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Investigation of the limit operating temperature of $LiNbO_3$ as substrate for SAW devices

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Background, Motivation and Objective

- SAW sensors are very good candidates to face the challenges of measurements in **harsh high temperature** environments
  - → Wireless
  - → Battery-free
- $LiNbO_3$-based SAW Reflective Delay Lines (RDLs) operating up to 400°C have been on the market for more than ten years
- This temperature limitation is due to :
  - → Degradation of the electrodes
  - → Lithium triniobate ($LiNb_3O_8$) segregation
- In this study, we suggest to re-explore :
  - → The **segregation process** of congruent $LiNbO_3$ crystals (cLN)
  - → The **influence of the electrodes**' nature
  - → Their impact on the SAW devices' performances

Statement of Contribution/Methods

Step #1:

- 150nm-thick aluminum or platinum films
- **Y128 cLN** substrates
- Reflective delay lines (Fig.1) with connected interdigital transducers (IDTs) [1]
- Resonance frequency = 433 MHz

Step #2

- Annealing in air atmosphere → **48 hours** at various temperatures ranging from **400 to 700°C**
  - → **Electrically characterized**
  - → **X-ray diffraction** → Investigate the lithium triniobate ($LiNb_3O_8$) formation and the phase evolution of the metallic IDTs.

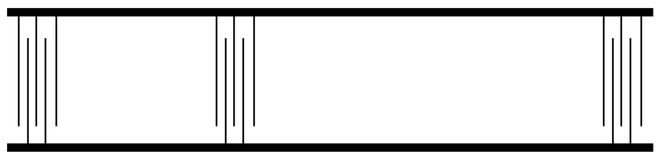

Figure 1: Reflective delay lines (RDL) with 3 connected IDTs design [1]

Results, Discussion and Conclusions

- Formation of $LiNb_3O_8$ observed after a 2-days annealing period at a temperature of 500°C (Fig.2).
- $LiNbO_3$ peak is not affected by the annealing process.
- Segregation kinetics depends on :
  - → **<u>The annealing temperature</u>**
  - → **<u>The nature of the electrodes</u>**.

➢ *Aluminum electrodes*

- Annealing at 400°C has almost no destructive effect on the device response (Fig.3). Whereas from 500°C onwards → Degradation due to :
  - → Alumina (Al_2O_3) formation
  - → **Dewetting effect**
- Annealing at 600°C :
  - → Irreversible **frequency shift**
  - → Strong **visual degradation** of the electrodes
- Limit for aluminum IDTs → Between 400 and 500°C for an operation period for several days

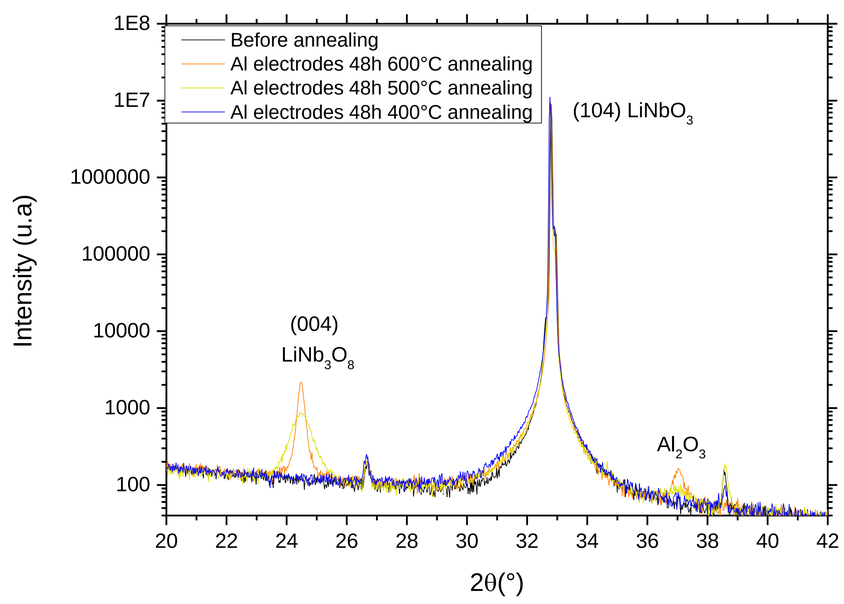

Figure 2 : X-ray diagram of LN Y-128, before and after annealing with and without Al IDTs on the top.

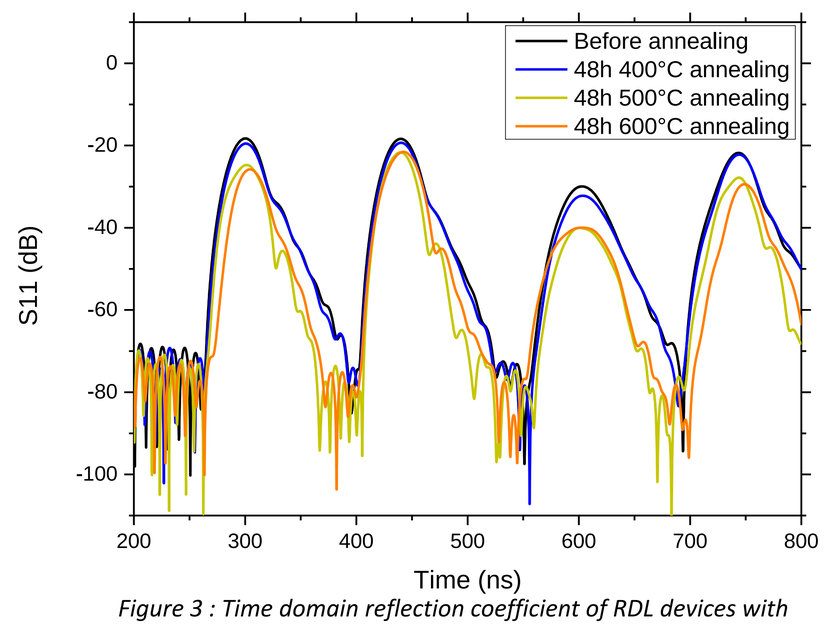

Figure 3 : Time domain reflection coefficient of RDL devices with aluminium IDTs

➢ *Platinum electrodes*

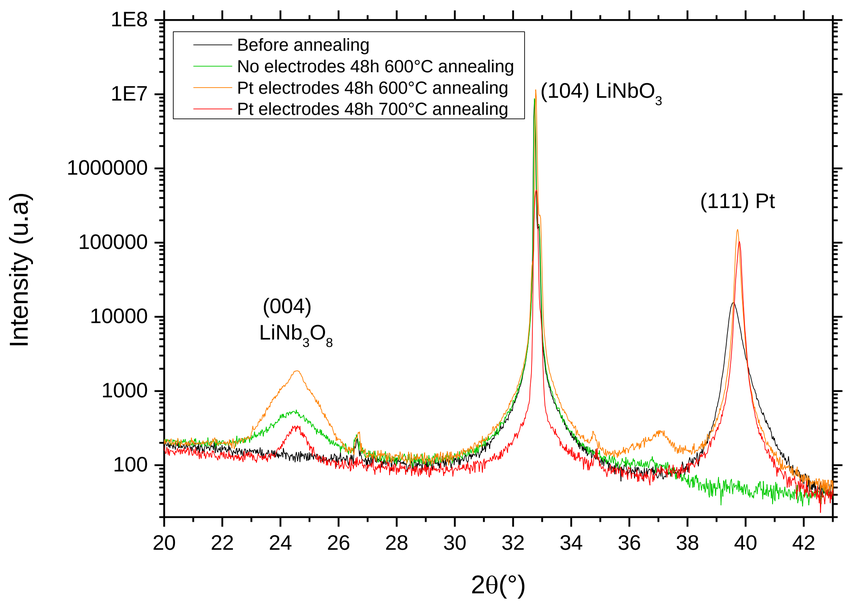

Figure 4 : X-ray diagram of LN Y-128, before and after annealing with and without Pt IDTs on the top.

- Aluminum-like $LiNb_3O_8$ formation kinetics for platinum
- $LiNb_3O_8$ less crystallized for the same annealing period (Fig.4)
- Increase in annealing time → $LiNb_3O_8$ more crystallized
- $LiNb_3O_8$ formation reaches a limit even with **extension of the annealing time or temperature**
- After a 48-hours annealing process at 600°C (Fig.5)
  - → Time domain response is not degraded
  - → Even improved → **Platinum IDTs recrystallization** (Fig.4).

- New horizons are possible regarding the use of $LiNbO_3$ for high-temperature applications up to 600°C
- Aluminum electrodes are a good alternative for medium lifetime devices up to 400°C
- Devices with platinum IDTs look stable up to 600°C
- Theses deductions were made with devices designed at 433MHz
  - → For higher frequencies, platinum electrodes would be less performant
- In order to push back the limits of cLN-based high-temperature SAW sensors, we need to find an innovative solution in terms of electrodes' nature:
  - → Need to withstand high temperatures without too many physical transformations and ionic exchanges with the substrate
  - → Need to have a low density

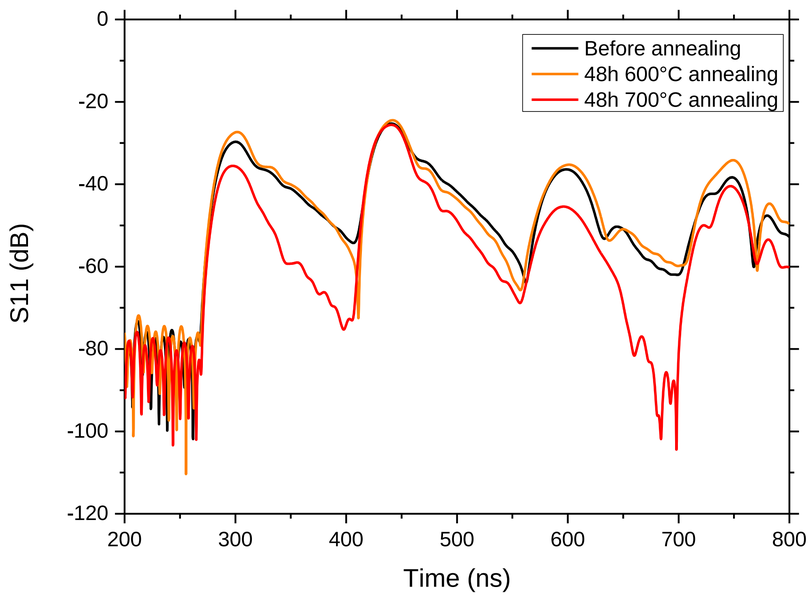

Figure 5 : Time domain reflection coefficient of RDL devices with platinum IDTs

[1] C. Floer *et al.*, *IEEE Trans. Ultrason., Ferroelect., Freq. Contr.*, 2019