resistance of a resonator with a given frequency can be
overall dimensions of the AlN plate. Consequently, the motional
resonant frequency of the device is effectively uncoupled from the
transduction electrodes and routing the excitation waveform, the
resonant frequency of the device is effectively uncoupled from the
overall dimensions of the AlN plate. Consequently, the motional
resistance of a resonator with a given frequency can be
significantly reduced by scaling up the lateral dimensions of the
structural material is being used [3,7]. Theoretical designs for low
motional resistance, GHz rectangular or annular plate resonators
are marked by extreme length to width or average radius to annular
width, respectively, which in practice result in unacceptable
mechanical compliance, inefficient use of layout area, and the need
for exacting fabrication tolerances.

INTRODUCTION

The demand for highly-integrated analog filtering and
frequency reference elements has spurred rapid innovation in the
area of vibrating RF MEMS [1]. To date however, no single
technology has emerged that can simultaneously deliver
monolithic, post-CMOS integration of IF and RF components that
can readily interface with 50 Ω RF systems. Thickness-extensional
FBAR resonators have proven the technical feasibility and
commercial viability of thin film piezoelectric Aluminum Nitride
(AlN) based processing technology for RF applications, but the
designs are practically limited to a single frequency per AlN
deposition and not scaleable to IF [2]. Air and solid dielectric gap
electrostatic contour mode resonators inherently do not suffer
either of the aforementioned limitations, but despite monumental
improvements have yet to demonstrate low motional resistance,
fundamental mode resonators suitable for RF filter synthesis [3,4].
AlN contour mode MEMS resonators have emerged as the premier
technology for realizing multi-frequency per chip, CMOS-
compatible, low-loss filters, but heretofore have been limited to
operating frequencies between 10 and 500 MHz [5,6].

The present work introduces a novel design for piezoelectric
contour mode MEMS plate resonators that effectively uncouples
the resonant frequency of the devices from their overall
dimensions by selectively patterning the transduction electrodes
and routing the excitation waveform as seen in Figure 1. The
ability to scale the lateral dimensions of the structural material
enables more mechanically robust devices that are capable of
attaining higher frequencies (803 MHz demonstrated) with reduced
motional resistances (24 Ω) and relaxed fabrication tolerances
(structural plate measures 51x100 µm). The electrode
configuration also suppresses the appearance of any lower or sub-
harmonic modes in the frequency response of the device.

THEORY

Piezoelectric and electrostatic contour mode MEMS
resonators based on rectangular or annular plates offer the ability
to prescribe frequency and motional resistance independently
within a limited design space, but are ultimately precluded from
reaching GHz fundamental modes by the need to define half-
wavelength features (on the order of several microns) in whatever

Figure 1: Optical micrograph of micromechanical resonator with
selectively patterned half-wavelength period electrodes. The
polarity of the electric excitation signal alternates between
adjacent top and bottom electrode pairs. The effective
characteristic lengths for determining frequency and motional
resistance are 6 and 900 µm, respectively.

Figure 2: Schematic of resonator cross-section showing selective
electrode patterning and signal routing. The polarity of each top
and bottom electrode pair alternates at half-wavelength intervals.
The period of the electrode pairs determines the operating
frequency of the resonator while the number of periods affects its
motional resistance.
The practical implication of the design is that half-wavelength features need only be defined in the thin metal electrodes, and the feasibility of fabricating such features in a production environment has essentially been proven by SAW device manufacturers (in fact SAW devices have more demanding fabrication requirements due to their lower acoustic wave speed). As with SAW devices, the nominal frequency of the resonator depends not only on the absolute dimensions but also the periodicity of the electrodes.

**FABRICATION PROCESS**

The resonators under investigation are fabricated using a variation of a previously published four-mask, low-temperature process [7]. The device consists of a thin film piezoelectric AlN structural layer sandwiched between Pt bottom and top electrodes. The approximate thicknesses of the AlN and Pt layers are 1.5 μm and 200 nm, respectively. A 300 nm low-stress silicon nitride layer is deposited between the silicon substrate and bottom electrode for electrical isolation. The AlN films are deposited using a single-module AMS Inc. sputtering tool.

**EXPERIMENTAL DETAILS**

The fabricated MEMS filters are tested in a Janis RF probe station with micro-manipulated ground-signal-ground (GSG) probes. All testing is performed in air at atmospheric pressure and ambient temperature. The $S_{11}$ parameter of the devices is extracted by an Agilent E5071B vector network analyzer with 0 dBm of signal power following a short-open-load calibration on a ceramic reference substrate. The admittance transformation is calculated by the network analyzer.

Figure 3 shows a plot of the admittance response of a piezoelectric contour mode MEMS resonator over a 200 to 1,000 MHz frequency range. The AlN plate in this instance measures 51 x 100 μm and has 9 pairs of Pt top and bottom electrodes with 3 μm line width and spacing. Notice the effective suppression of spurious modes achieved by the electrode configuration.

![Figure 3: Admittance response of a micromechanical resonator with 9 half-wavelength top and bottom electrode pairs showing effective suppression of spurious modes from 200 MHz to 1 GHz.](image)

Figure 4 shows the admittance response of the same resonator in the vicinity of its 803 MHz series resonance exhibiting 24 Ω motional resistance and a $Q$ factor of 1,300 when tested in air. A similar resonator with 7 pairs of 3 μm line and space electrodes displayed an 828 MHz resonant frequency with 58 Ω motional resistance and a $Q$ of 1,000 when tested in air.

![Figure 4: Admittance response of same resonator as Figure 3 showing resonant behavior. Testing is done in air with 0 dBm signal power. Data are measured directly on network analyzer.](image)

**CONCLUSIONS**

Novel piezoelectric contour mode MEMS resonators have been demonstrated that enable breakthrough increases in frequency and reductions in motional resistance. The performance gains stem from a technique for selectively patterning the transduction electrodes and routing the excitation waveform. An AlN resonator measuring 51 x 100 μm overall with 9 pairs of 3 μm line and space Pt electrodes has been tested at 803 MHz with 24 Ω motional resistance and a $Q$ of 1,300 in air. This technology promises to for the first time permit monolithic integration of post-CMOS compatible, low-loss filters spanning IF to RF that can readily be interfaced with existing 50 Ω RF systems.

**ACKNOWLEDGEMENTS**

This work was supported by DARPA grant No. NBCH1020005. The authors offer special thanks to AMS Inc. for their assistance with AlN deposition and tool installation, and to the UC Berkeley Microfabrication Laboratory staff for their support.

**REFERENCES**