Integration method delivers yield improvements, space savings in sensor arrays

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A new heterogeneous integration technique enables the integration of acoustic microsensors and radio frequency (RF) circuitry.

Bio/chemical sensing involves molecular recognition of species and the transduction of the biological or chemical information into a measurable signal. These types of sensors have been used to detect and measure essential information about the state of our environment.

In many cases, there is a need to incorporate sensors in arrays with different substrate coatings to improve sensitivity and selectivity. However, a key challenge in using multiple sensor systems is their integration with radio frequency (RF) electronic circuitry.

Furthermore, in the area of clinical analysis, there is a need for reliable biological sensors that can provide fast and accurate information for diagnosis of medical conditions. In addition, combating the threat of terrorism using chemical warfare agents also requires the use of bio/chemical sensors.

Integrating bio/chemical sensors with electronics improves functionality and leads to smaller, lower cost, and more portable detection instrumentation. The size reduction is primarily due to a reduced number of components needed to construct the sensors. Not only does this additional space allow for miniaturization, but it also provides more space for sensor arrays. In addition, by using different substrate coatings, the sensor can respond to different chemicals, which improves identification.

The integration of sensor arrays with electronics permits all RF signal processing to be performed on chip. This reduces the packaging complexity and cost of the detection system. However, while arrays offer improved sensing capabilities, when different sensors are all fabricated on one substrate there is usually a decrease in manufacturing yield as the number of array components increases.

To address this challenge, we use a ‘pick-and-place’ technique, where each wafer will be fabricated with only one type of sensor. The sensors will then be separated from the wafer substrate and placed on the array substrate.

This heterogeneous integration technique is used as a method of connecting acoustic devices with electronics. It enables the integration of various sensors in an array by processing the sensors and circuitry separately, and connecting them together in a subsequent step. With the integration of low-cost silicon circuitry and piezoelectrics, the desired functionality of an integrated sensor circuit can be achieved without sacrificing cost, yield, or reliability.

We are developing flexural-plate-wave (FPW) acoustic sensors that are designed to be implemented in a sensor array and co-integrated on a Si-CMOS circuit using the modified thin-film device (heterogeneous) integration technique. FPW sensors are highly sensitive to surface perturbations and indirectly sense analytes by detecting mass changes on the sensing plate surface.

As shown in Figure 1, the sensors are placed in an oscillating circuit, where changes in the oscillation frequency are used to determine changes in the wave velocity due to mass loading by the

Figure 1. FPW bio/chemical sensor.
Figure 2. Sensor integration flow. BCB: bisbenzocyclobutene (polymer). HF: hydrofluoric acid. TCE: trichloroethylene (solvent). 

analyte.\(^3\),\(^4\) Since FPW sensors are generated in thin plates, these devices are highly sensitive to loading and exhibit the highest mass sensitivities of any acoustic wave device.\(^3\),\(^4\)

In our approach, FPW sensors are fabricated on Si/SiO\(_2\)/Si native substrates, with the interdigitated transducers (IDTs) isolated from the active sensing surface. This design enables the sensors to be fabricated, separated from the native substrate, transferred, and bonded to the host Si-CMOS circuit.

Following integration, the FPW devices will be customized with either chemical membranes or biological functionalization. Our approach allows each sensor to be optimized independently before it is connected to the host substrate. This method provides the potential of incorporating new sensors and materials easily in the future. The process flow we developed for the integrated sensor is shown in Figure 2.

Currently, the FPW devices are designed to perform optimally for bio/chemical sensing applications, and will be fabricated using the process flow described above. Once completed, the sensors will be tested to characterize their performance. The CMOS chip will be designed, and a single FPW sensor will be integrated on it.

We plan to extend that work to integrate multiple sensors on the CMOS circuitry to achieve heterogeneously integrated FPW sensor arrays.

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References