RF MEMS Integration Present & Future Trends

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***Abstract* — RF MEMS technologies are rapidly being integrated into RF subsystems for a variety of applications of interest to the Department of Defense. New technologies such as RF high-Q MEMS resonators and micromechanical arrays are being developed that will enable filters and other high-performance passive components for fully integrated microsystems. Large off-chip filters will be replaced by arrays of MEMS resonators to enable monolithic chip-scale spectrum analyzers and channelizers. RF MEMS switches are being continually improved for low-loss, high-isolation switching with enhanced reliability critical to the performance of both military and commercial systems.**

***Index Terms* — Impedance matching, microresonators, interface phenomena, micromechanical signal processor arrays, microwave filters, microwave switches, Q factor.**

I. Introduction

The DARPA Microsystems Technology Office initiated a comprehensive basic research program in 2006 involving micro- and nano-electro-mechanical systems (MEMS and NEMS) to support the development of an enhanced fundamental understanding of selected aspects of micro- and nanotechnologies critical to their continuing development and effective transition into defense systems. The N/MEMS S&T Fundamentals program supports basic research on a range of topics at 11 individual university research centers. This program involves work at 36 leading universities, 55 cost-sharing companies, and 12 U.S. government laboratories. Several of these centers are conducting basic research in the area of RF MEMS, work that is principally directed toward understanding the reliability physics of RF MEMS switches and switched-capacitor devices, as well as realizing new RF MEMS resonators with high Q-factor, high frequency, low impedance, and CMOS compatibility.

This paper describes ongoing RF MEMS work at several of the N/MEMS S&T Fundamentals research centers. It also describes the recently launched Chip-Scale Mechanical Spectrum Analyzers (CSSA) program. The goal of this new program is to achieve revolutionary improvements in the f*Q product (3.0 GHz center frequency with a Q greater than 100,000), while simultaneously incorporating an input impedance less than 50 Ohms. Important to this program is also the ability to realize microelectromechanical resonator arrays consisting of over 100 components each with a 30 KHz separation in resonator frequency from its next nearest neighbor.

II. DARPA Programs

The stated goal of the N/MEMS S&T Fundamentals program is to advance a number of core technologies considered essential to the continuing advancement of NEMS and MEMS technology and its transition into applications important to the Department of Defense (DoD). The work is focused on cross-cutting fundamental issues that have a pervasive impact on the technical community and are capable of enabling revolutionary advances in micro/nano technology science, devices, or systems. Of particular interest is the integration of basic RF MEMS research science into defense systems through component-level demonstrations, such as specifically being advanced in the CSSA program.

A. N/MEMS S&T Fundamentals

The RF MEMS efforts within the N/MEMS S&T Fundamentals program are being pursued by three N/MEMS program centers. The DARPA Center for Micro/Nano Scaling-Induced Physics (MiNaSIP), which is located at the University of California, Berkeley, is engineering micro/nano interfaces to exploit the advantages of physical scaling laws in MEMS RF devices. The work is expected to yield revolutionary improvements in Q factor, signal loss, and impedance matching [1]-[2]. Fig. 1 demonstrates a Q factor greater than 140,000 and the impact of arraying resonators into mechanical circuits.

The DARPA Center for RF MEMS Reliability and

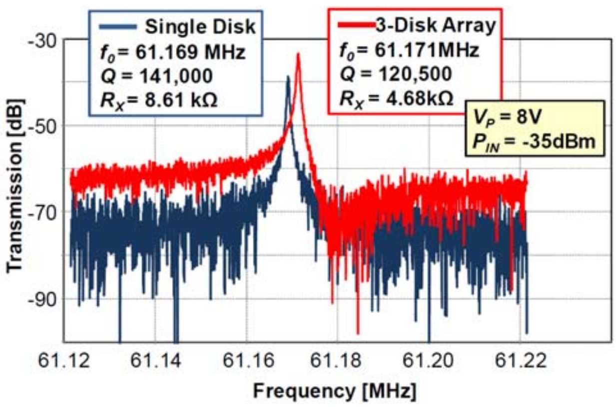

Fig. 1. Measured plots comparing the frequency characteristics of a standalone 61-MHz wine-glass mode micromechanical disk resonator (in blue) and a 3-disk array composite of them (in red) [1].

Design Fundamentals, located at the University of California, San Diego, is engaging in studies focused on new actuator design, developing an enhanced fundamental understanding of dielectric charging, and characterization of metal contacts in RF switches [3]-[4] . Fig. 2 shows an RF switch designed using the latest techniques. This architecture incorporates design features which limit sensitivity to stress gradients and temperature variations, resulting in a uniform pull-down voltage. The arc springs produce high contact force and fast switching time.

The DARPA Investigative Multi-Physics Modeling and Performance Assessment-driven Characterization and Computation Technology (IMPACT) Center for Advancement of MEMS/NEMS VLSI, located at the University of Illinois at Urbana-Champaign, is developing characterization and modeling methodologies addressing the multi-physics phenomena that govern MEMS-device functionality and affect both device performance and failure modes [5]-[6]. Fig. 3 illustrates a simulation of stress failure.

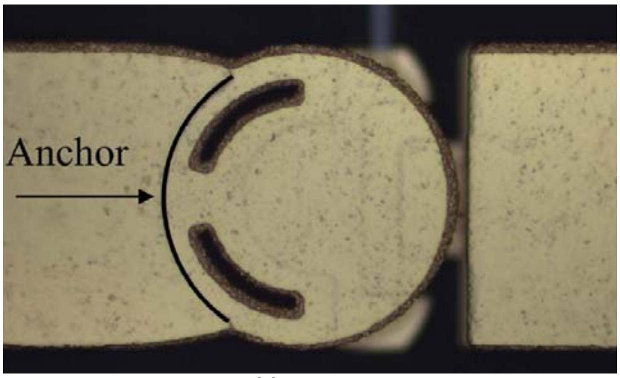

Fig. 2. Optical image of fabricated switch [4].

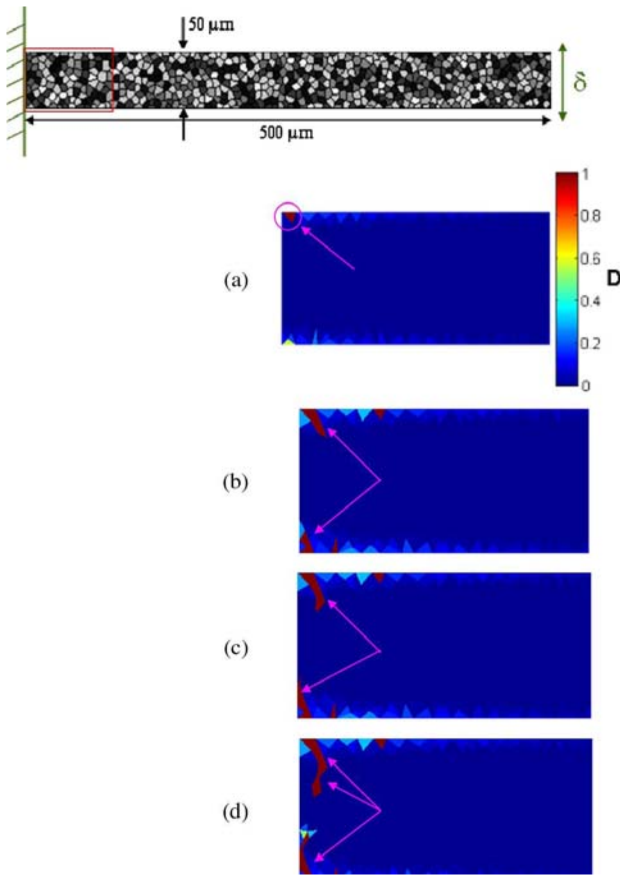

Fig. 3. Crack propagation (damage evolution) in the MEMS specimen under the cyclic bending loading. (a) Initiation at N = 80 239 cycles. (b) N = 120 088 cycles. (c) N = 121 418 cycles. (d) Final failure at N = 122 306 cycles [5].

B. Chip-Scale Spectrum Analyzers (CSSA)

The recently launched CSSA program seeks to build on the success of RF MEMS research from the N/MEMS S&T Fundamentals program and recent advances in RF MEMS technology [7]-[8]. Fig. 4 illustrates the acoustic band-gap technique used to constrain energy loss. CSSA will develop the most promising materials, fabrication, and device technologies enabling the fabrication and integration of passive components with very high Q (>100,000) for a variety of RF/microwave applications. Technologies emerging from this program will lead to component size reduction, lower dissipated power, and greater spectral efficiency for certain designs. In addition, CSSA technologies will enable new architectures for digitally reconfigurable software defined radios, analog circuits, and power-efficient filters based on arrays of miniaturized components.

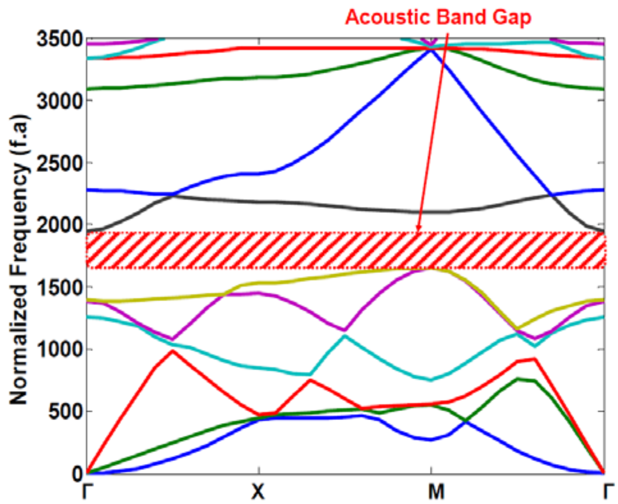

Fig. 4. The dispersion relationship of the IABG structure simulated in COMSOL® [8].

III. Five Lessons Learned

DARPA's experience in RF MEMS over the past decade has highlighted a number of recurring themes. These valuable lessons learned have yielded not only useful commercial and defense microsystems components, but they are also positive indicators for the upcoming technological revolution in nanosystems.

A. N/MEMS enables significant new levels of performance

MEMS and nanotechnology enable performance unattainable at macroscopic scales. Prior DARPA-funded work has demonstrated of Q factors > 140,000 and in separate component structures very high frequency mechanical filter operation (> 8 GHz).

A clearer understanding of nano-electro-mechanical properties through the N/MEMS S&T Fundamentals program is leading to substantial improvements in relay contact interfaces, surface interactions, and device lifetime.

B. Scaling – "Smaller is better"

Multi-domain scaling is the key to performance-driven MEMS and nanotechnology. Dimensional scaling of resonator structures leads to a substantial reduction in dissipative RF losses to the substrate. Similarly, thermomechanical noise scales linearly with decreasing base dimensions.

To further DARPA's goals, we have fostered development of more mature simulation and modeling tools at the nanoscale, in addition to material and device development.

C. N/MEMS integration

Substantial MEMS technology commitment drives systems integration and innovation. DARPA has invested in monolithic and discretely packaged RF MEMS components to enable applications that demand low power consumption and low-loss, high-speed operation, such as phased array radar, tunable filters, and switching matrices.

D. N/MEMS enables new opportunities

The CSSA program will produce ultra-fast, low-power, software-defined spectrum analysis. This capability will be used to identify unused spectrum, remove interferers prior to amplification, and rapidly switch channels. These capabilities are not currently possible with existing portable components.

E. Basic research infrastructure

A national MEMS basic research infrastructure is essential to the continued advancement of RF MEMS. Through growth of the basic research infrastructure under the N/MEMS S&T Fundamentals program, we can ensure vibrant academic collaboration with industry guidance to serve the DoD's future needs.

IV. CONCLUSION

DARPA is charting a course to develop essential technologies critical to the future of RF MEMS components and subsystems. We are not seeking to drive down component cost, but are instead targeting several opportunities for MEMS and nanotechnology that will enable new systems and revolutionize performance levels. A number of important fundamental science and technology issues are being explored in tandem with aggressively targeted applications in switching and filtering. Viewed together, this work will establish new benchmarks and lay the foundation for a clear path to the future of RF MEMS.

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