Advanced Bulk Acoustic Wave RF filter technologies with new topologies and materials

9th ESA ROUND TABLE ON MICRO AND NANO TECHNOLOGIES FOR SPACE APPLICATIONS
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Outline

- BAW/FBAR Filters
- VTT Background in BAW technology
- Laterally coupled BAW filters
- ScAlN for BAW filters, microacoustics and MEMS
- VTT capabilities in BAW development and manufacturing
Introduction – BAW Filters

\[ t = \frac{\lambda}{2} \]

\[ f_0 = \frac{v}{2t} \]
BAW/FBAR filters characteristics

- Frequency range: 1 GHz to several GHz
- Passband width up to ~4%
- Low insertion loss
- Steep roll-off, high stop-band-rejection
- Small size & mass
- Low temperature drift
- High power handling
- ESD robustness

- Very good filters for many RF applications!
BAW/FBAR Filter market and manufacturing

- The BAW/FBAR filter market is aimed practically solely at the mobile radio Front End Modules
- Volumes produced are massive, price & size pressure is high
- Major manufacturers: Avago Technologies, TriQuint Semiconductor, TDK-Epcos

- Availability for smaller volumes and special applications?
VTT Background in BAW Technology

- SMR filter technology developed for Nokia and its subcontractors late 90’s
- Design, device physics, manufacturing
- ZnO and AlN based devices
- Design software and methodology
- Later shift research focus to
  - Lamb wave devices (LBAW)
  - New materials (e.g. ScAlN)
  - Piezo-MEMS (resonators & sensors)
Laterally Coupled BAW filters
Laterally Coupled BAW filter – principle of operation

J. Meltaus, T. Pensala, K. Kokkonen, A. Jansman, IUS 2009

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Laterally coupled BAW filter – wider bandwidth devices

\[ \sim \lambda_{\text{even}}/2 \]

\[ \lambda_{\text{odd}} \]
31 finger LBAW filter, matched response

W = 3 µm
G = 2 µm
L = 200 µm
N = 31

Min IL: 2 dB
f₀: 1950 MHz
Rel 3-dB BW: 4.9%

Suppression level: 20 dB
(note nonpatterned bottom electrode)

Peak results from shear mode response

120 Ω || 5 nH

J. Meltaus, T. Pensala, IUS 2010
LBAW vs commercial Band II SAW filter

- Comparison to EPCOS WCDMA Band II SAW Filter
- LBAW response shifted 95 MHz down for ease of comparison
Wide band LBAW using two wave modes

Pass-band is due to thickness extensional mode

Side peak results from thickness shear resonance

Measured response, N=31
Matched with 120 $\Omega \parallel 5 \text{nH}$

Evanescent wave $\leftrightarrow$ Propagating wave

J. Meltaus, T. Pensala, IUS 2010

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Can you merge the two modes by clever acoustic design of the devices?

Move TS2 branch closer to TE1…

Evanescent wave $\leftrightarrow$ Propagating wave
Yes: A two-mode wide band LBAW filter

~10% bandwidth at 2 GHz
ScAlN for BAW filters, microacoustics and MEMS
Sc doped AlN

- Major limitation of AlN is the $K^2$ (and also high acoustic velocities)
- Addition of Sc into AlN [1]
  - Increases piezoelectric coefficients
  - Softens the material
  - Increases slightly permittivity
  - Electromechanical coupling $K^2$ boosted significantly

ScAlN sputtering

- Sc pellets embedded into a thick Al target
- Sc content tailoring easy
- 150 mm wafer size (100 mm also possible, 200 mm being studied)
- Processes for 5-6 at. % Sc and 13 at. % Sc developed
- BAW resonators and Piezo-MEMS devices manufactured

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AIN & ScAlN BAW resonator characteristics

~6.5 at. % Sc

PZD = 3.7 % (vs. 2.8 % of AlN)

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<thead>
<tr>
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<th>( k_{\text{eff}} )</th>
<th>( K^2 ) (%)</th>
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<tbody>
<tr>
<td>AlN</td>
<td>0.23</td>
<td>6.91</td>
</tr>
<tr>
<td>ScAlN</td>
<td>0.27</td>
<td>9.52</td>
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</tbody>
</table>

\[ \text{Q}_{\text{s}} = 300 \]
\[ \text{Q}_{p} = 290 \]
\[ \text{max } \text{QBode} = 535 \]

\(~13 \text{ at. % Sc}\)

PZD = 6.58 %

\( K^2_{\text{IEEE}} = 14.34 \% \)
Implications to filters and MEMS

- Pass Band width of 8 % and above possible with ladder filters
- Reserve $K^2$/bandwidth can be sacrificed for e.g. temperature compensation
- Modes that are not highly enough coupled in plain AlN may become usable for filters: Lamb waves [2]
- Force generation for MEMS devices improved while maintaining easy process integration (as opposed to PZT)
- Very efficient for vibration energy harvesting

- A whole new world of possibilities is opened

BAW, Piezo-MEMS processing capabilities at VTT

- Piezo sputtering
  - AlN dedicated tool 150 mm
  - ScAlN 150 mm experimental
  - PZT 150 mm

- Thin film & MEMS processing
  - W-SiO2 SMR
  - Backside released FBAR & MEMS
  - CSOI based Piezo-MEMS

- Local Ion Beam Trimming (next slide)

- Characterization
  - RF (VNA), temperature behavior

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Ion Beam Trimming

**AS DEPOSITED**

**TRIMMED**

<table>
<thead>
<tr>
<th>AIN</th>
<th>Pre-trimming</th>
<th>Trimmed</th>
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<tbody>
<tr>
<td>Max</td>
<td>998.3 nm</td>
<td>926.7 nm</td>
</tr>
<tr>
<td>Min</td>
<td>967.2 nm</td>
<td>921.3 nm</td>
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<tr>
<td>Average</td>
<td>983.6 nm</td>
<td>922.8 nm</td>
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<tr>
<td>Std. Dev.</td>
<td>7.5 nm</td>
<td>1.3 nm</td>
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<tr>
<td>Unif. (max-min)/max+min</td>
<td>1.6 %</td>
<td>0.3 %</td>
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Summary

- BAW in mass production for mobile devices but would be suitable for many special applications also (space, aviation, defence, …)
- Laterally Coupled BAW filters: wide bandwidth in small form factor
- ScAlN piezomaterial
  - Increased bandwidth, design freedom
  - New modes
  - MEMS
- VTT has a process line capable of BAW filter production, including trimming of devices