

Bandpass Filter Developed Using MEMS Technology Integration with Peripheral Circuits also Possible

New technologies that will contribute to miniaturization in mobile equipment and reduced power consumption in stationary equipment

Sony has developed a bandpass filter for the VHF band using MEMS* technology. Additionally, Sony has succeeded in integrating a MEMS filter with peripheral circuits on a single chip by adding MEMS processing into the existing BiCMOS process. Sony has also demonstrated the possibilities for further miniaturization and thickness reductions in mounting and for even lower power consumption. Sony announced these technologies in December last year at IEDM 2005.

* MEMS: Micro Electro-Mechanical Systems
Collective term for ultraminiature systems that integrate three-dimensional movable parts, sensors, and other functions by applying LSI fabrication techniques to perform machining operations at the micro and nano levels. The Sony Semiconductor Group has already used this technology to develop the GLV (Grating Light Valve) display device. Sony exhibited the GxL imaging technology that uses these concepts and technologies at EXPO 2005, Aichi, Japan. (See CX-NEWS, Vol. 40)

1 MEMS Filter Development (1)

Moving up to a three-port resonator design

Currently, there are limits to the miniaturization of the widely-used low-frequency SAW (surface acoustic wave) filters due to their physical characteristics. In contrast, even further miniaturization is expected for MEMS filters. The bandpass filters are created by combining four resonators electrically. Therefore, the improvements of the resonator characteristics should be first performed.

The resonator consists of a collection of parallel-coupled micromechanical resonators. For these resonators, Sony has adopted a structure (the clamped-clamped beam structure) in which a beam is held fixed at both ends and resonated. One of Sony's unique improvements here is to switch from the two-port resonator, which has been widely reported by several research organizations to the three-port resonator. (See figure 1.) The beam resonance mode was changed from first order (a single wave) to second order (two waves), and the input and output signal lines were placed under the beam independently. These design improved the signal-to-noise ratio in resonance curve by suppressing signal leakage. A subsidiary effect here is that the influence of manufacturing variations in the patterning is reduced because this second-order flexion mode uses a longer beam length than the first-order vibration mode. Figure 2 shows the frequency spectrum of this newly-developed three-port resonator.

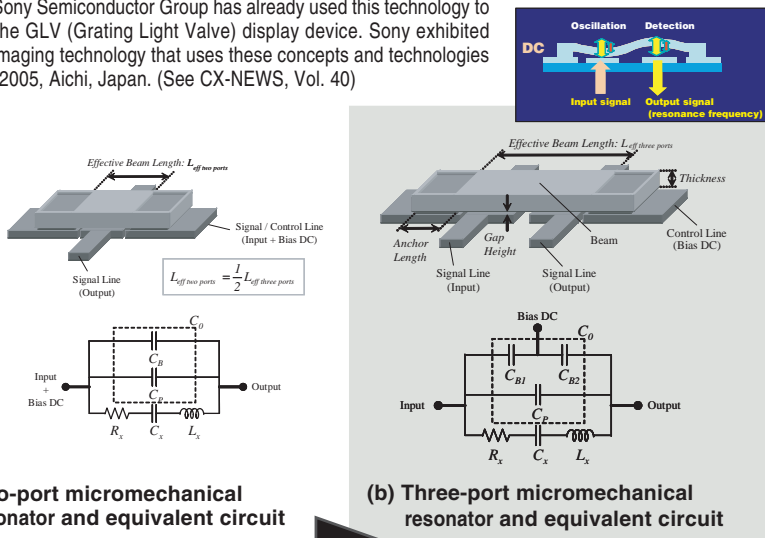


Figure 1 Improving the Resonator from the Two-Port to the Three-Port Structures

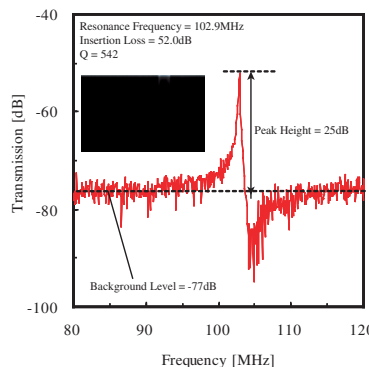
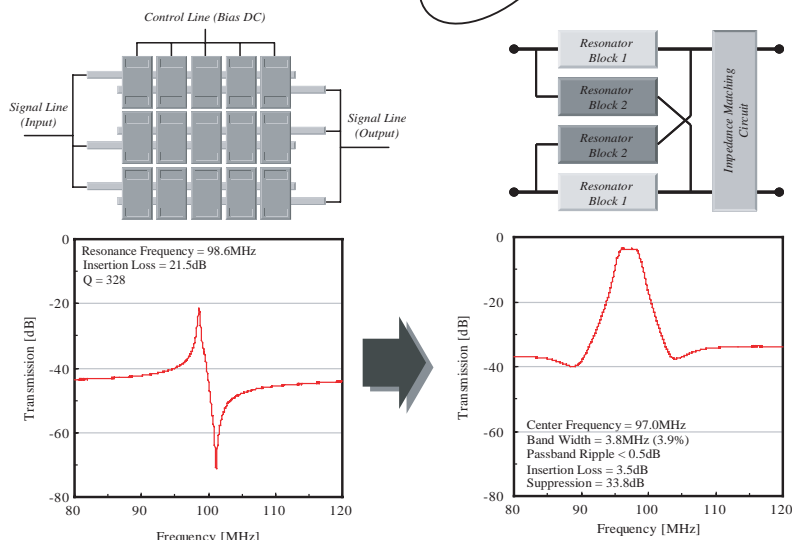


Figure 2 Frequency Spectrum for Three-Port Resonator

2 MEMS Filter Development (2)

Adjusting the frequency characteristics with the parallel beam layout

Next, Sony increased the signal level by arranging multiple resonators in parallel. (See figure 3-a.) While in general, a resonator using MEMS technology has a property of high Q-value (the resonance peak is sharp), this characteristic becomes, inversely, disadvantageous when it is necessary to pass a wider bandwidth. Sony, however, was able to verify that the Q-value changes with the layout pattern. Sony proved that it is possible to optimize the frequency characteristics for the purpose at hand.



(a) A Q-value appropriate for the bandpass filter is acquired by adjusting the resonator parallel coupling pattern. (b) Lattice-type bandpass filter circuit and frequency characteristics

3 Integration to an Existing Silicon Process

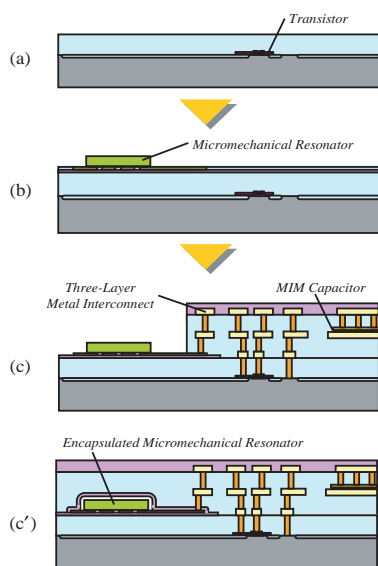
Embedding LSIs and MEMS devices

Sony next created an embedded MEMS filter chip that consists of this MEMS filter and the impedance matching circuit as the next stage.

Polysilicon resonators are formed after the FEOL (front end of line) process in the BiCMOS process, and after the multilayer interconnect process has completed, the ILD (interlayer dielectric) and the sacrificial layer around the MEMS resonators are removed with buffered-HF treatment. (See figure 4.) At this time, the critical point is how well the space for the resonator's motion can be acquired without damaging the metal interconnects.

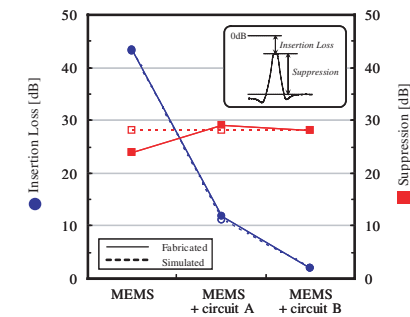
The fabricated filter properties coincided with the calculated one. (See figure 5-a.) Furthermore, no significant influence on the transistors embedded on the same chip was seen. (See figure 5-b.) The result of this was that Sony had shown that it was possible to manufacture an embedded MEMS filter RF IC using an existing semiconductor process.

Figure 3 Design Scheme of MEMS Bandpass Filter using Four Resonators

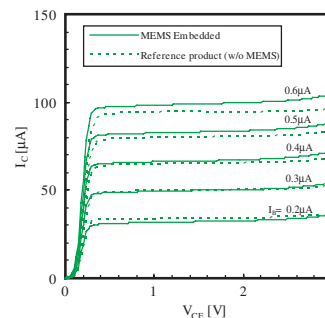


(a) Circuit elements are formed in the previously existing FEOL process. (b) The polysilicon resonators are formed. (c) After forming the three-layer metal interconnects and MIM capacitors, the ILD and the sacrificial layer are removed. (c') Sony has also developed technologies for MEMS encapsulation throughout wafer process.

Figure 4 Process Flow for Embedded MEMS Filter Fabrication



(a) Insertion loss and suppression of MEMS filter



(b) Transistor V_{CE} - I_C characteristics

Figure 5 Devices Characteristics of Embedded MEMS Filter Chip

IEDM 2005

International Electron Devices Meeting

– After the Presentation –

Since this was my first presentation in English at an international conference, preparing for it was a lot of work. But I made it through to the end. From the questions and comments after the presentation, I felt that there had been a good response. This presentation also gave me a chance to interact with well-know researchers in the field and was a valuable experience that expanded my perspective on my work.



Shun Mitarai Preparing for the Presentation (See the following page for a discussion.)



From Micromachines to MEMS

More than just components, these devices are now integrated into System LSIs.

How was this MEMS filter created?
How will MEMS technology develop in the near future, and what will change?
This section presents the words of the developers themselves.

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Making the Motivation Clear

What has prevented the realization of practical MEMS filters so far?

Yamashita: Until now, research on MEMS filters was mostly carried out at US universities. The earliest research was concerned with explicating the principles of operation, and either extremely high voltages were required, or the researchers were satisfied as long as the phenomenon was verified, no matter how small the transmitted signal. Those works were not applied directly for consumer electronics products. In contrast, we had the explicit motivation of developing a device with practical characteristics, and the filter characteristics that we were targeting were comparatively clear. Thus in our work it was never a matter of saying “OK, I understand” and that being the end of it when we understood some phenomenon, but rather always a matter of, “OK, what can I do with

this now?”, that is, we always had a firm grasp of the direction we wanted to go, namely of always explicitly moving towards improvements. The idea of moving from a two-port to a three-port structure was an example of this.

Ikeda: Normally, we would have pursued research and development limited to the two-port structure. It is easily expected that the shorter mechanical beam shows the smaller signal attenuation. However, we took the exactly opposite approach.

Mitarai: As for high-frequency region, it was hard to design high signal-to-noise ratio devices using two-port resonator.

Yamashita: The beam, which is a mechanical device, operates as a capacitor that isn’t even needed and transmits signals as leakage. If we could isolate the input and output signal lines, the leakage signal could be reduced relative to the vibrational component. We were not convinced of this be-

fore we started, rather, it was something we found by trial and error.

Ikeda: At a group session, someone drew the vibrating element on the whiteboard in the form of a wave. When you draw a picture of a waveform, you don’t draw a single wave, but two or three or more. These correspond to the second order and higher order oscillation modes. The key point here was that instead of erasing them immediately, we decided to prototype and measure them.

Yamashita: This process is the fascination of MEMS research and developments. Even though the devices are on the micro scale, in principle, they vibrate in ways that are no different from a guitar string or a plank that you can see with your eyes. We were able to come up with new ideas by returning to the basic concept that more than a semiconductor development issue, this was a vibrating board in the form of a beam clamped at both ends.

Sony exhibited the GxL imaging technology that uses these concepts and technologies at EXPO 2005, Aichi, Japan. (See CX-NEWS, Vol. 40.)



The Significance of Imaging the Motion

The integration of mechanical motion and electronic circuits also has stimulated a synergy between engineers from different specialties.

Yamashita: Although I was originally an end-product person, in the MEMS department, we built a team that consisted of engineers from different specialties, including process engineers, device designers, and simulation and measurement specialists. When someone would say something, everyone else would think “Oh, so that’s how it is”, and when someone else would interpret something from another viewpoint propose new idea, everyone else would think “Oh, right. Of course”. This is actually closer to the way things happen in end-product design than in semiconductor groups.

Ikeda: Every day we’d seen interactions such as the following. A device designer would hover over Mitarai, commenting on his work. “Hey, if you could hold the resonator gap height to levels such as this, we’d get even better characteristics.” But Mitarai would respond “That’s unreasonable. But I’ll try to hold it to this level.”

Mitarai: The simulation software shows us a result of vibration analysis with an animation (see the top figure at the right), and we’d watch it and discuss, for example, what was the most efficient position for the lower electrode would be.

Yamashita: It is extremely important to be able to visually image the actual operation of the device. Depending on their main field, there are people who would search for the cause of the electrical signal leakage, and there are people who would view the system as a pure mechanical system. Even if what people would see in the system differed with the person, as long as we had a common image, then we could discuss the system in terms of that image. This can be said to be the unique feature of MEMS. Inversely, even for two systems that are both MEMS, for example, the GLV optical diffraction grating and this bandpass filter, it goes without saying that the images we need to work with will be different. For people who take pleasure in this sort of thing, these are research projects in which there is value in participating, even if one’s area of specialization differs.

Ikeda: When I was involved with the GLV project, I would often keep the image of the product in my mind while walking around TV showrooms. Since this filter development project started, I’ve found home construction sites and the structure of Tokyo’s Rainbow Bridge more interesting. Because houses and bridges and resonators all consist of pillars and beams. When looking at these projects, I’d be tempted to say something presumptuous, for example, “Hey, if you changed the design like this, it would be able to withstand vibrations better.” With MEMS devices, it’s easy to see how their function directly links to the final product.

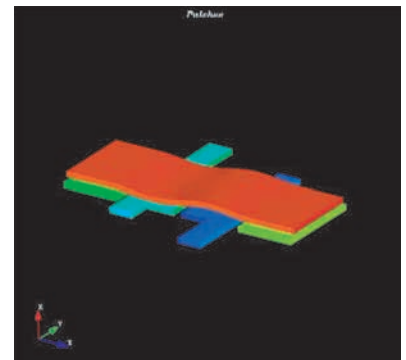
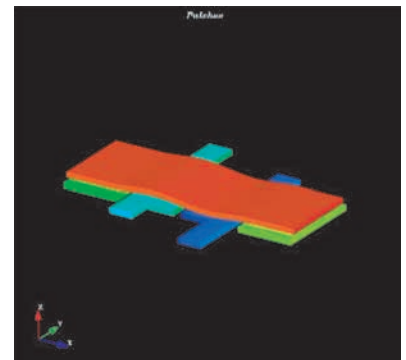
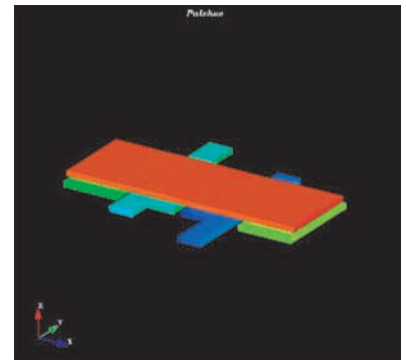
Asking Once Again What Semiconductors are Capable of

How will MEMS technology change our concepts of semiconductors, end products, and creative production (“monozukuri”)?

Mitarai: Well, the first thing I’d like to do soon for our MEMS devices is to be commercialized.

Ikeda: MEMS (micromachine) technology already has a long history in consumer applications, for example it is widely used in printer head nozzles and pressure sensors. Semiconductor technology has contributed some of the manufacturing techniques used. This technology, that is, the manufacturing and material technologies used, is now mature, and tools unique to MEMS, such as sacrificial layer etching, are commercially available. In my opinion, “motion” will be introduced into system LSIs as a newly emerging function.

Yamashita: I think that micromachines have finally developed into practical components. MEMS devices have been applied as discrete components in products such as the acceleration sensors used in automotive air bag systems. If the technology progresses just one step further, these components that were previously external parts will come to be included on the LSI itself. Except for the interface with external systems, parts that operate in places that can’t be seen will rapidly be integrated onto single chip solutions. This will increase the flexibility we have in end product design and allow us to provide end users with products that are even easier to use. I think that it is a natural progression for semiconductor engineers to be aiming for that.



■ Verifying the structure and vibration with animation on the simulator screen

The amplitude of the vibration is exaggerated.

Mitarai: If I were to say what has changed after joining MEMS department, one thing is that I grew to read not only the semiconductor magazines, but the electronics magazines as well. While it is also the case that I am being asked to do things that I’d like to do anyway, nowadays I look at a lot of things and wonder how they could be improved by using MEMS technology. I am sometimes surprised at the degree to which I’ve been caught up in this.

Yamashita: I think that it is important for semiconductor engineers to imagine how components that one has been in charge of are taken advantage of in end products and in what way they are provided to the end user. Only being able to see the area that one is in charge of is inimical to the spirit of creative production (“monozukuri”), and is not a state of mind from which revolutionary ideas will be born.