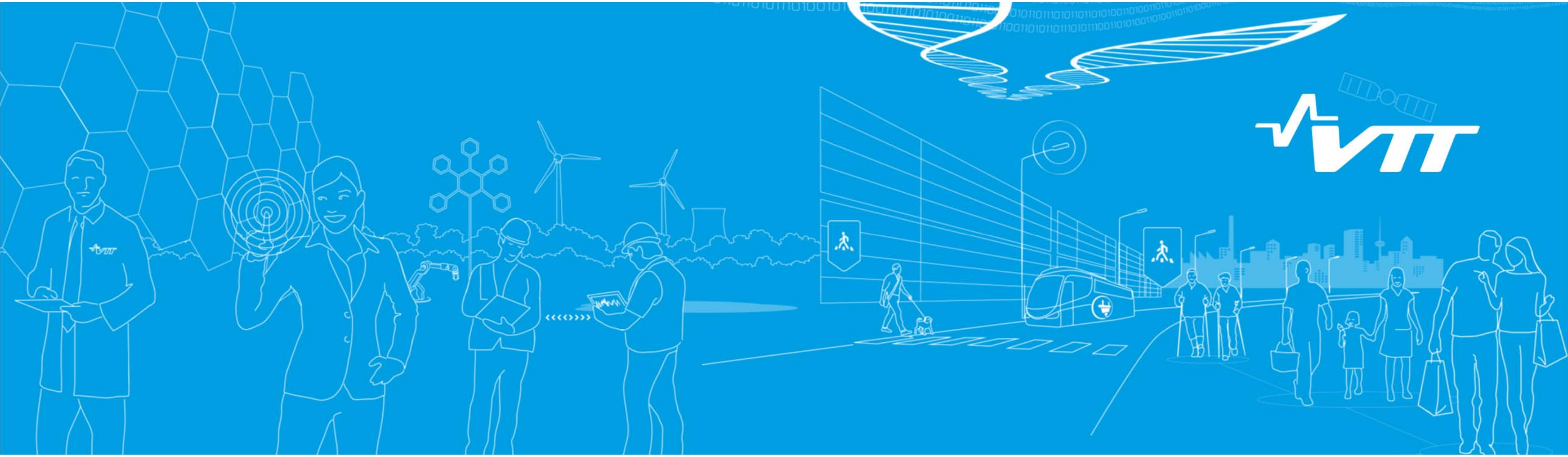


Advanced Bulk Acoustic Wave RF filter technologies with new topologies and materials

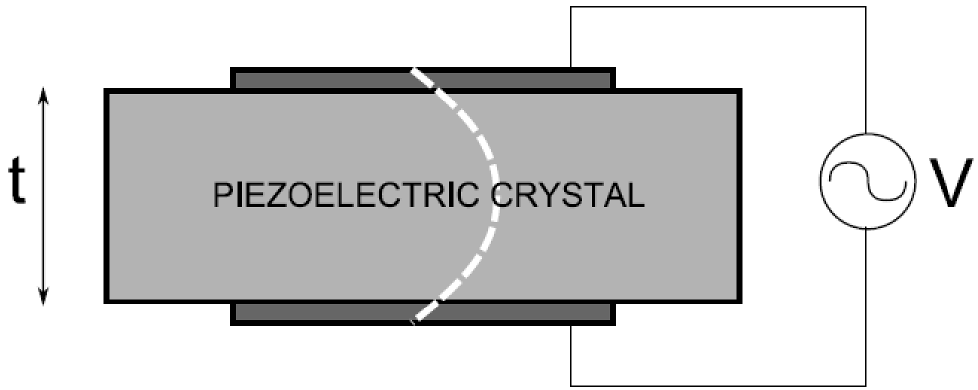
9th ESA ROUND TABLE ON MICRO AND NANO TECHNOLOGIES FOR SPACE APPLICATIONS

T. Pensala, J. Meltaus, T. Riekkinen
VTT Technical Research Centre of Finland

Outline

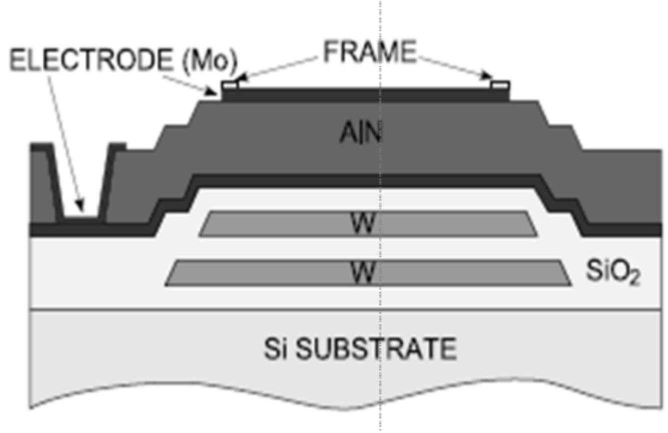
- BAW/FBAR Filters
- VTT Background in BAW technology
- Laterally coupled BAW filters
- ScAlN for BAW filters, microacoustics and MEMS
- VTT capabilities in BAW development and manufacturing

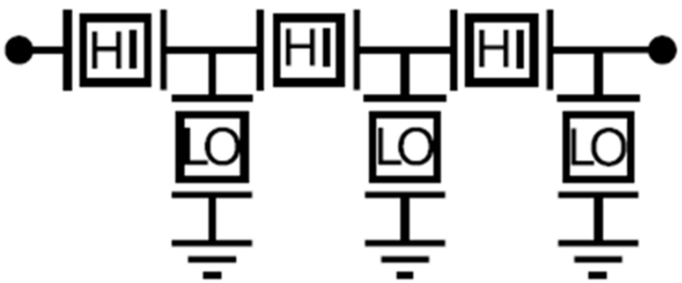
Introduction – BAW Filters

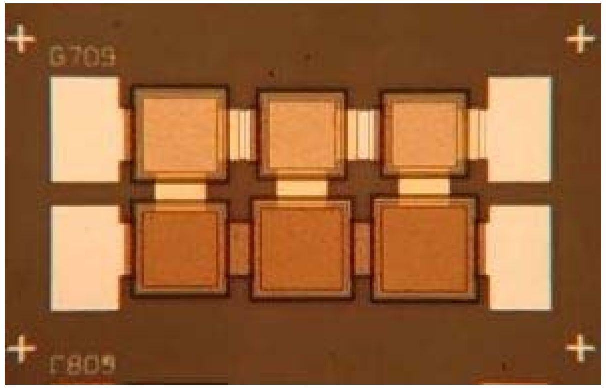


$$t = \lambda/2$$

$$f_0 = \frac{v}{2t}$$

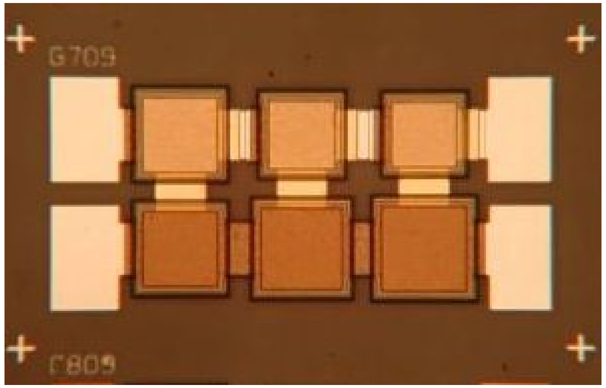


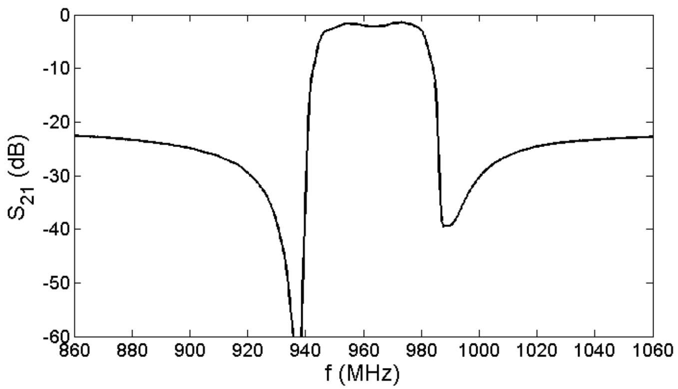




BAW/FBAR filters characteristics

- 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!

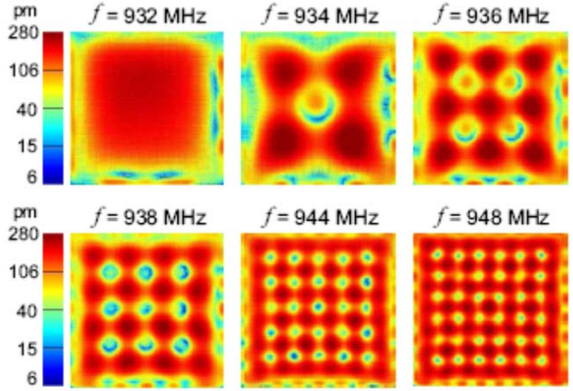
BAW/FBAR Filter market and manufacturing

- 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?

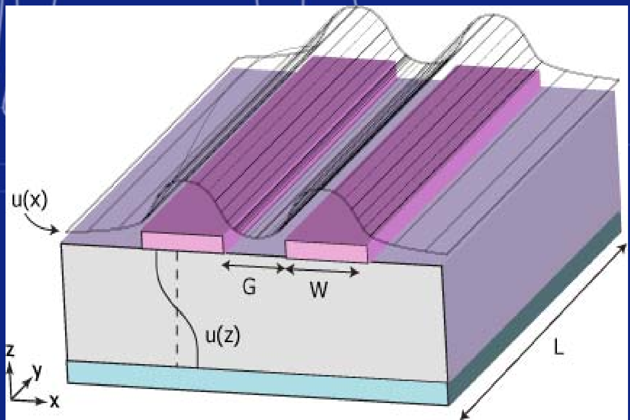
VTT Background in BAW Technology

- 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)

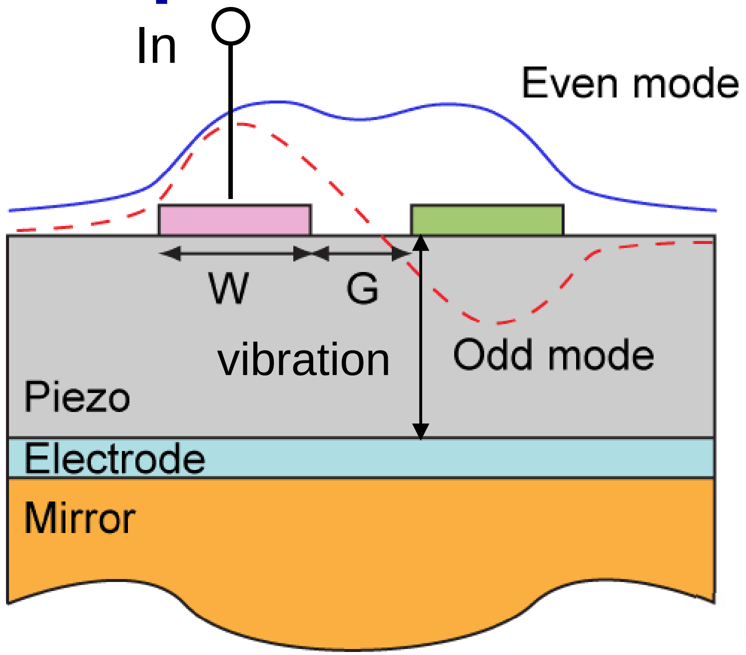


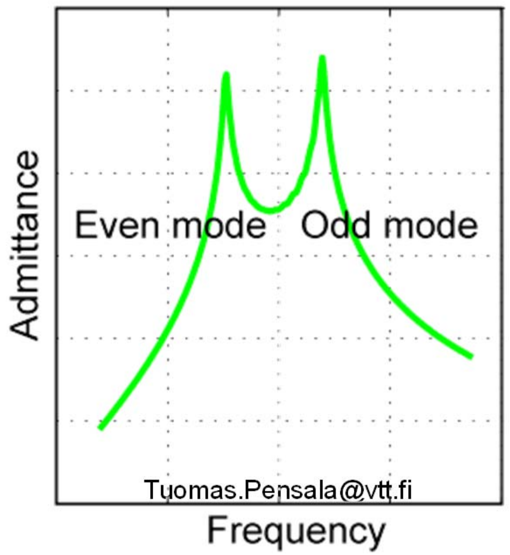
K.Kokkonen/Aalto University

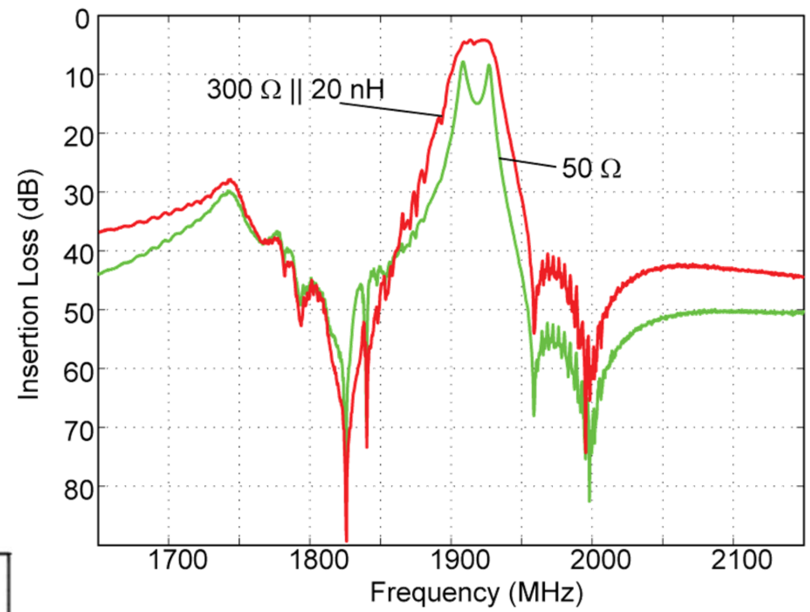
Laterally Coupled BAW filters



Laterally Coupled BAW filter – principle of operation







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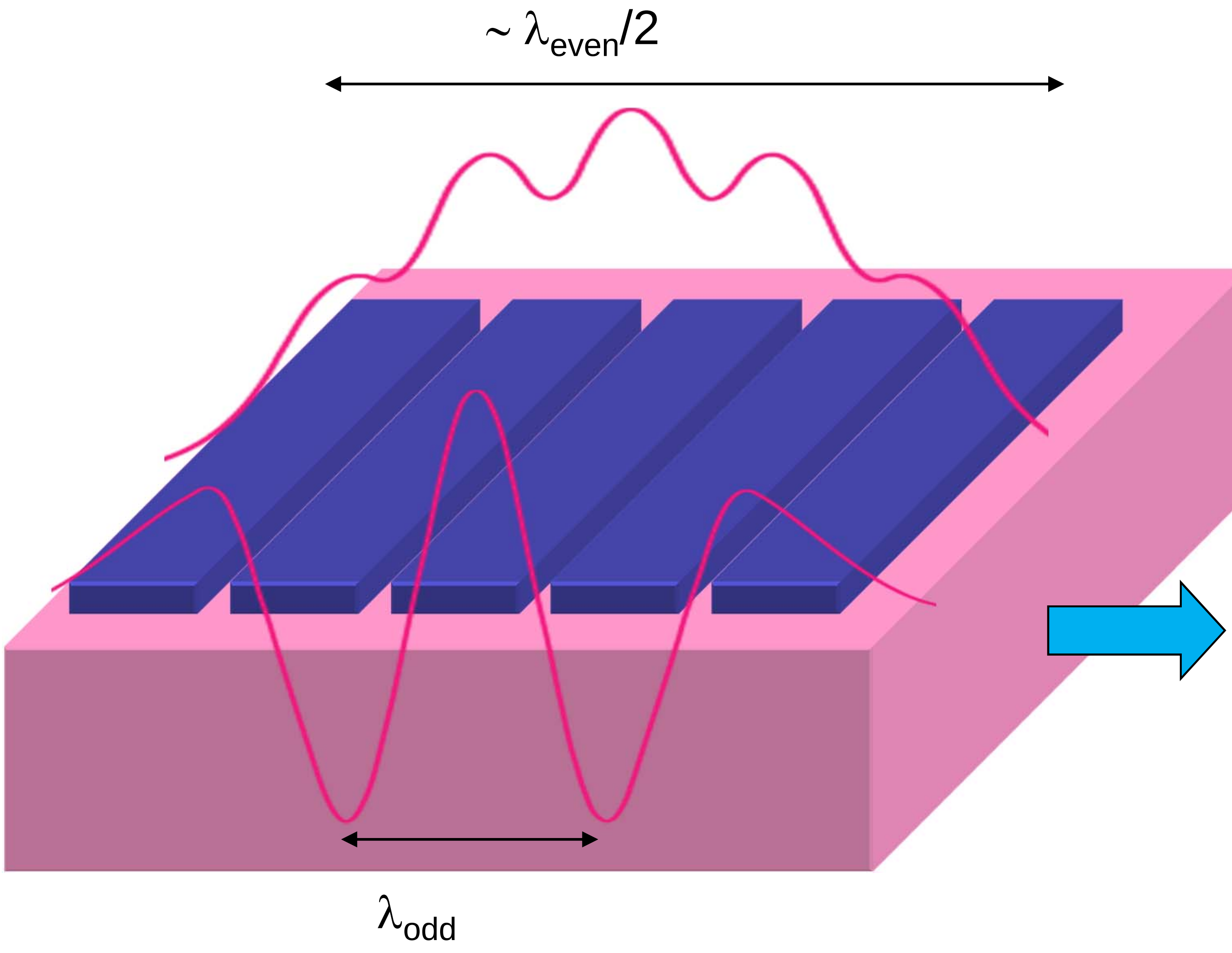
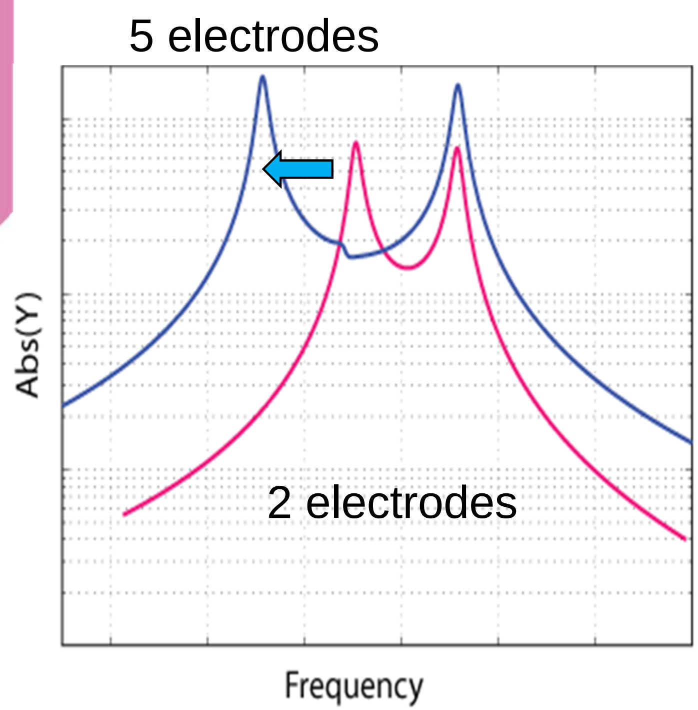
Laterally coupled BAW filter – wider bandwidth devices

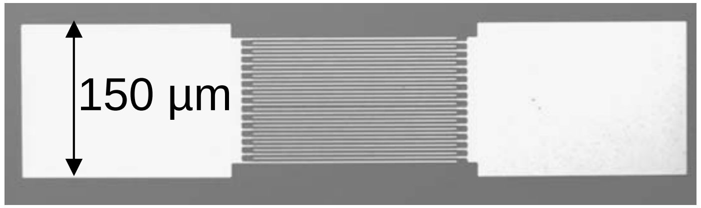




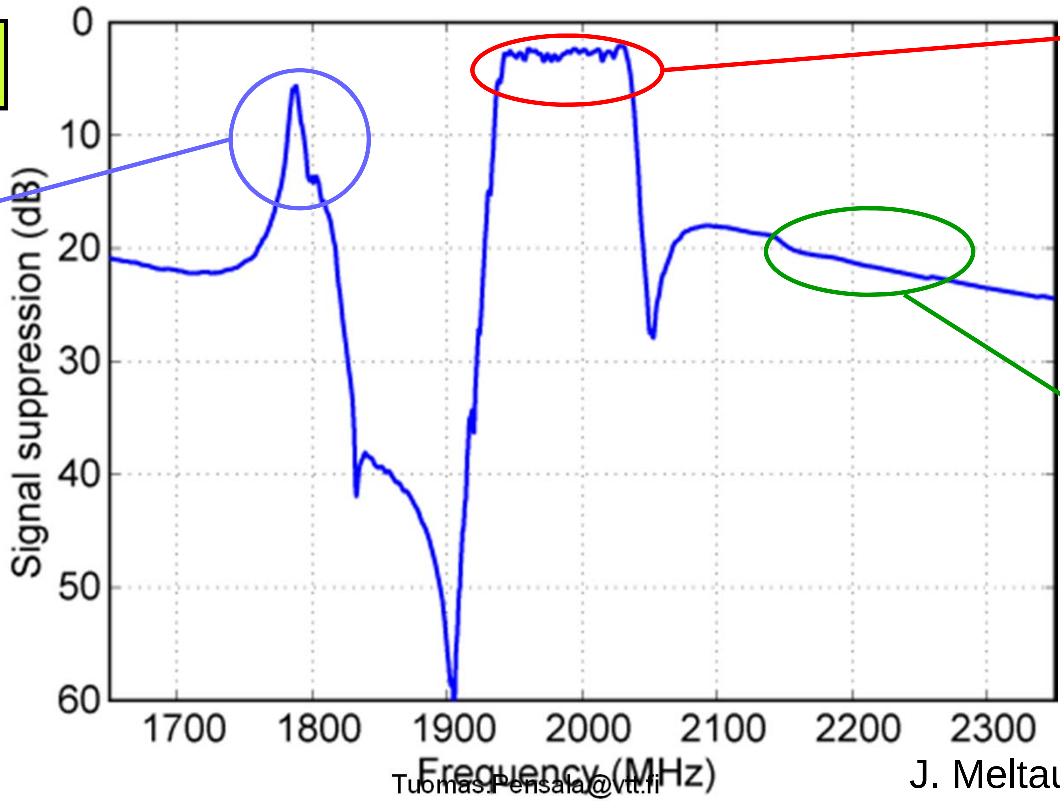
31 finger LBAW filter, matched response

W=3 µm
G=2 µm
L=200 µm
N=31

120 Ω || 5 nH



Peak results from shear mode response



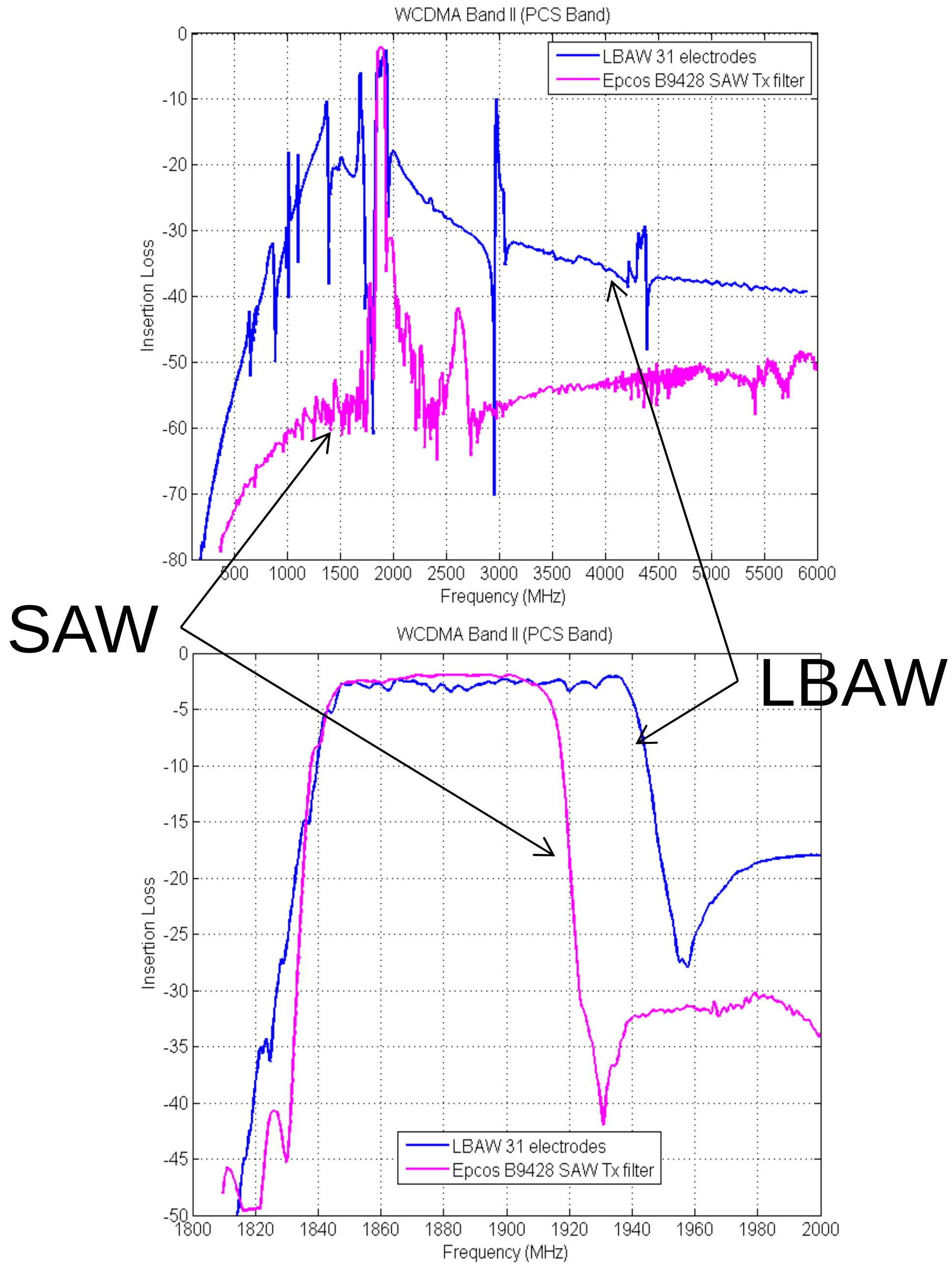
Min IL: 2 dB
f_0: 1950 MHz
Rel 3-dB BW: 4.9%

Suppression level: 20 dB
(note nonpatterned bottom electrode)

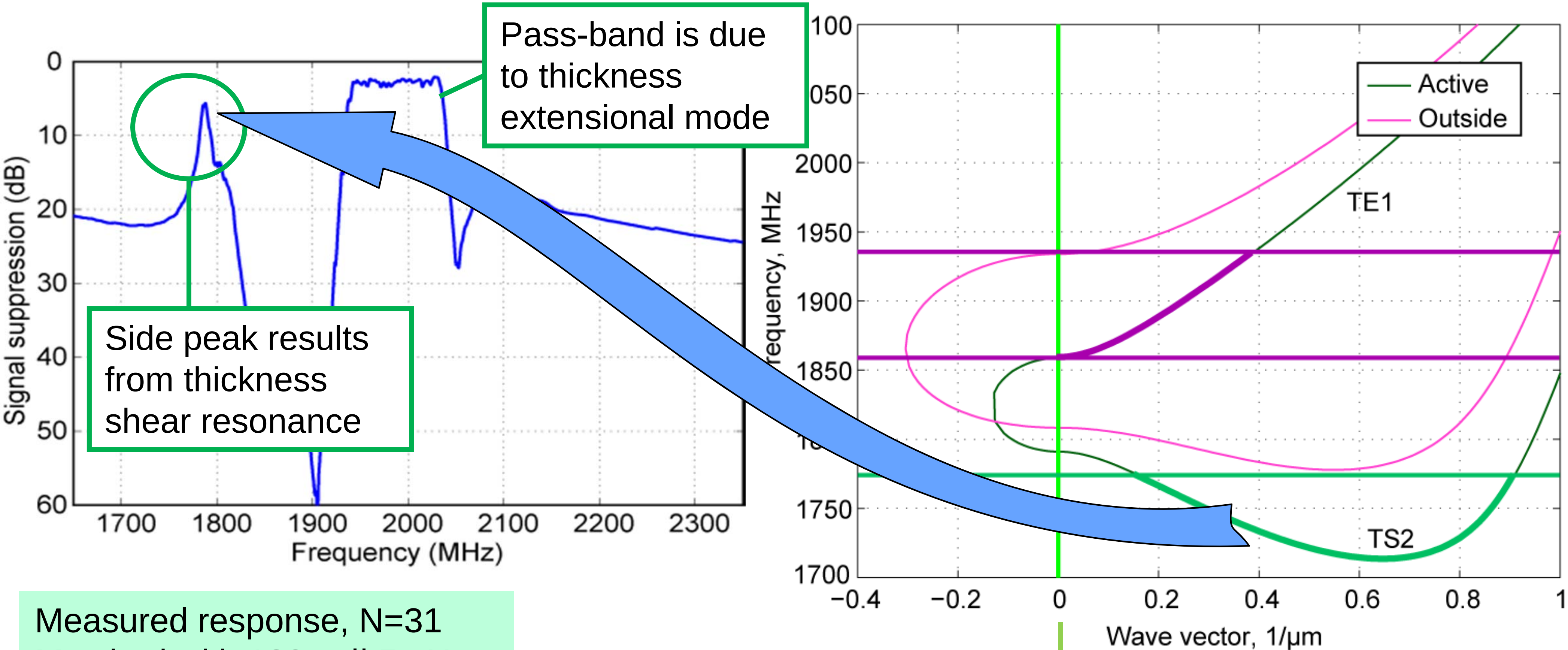
J. Meltaus, T. Pensala, IUS 2010

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

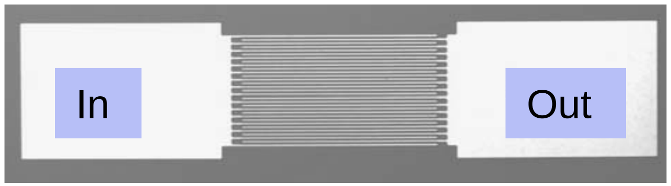


Wide band LBAW using two wave modes



Evanescent wave ← | → Propagating wave

Measured response, N=31
Matched with 120 Ω || 5 nH



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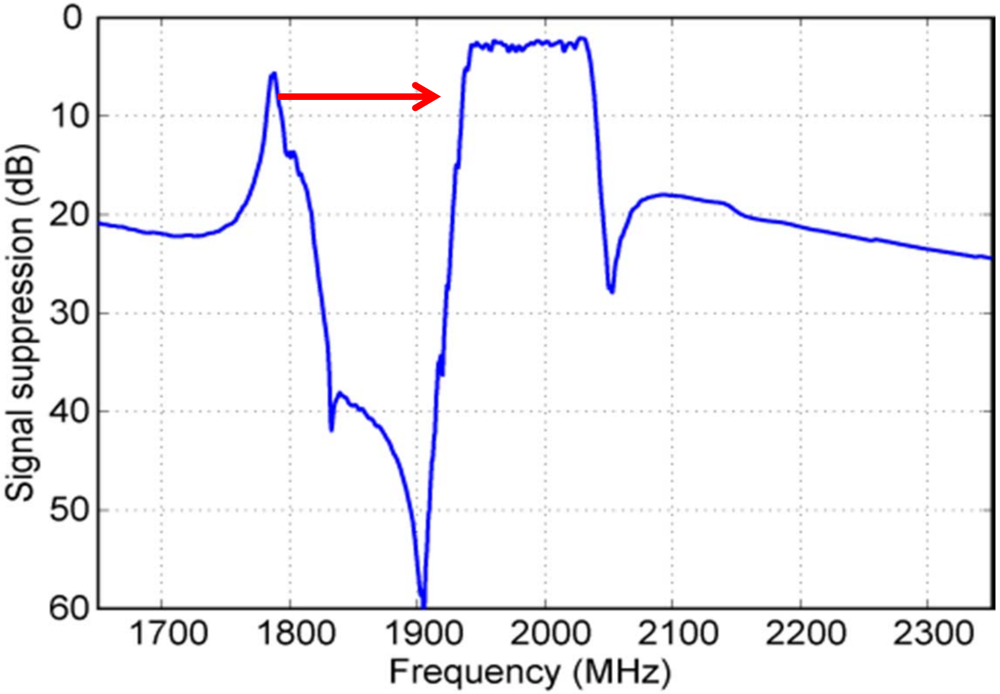
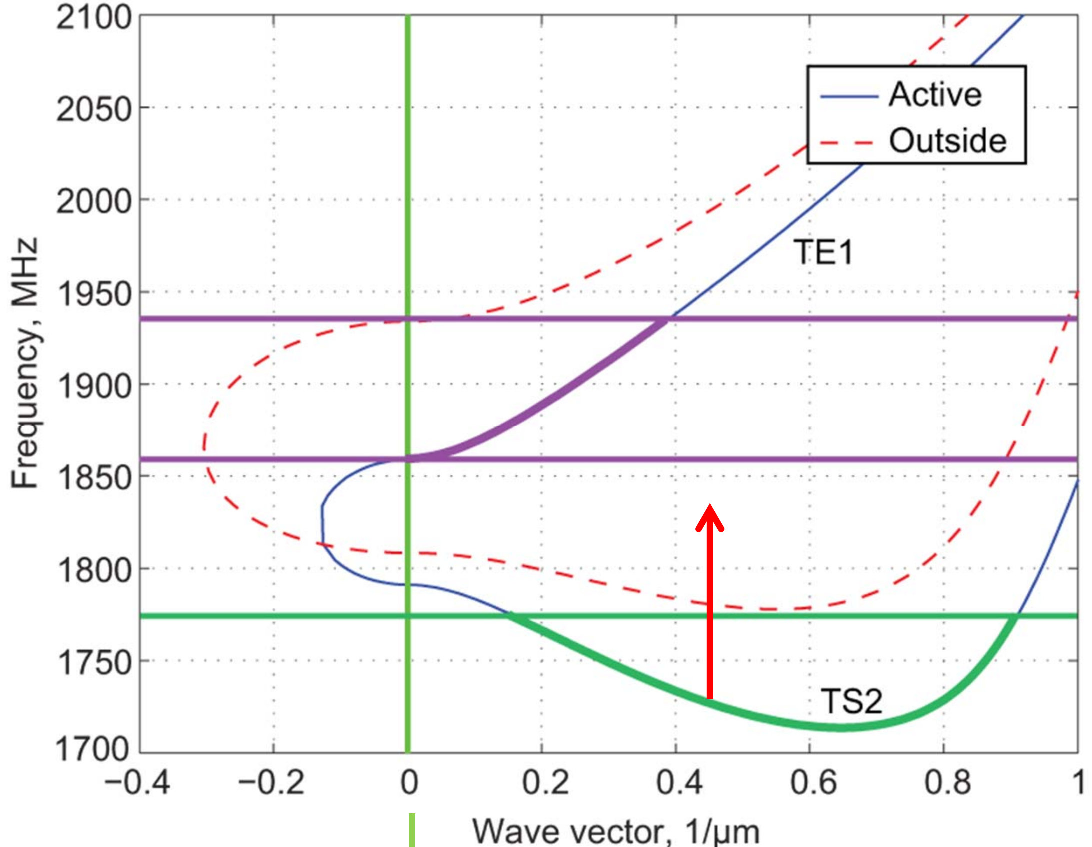
Can you merge the two modes by clever acoustic design of the devices?

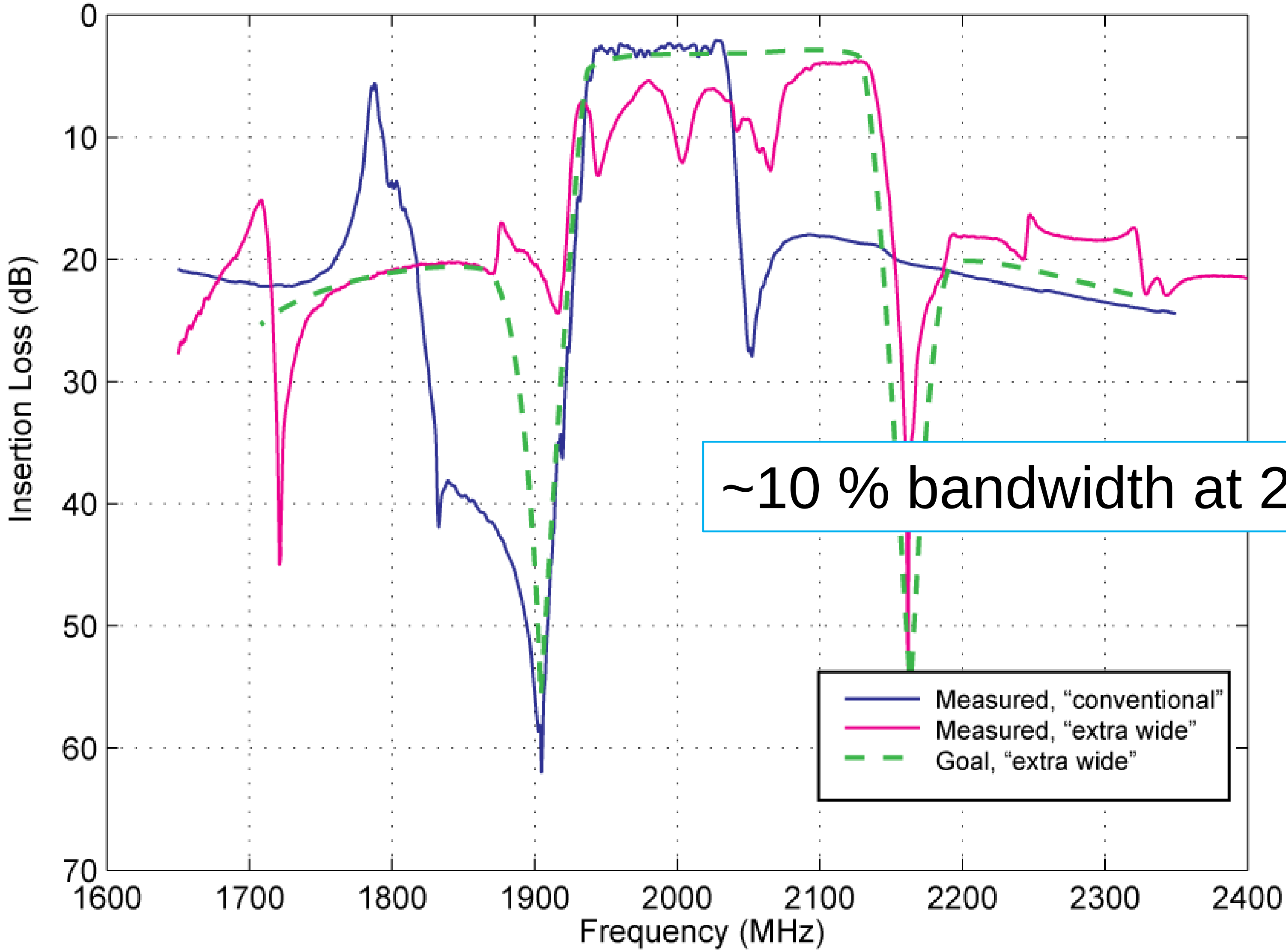




Move TS2 branch closer to TE1…

Evanescent wave ← | → Propagating wave

Yes: A two-mode wide band LBAW filter

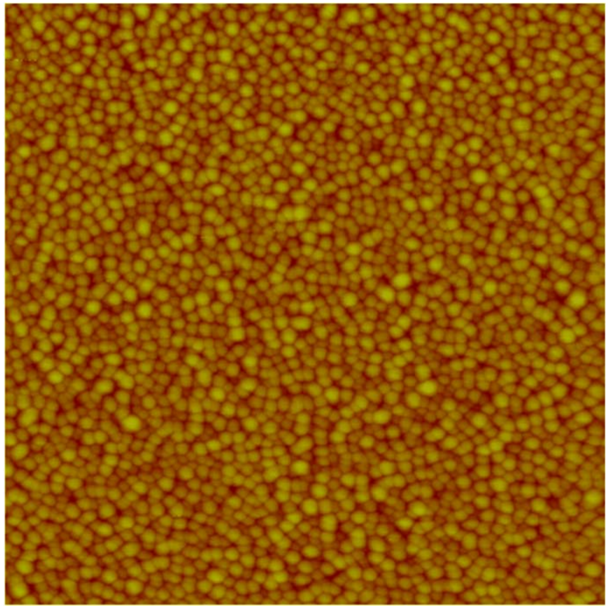


~10 % bandwidth at 2 GHz

ScAlN for BAW filters, microacoustics and MEMS

Sc doped AlN

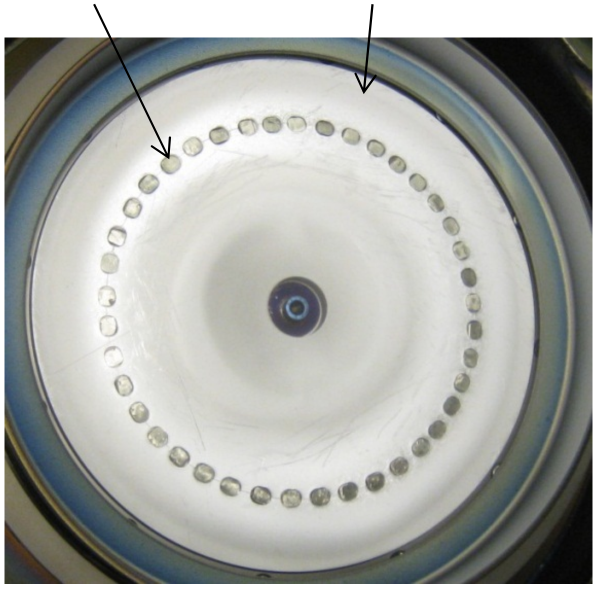
- Major limitation of AlN is the K^2 (and also high acoustic velocities)
- Addition of Sc into AlN [1]
  - Increases piezoelectric coefficients
  - Softens the material
  - Increases slightly permittivity
  - Electromechanical coupling K^2 boosted significantly



[1] Akiyama et al., ”Influenceof growth temperature and scandium concentration on piezoelectric response of scandium aluminium nitride alloy thin films”, Applied Physics Letters, (2009) p. 162107 .

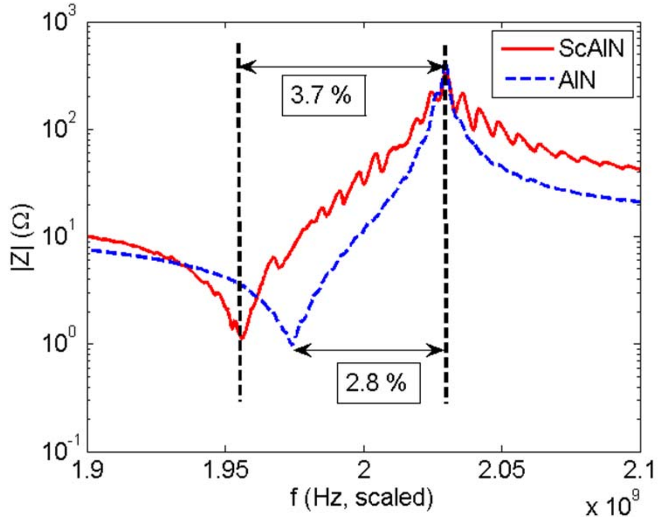
ScAlN sputtering

- 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



AlN & ScAlN BAW resonator characteristcs

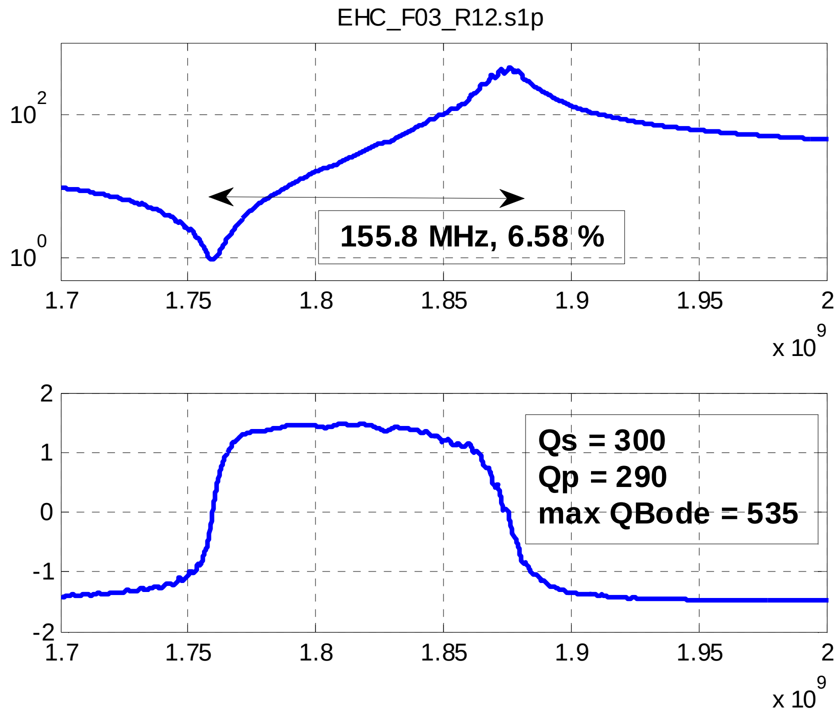
~6.5 at. % Sc



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

	k_{eff}	K^2 (%)
AlN	0,23	6,91
ScAlN	0,27	9,52

~13 at. % Sc



- **PZD = 6.58 %**
- **K^2_{IEEE} = 14.34 %**

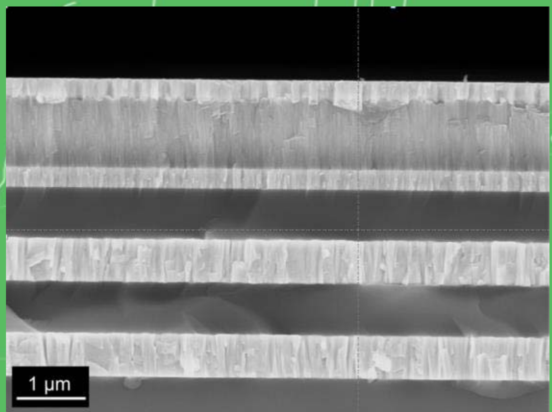
Implications to filters and MEMS

- 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

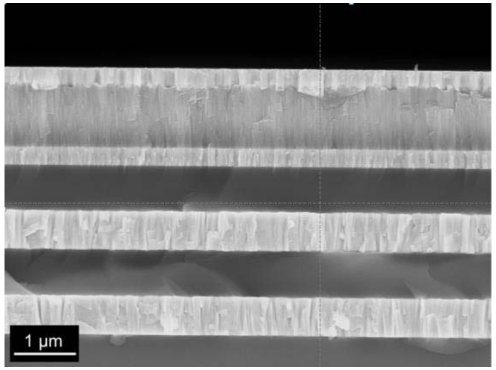
[2] Konno et al., ”ScAlN Lamb Wave Resonator in GHz Range Released by XeF_2 etching”, Proc. IEEE Ultrasonics Symposium, (2013).

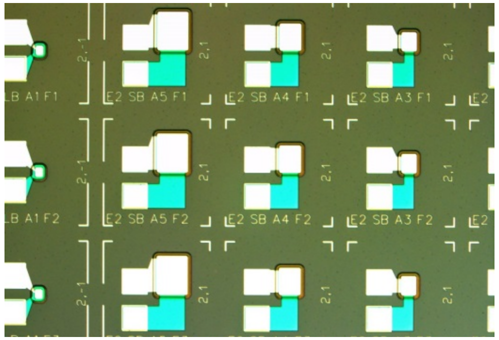
VTT BAW capabilities

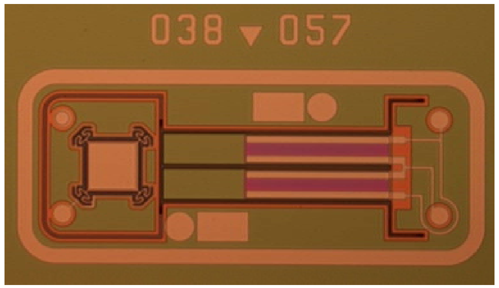


BAW, Piezo-MEMS processing capabilities at VTT

- 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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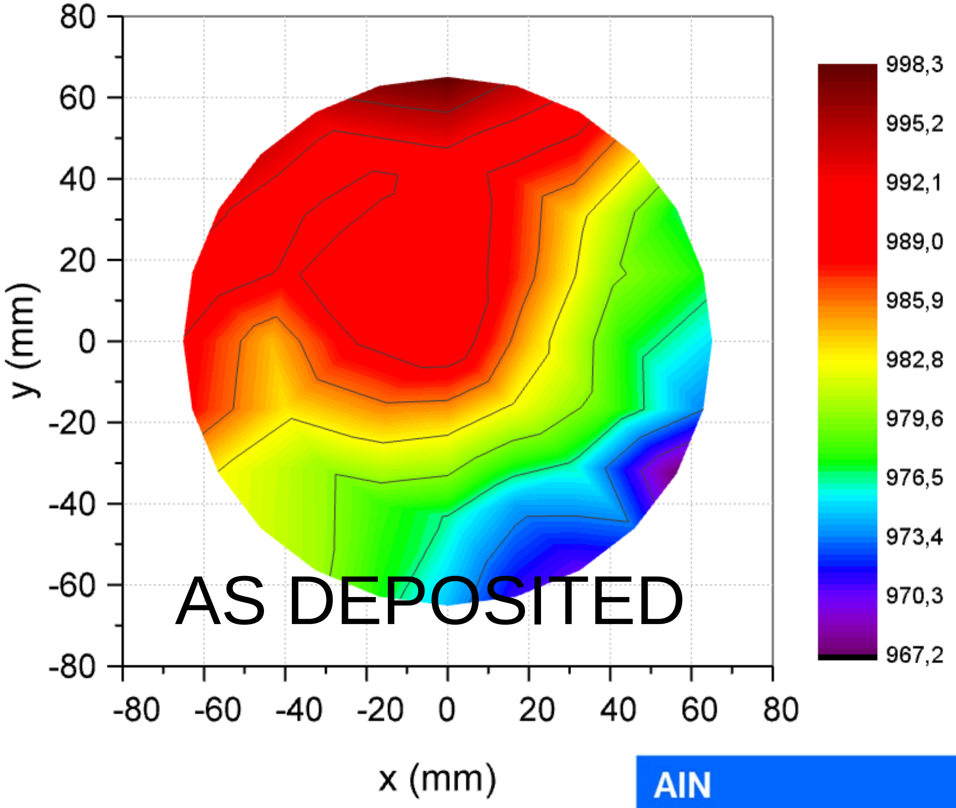
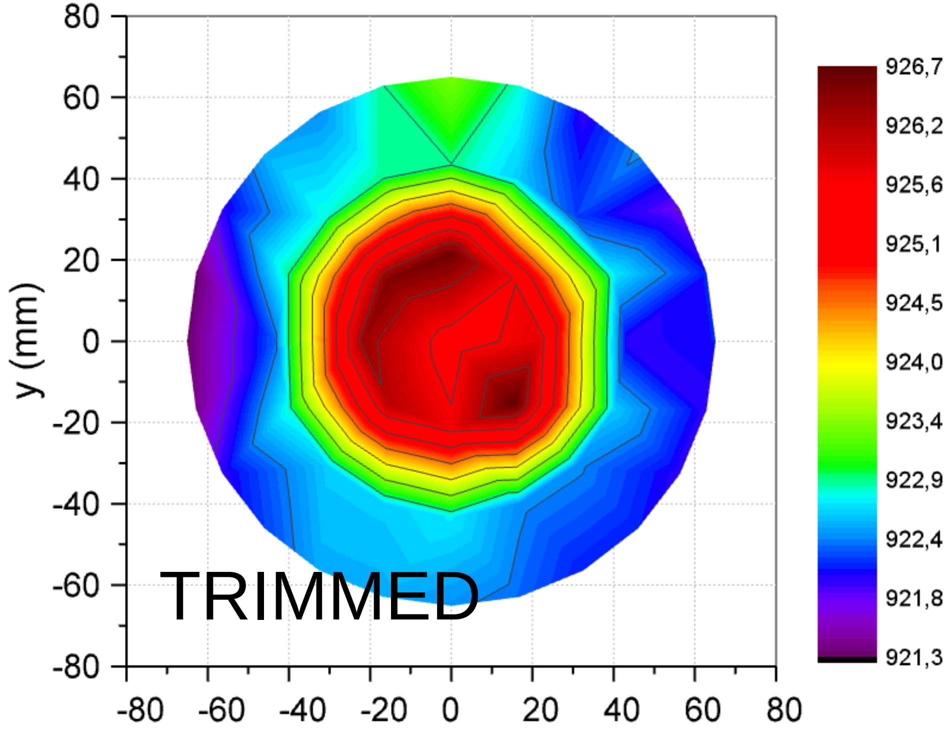
Ion Beam Trimming

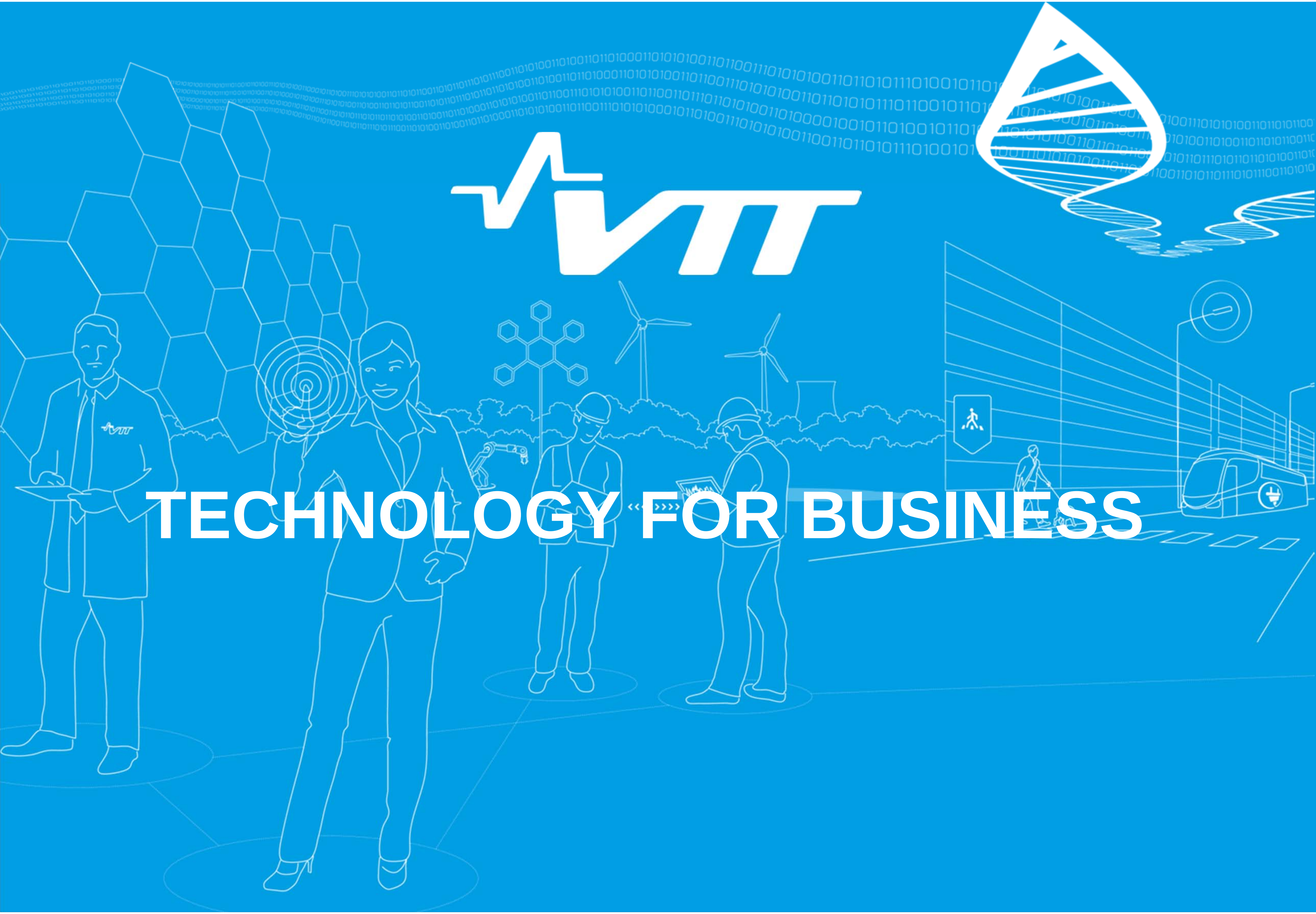




AIN	Pre-trimming	Trimmed
Max	998.3 nm	926.7 nm
Min	967.2 nm	921.3 nm
Average	983.6 nm	922.8 nm
Std. Dev.	7.5 nm	1.3 nm
Unif. (max-min)/max+min)	1.6 %	0.3 %

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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