmospheric nuclear explosions. In the photo, Jim and Gerhard were attempting to confirm their measurements at the source, but condensation on the electrometers resulted in not being able to get data on the last of the Apollo launches.

Gerhard Sessler left Bell Labs in 1975 and headed to the Technische Hochschule of Darmstadt (now the University of Darmstadt) in Germany. The reasons for his move were interesting. First, he felt that Bell Labs was a place where experience was not valued as highly as at a university. Second, he also saw the beginning of the pendulum swing where the word "relevance" was introduced when reviewing research projects. At Darmstadt, Sessler continued to explore acoustic transducers and played a pivotal role in the research and development of silicon-based microphone systems. When asked what inspired him to move into the silicon microphone, Sessler responded "it was in the air." Having a good sense of smell apparently is a good attribute for a researcher. Sessler fortunately happened to have an academic colleague and friend who was head of the silicon fabrication facility at Darmstadt. The link to silicon bulk machining was made and Sessler and his student Dietmar Hohm produced the first working silicon condenser microphone devices based on bulk machining of silicon.[14] An interesting sideline here is that Bell Labs was also working on its own silicon microphone. However this effort dissolved without much success after the initial devices showed poor acoustic performance due to a diaphragm that was too stiff, (even after extensive doping in an attempt to lower the bending stiffness). Bell Labs also was an early innovator in using Micro-Electro-Mechanical Systems (MEMS) and actually experimented in MEMS microphones, but these devices remained laboratory experiments since there was no interest in the company to produce actual devices for the market. Parallels to how the electret was ignored cannot be overlooked.

As one can see, there is a strong historical thread that binds the invention of the microphone in 1876 to today's MEMS silicon microphones. Gerhard Sessler and Jim West played key roles in the invention of the current ubiquitous electret and the future silicon MEMs microphones for consumer microphone applications.

Stata and micro-electro-mechanical-systems (MEMS)

After graduating from the Massachusetts Institute of Technology (MIT) in 1957 Ray Stata pursued his ambition to create a company that would be a place for creative engineers to develop innovative electronic components. In 1959, he had a chance meeting in Harvard Square with Matthew Lorber, a former MIT classmate. They started a company called Solid State Instruments which they sold to Kollmorgen Corporation soon thereafter. Mr. Stata became a vice president of marketing with Kollmorgen's Inland Controls Division. With the nest egg from the sale of Solid State Instruments and the experience at Kollmorgen, Stata and Lorber founded Analog Devices Inc. (ADI) in January 1965. Their first product was a general-purpose operational amplifier—a hockey-puck sized module used in test and measurement equipment. The focus from the very beginning was on high performance operational amplifiers that delivered real value to their customers (see Figs. 7-8).

Analog Devices continued to grow. In 1969, with annual sales in excess of $8.7M, the company went public generating the cash it needed to become an integrated circuit (IC) manufacturer. In parallel with other product innovations, the acquisition of Pastoriza Electronics began what would eventually become Analog Devices' domination of the analog-to-digital and digital-to-analog converter marketplace.

Throughout these early years Ray Stata wanted to create an engineering-driven technology company where engineers could focus on product performance. With this focus in the core areas of operational amplifiers, analog to digital and digital to analog converters and digital signal processors (DSPs) Stata created a set of products with very broad usage in the audio and acoustics world today.

Since founding ADI, Ray Stata has continuously fostered a strong sense of "entrepreneurship" in the company. New ideas are encouraged and many are given space and funding to be developed as potential breakthrough products. In the mid–1980's, some ADI engineers began to explore a new technology called MEMS. By 1989 working prototypes of MEMS accelerometers were demonstrated and significant funding was identified to further explore the technology and develop a product for the market.

The core element of a typical MEMS accelerometer is a moving beam "proof mass" structure. This element is typically comprised of two sets of fingers; one set fixed to a solid ground plane on a substrate and the other set attached to a known mass mounted on springs that can move in response to an applied acceleration. Under acceleration there is a change in capacitance sensed between the fixed and moving beam fingers.[15]

The dimensions of these MEMS structures are in the order of microns, requiring very high precision silicon photolithography and etching process technologies. These devices also need very low-noise electronic circuits to read out extremely small changes in capacitance (in the order of femtofarads). MEMS structures are typically formed from single crystal silicon or from polysilicon deposited at very high temperatures on the surface of a single crystal silicon wafer. Structures with very different mechanical characteristics can be created using this flexible technology.

While the full potential of the market opportunity for MEMS accelerometers was not fully clear in the late 1980's, the market for automotive accelerometers for airbag deployment was identified as one of the most promising opportunities. The incumbent technology used at the time was a ball and tube sensor[16] which was a relatively large and expensive solution. In the period from 1991 to 1997, with significant investment two of ADI's accelerometers were released and began to successfully penetrate the automotive market for airbag deployment. The small size and relatively low cost of MEMS accelerometers helped to fuel the broad adoption of airbags as standard features in all automobiles.

However, while MEMS was achieving recognition and success in the marketplace, there were challenges associated with developing a high yielding stable manufacturing infrastructure for the technology.[17] During this critical period Ray Stata played a key role as the senior management advocate for the technology. From 1997 to 2000 Mr. Stata championed MEMS at ADI by stepping in as the acting General Manager of the MEMS division and leading the business through a critical stage of its development.[18] Today, ADI is recognized as one of the leaders in MEMS accelerometers and gyroscopes with products in a broad range of areas, including automotive, industrial and consumer markets (see Fig. 9). Who could have imagined that this core MEMS technology designed specifically for air bag deployment in automobiles would find ubiquitous use as a breakthrough enabling technology for the Nintendo Wii? Building on this strong foundation in inertial sensors and on the core business of converters and amplifiers ADI has recently announced a range of high performance MEMS microphones.


Fig 7. Matt Lorber and Ray Stata circa 1965. (Source: Analog Devices)


Fig 8. Ray Stata presents operational amplifiers. (Source: Analog Devices)

A brief history of the evolution of MEMS microphones

Pressure sensors are the earliest example of commercial success of silicon micromachining dating back to the 1960's and 1970's. In 1982 Peterson[19] comprehensively described the status of micromachining technology in his paper "Silicon as a Mechanical Material." There was no specific mention of the use of the technology to produce microphones.

In 1983 Royer *et al.*[20] described a micro machined silicon microphone based on the piezoelectric effect. The sensing element was a deflectable diaphragm composed of silicon and zinc

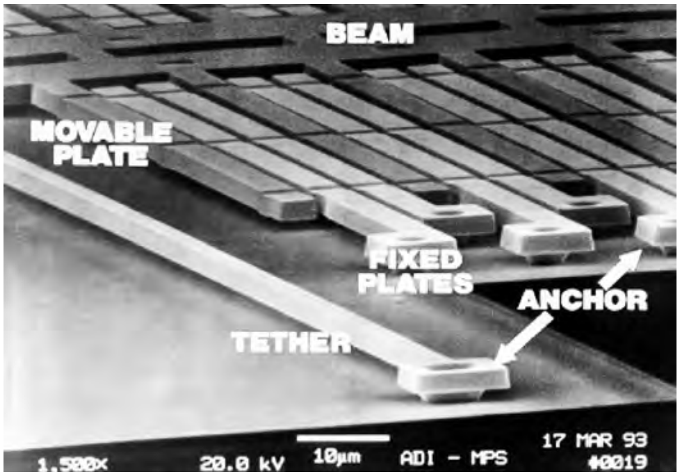


Fig 9. ADXL50 MEMS Accelerometer Structure. (Source: Analog Devices)

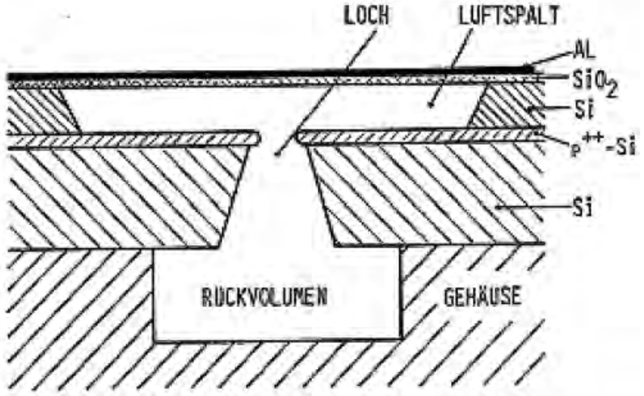


Fig. 10. Hohm and Sessler 1983 patent.[21]

oxide (ZnO). The objective of this work was to create a microsensor that could possibly be used to monitor film thickness in the IC wafer fabrication area as a process control tool.

In July 1983 Dietmar Hohm and Gerhard Sessler applied for a German patent titled "Silicon-based capacitive transducers incorporating silicon dioxide electret,"[21] (Fig. 10). This first version of a microphone used a silicon dioxide charged electret backplate and is described in detail in Hohm and Multhaupt (1984).[22] The prototype was comprised of a 10 mm x 10 mm backplate produced from p-type silicon with a 2 micron thick silicon dioxide top layer. The diaphragm was a 13 micron thick Mylar membrane with an aluminum coating separated from the backplate by a 30 micron thick polymer ring. A 1 mm diameter hole in the backplate provided a path to a back volume formed with the microphone housing. The long term charge stability of the SiO_2 electrode was evaluated over 20 months and found to have no measurable decay. In 1989 Murphy *et al.*[23] described prototypes of a silicon electret microphone produced using a silicon backplate wafer with a SiO_2 coating as the electret and using a second wafer with etched through holes to form a spacer for the diaphragm.

In 1989 Hohm and Hess[24] presented an externally biased silicon microphone comprised of a diaphragm formed on one silicon wafer and the backplate formed on a second wafer and the system bonded together to form a microphone (Fig. 11). The backplate was made from a silicon wafer with a SiO_2 electrode layer which also included a spacer layer to form the electrode gap. Two rectangular slits were formed in the backplate to reduce the stiffness of the air layer between the diaphragm and back plate. The diaphragm was made from a silicon nitride (Si_3N_4) layer produced on a separate silicon wafer. Both diaphragm wafer and backplate wafer were glued together to form the final transducer which measured 1.7 mm x 2 mm. Experimental

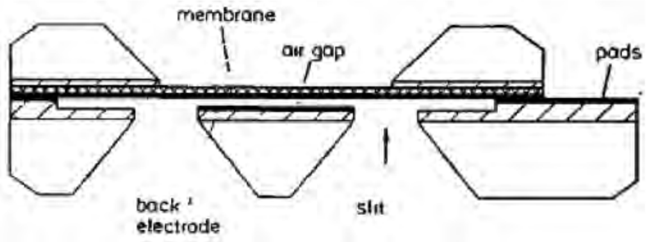


Fig 11. Cross-section of Silicon Microphone.[24]

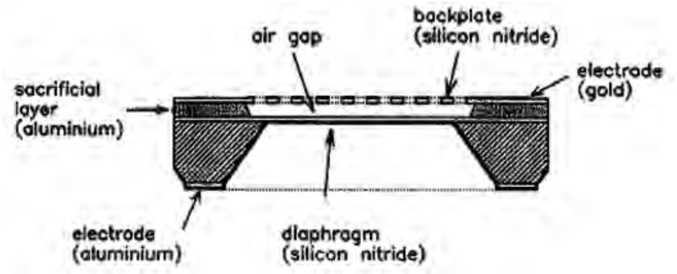


Fig 12. Single chip silicon condenser microphone. [27]

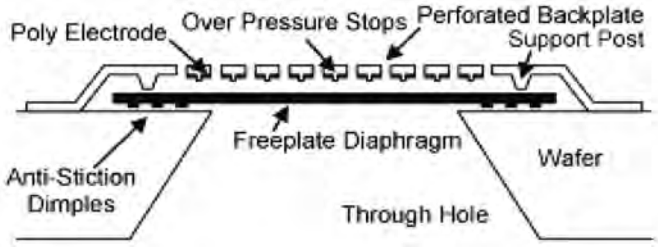


Fig 13. Knowles SiSonic® MEMS microphone cross-section.[29]

measurements were made using a 28V DC bias and they reported open-circuit sensitivity measurements comparable to conventional microphones. In their conclusion, Hohm and Hess predicted that "silicon microphones will probably find applications in all fields where small dimensions rather than high signal-to-noise ratios are desired." This was the first subminiature condenser microphone with a diaphragm less than 1 mm x 1 mm.[25]

In 1990 Bergqvist *et al.*[26] described work at the Federal Institute of Technology in Lausanne on a silicon microphone that had a highly perforated backplate and a 5 volt bias. They described a wafer fabrication process they claimed was suitable for high volume manufacturing. The diaphragm and backplate were fabricated on two separate wafers that were subsequently joined together using wafer bonding.

Scheeper *et al.*[27] presented a MEMS microphone fabricated on one silicon wafer in 1992. The diaphragm and highly perforated backplate was formed with vapor deposited silicon nitride and used an aluminum sacrificial layer to form the gap between the diaphragm and backplate (Fig. 12). A flat frequency response from 100 Hz to 14 kHz was reported from the structure. A detailed discussion of the early development of MEMS microphones in the 1980's and early 1990's can be found in Sessler (1996) [24] and Scheeper *et al.* (1994).[28]

The first commercialization of MEMS microphones was in 2003 when Knowles released the SiSonic® surface mount MEMS microphone.[29] Knowles began development of MEMS microphones in the early 1990's. At that time the target application was hearing aids but the focus changed to the consumer market where they were able to exploit opportunities in the mobile handset market.[30] Today Knowles has shipped in excess of 300 million MEMS microphones into general consumer applications including cell phones, digital cameras and Bluetooth headsets.[31] The Knowles microphone incorporates a MEMS element and a complimentary metal oxide microscope (CMOS) die combined in a surface mount acoustic package. The sensor die consists of a compliant diaphragm separated from a highly perforated, rigid backplate (Fig. 13). The diaphragm is fabricated from 1 micron thick polysilicon and has a 0.5 mm effective diameter. The diaphragm separation from the backplate is maintained at 4 microns by a series of support posts.[29]

In 2005 Sonion, a Danish audio transducer manufacturer, launched the SiMic,®[32] consisting of a MEMS sensing element and a signal conditioning application-specific integrated circuit (ASIC) both mounted directly to a silicon substrate carrier. The all-silicon microphone package measured 2.6 mm x 1.6 mm x 0.865 mm.[33] The development of the Sonion MEMS microphone began in 1993 as collaboration with the Microelectronics Center at the Technical University of Denmark (DTU). Pulse is a division of Technitrol who purchased all of Sonion, including the Sonion MEMS microphone. More information on Pulse can be found on the web.[34]

Another approach to MEMS microphones is the integration of the MEMS sensor element and the sensor electronics on one single silicon chip. Bernstein and Borenstein[35] described a MEMS microphone with a 1 mm diaphragm supported by springs, a plated gold perforated backplate and an on-chip buffer amplifier. Pedersen *et al.*[36] proposed an integrated microphone with a digital output. The microphone sensing element was a polyimide structure deposited on a standard CMOS circuit wafer (Fig. 14). The advantage of polyimide is that it can be deposited at low temperatures that will not affect the CMOS devices.

Neumann and Gabriel [37] described an integrated CMOS MEMS microphone in 2003 that is the basis for the Akustica MEMS microphone product launched in 2006. The diaphragm is formed from the top level metal and oxide layers of the CMOS wafer, after circuit fabrication is complete. A serpentine metal and oxide mesh pattern repeats within the diaphragm area and underlying sacrificial polysilicon is etched away to form a suspended diaphragm (Fig. 15).[38] A conformal coated polymer is then deposited over the mesh area to form an airtight seal over the cavity.

In 2006 Weigold *et al.*[39] described a MEMS microphone with a 0.5 mm diaphragm mounted on springs to maximize sensitivity using a low bias voltage. The backplate is formed from the device layer of a SOI (Silicon on Insulator) wafer and the 1 micron thick diaphragm is formed using polysilicon deposition. Figure 16 shows a scanning electron microscope (SEM) micrograph of the diaphragm top surface showing the spring support mechanism. This technology is the basis for the Analog Devices MEMS microphone.

We have traced the evolution of MEMS microphone technology through the years from the early work by Sessler to the

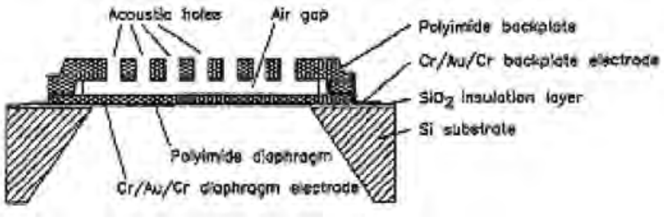


Fig 14. Polyimide capacitive microphone.[36]

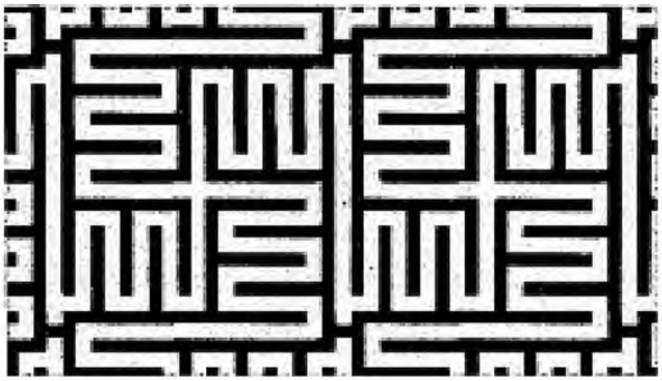


Fig. 15. Akustica serpentine mesh diaphragm design.[38]

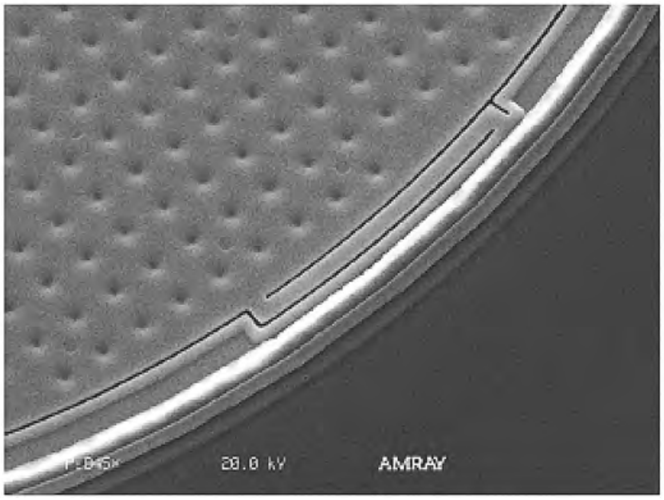


Fig 16. Scanning Electron Microscope micrograph of Analog Devices microphone diaphragm.[39]

recent commercial success of Knowles. It is further fascinating to examine the parallels between the early days of electret condenser microphone commercialization and what is happening today in MEMS. With Gerhard Sessler's and Jim West's background in electret microphones and MEMS and Ray Stata's contributions to MEMS, converters and amplifiers, the meeting at Reeves-Reed arboretum was a unique historical event.

Electret condenser microphones meet micro-electro-mechanical-system microphones

It is very interesting to reflect on the evolution of a technology from the early development phase to ultimate commercial success. More interesting is the unique opportunity to witness a discussion between such industry veterans who played a sustained role in creating and developing successful products that have achieved ubiquity.

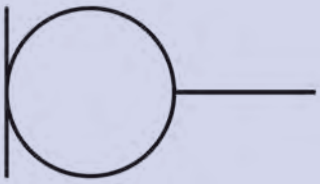
Interestingly, their informal discussion began with some keen observations of the state of consumer electronic devices in the 1960's. At that time consumer products were mostly items like television sets and radios. Audio tape recorders were just beginning to emerge for the consumer market and most recorders used external microphones to minimize mechanical noise pickup in the microphone from the recorder motor. Sessler and West noted that the electret condenser microphone offered significant potential advantages in terms of small size and vibration sensitivity versus the dynamic microphones that

Fig 17. Ray Stata, Gerhard Sessler and Jim West discuss microphones in handsets. (Source: Analog Devices)

were available at the time. Sessler and West also reflected on the resistance to the technology which now ships in excess of two billion units per year into every segment of the market today. Similarly, Stata reflected on the early days of MEMS accelerometers when no one envisioned that it would become one of the core technologies in cell phones and video games. Companies like Motorola with pressure sensors, Texas Instruments with the digital light processing (DLP) and Analog Devices with accelerometers and gyroscopes were the early pioneers for the technology. Knowles created a major stir when they released the first commercially available MEMS microphones several years ago.

MEMS microphones have had considerable success because they address one of the key weaknesses of electret condenser microphones, namely reduced sensitivity through reflow solder temperatures. There is continued work in the electret world to create more stable electrets and there has been success reported in the last few years. Sessler commented that he still thinks it is too early to write-off the ECM but agreed that MEMS offers significant potential advantages. Stata stated that he feels that one of the key advantages that MEMS offers is the controllability of the photolithographic process for MEMS creating very stable unit-to-unit performance. He believed that the ability to integrate better the underlying electronics into the package with the transducer is significant. For instance, the inclusion of an analog-to-digital converter and programmable amplifier opens up opportunities to drive further miniaturization of end-user products while significantly enhancing performance with respect to power supply noise rejection, radio frequency interference (RFI), and electromagnetic interference (EMI) immunity of the digital output signals. All agreed that one major challenge in consumer devices is the continuing drive for higher performance in smaller devices. Jim West commented on the need for microphones to have better performance and more functionality and be able to fit into smaller and smaller products. Jim was especially interested in the use of multiple microphones to reduce background noise and improve audio quality in cell phones and mobile devices.

More than 50 years after the invention of the electret microphone the product is still the lowest-cost, highest-volume microphone in use. MEMS microphones are gaining a share in the market addressing some of the new demands of the market not readily met by the electret condenser microphone. It will be very interesting to look back 50 years from now and see what has transpired.**AT**



(Source: Analog Devices)

Western Electric 630A microphone (Source: mh acoustics)

THE ORIGIN OF THE MICROPHONE SYMBOL

The Western Electric 630A moving coil microphone was a radical design that was introduced in the early 1930s. The design was a moving coil microphone housed with a "transmitter attachment" which was comprised of a 3 1/4 inch silk screen baffle. The baffle was designed to reduce on-axis acoustic pressure buildup on the relatively large microphone diaphragm as well as enhance the response of signals arriving from the rear of the microphone. Thus, the baffle acted as a passive acoustic device that gave the microphone a nondirectional response.[1] This microphone became known as the "8 ball" microphone and its unique shape became the basis for the standard microphone symbol.

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Kieran Harney, a product line manager in the Micromachined Products Division of Analog Devices Inc. (ADI), is focused on the development of new MEMS technologies. He joined ADI 22 years ago as a semiconductor packaging engineer in Limerick, Ireland; served as assembly and test manager in the Philippines from 1994 to 1997; and assumed responsibility for assembly, test, and advanced package development in Cambridge, MA, in 1997. Kieran received a manufacturing engineering degree in 1983 and an MBA in 1993, both from the University of Limerick, Ireland.

Gary W. Elko was born in Philadelphia, PA in 1955. He graduated from Cornell University with a BSEE degree in 1977. He then followed his interests in acoustics and signal processing and received M.S. and Ph.D. degrees from Penn State University in 1984. After graduation, he joined the Acoustics Research Department at AT&T Bell Laboratories where he worked on electroacoustic systems and signal processing for hands-free audio communication and room acoustics. He is president of mh acoustic LLC, a company he founded in 2001 along with former Bell Labs colleagues in Summit, NJ. He has over 25 patents and patent applications and has published more than 60 papers. He is a past associate editor of the Institute of Electrical and Electronics Engineers (IEEE) *Transactions on Acoustics, Speech and Signal Processing* and is a Fellow of the Acoustical Society of America and the IEEE.