RTT TECHNOLOGY TOPIC September 2012

Acoustic Filters

Acoustic filters are the workhorse of the mobile broadband industry, used in the front end of almost every cellular phone and defining the way in which we use and share spectrum.

Their present and future performance has a major influence on data throughput efficiency which in turn determines the user experience and user value.

In this month's technology topic we review the impact of material and manufacturing innovation on acoustic filter performance and the impact this will have on network economics and data delivery cost.

Acoustic Filter Options – SAW and BAW devices

Acoustic filters include Surface Acoustic Wave devices where an acoustic wave travels across the **surface** of a substrate and Bulk Acoustic Wave devices where an acoustic wave travels through the **body (bulk)** of the device. BAW devices when used as resonators are either **F**ilm **B**ulk **A**coustic **R**esonators (FBAR) or **S**olidly **M**ounted **R**esonators (SMR).

For a given frequency of resonance, sound waves travelling at several hundred meters per second have shorter wavelengths than electrical signals travelling at the speed of light. The dimensions of an acoustic resonator are therefore several orders of magnitude smaller than a co axial resonator. SAW and BAW filters are typically 10% of the volume of equivalent ceramic based filters.

The introduction of SAW Devices

SAW filters first started to be used in the 1970's initially for pulse compression radar but then as oscillators and band pass filters for domestic TV.

Domestic TV filters were implemented as IF filters at 72 MHz. These worked well and still work well today though were and are sensitive to image channel interference from channels on a nine channel off set (nine times eight = 72 MHz). Most but not all present day TV's are now direct conversion receivers but the continued presence of older design receivers means channel off sets still need to be considered.

The use of SAW devices in televisions meant the devices were manufactured in volume. This resulted in a price reduction. In the 1980's they started to be used in cellular phones. Today billions of SAW devices are manufactured for the cellular handset market.

SAW Device Properties and Materials

SAW filters exploit the properties of an acoustic wave launched across the surface of the device. The properties of the acoustic wave are combined with the piezo electric effect discovered by Jacques and Pierre Curie in 1880.

The surface wave is the Rayleigh wave, predicted mathematically by John William Strutt, Lord Rayleigh in 1885. A Rayleigh wave rolls along the ground in the same way that a wave rolls across a lake or an ocean. Because it rolls, it moves the ground up and down and side-to-side in the same direction that the wave is moving.

Other wave effects are also exploited in acoustic devices including leaky waves and love waves. Leaky waves have potentially lower loss at higher frequencies but have less design flexibility. Rayleigh wave devices generally produce lower ripple and better (low) group delay characteristics.

Many materials exhibit piezo electric properties but to be useful the material has to be anisotropic with properties dependent on the orientation relative to the internal arrangement of the atoms. This means that crystalline materials are normally used.

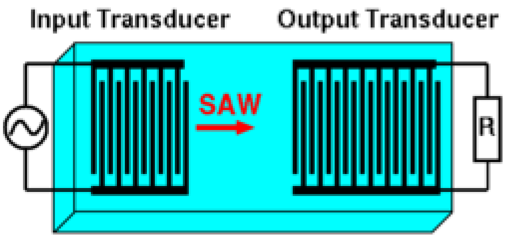
For SAW filters the choice of crystalline material for the piezo electric substrate is either quartz, lithium niobate, lithium tantalate or lanthanum gallium silicate. Lithium tantalate (LiTao3) and lithium niobate (LiNbo3) are presently preferred as they offer higher piezoelectric coupling than quartz.

The wave is generated and guided by an input and output interdigital transducer, two electrodes of aluminium deposited at either end of the substrate using photolithography.

When a voltage is applied the gaps between the electrodes have electrical fields. The piezo electric effect translates this into mechanical stress (flexing of the substrate) which acts as the source of the surface wave.

If the frequency is chosen such that the SAW wavelength equals the transducer pitch, the waves generated by the subsequent gaps will be in phase and therefore will reinforce each other

SAW filter



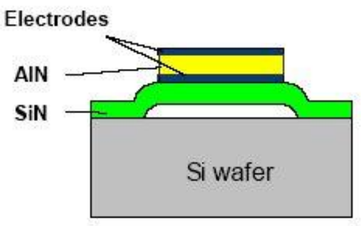
BAW Devices – properties and materials

Bulk acoustic wave (BAW) devices were first discussed in academic papers in the 1980's

In BAW devices the resonance is in the body (bulk) of the material rather than on the surface and the frequency is a function of the thickness of piezo electric material deposited on a substrate.

Devices are typically manufactured using a thin film semiconductor process to build a metal aluminium nitride or zinc oxide metal sandwich suspended in an air cavity. The electrode materials are molybdenum, tungsten or ruthenium.

FBAR filter



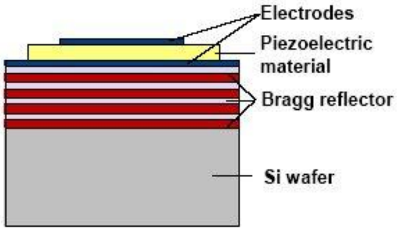
FBAR-surface micro-machining

Bulk devices have lower parasitics which means that insertion loss can be lower for a given steepness of filter sidewall. They can also handle more power and operate at higher frequencies (up to 10 GHz).

The difference between an FBAR and SMR BAW filter

The difference between an FBAR BAW device and solidly mounted resonator (SMR) BAW is the means by which the acoustic energy is trapped. In an FBAR there is an air cavity on either side of the resonator. An SMR BAW uses a Bragg reflector under the resonator. An acoustic Bragg reflector is made up of alternating layers of high and low acoustic impedance material at odd multiples of a quarter wavelength.

SMR Resonator



SMR-type resonator

In an FBAR the edges of the resonator compromise Q. In an SMR BAW the Bragg reflector reduces coupling efficiency. FBAR and SMR BAW devices however both generally exhibit better temperature stability and higher Q than SAW filters in equivalent applications.

Manufacturing challenges – size cost and performance inter dependencies

For both types of BAW device the challenge in the 1990's was to find a way of making a sputtered piezoelectric film with equivalent Q to the crystal grown (cultured) lithium tantalate or niobate used in SAW devices.

Substantial R and D and manufacturing investment by companies such as Avago (previously Agilent previously HP) and Infineon (previously Siemens) produced commercial products that began to be adopted in cellular phones from 2002 onwards.

SAW devices have the benefit of fully depreciated fabrication facilities and thirty to forty years of manufacturing experience. BAW devices potentially leverage mainstream CMOS production.

Infineon made improvements to the Bragg reflector to accommodate longitudinal and shear wave effects (shear waves leaking through the reflector). This improved the Q of SMR BAW devices.

For FBAR devices, Agilent (now Avago) chose aluminium nitride for the piezo electric substrate and molybdenum (Mo) for the electrode on the basis that these were likely to be more compatible with high volume semiconductor production. Aluminium nitride etches well in chlorine gas and molybdenum etches well in fluorine. Molybdenum has good stiffness and electrical conductivity.

Most of the manufacturing challenges for SMR and FBAR BAW devices relate to the control of the thickness and uniformity of the deposition layer. Uniformity is not just thickness but also the uniformity of acoustic values (velocity and density).

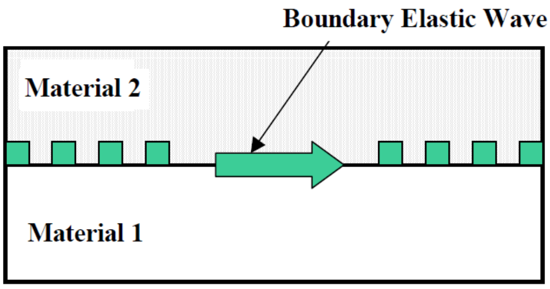
The deposition process on its own does not provide sufficient resolution and accuracy and additional trimming using ion beam etching is required.

The dielectric layers are easier to trim but adding trim tolerance to these layers increases coupling loss which translates into additional insertion loss. Any trimming process implies a trade-off between resolution, accuracy and throughput and yield. This determines the manufacturing cost per device to which needs to be added the ROI on R and D and manufacturing.

Boundary elastic wave filters

Vendors are looking at new approaches to integrating the RF IC and filter functions. The cavity space needed in a SAW device makes this difficult to achieve. One solution exploits the properties of a boundary acoustic wave also known as a boundary elastic wave device in which the wave travels in the interface of two adhered materials.

Boundary Elastic Wave Filter
http://www.murata.com/ninfo/nr0731e.pdf



New applications

Improved process control has therefore produced and continues to yield useful performance improvement. When coupled with temperature compensation techniques these devices have solved problems which were previously unsolvable, the proximity of LTE Band 13 to public safety radio band allocations in the US 700 band is one example.

However temperature compensation is only effective over relatively narrow channel bandwidths, Band 13 is a 10 by 10 MHz LTE channel plan.

Regulators are currently considering significantly more ambitious band plans in the 700 MHz band in Europe, Asia and Latin America both in terms of operational bandwidth, guard bands and the duplex gap.

As with all 700 MHz mobile broadband allocations these systems will need to coexist with high power TV transmitters and TV receivers with poor selectivity and limited dynamic range.

This will require another big improvement in acoustic filter performance.

Ends.

Acoustic filter performance is one of the many topics addressed in RTT's latest book '**Making Telecoms Work- from technical innovation to commercial success'** available from the **RTT book shop.**

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