Commercial CMOS-Integrated RF-MEMS

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RF-MEMS bring great promise for enabling high performance tunable and reconfigurable communications and radar applications[1]. They have been under development for nearly two decades by many groups but until recently have been kept out of deployment by cost, packaging and reliability challenges. We report on technology features underlying a qualified production process for RF-MEMS switchable capacitors integrated into 0.18 μm CMOS on 200mm wafers. CMOS and capacitive RF MEMS switches in single tunable chip enables small size and effective digital interface and control for any application which needs extreme linearity, low insertion loss and low power operation [2].

The MEMS are fabricated using standard CMOS back-end-of-line (BEOL) dielectrics and metals. The devices are sealed into hermetic cavities with multi-layer thin-film deposition, enabling standard IC packaging (figure 1). The MEMS materials, process sequence and design were carefully selected to provide high yield across expected manufacturing process variations and stable operation over a wide range of environmental conditions. A strong track record of manufacturing at IBM has been established since late 2011 and has demonstrated high yields and reliability [3].

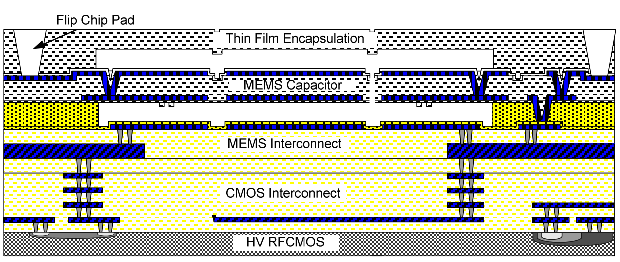

Figure 1: wiSpry RF-MEMS cross section

The MEMS devices are arrayed on each die to provide a wide flexible range of tuning capability. The wafers are solder-bumped, thinned and diced using standard semiconductor back end suppliers for assembly into tunable RF modules or other hybrid assemblies (figure 2). Development of wafer level chip scale packaging (WLCSP) for direct circuit board mounting is underway and should be available in early 2013.

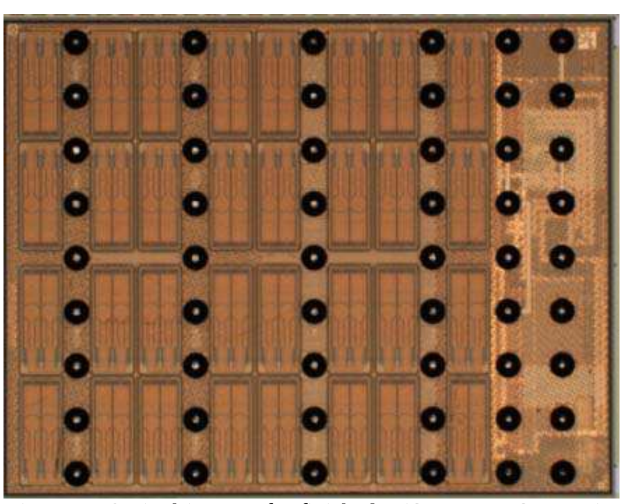

Figure 2: Optical image of a finished WiSpry MEMS capacitor array chip including solder bumping.

The devices are electrostatically actuated using voltages generated on-chip. The RF and control electrodes are isolated to minimize interaction between the digital and RF portions of the circuit. Figure 3 shows the vertical profile of two adjacent RF-MEMS switched capacitor devices, one actuated in the high capacitance state and one unactuated in the low capacitance state. The composite metal-insulator beam has a thermal coefficient of expansion that is similar to the silicon substrate to minimize the impact of temperature variation.

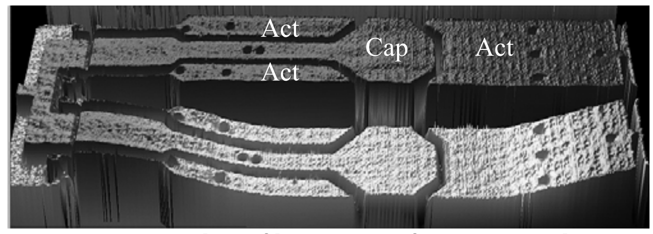

Figure 3: Optical profiler image of non-actuated (top) and actuated (bottom) MEMS capacitor beams indicating the RF capacitor head (Cap) and actuators (Act).

The devices in the array are digitally controlled. Figure 4 shows typical capacitance voltage curves for the MEMS devices. The device actuation hysteresis and low capacitance slope at the control voltage points provides margin for stable operation over a wide range of operational and environmental parameters.

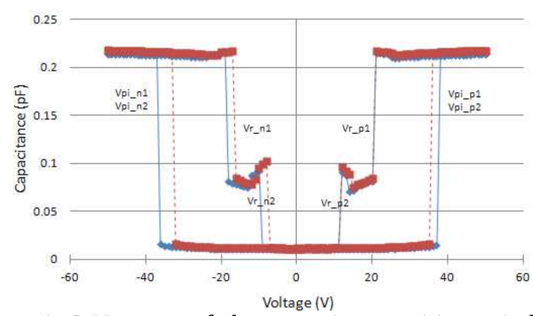

Figure 4. C-V curves of electrostatic capacitive switches

In conclusion, we have presented a qualified production process for RF-MEMS switchable capacitors integrated into 0.18 μm CMOS on 200mm wafers for application in high-volume commercial RF platforms such as those ised in smartphones and tablets.

The authors sincerely wish to acknowledge IBM Microelectronics, Essex Junction, VT, for their creativity and dedication as our manufacturing partner.

[1] J. Hilbert, IEEE Communication Magazine, pp. 68-74, August, 2008.
[2] S. Natarajan, S. Cunningham, A. Morris, & D. DeReus, "CMOS Integrated Digital RF MEMS Capacitors", 11th Meeting on Silicon Monolithic Integrated Circuits in RF Systems, Phoenix, AZ, Jan. 17-19, 2011, pp. 173 - 176
[3] Stamper, A.K. et al., "Planar MEMS RF capacitor integration", Solid-State Sensors, Actuators and Microsystems Conference (TRANSDUCERS), 2011 16th International, pp. 1803 - 1806