MEMS Sensor/IC integration for miniaturized TPMS (e-CUBES)

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Sensor networks are researched in various automotive applications, in particular in tire pressure monitoring systems (TPMS) installed as autonomous sensor nodes. A tire-mounted TPMS should ideally weight less than 5 grams and have a volume less than 0.5 cm^3. Typically, the miniature system must include a microelectromechanical system (MEMS) sensor, application specific integrated circuits (ASICs), power supply, a radio and an antenna. Ultra low power consumption is required for all the components because a 10-year lifetime is mostly targeted in the automotive industry. Presently, the battery is one of the largest components in most wireless sensor nodes and the TPMS is not an exception. A combination of a battery and an energy harvester are foreseen to be the only possible solution for a future TPMS unless a large shift in battery technology takes place.

The given specification with regard to volume requires a close integration of the components. Three years of process development is about to result in a TPMS demonstrator with an overall tight integration where the MEMS sensor and the ASICs are truly 3D stacked. The automotive demonstrator is one out of four wireless sensor networks that are developed as part of the European project e-CUBES [1]. In general, the goal of the e-CUBES project is to advance the microsystem technologies to allow for cost effective manufacturing of highly miniaturized, truly autonomous systems for ambient intelligence.

MEMS and ASIC integration is as much a logistical as a technological challenge. Few companies have MEMS, ASIC and also packaging facilities in-house. Companies that may have their core competence in different market segments need to be coordinated and share insight to each others technologies. Chips and wafers must fit into various equipments with regard to size, shape and contamination level. Materials must be matched and design rules shared.

3D integration of MEMS sensors and their accompanying ASICs has already been demonstrated as feasible for particular devices. CMOS image sensors are probably the most famous example of successful true 3D integration of sensor and ASIC. Chip stacking reduces the overall footprint of systems remarkably. However, stacking of MEMS sensors is in general not trivial. Thinning and TSV etching into substrates of reduced thickness are becoming more common procedures for 3D integration of ICs, but these process steps may ruin important mechanical properties of MEMS.

The original perception of an e-CUBE and the present solution for the TMPS demonstrator can be compared in Figure1. Technological challenges for the stack related to 3D integration are the various TSVs and interconnections. Throughout the stacking sequence the microcontroller ASIC is kept as a wafer while the remaining devices are chip to wafer bonded layer by layer. The interconnection of the transceiver ASIC (TX) and the microcontroller is realized with SnAg microbumps [2,3] as shown in Figure 2a. The vias in the TX are tungsten-filled ICVs as developed by Fraunhofer IZM [4,5] and shown in Figure2b. A Planoptik [6] cap wafer combined with Au stud bump bonding (SBB) is used to stack the MEMS sensor onto the TX. The bulk acoustic resonator (BAR) device is also stacked onto the TX with Au SBB. A cap wafer with hollow vias [7] is stacked onto a dummy TX wafer with Au SBB in order to prove the applicability of this technology combination as an alternative as illustrated in Figure 3.

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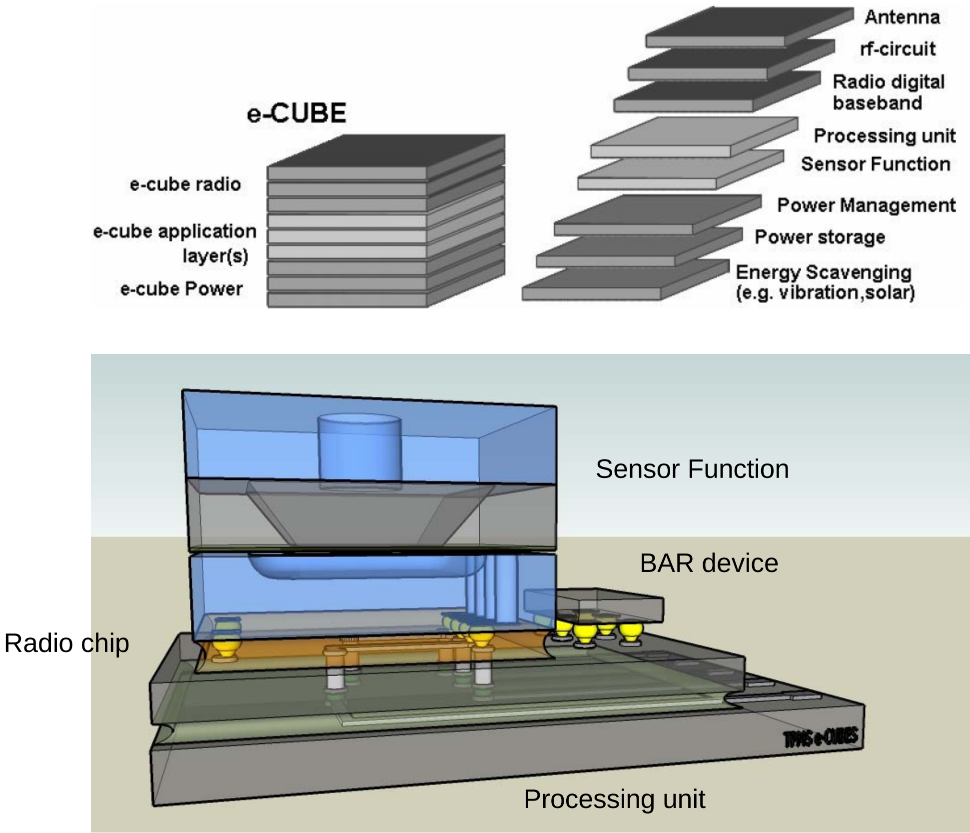

Figure 1: Original idea for an e-CUBE (top) and the e-CUBE being realized for an automatic demonstrator (below).

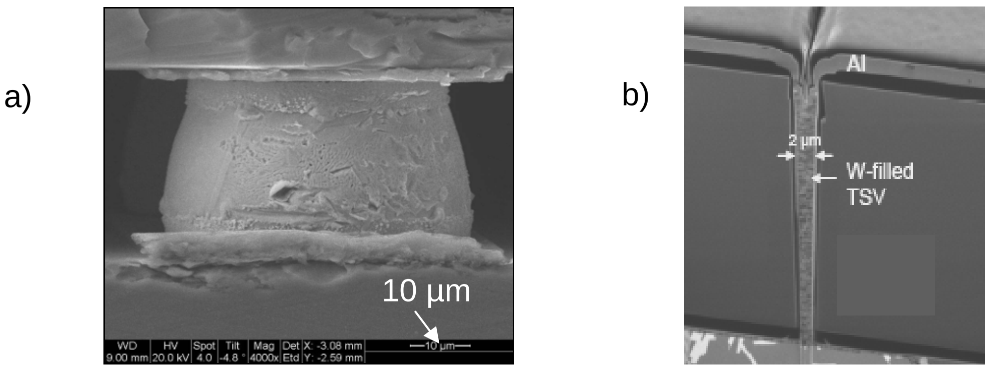

Figure 2: a) A SnAg microbump for interconnection. b) A tungsten filled TSV (Source: Fraunhofer IZM).

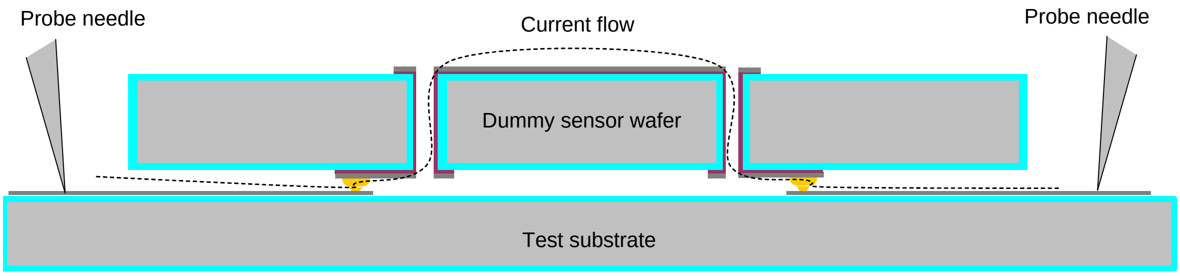

Figure 3: Hollow vias in a dummy sensor wafer as an alternative solution to Planoptik wafers. The sensor is chip to wafer bonded with Au SBB to a substrate wafer with Daisy chains for tests.