Silicon-based MEMS Microphone For Automotive Applications

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With microphones being used ever more frequently in the automotive sector in a variety of different applications, ensuring their reliability in the face of the diverse temperatures, vibration and shock they are subject to is of paramount importance. In this light, silicon-based MEMS microphones, thanks to their robustness against shock and lower sensitivity to temperatures, amongst other things, may prove to be more advantageous options than standard Electret Condenser Microphones.

Microphones in automotive environments

In recent years, applications in the automotive sector that utilise "sound" as input have become more and more common. The use of microphones in vehicles was mainly driven by the introduction of hands-free devices and parking assistance systems. Nowadays, microphone-dependent technologies have expanded to offer more than just convenience and safety for top-of-the-range vehicles. Even in the mid-class, drivers value the use of hands-free microphones and the regulated noise dependent volume controls of car stereos and entertainment units because these technologies actively reduce the chance of accidents. Voice recognition enables users to command and control various functions without taking their hands off the steering wheel. Drivers of sports cars enjoy their specific engine sound – the result of active sound control - whereas businessmen appreciate the low noise levels in the cabin delivered by active noise reduction systems.

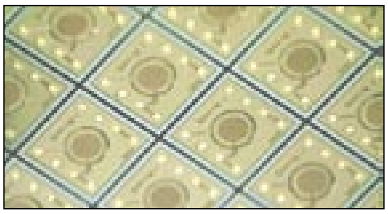


Figure 1 - MEMS microphones within 6-inch wafer, close-up

All these applications require a stable microphone which functions reliably over a wide temperature range and which is robust to vibration and shock. Since standard Electret Condenser Microphones (ECMs) are temperature sensitive and thus less stable, it is hard to achieve consistent performance for automotive applications over temperature, and especially over time. Silicon-based MEMS microphones offer various advantages over ECMs, as will be discussed below.

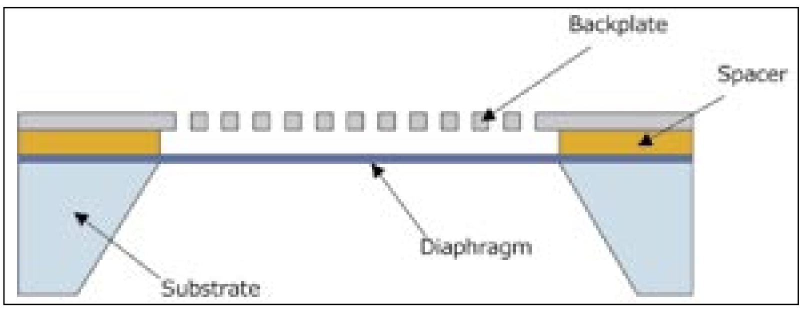
MEMS microphone development and current status

In 1988 Knowles Electronics began development of a silicon-based microphone. The original intention was to create a component suitable for the hearing aid industry. During the early stages the actual microphone was embedded in a conventional metal housing. Very high specification levels and the relatively low volume of this market made it difficult to justify silicon microphone production.

In 1997 Knowles began development of a MEMS microphone based on 6-inch wafers, with cost being a key factor. After another 5 years of MEMS and package development, the SiSonic microphone was launched onto the consumer electronics market. Batch fabrication enables mass production with almost no variation in key performance factors.

By the end of October 2006, Knowles Acoustics had already shipped more than 300 million SiSonic SMD microphones to consumer electronic manufacturers. The majority of these microphones are currently used in mobile phones. Manufacturers of digital cameras, computers, PDAs, and MP3 players also value the advantages of a stable surface mountable acoustic component. The SiSonic microphone replaces more and more conventional Electret Condenser Microphones (ECMs), which are temperature sensitive and therefore less stable.

Figure 2 - Cross-section of MEMS condenser microphone design principle



SiSonic microphone – principle and construction

SiSonic belongs to the group of condenser microphones. As shown in Figure 2 there are two electrodes involved, which form a capacitor. The back plate, which is the static electrode, is highly perforated and hence "acoustically transparent". The flexible electrode - the dia-

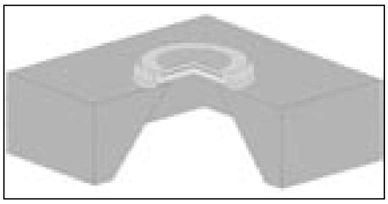


Figure 3 - Cross-section through SiSonic MEMS unit

phragm - is suspended and susceptible to pressure changes in the air and can vibrate when exposed to sound. The vibrations of the diaphragm actually modulate the value of the capacitor itself. These modulations are electrically amplified and can be used for communication devices, as input for noise reduction, active sound control or sensor applications.

SiSonic construction design details

The entire SiSonic condenser microphone is a square die manufactured entirely from silicon. The back volume is formed by silicon substrate as shown in Figure 3.

The actual diaphragm of the microphone is approximately 600µm in diameter. The back plate consists of composite of silicon nitride and poly silicon whereas the poly silicon layer acts as the conductive element of the back plate forming the static electrode. Figure 4 shows the back plate (electrode) in detail.

MEMS design with free-floating diaphragm

In order to avoid the influence of film stress, Knowles Acoustics decided to pursue an approach with a patented free-floating diaphragm. Only one physical connection between the diaphragm and the substrate allows an electrical connection to charge the diaphragm. The microphone diaphragm is supported, but not physically attached, by posts that follow a circular pattern around the edge of the diaphragm. In Figure 4, the support posts can be recognised from the opposite side of the back plate electrode. Figure 5 shows the poly silicon diaphragm. In the electrostatically charged state with internally biased voltage, the support posts establish a gap between the diaphragm and the back plate.

CMOS circuit with voltage regulator and microphone bias supply

The CMOS circuitry of the SiSonic microphone contains a voltage regulator, the bias voltage supply, and a low impedance output stage. The voltage regulator allows a wide supply voltage range typically 1.5V to 3.6V. Within this range no sensitivity variation occurs. The bias voltage supply for the static charge of the MEMS microphone generates a bias voltage to charge the diaphragm. This charge pump principle is similar to a high-class studio condenser microphone. As no electret material is being used, the microphone does not lose any sensitivity over time or due to exposure to high temperatures. This is the most critical point for a stable SMD microphone.

The CMOS circuit also provides model dependent interfaces. Besides a single-ended version with and without a scalable amplifier, there is also a model with differential output as well as a digital microphone version available. Figure 6 shows the model with digital

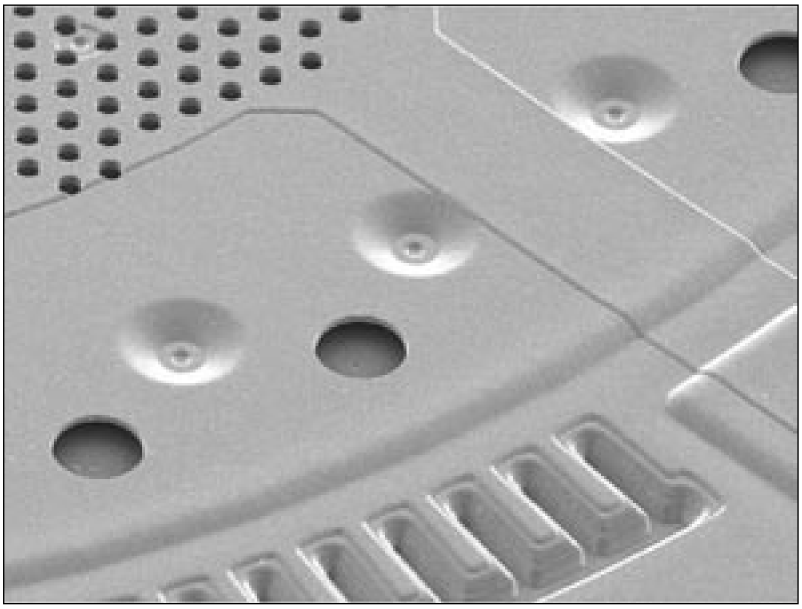
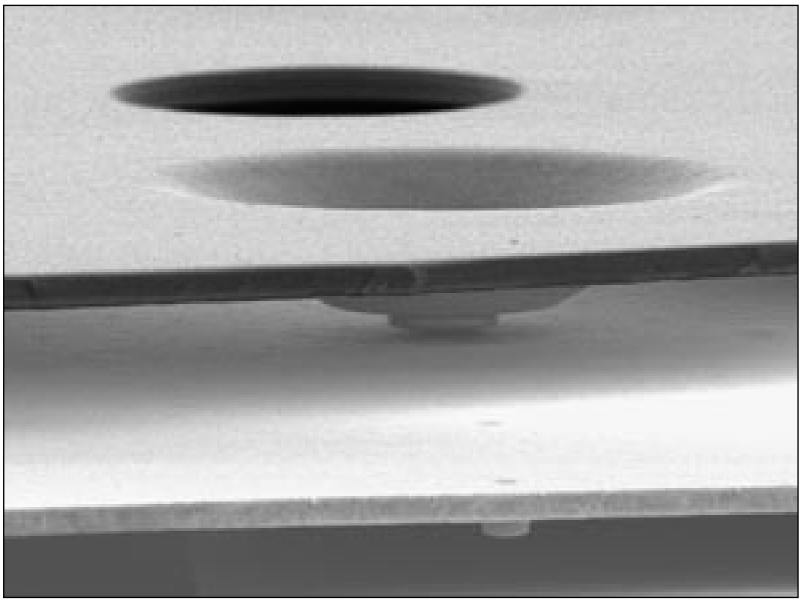


Figure 4 - Back plate of Sisonic MEMS microphone
Figure 5 - Poly Silicon diaphragm (light grey) with Back Plate support post



interface in its housing (housing with lid removed for demonstration purposes).

Technical data

The SiSonic microphone has equivalent, or in many cases improved performance characteristics to ECMs. The nominal inherent noise level is 37dB despite the small diaphragm surface. The nominal sensitivity is 42dBV(0dB=1V/Pa). The typical frequency response curve is shown in Figure 7 (10Hz - 10kHz). The low corner frequencies are 15Hz (-3dB), and 8Hz (-6dB), which allows subsonic operation.

As a result of well-controlled batch fabrication processes, frequency response and corner frequency have much smaller tolerances compared to ECMs. The same applies to the phase response of the microphone. The output impedance is less than 300Ohms while traditional ECMs are commonly rated at 1.5kOhms. The microphone can handle sound pressure levels of up to 115dB. The harmonic distortion at 100dB is typically below 1%.

Low vibration sensitivity and shock resistance

Low vibration sensitivity of a microphone is desirable in many areas. The automotive environment is especially challenging in terms of vibration, body noise and shock. Vibrations are partly transferred into an unwanted part of the electrical signal and are either perceived as disturbing noise within speech applications or mislead command/control units. Mechanical vibration isolation is necessary in conjunction with ECMs, and is very often a mechanically challenging and space consuming solution, and therefore very costly. The SiSonic microphone has a major inherent advantage because of its physical size. Due to the low mass of the diaphragm and the mass of the air in the vicinity of the diaphragm, the SiSonic microphone is far less sensitive to vibrations than a conventional ECM. Figure 8 shows a size comparison between SiSonic and a 4mm ECM. The surface area of the SiSonic diaphragm is only 4% of a 4mm ECM.

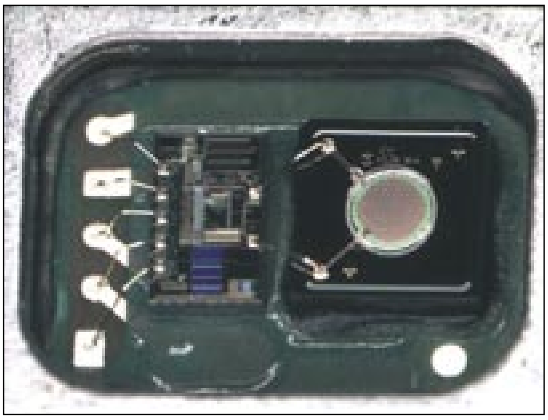


Figure 6 - MEMS die and CMOS circuit of digital SiSonic in open FR4 housing

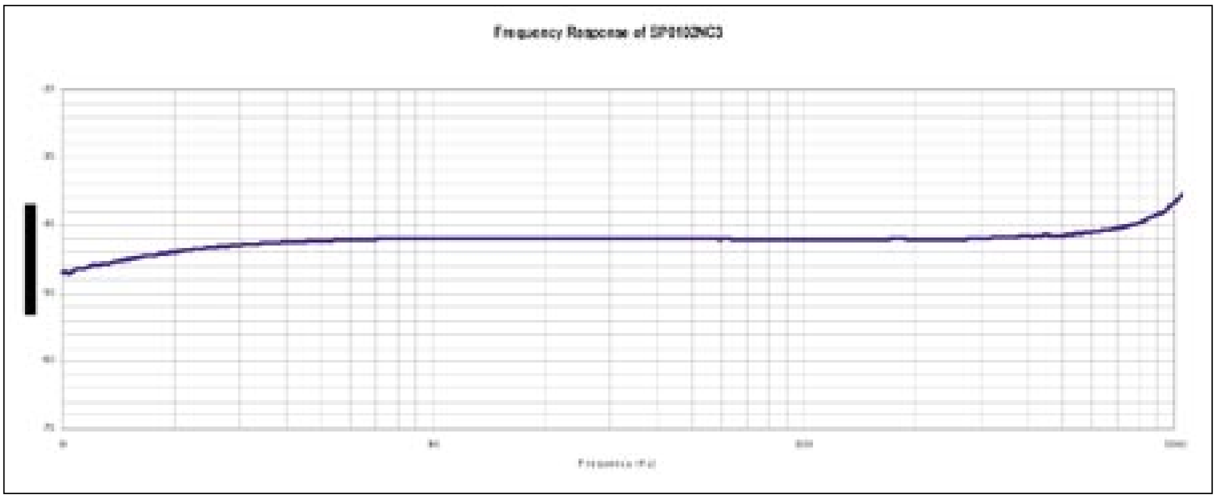
Figure 9 shows a comparison of the vibration sensitivity of the SiSonic microphone (directly attached to a PCB), a 6mm ECM with and without an additional rubber holder. The vibration sensitivity of a SiSonic microphone is 10dB below a 6mm ECM without rubber holder and at least 6dB below the part with additional rubber gasket. In some automotive applications ECMs with a diameter of 10mm are used. These microphones exhibit even higher vibration sensitivity than 6mm ECMs. It is anticipated that due to obsolescence these microphones will disappear from the market soon.

Adding a rubber gasket to the ECM couples another mass-spring load. The resonance peak of this assembly at 3.8kHz leads to a higher vibration sensitivity in the frequency band from 2-5kHz, which is still at the upper end of the speech band. There is only a slight improvement below 1kHz over the ECM conducted directly to the board. SiSonic microphones are very robust against mechanical shocks. SiSonic withstands shocks of 12000G, whereas ECMs are only rated for up to 3000G.

High power supply rejection

Due to its internal supply voltage

Figure 7 - Typical frequency response curve of the SiSonic silicon microphone, frequency band 10Hz -10kHz



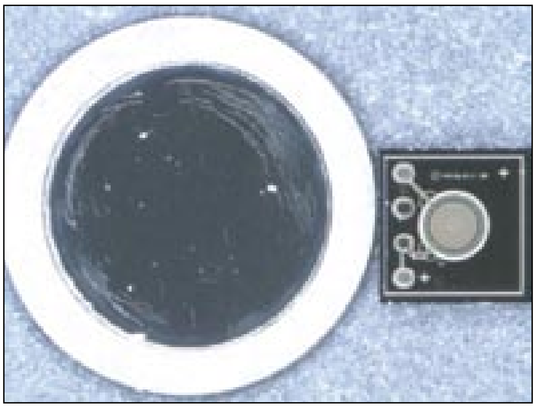


Figure 8 - Size comparison of SiSonic and 4mm ECM

regulator, SiSonic has a very efficient attenuation of any AC modulations within the power supply line. Figure 10 shows the PSRR (Power Supply Rejection Ratio) of a Standard SiSonic (blue), Amplified SiSonic (green) compared to an ECM (red). The PSRR of a standard SiSonic is 50dB, significantly better than an ECM, which only has a PSRR of 2dB. Amplified SiSonic microphones provide a PSRR of at least 30dB and at the low frequency end 40dB (100Hz). Low PSRR is especially important for integration into automotive applications since occurrences of supply voltage variations and peaks/spikes are not uncommon.

Temperature performance

The SiSonic microphone is an SMD component. It withstands the usual lead-free reflow solder profiles with 260°C for 30 seconds 5 times. The operational temperature range is -40°C to +105°C and therefore far wider than ECM ratings. Some special models of ECMs are rated to operate at temperatures up to 85°C with deviations in sensitivity.

SiSonic Product Qualification does include high temperature test at 105°C for 1000hrs under biased condition. Other parts of the SiSonic product qualification which are important for automotive integration are: temperature/humidity tests at 85°C/85% RH for 1000hrs biased, low temperature biased life test at -40°C/1000hrs, and thermal shock test -40°C/+125°C with 100 cycles. Under the above environmental conditions the standard deviation of the sensitivity is max 1dB.

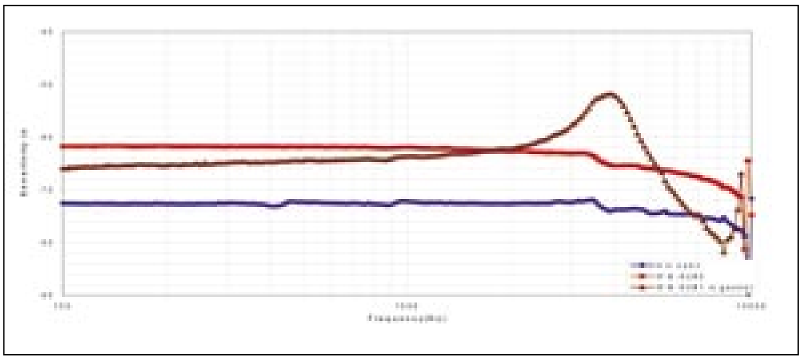


Figure 9 - Vibration sensitivity of SiSonic microphone (black), a 6mm ECM without (grey) and with a rubber holder (light grey). All microphones were attached to a PCB

Figure 10 - PSRR of SiSonic (blue) vs. ECM (red), green curve shows PSRR of amplified SiSonic