A Brief Overview of FBAR Technology

White Paper

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Introduction

FBAR is a breakthrough resonator technology being developed by Agilent Technologies. This technology can be used to create the essential frequency shaping elements found in modern Wireless systems, including filters, duplexers, and resonators for oscillators.

FBAR stands for Film Bulk Acoustic Resonator. Examining the components of this name help explain the nature of FBAR technology.

Film:

FBAR resonators are created using a thin film semiconductor process to build a Metal-Aluminum Nitride-Metal sandwich in air.

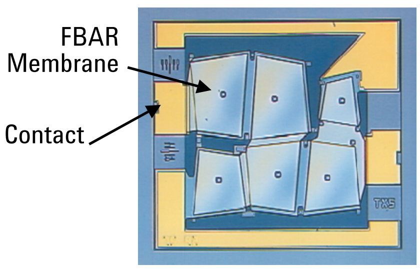


Figure 1. Top view

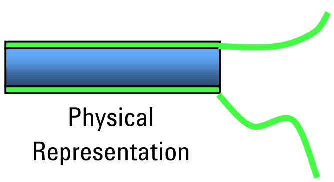


Figure 2. Side view

Bulk:

When an alternating electrical potential is applied across the Metal-Aluminum Nitride-Metal sandwich, the entire Aluminum Nitride (AlN) layer expands and contracts, creating a vibration. This resonance is in the body (bulk) of the material, as opposed to being confined to the surface as is the case for Surface Acoustic Wave (SAW) devices. One advantage of bulk resonators is the intrinsically better power handling characteristics compared to the interdigitated structures used in SAWs, especially at higher frequencies where the pitch of the interdigitated structures must be reduced.

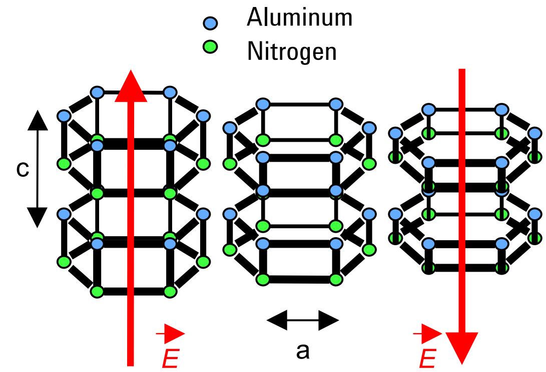


Figure 3. AlN expansion and contraction in the presence of an E field

Acoustic:

The vibrating membrane creates a high Q mechanical (acoustic) resonance. Recalling the relationship frequency x wavelength = speed, it becomes apparent that for a given frequency of resonance, sound waves traveling at several hundred meters per second will have much shorter wavelengths than will electrical signals moving at the speed of light. Consequently, the dimensions for an acoustic resonator at a given frequency are several orders of magnitude smaller than for a coaxial-based resonator, enabling acoustic devices to fit easily on a semiconductor chip. SAW devices also share this advantage over ceramic resonators.

Resonator:

As alternating voltage is applied across the AlN stack, the polarization vector **P** of the stack will change in phase. At some voltage $V(f_s)$, **P** will be in-phase with the vector **E** created by the applied potential, creating a series resonance. At some voltage $V(f_p)$ **P** with be 180 degrees out-of-phase with **E**, creating a parallel resonance. These resonances can be characterized by the following equations:

Figure 4. Series Resonance:

$$f_s = (L_m C_m)^{-1/2}$$

$$R_s = R_{series} + R_m$$

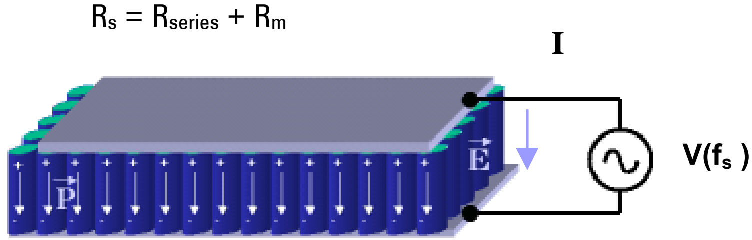


Figure 5. Parallel Resonance:

$$f_p = (L_m C_m)^{-1/2} (1 + C_m/C_p)^{-1/2}$$

$$R_p = Z^2_{plate} (R_m + 1/G_{shunt})^{-1}$$

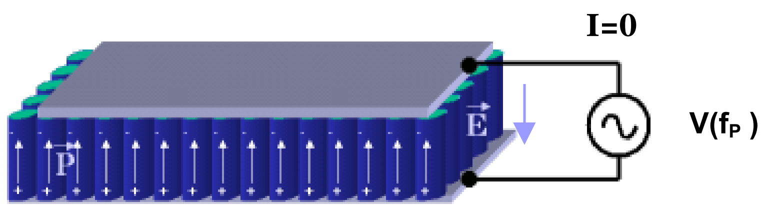
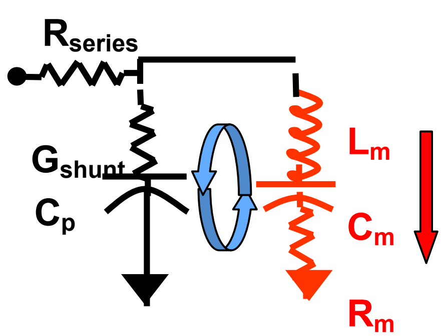


Figure 6. Equivalent Circuit:

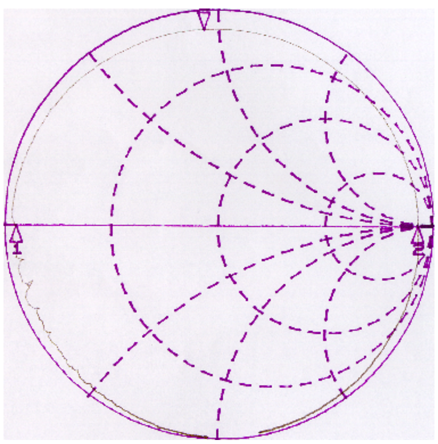


A piezoelectric coupling is used to access these acoustic resonances to create an electrical resonator. Resonators can in turn be built into networks that provide signal shaping (filtering). Resonators can also be used to construct devices such as Voltage Controlled Oscillators (VCOs).

Performance:

The high Qs and coupling coefficients achieved in by FBAR technology allow structures to be created that rival present state-of-the-art ceramic resonators and SAW resonators. Qs in excess of 1000 have been realized. This translates into very steep filter roll-off: more than 40 dB rejection in <10 MHz or 50 dB rejection in <15 MHz has been achieved.

Figure 7. FBAR Q Circles



When compared to ceramic-based products, FBAR-based solutions offer significant advances in miniaturization. Products can be realized in less than 10% of the volume of present ceramic-based solutions. The electrical performance of FBAR prototypes is already within a few decibels of the performance of the current generation of CDMA PCS ceramic duplexers, and it is expected that FBAR-based products will offer equivalent performance to ceramic-based competitors.

Figure 8. Ceramic Duplexer – 1997-1998

Ceramic Duplexer '97- '98
8.5 x 28 x 5.5: 1309 mm^3

Figure 9. Ceramic Duplexer -- 1999

Ceramic Duplexer '99
5.5 x 24.5 x 5: 674 mm^3

Figure 10. Agilent Technologies FBAR-based solution.

Agilent Technologies 2 3x3 LCCs
on PCB complete solution
5.6 x 11.9 x 1.9: 127 mm3

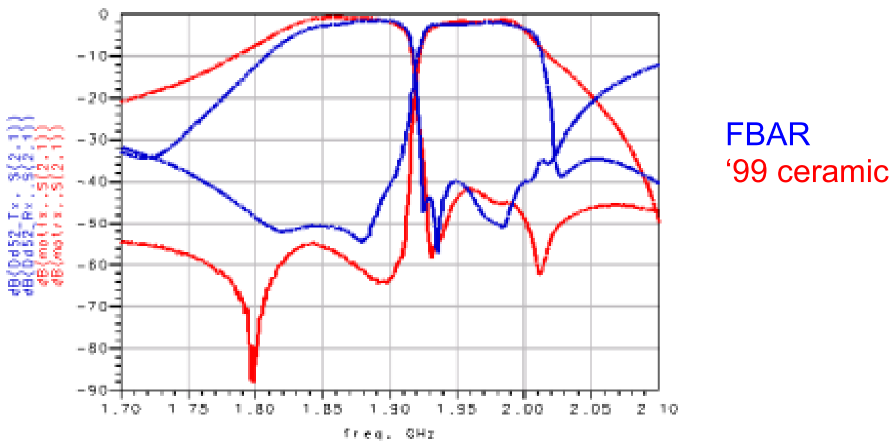


Figure 11. Prototype Passband Performance

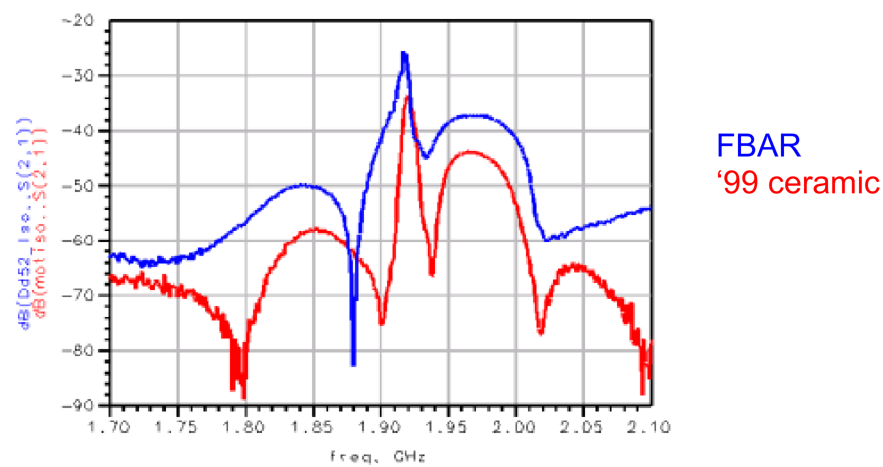


Figure 12. Protytpe Isolation Performance.

When compared to SAW devices, FBAR devices can offer improvements in electrical performance, including the potential for lower insertion loss, steeper filter "sidewalls", and better power handling. Many of these advantages derive from the lower parasiticics associated with a bulk device, as well as the elimination of Bragg reflectors from the topology. Some of this performance margin can be traded for improvements in bandwidth, eliminating the need for split-band solutions. Additionally, while the difficulties of obtaining high power handling characteristics in fine-pitched interdigitated structures presently limit SAW-based duplexers to the cellular bands, FBAR technology extends easily to PCS frequencies, and can be used to create resonators that operate to frequencies above 10 GHz.

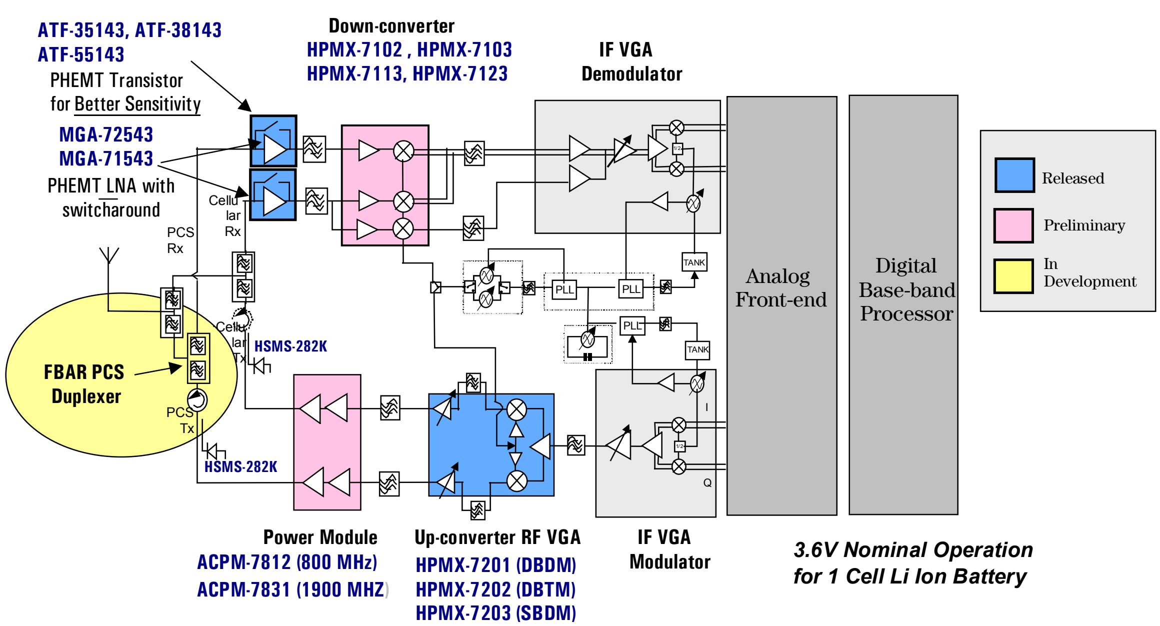
FBAR technology is compatible with both Silicon and Gallium Arsenide (GaAs) wafer processing, opening the door for integrated radio solutions that include both active elements and filtering within the same semiconductor package, and eventually on the same chip. SAW devices are commonly constructed on Lithium Tantalate ($LiTaO_3$) or Lithium Niobate ($LiNBO_3$), higher-cost substrates that are likely limited to integration into multi-chip modules. The relatively large size of

ceramic technology devices makes these devices inappropriate for integration.
A quick comparison of the three technologies is presented below:

	Ceramic	SAW	FBAR
size (PCS duplexer)	675 mm^3	140 mm^3 (cellular band)	126 mm^3; going to <50 mm^3
electrical (I.L., roll-off)	excellent	good	excellent
power handling	best (>35 dBm @ 2 GHz)	fair (31 dBm @ 900 MHz)	good (>32 dBm @ 2 GHz)
temperature coefficient	0 to -5 ppm/C	-35 to -94 ppm/C	-20 to -35 ppm/C
ESD robustness	excellent	fair	good
frequency range filters: duplexers:	 cellular/PCS cellular/PCS	 IF-cellular-PCS cellular/PCS?	 cellular-PCS-mw cellular-PCS-mw
integration	no	Multi-Chip Module (MCM)	MCM ; future full integration

Product Roadmap

At present the duplexer is one of the largest elements in a PCS handset. Our first product will be a US PCS duplexer for CDMA handsets, where FBAR technology's unique combination of small size and excellent electrical performance can provide unprecedented opportunities for miniaturization. Duplexers for cellular band systems are expected to follow quickly. These products will be part of Agilent Technologies' CDMAdvantage chipset.



CDMAdvantage Chipset

References:

PCS 1900 MHz duplexers using thin film bulk acoustic resonators (FBARs), R Ruby, P Bradley, J D Larson III and Y Oshmyansky *Electronic Letters* 13 May 1999 Vol 35 No 10

A BAW Antenna Duplexer for the 1900 MHz PCS Band, J Larson III, R Ruby, P Bradley, Y Oshmyansky

A PCS 1900 MHz Duplexer using Thin Film Bulk Acoustic Resonators (FBARs), R Ruby J Larson III, P Bradley, Y Oshmyansky, *HP Laboratories Technical Report*, HPL-1999-46, March 1999

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