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Editorial: Design and analysis of CMOS-MEMS transducers

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Editorial on the Research Topic
Design and analysis of CMOS-MEMS transducers

Throughout human history, certain technologies/discoveries (e.g., fire, wheel, agriculture, printing, *etc.*) have had an unparalleled effect on the lifestyle. Integrated Circuit (IC) technology had an imitable impact on day-to-day lives in the late 20th century. The rapid growth in the performance of computation and its related applications was possible due to the regular shrinking of transistor size following Moore's law (Moore, 2006). There is a growing demand for low-power, high computation, high data rate, and wireless chips in industry, automobiles, hospitals, homes, and personal devices. The recent semiconductor shortage due to the pandemic disrupted manufacturing directly affects the economy of many countries (Saracco, 2022). This has resulted in renewed interest in the acquisition of semiconductor technologies around the world. The pervasive adoption of 5G communication systems, electronic vehicles, high-performance computing, virtual reality, and personal entertainment devices is constrained by the complex and expensive fabrication technology required to continue device scaling with more-Moore (Yeric, 2016).

Microelectromechanical Systems (MEMS) have been used to realize complex functions like sensors and actuators. MEMS can be combined with circuits to provide more-than-Moore functionality. The technology scaling has resulted in system-on-chip (SoC) which incorporates analog, digital, and RF circuits to satisfy multiple applications (i.e., more-than-Moore). This was extended with MEMS to the system-in-package (SiP) incorporating an accelerometer, gyroscope, barometer, magnetometer, heart-rate sensors, etc., with SoC in a package (Lammel, 2015). Traditionally, piezoelectric MEMS has seen greater interest due to the larger electromechanical coupling coefficient and direct replacement with quartz systems. Piezoelectric materials are not compatible with the CMOS fabrication process and require SiP. This limits device performance due to the parasitic effect of inter-package interconnects (Pillai et al., 2016). The fast data rate of modern SoC requires a small form factor to reduce the parasitic effect from PCB routing. With the advent of the Internet of Things (IoT), smart gadgets are needed to prevent congestion of the widely used 2.4 GHz band. Smart devices can collect data and process it to give predictive analysis, e.g., fall detection and call for assistance, warning about irregular heartbeats, increase in particulate matter, etc. A Smart system-on-chip (S-SoC) is the next logical step. A conceptual smart system on chip schematic for MEMS and circuit integration is depicted in Figure 1. The S-SoC would have sensors for the detection of physical, chemical, optical, and biological quantities. It would also have a MEMS transceiver integrated with

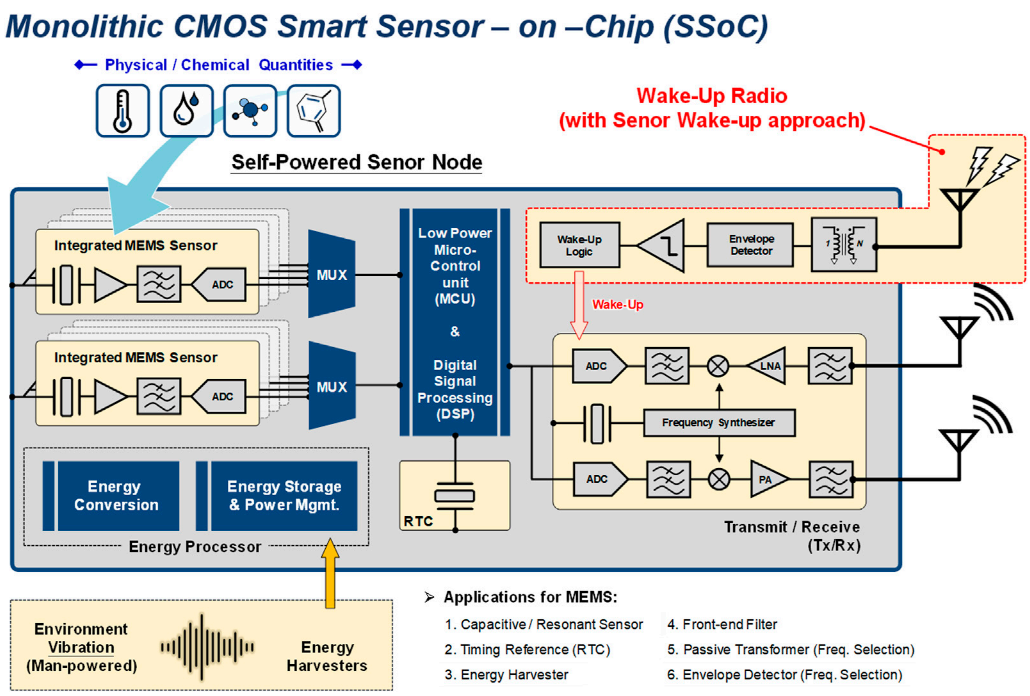

FIGURE 1
Conceptual CMOS-MEMS integration schematic of a monolithic Smart System-on-Chip (S-SoC) IC featuring MEMS sensors, actuators, and transceiver with signal processing circuit.

a signal processing circuit and energy-harvesting MEMS for low-power operation. The ability of a CMOS process for rapid prototyping, volume manufacturing, low cost, and compact system (monolithic integration) makes them attractive candidates for IoT. The Research Topic "*Design and Analysis of CMOS-MEMS Transducers*" aims to highlight various transduction mechanisms, fabrication processes, and device architectures to meet diverse application specifications.

Typically, CMOS-MEMS utilizes the material layer stack of the standard CMOS technology node to realize microstructures and selective etching to release them. One of the main reasons for the silicon revolution was the access to a foundry (TSMC, GlobalFoundries, UMC, etc., for fabless design houses. A similar initiative was implemented for MEMS with MUMPS but it lacks support for CMOS-MEMS. Taiwan Semiconductor Research Institute has worked with CMOS foundries to develop a multi-user MEMS platform through CMOS technology to support designs targeting various applications using the 0.35 and 0.18 μm standard CMOS process. Tseng covers in detail the capabilities of the platform and steps in the fabrication of MEMS using a standard CMOS process.

A variety of transduction techniques can be utilized for the excitation and sensing of micromechanical designs. Capacitive transduction is widely used in MEMS for accelerometers, pressure sensors, frequency and timing references. Chiu et al. cover the working principle, design, and release of tunable CMOS-MEMS accelerometers with an interface circuit design. A timing/frequency reference is an integral part of the IoT system which can be served by a monolithic CMOS-MEMS oscillator. Li discusses the effect of circuit architecture and non-linear operation on oscillator phase noise performance and the selection of an optimal condition for improvement in oscillator phase noise. A MEMS-based switch capable of high isolation is in demand for transceivers. Tsai and Li describe prior work done in CMOS-MEMS switches and resonant switches (resoswitches) to improve sensitivity and reliability. In addition, the use of resoswitches for the detection of surface manipulation and pulse width modulators is also demonstrated.

Electrothermal transduction is often used for flow sensing. A heater is maintained at a certain temperature. The flow of gas causes heat loss through convection, resulting in a temperature change. This can be detected directly as temperature changes or by measuring the power required to maintain the constant temperature. Wang et al. present the analysis, design, and post-process release of the CMOS-MEMS nanoscale hot-wire flow sensor. The piezoresistive effect of polysilicon can be combined with electrothermal transduction to realize a MEMS oscillator for timing and sensing application. Zope and Li present a thermal-piezoresistive resonator with in-depth analysis for design optimization, an electrical model for co-simulation with interface circuit and experimental verification for a timing reference, mass and pressure sensing applications.

The p-n junction can be used as an optical detector due to the photoelectric effect. Lee et al. demonstrate a CMOS-MEMS gas sensor combining photodetection and temperature sensing with heterogenous integration of the LED with a CMOS chip.

SHF oscillators are crucial to enable a monolithic wireless S-SoC. Rawat et al. cover the research done on unreleased resonant body transistors to realize high-Q GHz resonators using the MOSFET as the resonant element. They also cover the use of piezoelectric and ferroelectric layers in the CMOS memory platform for high-efficiency RBTs.

In summary, this Research Topic offers a variety of designs, transduction mechanisms, fabrication approaches, measurements, and potential applications using CMOS-MEMS integration, thus hopefully inspiring more scholars, engineers, and scientists to get involved in this emerging field.

Author contributions

AZ did the write up under S-SL's guidance.

Conflict of interest

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