ELECTRICAL AND COMPUTER ENGINEERING SEMINAR

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High-Q Strong Coupling Capacitive-Gap Transduced RF Micromechanical Resonators

Monday, February 3rd

138 ISEC

11:00 am – 12:00pm

Abstract:

This talk presents a hierarchical, intuitive, and technology agnostic procedure for designing RF channel-select filters, followed by an actual demonstration that consists of 96 mechanically coupled capacitive-gap-transduced polysilicon disk resonators, centered at 224MHz with only 0.1% (9kHz) bandwidth, all while attaining 2.7dB insertion loss and more than 50dB out-of-channel stopband rejection, solidly confirming the validity of the design method. Two distinct methods then follow that aim to increase the resonator electromechanical coupling coefficient (kt2), which substantially improves the functionality of the demonstrated filter for future applications, e.g., ones that require higher-order with sharper roll-off characteristics and less passband ripple. Specifically, single-digit-nanometer electrode-to-resonator gaps have enabled 200-MHz radial-contour mode polysilicon disk resonators with motional resistance Rx as low as 144Ohm while still posting Q's exceeding 10,000, all with only 2.5V dc-bias. The demonstrated gap spacings down to 7.98nm are the smallest to date for upper-VHF micromechanical resonators and fully capitalize on the fourth power dependence of motional resistance on gap spacing. The scale here is perhaps best conveyed with the recognition that this gap corresponds to only 16 SiO2 molecules! High device yield and ease of measurement debunk popular prognosticated pitfalls often associated with tiny gaps, e.g., tunneling, Casimir forces, low yield, none of which appear. The tiny motional resistance, together with kt2's up to 1% at 4.7V dc-bias and kt2-Q products exceeding 100, propel polysilicon capacitive-gap transduced resonator technology to the forefront of MEMS resonator applications that put a premium on noise performance, such as radar oscillators.

To increase functionality even further, the rest of this talk introduces a fabrication and post-processing method using CMOS-compatible ruthenium metal that allows integration of micromechanical devices, such as the aforementioned RF filters, atop CMOS. To this end, introduction of tensile stress via localized Joule heating has yielded some of the highest metal MEMS resonator Q's measured to date, as high as 48,919 for a 12-MHz ruthenium micromechanical clamped-clamped beam, defying the common belief that metal Q cannot compete with conventional micro machinable materials. The low-temperature ruthenium metal process, with highest temperature of 450°C and paths to an even lower ceiling of 200°C, further allows for MEMS post-processing directly over finished foundry CMOS wafers, thereby offering a promising route towards fully monolithic realization of CMOS-MEMS circuits, such as needed in communication transceivers. This, together with its higher Q, may eventually make ruthenium metal preferable over polysilicon in some applications.

Bio:

Alper Ozgurluk received the B.S. degree in electrical and electronics engineering from Bilkent University, Ankara, Turkey, in 2012 and the Ph.D. degree in electrical engineering and computer sciences from the University of California, Berkeley, CA, USA, in 2019. The first part of his Ph.D. research focused on the design, fabrication, and testing of medium-scale micromechanical circuits using capacitive-gap transduced disk resonators as building blocks to demonstrate RF channel filters for ultra-low power radio applications. During his Ph.D., he also worked on design and fabrication methods to shrink the gaps of capacitive-gap resonators to single-digit-nanometers transforming the performance of such devices. The last part of his Ph.D. mainly focused on CMOS-compatible resonator materials and post-processing techniques that could provide decent performance much needed for CMOS-MEMS integration. In 2019, he joined Apple Inc. as a Display Exploration Engineer.