MEMS as Low Cost High Volume Semiconductor Solutions It's all in the Packaging and Assembly

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ABSTRACT

Micro-electromechanical (MEMS) oscillators are now in production and shipping in quantity. Early development of micro mechanical devices provided the understanding that metal beams could be fabricated and they would resonate as a time reference. The issues of performance and price have prevented silicon entry into the quartz dominated market until recent developments in semiconductor processing and assembly. Today MEMS oscillators are the world's smallest programmable precision oscillators and are displacing quartz technology in the +/– 50 ppm accuracy spec. New oscillators extend the technology with spread spectrum, voltage control, and improved jitter performance. New ultra-thin packaging, made possible by the small encapsulated MEMS resonators, provides the word's thinnest precision oscillators.

BACKGROUND

Resonators are one of the earliest MEMS devices to be published. However, it has taken forty years to surmount the many difficulties involved in building commercially viable oscillators that can successfully compete with quartz.
Figure 1 shows an early resonator published by H. C. Nathanson in 1967 [1,2]. From this beginning, research spanning many universities and companies has lead to the commercial oscillators described in this paper.

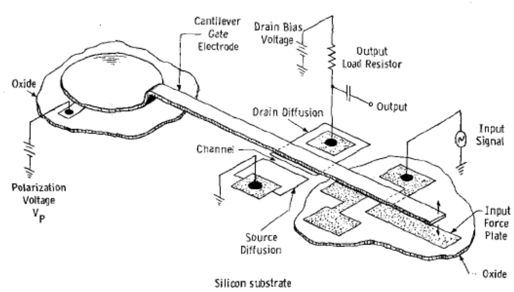

Figure 1. One of the first MEMS resonators, after H.C. Nathanson [2].

The vast semiconductor infrastructure has enabled new breakthrough technology development and cost reduction. For MEMS resonator improvements the primary developments have been in material selection [3], packaging [4], resonator design, and oscillator electronics.

FABRICATION: "0" LEVEL PACKAGING

MEMS require special consideration for packaging. The micro mechanical elements can be rendered inoperative or performance can be impaired if the part is not hermetically sealed. Several successful solutions are common today but all involve significant cost. It have been stated that packaging is up to 70% of the total cost of MEMS.

Reliability, Packaging, Testing, and Characterization of MEMS/MOEMS VII, edited by Allyson L. Hartzell, Rajeshuni Ramesham, Proc. of SPIE Vol. 6884, 68840K, (2008) · 0277-786X/08/$18 · doi: 10.1117/12.778250

SiTime has developed manufacturing processes that seal and encapsulate the resonator cavities at high temperature and protect them under thick and durable silicon covers. This produces low-drift resonators [5] that can be molded into standard low cost semiconductor packages. Figure 2 shows the process steps in the formation or the MEMS resonator…from resonator definition to encapsulation and wiring. Figure 3 shows the SEM cross sections of the actual resonator.

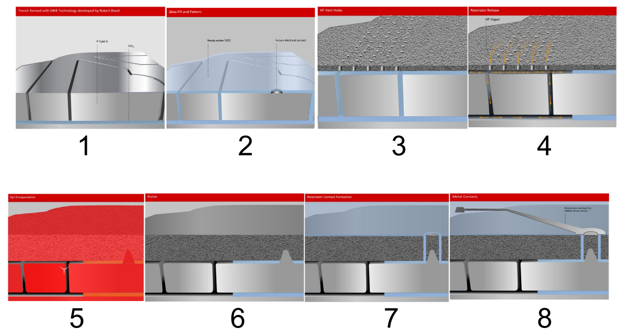

Figure 2. The MEMS fabrication process includes (1) defining the resonator shape, (2) covering the resonator with protective oxide and (3) silicon, etching via access to sacrificial oxide, (4) releasing the resonator with an oxide etch, (5) sealing the resonators and growing a thick encapsulation at high temperature, and (6) CMP surface (7) Electrical isolation (8) forming electrical contacts and interconnects.

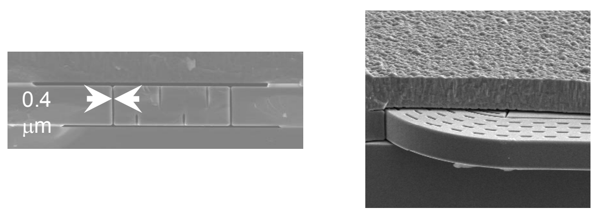

Figure 3. The MEMS resonators – SEM cross section showing small gap and protected beam.

ASSEMBLY QFN (QUAD FLAT NO-LEAD)

The MEMS resonators are molded with CMOS oscillator circuits into QFN-type packages that have standard quartz footprints. Figure 4 shows a package drawing.

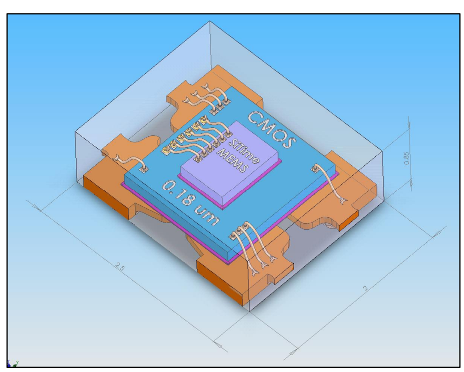

Figure 4. The MEMS resonators are packaged with CMOS oscillator circuits in QFN-type packages with standard quartz oscillator footprints.

The assembly process incorporates two developments in semiconductor production today. It is believed however this is the first time both are used together. Chip on lead construction is used in order to conserve space and stacked die construction, where the MEMS die is mounted above the CMOS chip provides for a good thermal connection, needed for accuracy over the entire temperature range. In the small package size (2.0mm x 2.5 mm) space is of great concern. The use of these two steps in a single package brings low cost assembly and MEMS together. Figure 5 graphically depicts the assembly process.

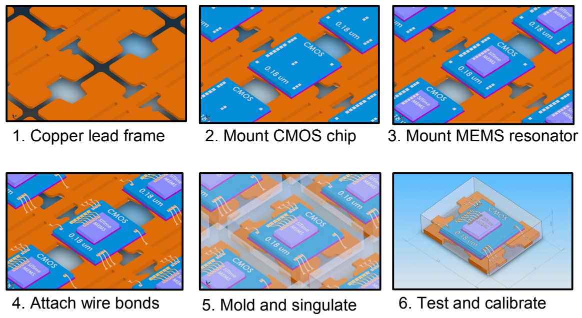

Figure 5. The MEMS QFN assembly showing chip on lead construction and stacked die

Specifications are typical of commercial quartz oscillators, for example the MEMS oscillators shown in Figure 6 easily exceed the standard 50 ppm frequency stability specification.

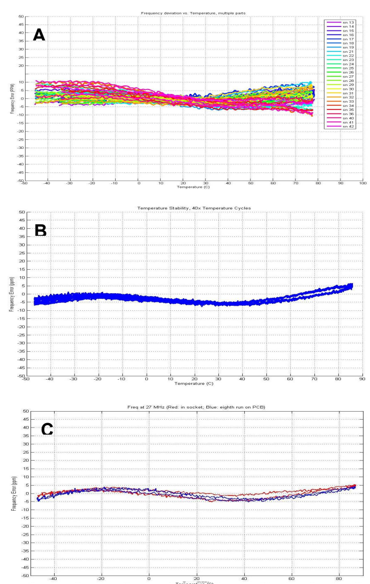

Figure 6. Frequency Stability is shown for (A) a set of parts cycled over temperature, (B) one part over 40 temperature cycles, and (C) one part socketed and tested, then soldered to a PCB and retested. The plots are scaled so the full range is the +/– 50 ppm specification limit.

These oscillators are small, highly reliable, mechanically robust, and cost effective. The reliability is high because the fabrication tools and techniques are adopted from standard electronics production that has been optimized for quality and consistency. The oscillators are robust because they are small and have very high mechanical resonant frequencies. In tests over shock, vibration, acceleration, and temperature extremes they performed better than the quartz technology they are replacing.

Silicon oscillators have operated within specification through shocks of 30,000 g, vibration of 40 g over 5-20 kHz, constant acceleration to 4000 g, and PCB max-bending. A NASA study showed that standard production parts operated reliably from –110 to +100C. Of course the oscillators also pass all standard industrial electronics tests including ESD, MSL-1, thermal shock, HTOL, etc, and are fully qualified.

PRESENT AND FUTURE PRODUCTS

The world's first commercial MEMS oscillator, the SiT8002, is presently in production at over 300k units per week, with over 1M units shipped.

The SiT8002 is a programmable oscillator offering output frequencies of 1-125 MHz, with accuracy of 50 ppm, supply voltages of 1.8 to 3.3 V, choice of chip enable or output enable, in standard package sizes from 7.0x5.0mm down to 2.5x2.0mm. These are the world's smallest programmable oscillators.

Recent developments in design and packaging have advanced the solutions for precision time reference to include four new products: An extremely low jitter programmable oscillator, a spread-spectrum oscillator, a voltage controlled oscillator, and an ultra thin packaged oscillator.

The SiT8102 low jitter oscillator is programmable from 1 to 200 MHz and has <3pS wideband RMS jitter. This is the lowest jitter of any general purpose programmable oscillator (quartz or MEMS) and is suitable for many applications that could previously only be served by fixed frequency quartz oscillators. Figure 7 shows the output quality. This oscillator is also available from 1.8 to 3.3 V in the full range of packages. Sample quantities are now available.

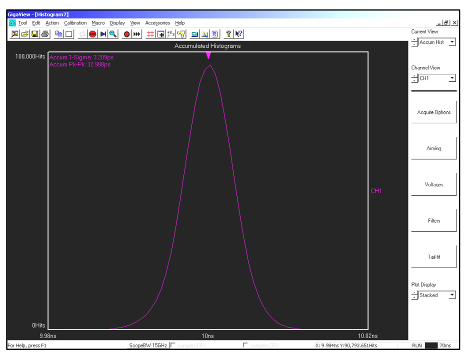

Figure 7. The SiT8102 has the lowest jitter of any general purpose programmable oscillator. Plot from a Wavecrest SIA-4000 of 3.2ps RMS jitter (spec is <5ps).

The SiT3800 voltage controlled oscillator is programmable from 1-200 MHz. The advanced architecture produces an extremely linear frequency control with 50 and 200 ppm programmable ranges. This oscillator is also available from 1.8 to 3.3 V in the full range of packages. Sample quantities are now available. These are the word's smallest precision voltage controlled oscillators.

The SiT9001 is a programmable spread spectrum oscillator. Applications include computers, printers and peripherals that must meet strict RF emissions criteria. It is function and package compatible with the SiT8102, so that application changes from fixed to spread frequency can be made late in product design cycles. Figure 6 shows a typical spectrum of a fixed v. spread clock, showing 8 dB reduced peak height.

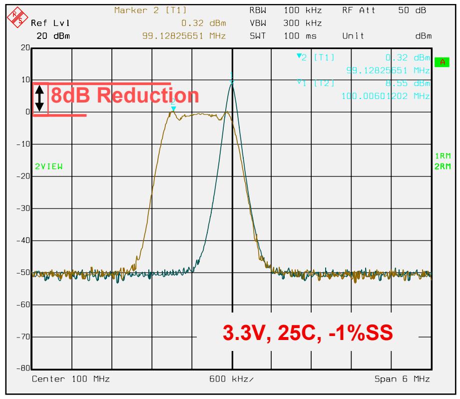

Figure 6. The SiT9001 spread spectrum oscillator is programmable for various frequencies and spreads. This plot shows a peak reduction of 8dB compared to a non-spread clock.

The SiT9001 is the word's smallest programmable spread spectrum oscillator, and is available in sample quantities.

The SiT8102UT is an ultra-thin packaged SiT8102 for applications that require 0.4 mm maximum thickness. Figure 7 shows a photograph of this device.

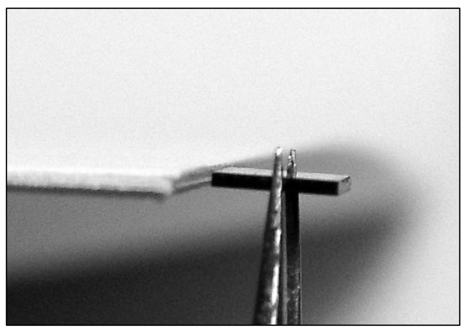

Figure 7. The 0.4 mm thick SiT8002UT is shown next to four sheets of standard printer paper.

The SiT8102UT is the word's thinnest precision oscillator and is a factor of two thinner than standard quartz oscillators. Only through advanced packaging and assembly could a tiny oscillator be created.

CONCLUSION

MEMS-based timing references are now displacing quartz oscillators. Programmable MEMS oscillators with output frequencies from 1 to 125 MHz are in production. Low jitter, voltage-controlled, and spread-spectrum, oscillators are now available in sample quantities. Ultra-thin oscillators are available in pre-production quantities. These are the world's smallest programmable oscillators, lowest jitter programmable oscillators, smallest voltage-controlled oscillators, smallest spread-spectrum oscillators, and thinnest precision oscillators.

ACKNOWLEDGMENTS

SiTime would like to thank Jazz Semiconductor and Robert Bosch GmbH for their contributions and support.

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