Th01E-2

A Manufacturable AlScN Periodically Polarized Piezoelectric Film Bulk Acoustic Wave Resonator (AlScN P3F BAW) Operating in Overtone Mode at X and Ku Band

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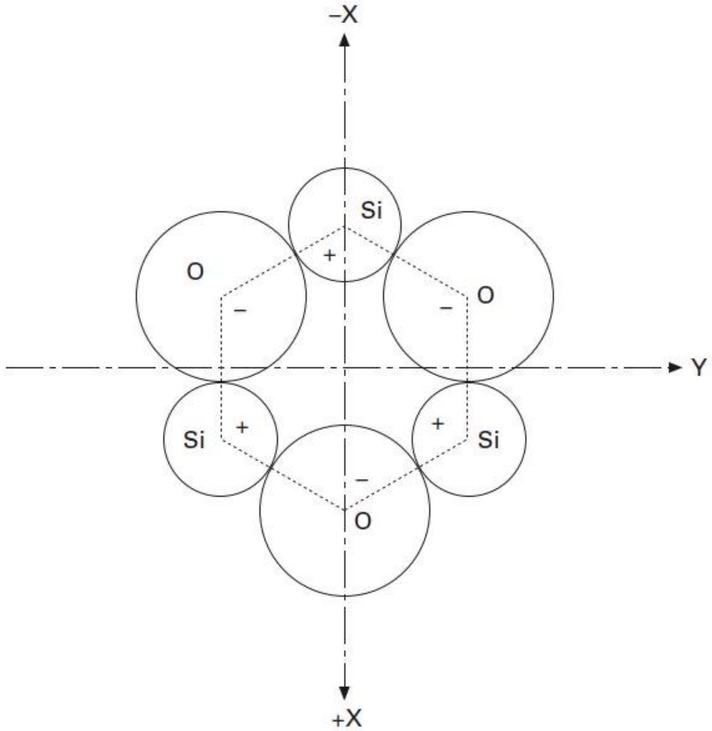
Outline

- Introduction/Motivation
  - BAW, XBAW
  - DARPA COFFEE
- P3F Technology
  - Concept, History
  - Approaches
- P3F Results
  - As-Grown P3F
- Outlook
  - SOTA
  - Applications

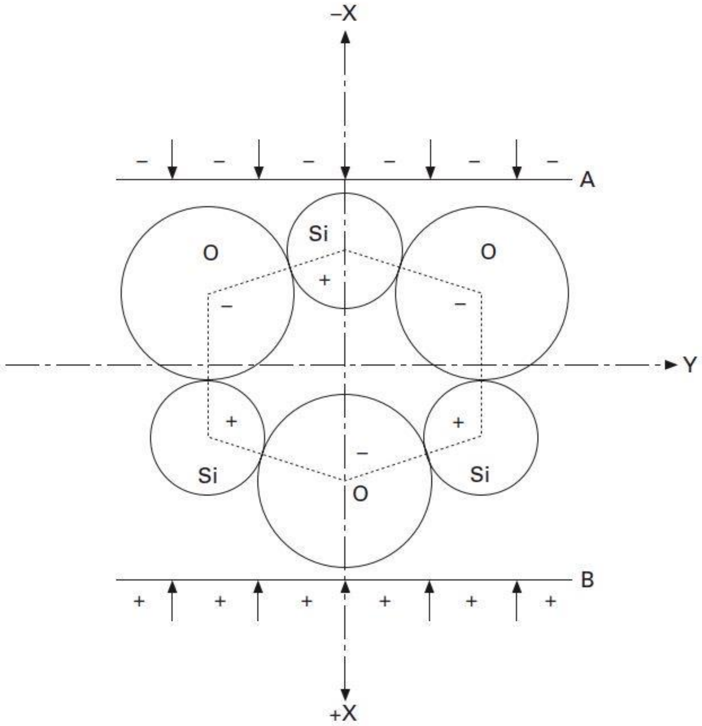
Piezoelectric Effect

- Electro-Mechanical Energy

Ex: Si and O atoms in quartz

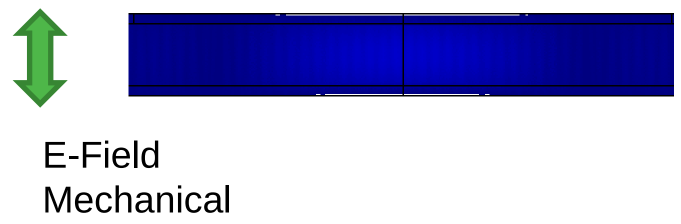


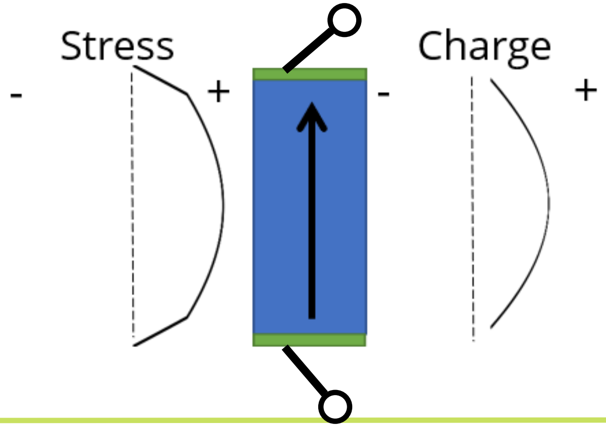
Stress/electric – direct longitudinal piezoelectricity

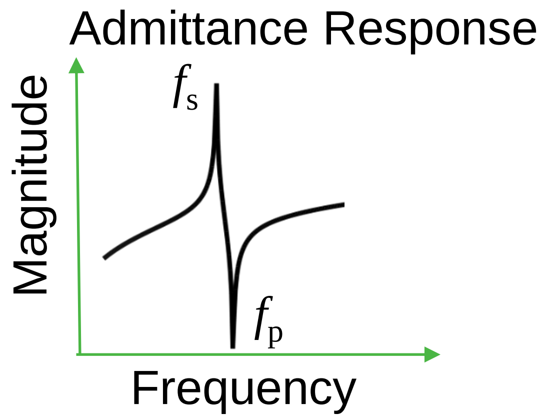


Kenji Uchino, "Advanced Piezoelectric Materials", Woodhead Publishing, 2010

Bulk Acoustic Wave

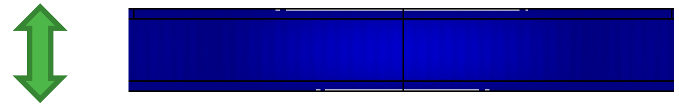




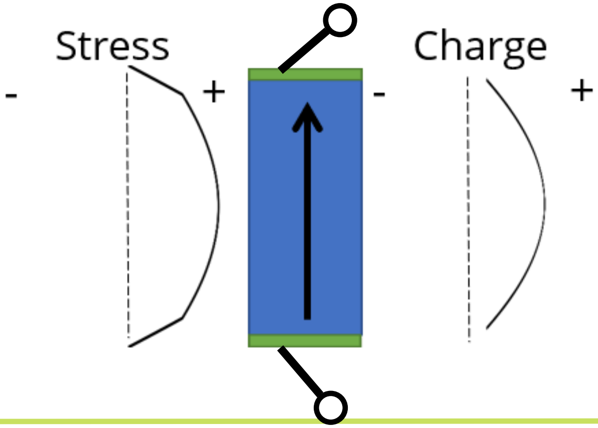


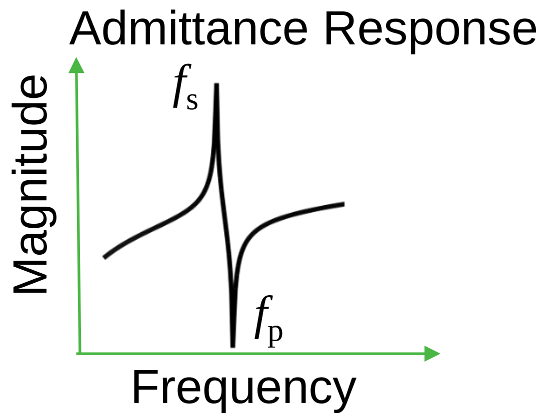
BAW

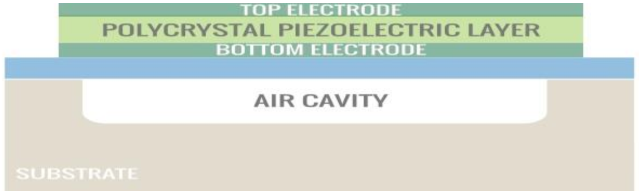
Bulk Acoustic Wave



E-Field
Mechanical



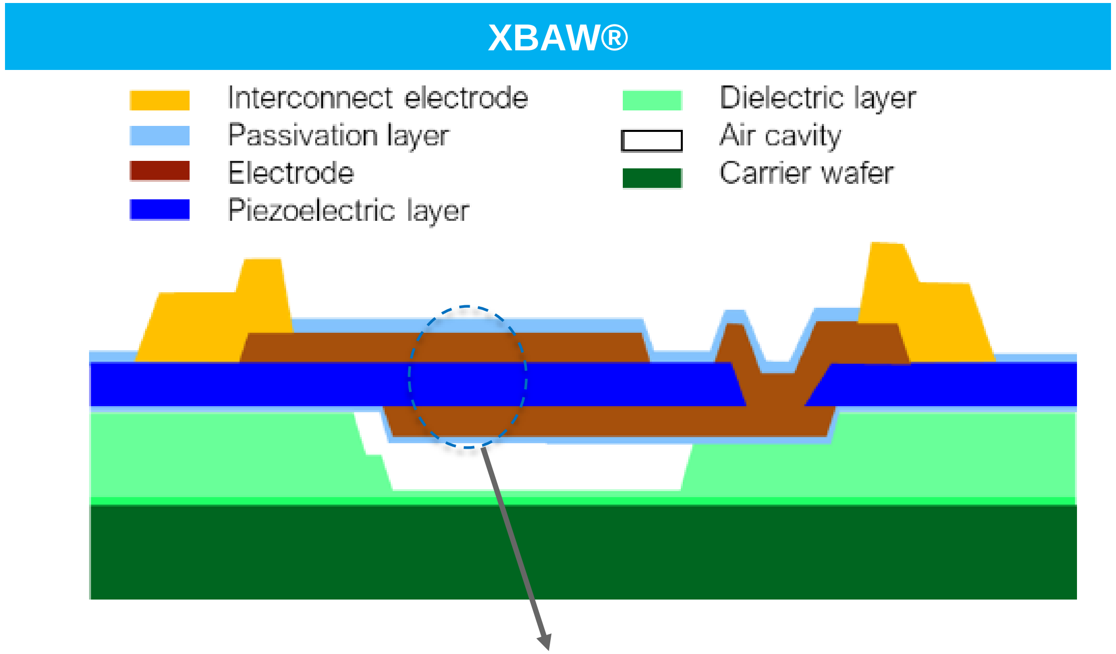


	Poly Solidly-Mounted Resonator (SMR)	Poly Film Bulk Acoustic Resonator (FBAR)	High Purity Bulk Acoustic Resonator (XBAW)
Structure			
Features	▪ 1 Air Interface	▪ 2 Air Interfaces	▪ 2 Air Interfaces ▪ 2-sided engineering ▪ Smooth & continuous piezoelectric ▪ Choose - single crystal / PVD ▪ Continuously selectable Sc% ▪ Initial growth layer removal

XBAW

XBAW

- Unique, patented transfer process
- Continuous and non-interrupted piezoelectric film
- Flexible materials
  - ➢ AlN
  - ➢ AlScN
    - High Sc % polycrystalline & single-crystalline
  - ➢ Initial Layer Removal
- Si substrate platform
  - ➢ 150 mm today
  - ➢ Scalable to 200 mm
- Bolt On Wafer Level Package



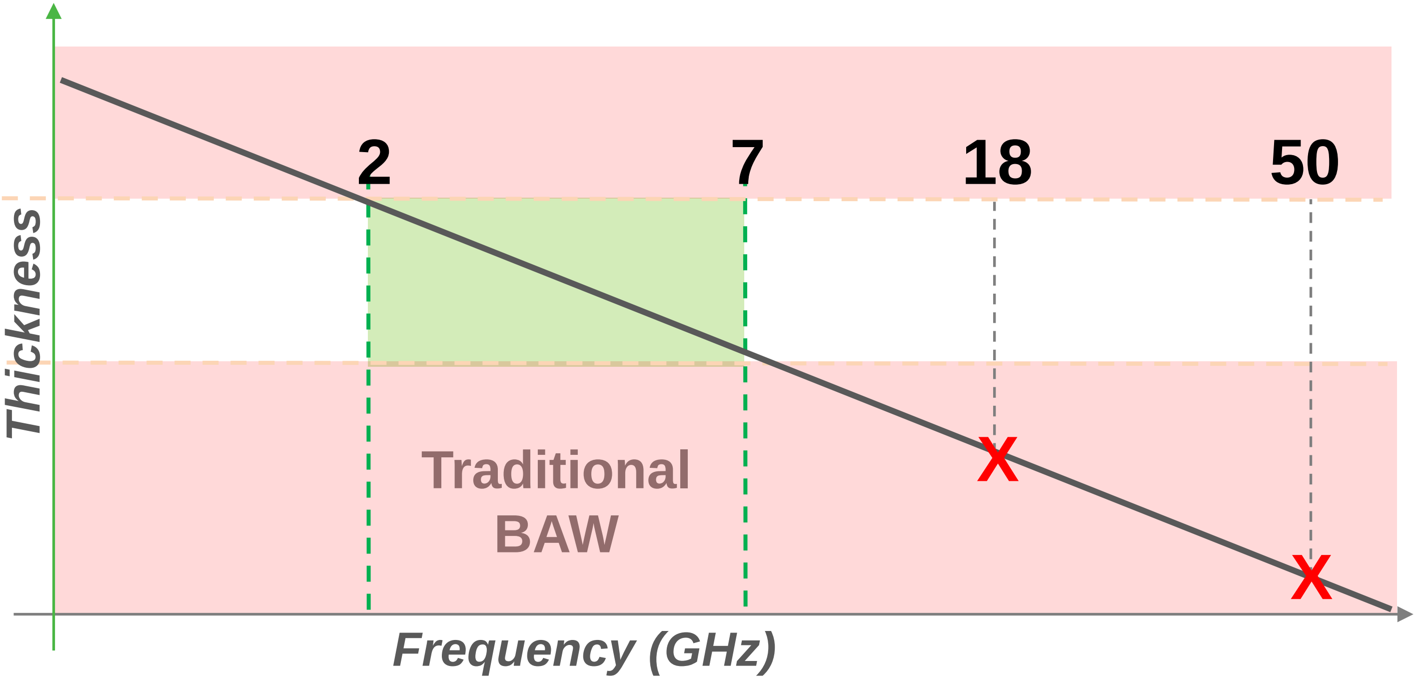
2 air interfaces, both sides engineered, smooth & uninterrupted PZ film
→ Enables High Q & High FOM

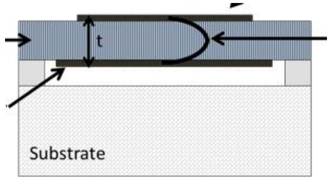
Why P3F ?

- Film Too THICK
- Process HARDER
- Area Too LARGE

Manufacturable BAW

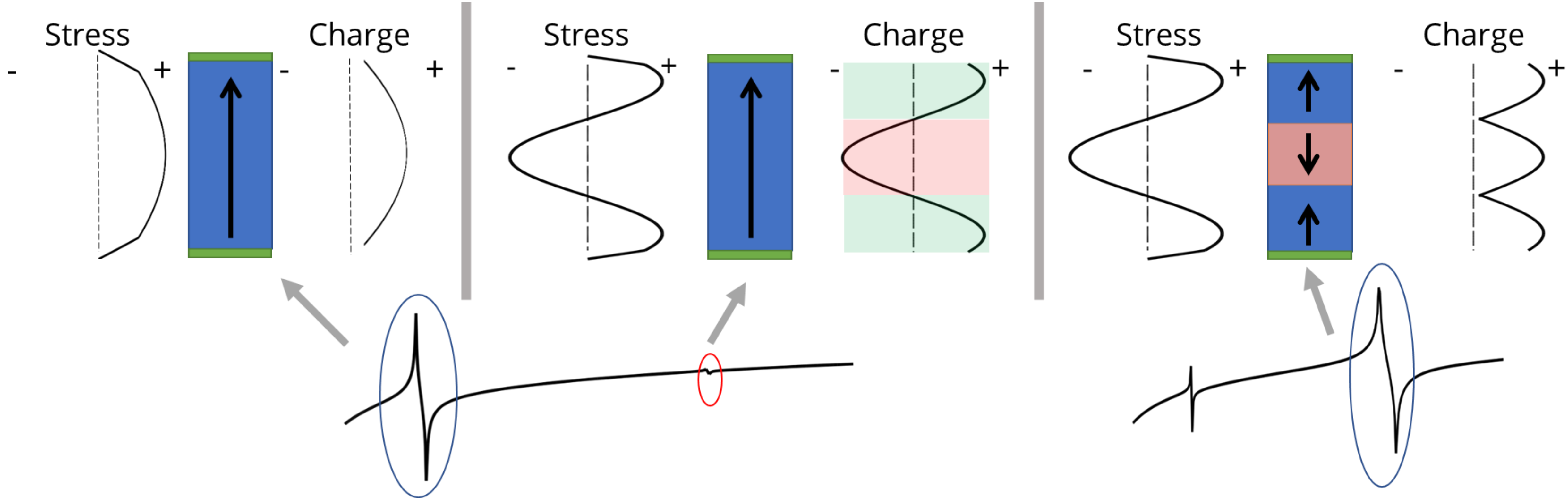
- Film Too THIN
- Res. Too SMALL
- Q, Power POOR





P3F

What is P3F ?



XBAW

First Reported P3F

- Z-cut Lithium Niobate
  - Heat treatment
  - Ti diffusion

1986 ULTRASONICS SYMPOSIUM — 719

PARTIAL DOMAIN INVERSION IN $LiNbO_3$ PLATES
AND ITS APPLICATIONS TO PIEZOELECTRIC DEVICES

Kiyoshi Nakamura, Haruyasu Ando and Hiroshi Shimizu

Department of Electrical Communications, faculty of Engineering
Tohoku University, Sendai, Japan

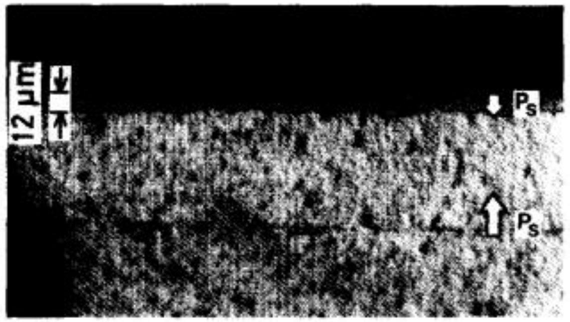
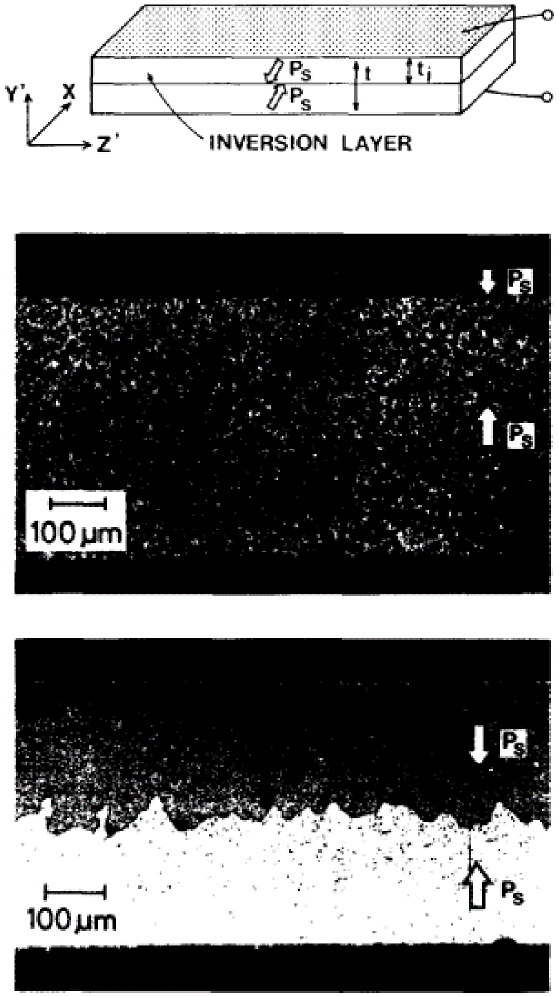


Fig.1 Etched cross section (-Y face) of a z-cut plate Ti-diffused at 1030°C for 5 h. The arrows indicate the sense of the spontaneus polarization Ps.



(a)

(b)

Fig.2 Etched cross section (+Y face) of z-cut plates heat-treated at 1110°C (a) for 4 h in Ar atmosphere and (b) for 5 h in air.

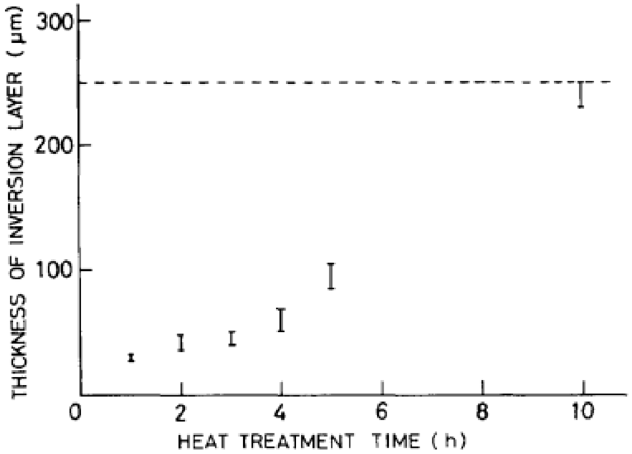


Fig.3 Thickness of the inversion layer in 500 μm thick z-cut plates heat-treated at 1110°C in air, as a function of treatment time.

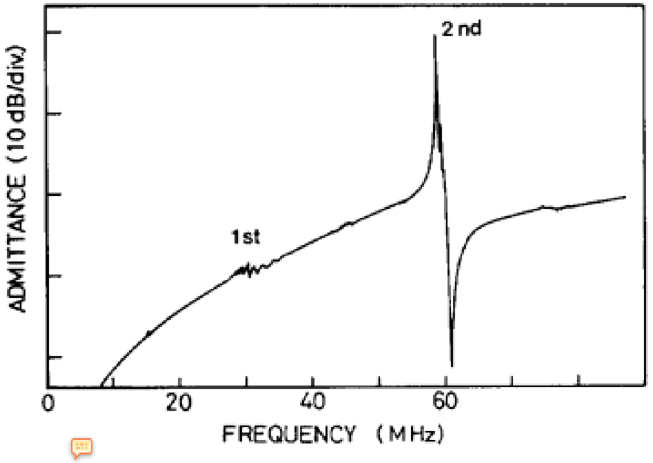


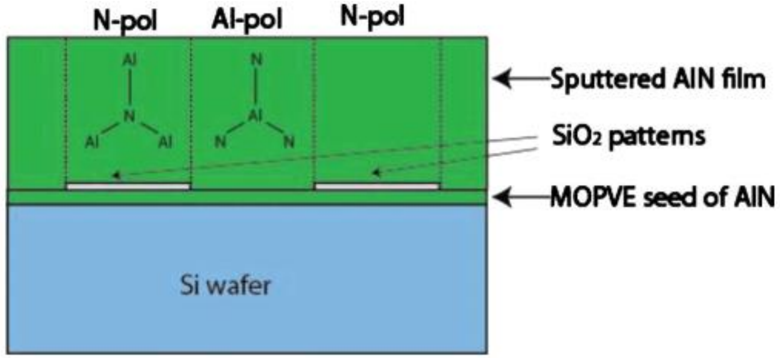
Fig.7 Measured admittance response of a Z-cut plate where the domain boundary is located near the median plane.

XBAW

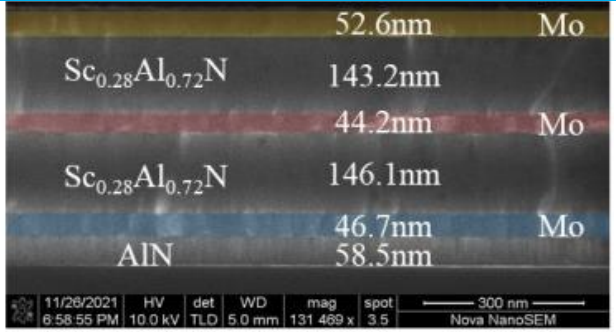
Approaches to realize P3F

- Oppositely polarized layers reported by several researchers
- Electrical Poling (Tabrizian, Olsson)
- Ion beam irradiation (Yanagitani),
- Al seed layer (Larson, Muralt)
- Doping (Akiyama)
- Bonding (Lu)

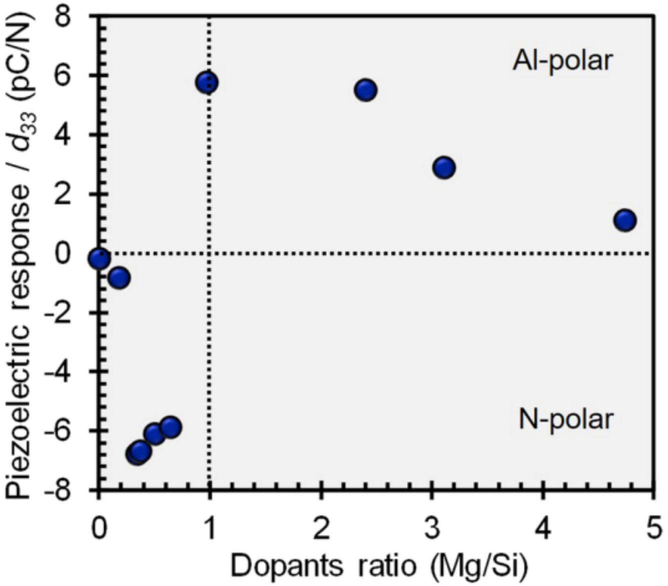
Seed Layer, Muralt, et al.



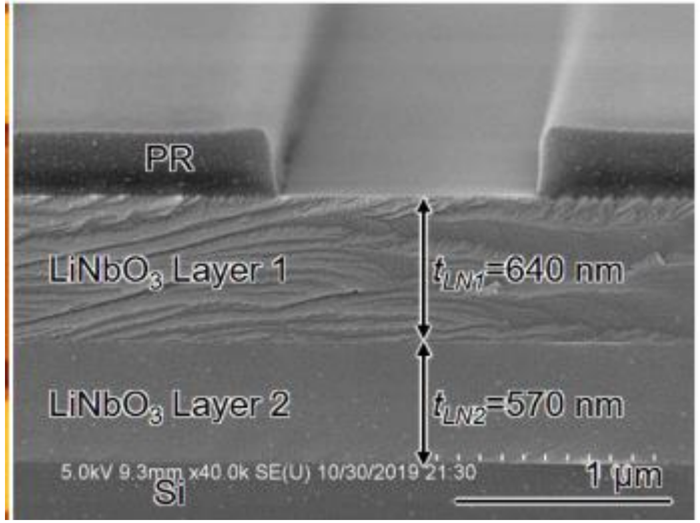
Electrical Poling, Tabrizian, et al.



Doping, Akiyama, et al.

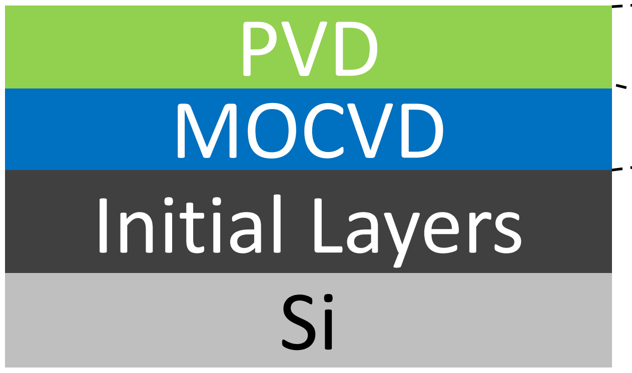


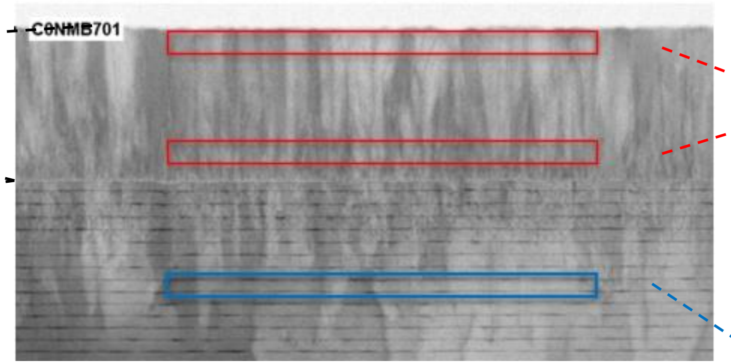
Bonding, Lu, et al.

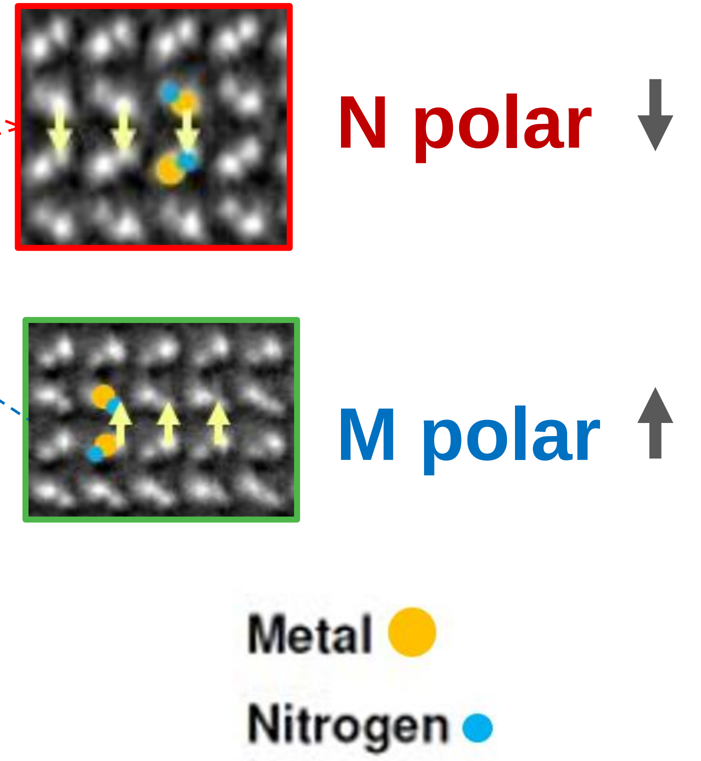


XBAW

Akoustis' As-Grown P3F







- ✓ TEM Data directly shows polarity inversion

iDPC TEM

Distribution Statement "A" (Approved for Public Release, Distribution Unlimited)

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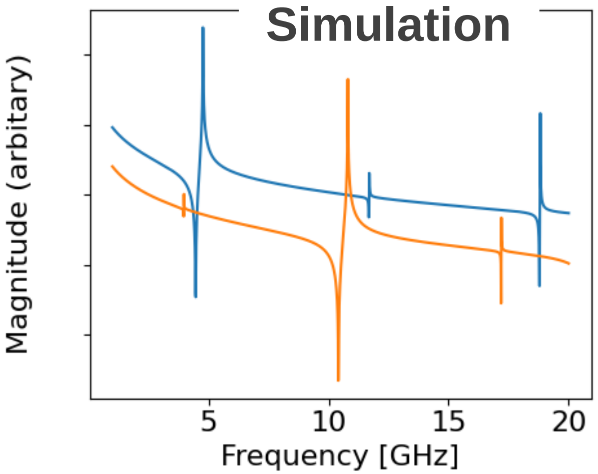
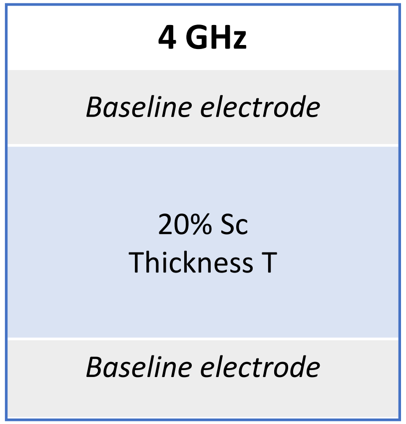
Akoustis' As-Grown P3F



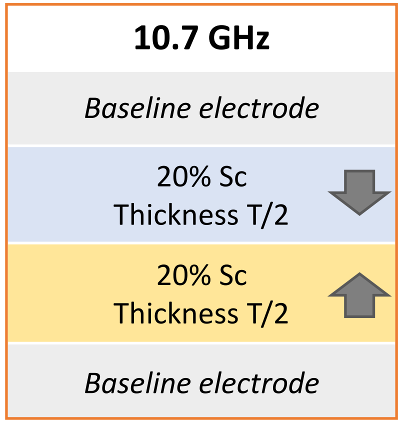
Baseline vs P3F

- Same total PZ thickness
- Same Electrodes
- Baseline Res. → 4GHz
- 2 Layer P3F Res → 10.7GHz

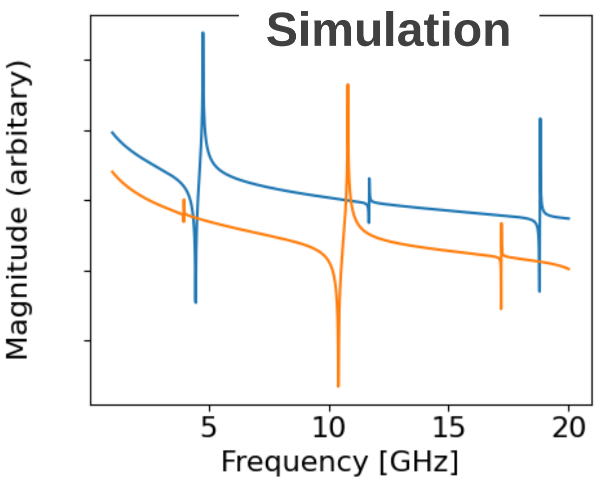
1-Layer Baseline



2-Layer P3F



✓ As-Grown P3F Proof of Concept



Baseline vs P3F

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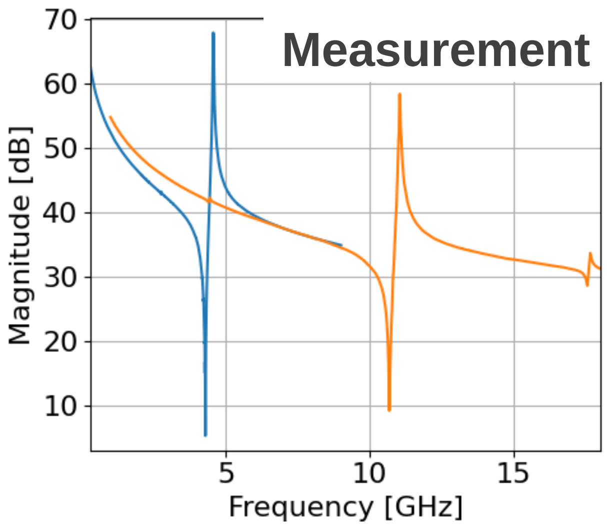


1-Layer Baseline

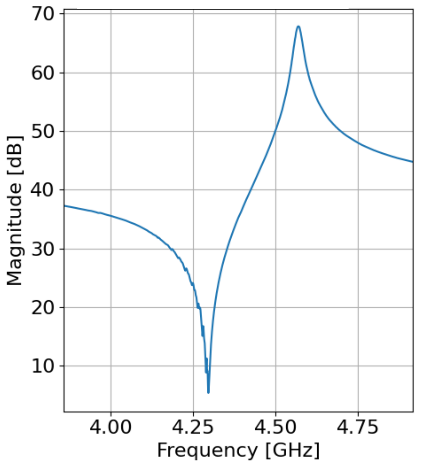
4 GHz

Baseline electrode

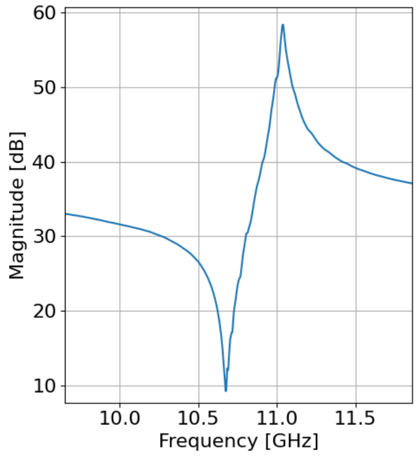
20% Sc
Thickness T

Baseline electrode

Meas. 4GHz



Meas. 10.7GHz



2-Layer P3F

10.7 GHz

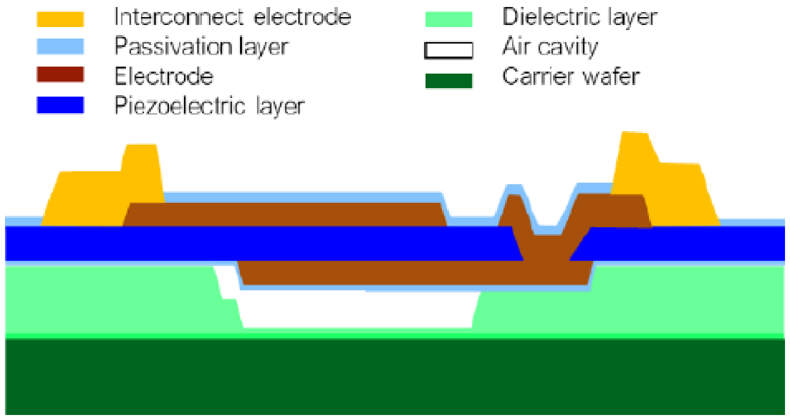
Baseline electrode

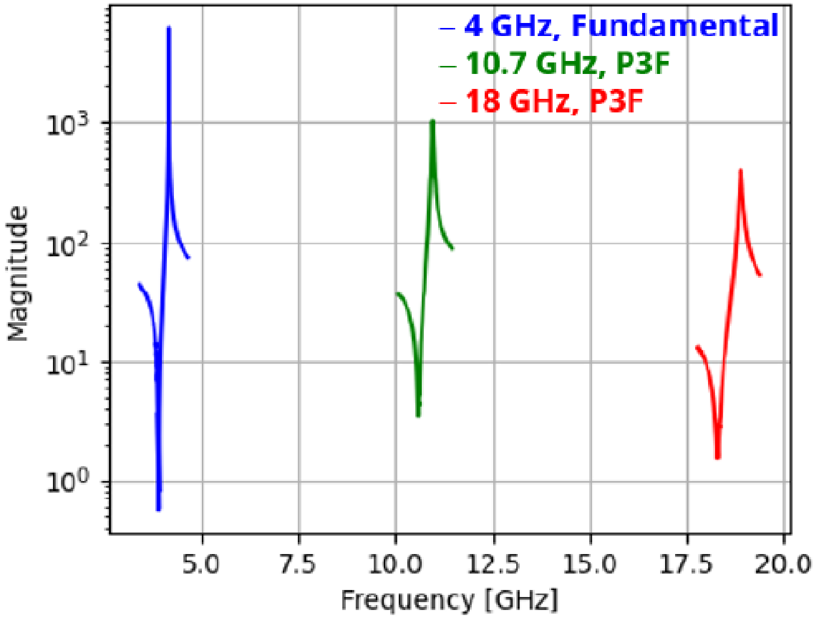
20% Sc
Thickness T/2 (↓)

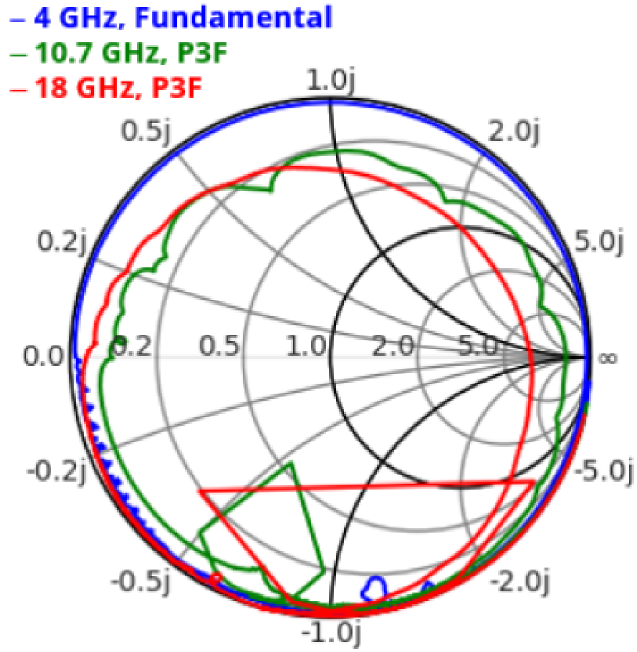
20% Sc
Thickness T/2 (↑)

Baseline electrode

✓ Akoustis' As-Grown P3F – 18GHz







✓ P3F Processed Just Like Baseline XBAW

✓ Proof Of Concept

✓ 18 GHz Demonstration

XBAW

P3F Benchmarking

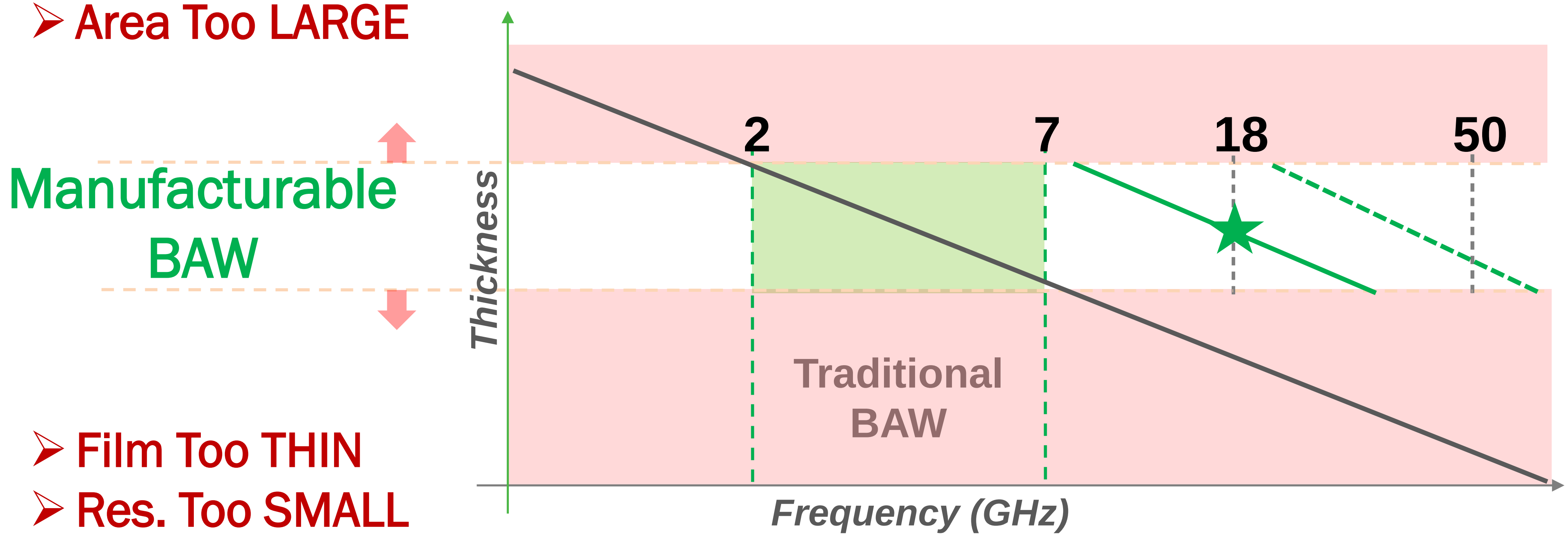
Table 1. Resonator performance summary and comparison with published works

Material	Freq. Scaling Approach (Realization)	f_s (GHz)	f_p (GHz)	k_t^2	Q_s	Q_p	FoM I $k_t^2 \times Q_p$	FoM II $k_t^2 \times Q_p \times f_p$	*Source*
32 % Sc-doped AlN	Traditional	3.61	3.94	19.00%	776	574	109	429	*[10]*
32 % Sc-doped AlN	Traditional	4.8	5.23	18.70%	545	630	118	617	
28 % Sc-doped AlN	No poling	7.04	7.32	10.10%	-	115	12	85	*[22]*
28 % Sc-doped AlN	Periodically Polarized (Electrically Poled)	13.4	13.97	10.70%	-	151	16	226	*[22]*
AlN	Overtone	33.4	33.9	1.70%	110	85	1.4	49	*[18]*
LiNbO3	Periodically Polarized (Bonded)	9.05	9.9	3.71%	-	636	24	234	*[19]*
20 % Sc-doped AlN	Traditional	4	4.25	13.80%	1271	909	125	533	*This work*
20 % Sc-doped AlN on 20% Sc-doped AlN	Periodically Polarized (As-Grown)	10.68	11.05	7.94%	150	342	27	300	
30% Sc-doped AlN on 20% Sc-doped AlN	Periodically Polarized (As-Grown)	18.4	19	7.55%	180	260	20	373	

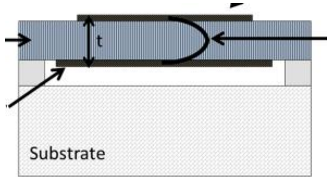
[Vetury, IMS'23]

✓ This is Why P3F

- Film Too THICK
- Process HARDER
- Area Too LARGE



- Film Too THIN
- Res. Too SMALL
- Q, Power POOR



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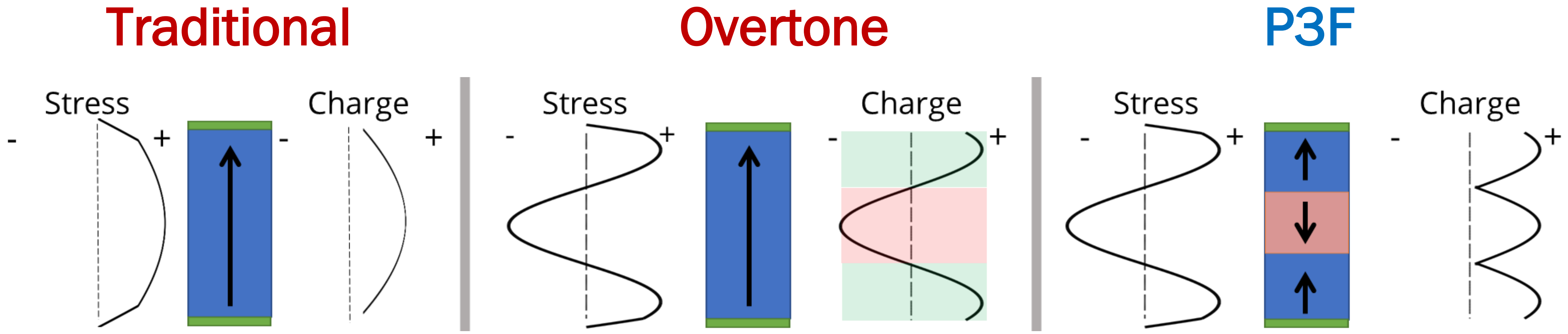
Akoustis Manufacturable P3F



- ✓ P3F - No charge cancellation → High Coupling
- ✓ P3F - Maintains thickness → High Power , Q , Linearity
- ✓ P3F - Easy Growth + Easy Process → Manufacturable
- ✓ P3F - 18GHz Resonators → Demonstrated

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Possible P3F Applications

Backhaul

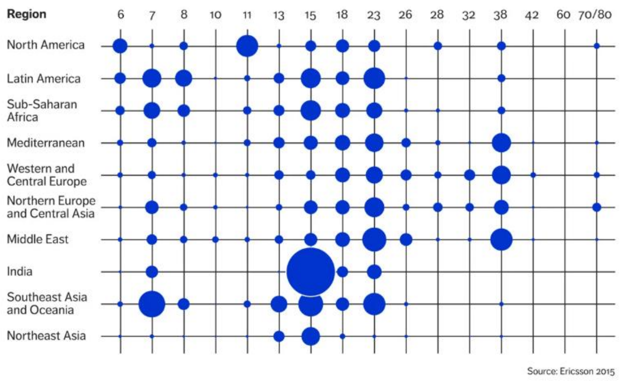
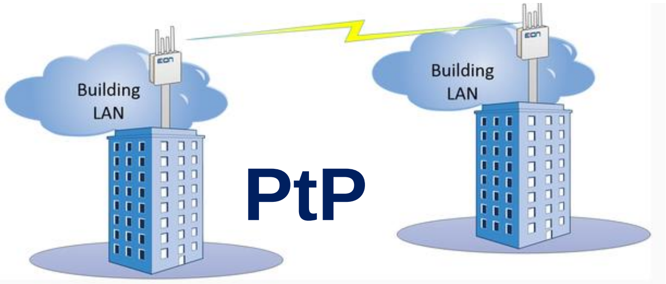


Figure 1: Global use of microwave backhaul

https://www.ericsson.com/en/reports-and-papers/ericsson-technology-review/articles/microwave-backhaul-gets-a-boost-with-multiband



https://www.wifimax.nz/point-to-point.html

XBAW

Summary

- We Need High Frequency Filters
- P3F Breaks Traditional Thickness-Frequency Trade-off
- Akoustis Developed A Manufacturable P3F Tech.
  - High FoM 18GHz Resonators Demonstrated
  - Low Loss 16GHz Filters Demonstrated