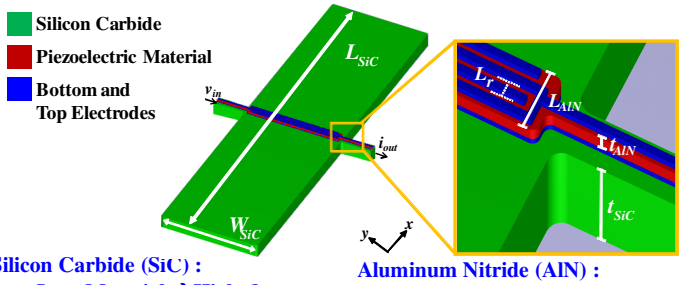
SAND2011-0455C

SILICON CARBIDE LATERAL OVERTONE BULK ACOUSTIC RESONATOR *with* ULTRAHIGH QUALITY FACTOR

Maryam Ziaei-Moayyed, Scott Habermehl, Darren Branch, and Troy Olsson
Sandia National Laboratories, Albuquerque, NM, USA

LATERAL OVERTONE BULK ACOUSTIC RESONATOR (LOBAR)

• The LOBAR design decouples the piezoelectric transduction and energy storage mechanisms, resulting in high $f.Q$ and $k_t^2.Q$ at microwave frequencies.
• Lithographically defined frequencies and bandwidths
→ multi-bandwidth, multi-frequency cognitive radios



Silicon Carbide (SiC) :
Low Loss Material →High Q
SiC has the lowest phonon-phonon damping
SiC has high acoustic speed, high mechanical and chemical strength

Aluminum Nitride (AlN) :
High Transduction Efficiency → High k_t^2
AlN is a piezoelectric material that efficiently couples the acoustic and electrical domains resulting in low motional impedance

THEORY and SIMULATION

High number of overtones stored in resonator →Higher Quality Factor

$$Q = 2\pi \frac{E_{Stored}}{E_{Lost}}\Big/_{Cycle}$$

$$Q_{LOBAR} \approx \left[\frac{\frac{1}{Q_{SiC}} + \frac{l_{AlN}}{l_{SiC} Q_{AlN}}}{1 + \frac{l_{AlN}}{l_{SiC}}}\right]^{-1}$$

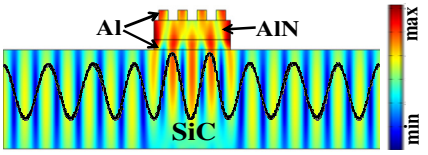
The resonance frequency of LOBAR is defined lithographically by the interdigitated electrodes on AlN (L_r =2× Al finger width);

$$f_{LOBAR} = \frac{1}{2L_r}\sqrt{\frac{E_{eff}}{\rho_{eff}}}$$

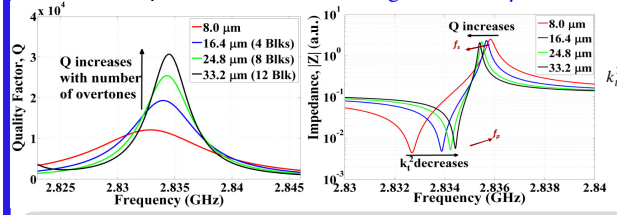
E_{eff} and ρ_{eff} are the effective Young's modulus and mass density of the composite SiC-Piezoelectric stack

At 3 GHz, L_r=7.52µm for AlN transducer with 4 fingers

LOBAR Simulations in COMSOL® showing Displacement Mode Shape in the x-direction



For optimum $f.Q$ and insertion loss need to maximize energy coupling from the piezoelectric AlN stack to the low loss SiC
→ For 1µm SiC, t_{AlN}=200nm, and t_{Al}=100nm
Frequency of the composite stack should matches that of the SiC ends to minimize impedance → SiC stack length of 12.25µm

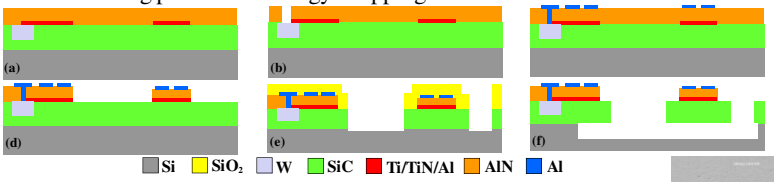


$$k_t^2 = \frac{\pi}{2}\frac{f_s}{f_p}\frac{1}{\tan\left(\frac{\pi}{2}\frac{f_s}{f_p}\right)}$$

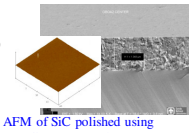
As wavelengths of SiC are added→ Quality factor increases and k_t^2 decreases

FABRICATION PROCESS

The Silicon Carbide LOBARs were fabricated in a CMOS-compatible surface micromachining process → Energy Trapping in All 3-axis



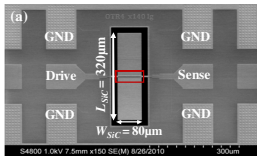
•Highly textured Cubic 3C-SiC (111) film was deposited using LPCVD
•SiC film has as-deposited tensile stress of <150MPa
•SiC film was polished to a surface roughness of <1nm, which is critical for high Q resonators

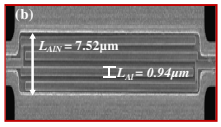


SEM and AFM of SiC polished using Tungsten CMP: rms < 1nm

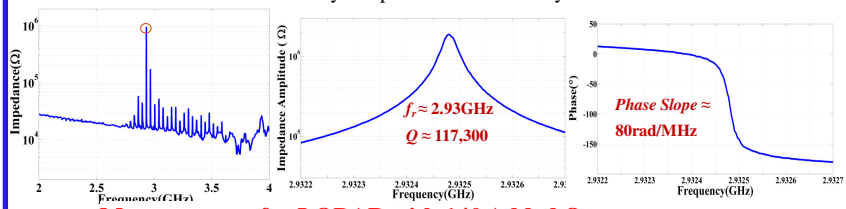
RESULTS

Scanning Electron Microscope (SEM) images of a silicon carbide lateral overtone bulk acoustic resonator with 140 added overtones

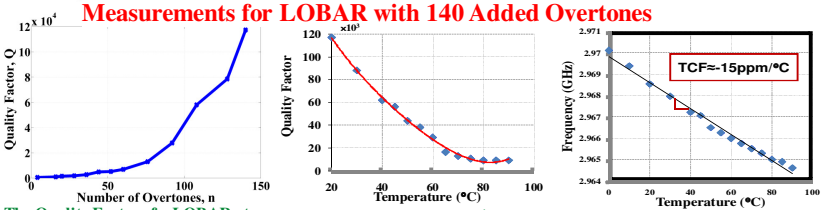




The wide span two port impedance response of the LOBAR from its transmission response in air shows the peaks corresponding to the higher order harmonics of the SiC length extensional resonance transduced by the piezoelectric AlN layer



Measurements for LOBAR with 140 Added Overtones



The Quality Factor of a LOBAR at 3GHz increases from <500 for one overtone to >100,000 for 140 overtones

The Quality Factor has a T^4 dependence
→ LOBAR operates in Landau-Rumer regime
→ Good on-chip temperature sensor

Temperature stability of uncompensated LOBAR

REFERENCES

[1]G. R. Kline, L. M. Lakin, and K. T. McCarron *IEEE Frequency Control Symp.* **1993**, 718-721.
[2]H. Yu, C. Y. Lee, W. Pang, H. Zhang, A. Brannon, J. Kitching, and E. S. Kim *IEEE trans. on Ultrasonics, Ferroelectrics, and Freq. Control* **2009**, 56, 400-403.
[3]R. Tabrizian, M. Rais-Zadeh, and F. Ayazi *Int. Conf. on Solid-State Sensors, Actuator, Microsystems* **2009,** 2131-2134.
[4]S.A. Chandorkar, M. Agrawal, R. Melamud, R. N. Candler, and T. W. Kenny *Intl. Conf. on Micro Electrical Syst.***2005**, 74-77.
[5]G. Piazza, P. J. Stephanou, and A. P. Pisano *J. Microelectromech. Syst.* **2006**, 15 (6) , 1406-1418.
[6]Y. T. Yang, K. L. Ekinci, M. H. Huang, L. M. Schiavone, M. L. Roukes, C. A. Zorman, and M. Mehregany *App. Phys. Lett.* **2001**,78(2), 162-164.
[7]G. K. Ho, R. Abdolvand, and F. Ayazi *IEEE Intl. Conference on Micro Electro Mechanical Systems* **2007**, 791-794.

ACKNOWLEDGEMENTS

• Microelectronics Development Laboratory Staff at Sandia National Laboratories for device fabrication
• DARPA/MTO CSSA program for funding (Program Managers: Dr. Dennis Polla and Dr. Sanjay Raman)
• Rockwell Collins and Draper Labs for technical discussions
• Sandia National Laboratory is multiprogram laboratory operated by the Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Sandia National Laboratories

Contact: mziaeim@sandia.gov