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Investigation of the limit operating temperature of LiNbO₃ 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
- LiNbO₃-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 (LiNb₃O₈) segregation
- In this study, we suggest to re-explore :
 - The **segregation process** of congruent LiNbO₃ 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 (LiNb₃O₈) formation and the phase evolution of the metallic IDTs.

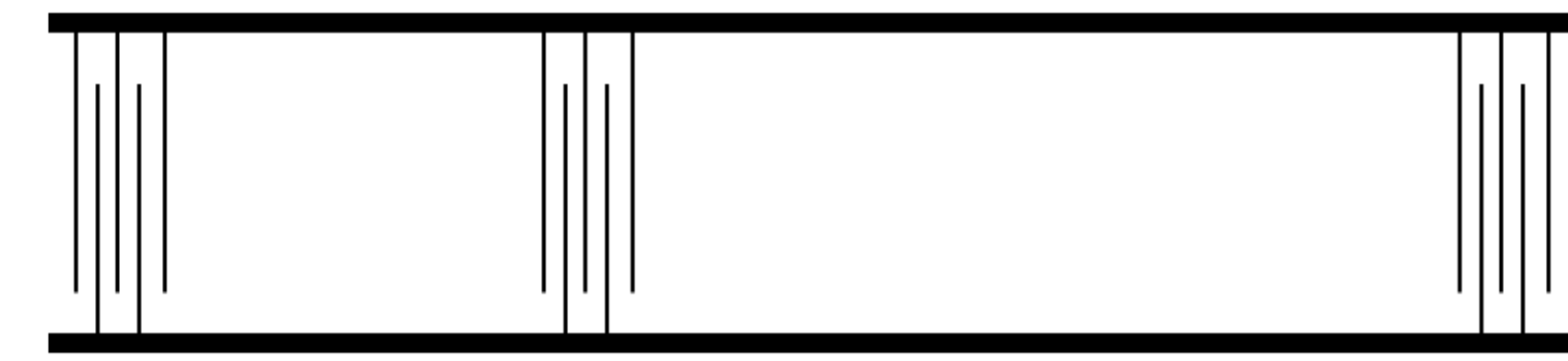


Figure 1: Reflective delay lines (RDL) with 3 connected IDTs design [1]

Results, Discussion and Conclusions

- Formation of LiNb₃O₈ observed after a 2-days annealing period at a temperature of 500°C (Fig.2).
- LiNbO₃ peak is not affected by the annealing process.

- Segregation kinetics depends on :
 - **The annealing temperature**
 - **The nature of the electrodes.**

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 (Al₂O₃) 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

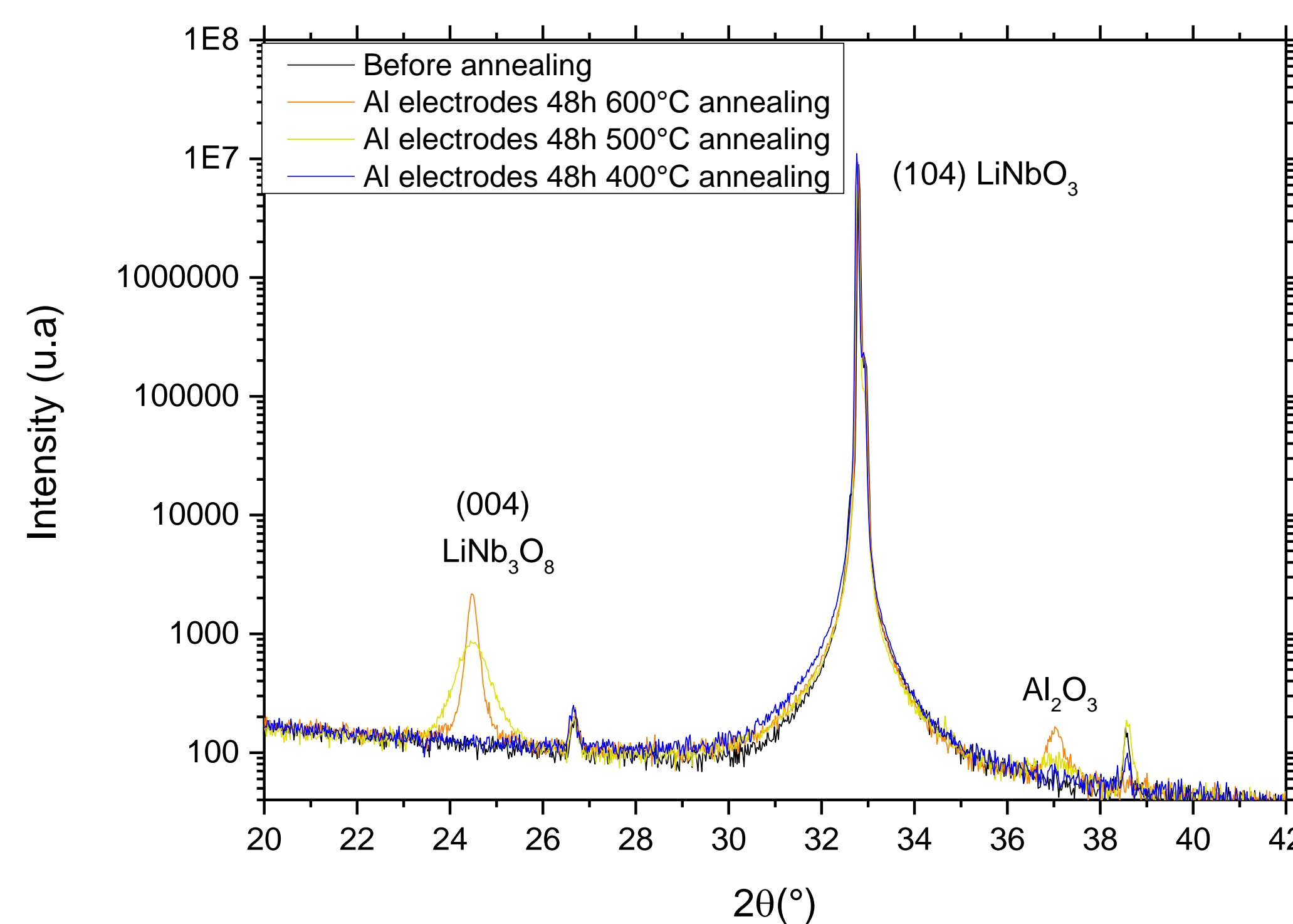


Figure 2 : X-ray diagram of LN Y-128, before and after annealing with and without Al IDTs on the top.

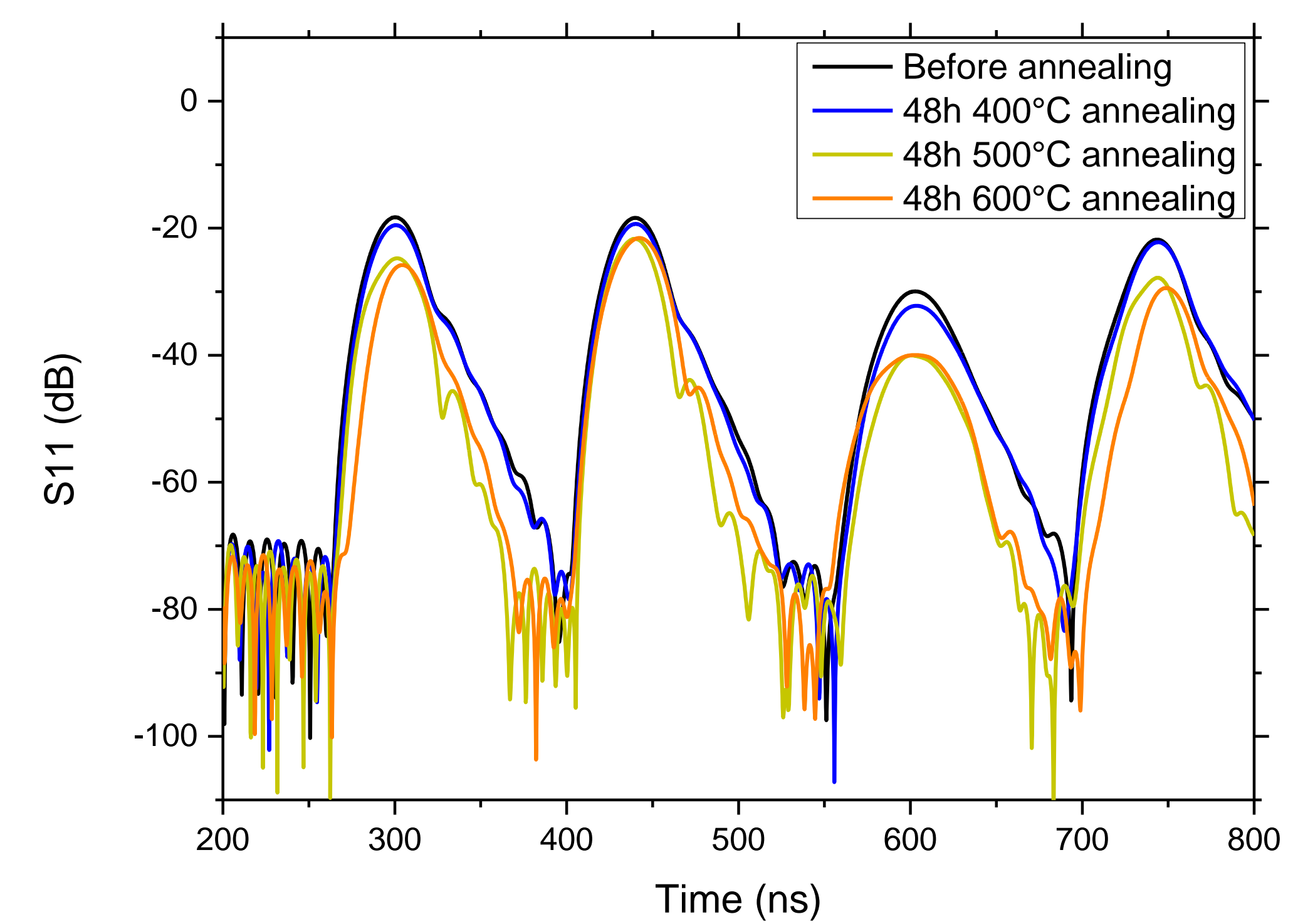


Figure 3 : Time domain reflection coefficient of RDL devices with aluminium IDTs

Platinum electrodes

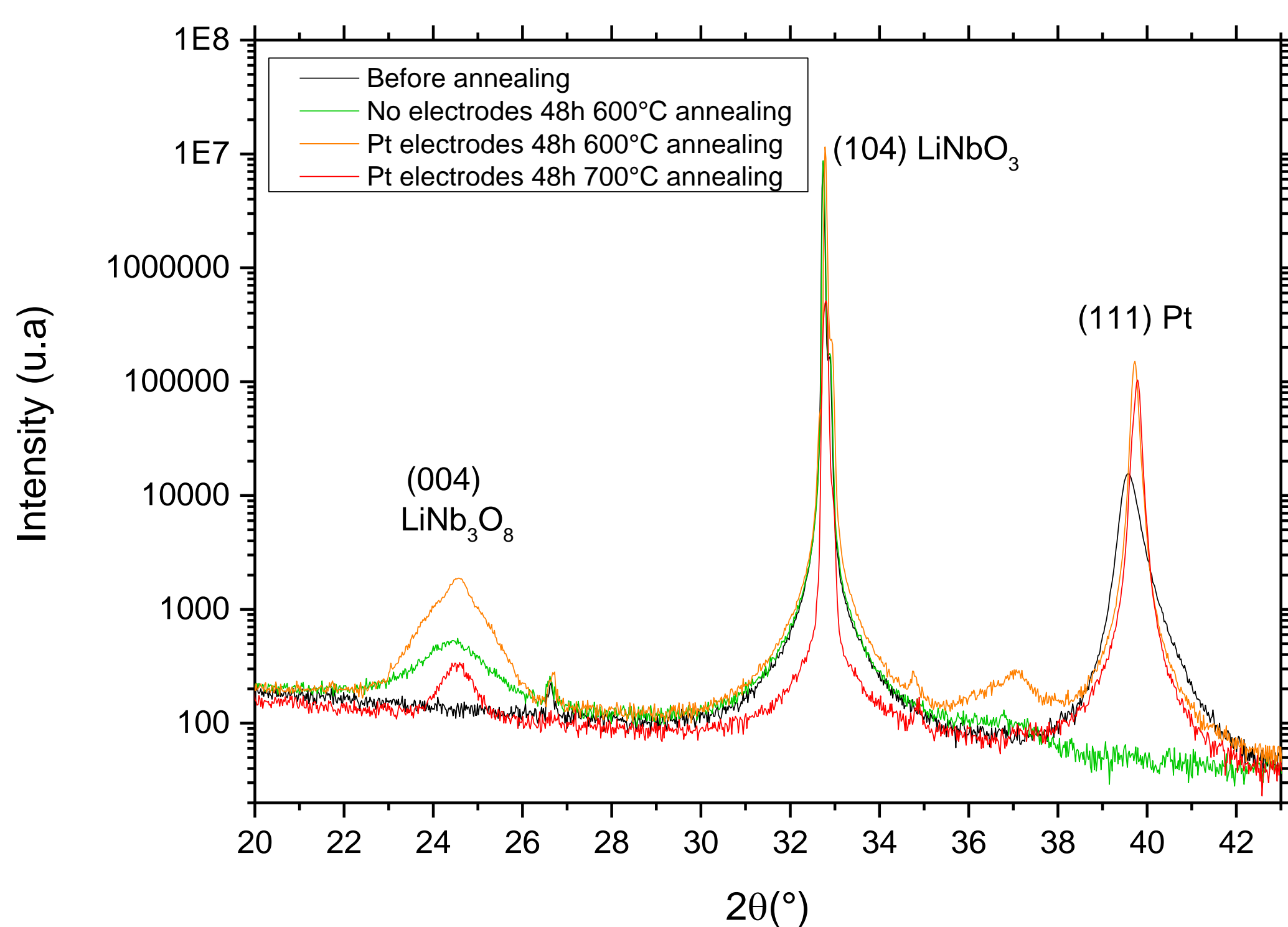


Figure 4 : X-ray diagram of LN Y-128, before and after annealing with and without Pt IDTs on the top.

- Aluminum-like LiNb₃O₈ formation kinetics for platinum
- LiNb₃O₈ less crystallized for the same annealing period (Fig.4)
- Increase in annealing time → LiNb₃O₈ more crystallized
- LiNb₃O₈ 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 LiNbO₃ 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
- These 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

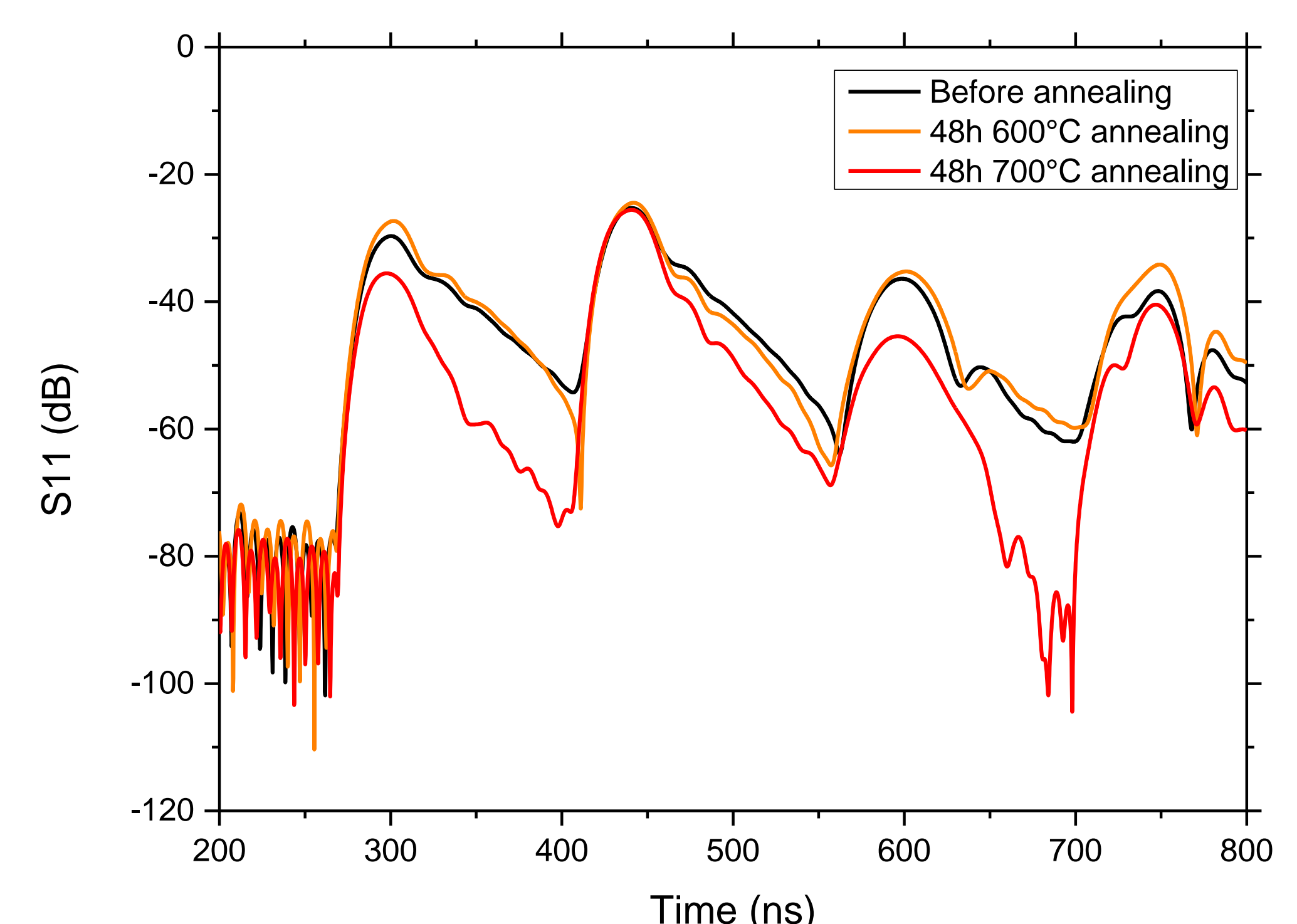


Figure 5 : Time domain reflection coefficient of RDL devices with platinum IDTs