Study of Different Piezoelectric Material Stroke Displacement With Respect to Temperature Using An SRF Cavity

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Introduction

- Piezoelectric (piezo) actuators have a wide array of applications such as in resonance control in SRF linacs and various experiments in dilution refrigerators (heat capacity μWs)
- In these applications a large stroke and small heat dissipation is crucial, two piezo materials will be compared with these characteristics
- PZT is the most widely used material for actuators, it provides a larger stroke but it heats up rapidly

Table 1: Comparison of PZT and $LiNbO_3$ figures of merit. The stroke for $LiNbO_3$ is from -500 V to 500 V. For PZT it is 0 to 100 V.

	PIC 050	PIC 255/252
Material	$LiNbO_3$	PZT
Length [mm]	36	18
Cross-section [mm^2]	100	100
Stroke (300 K) [μm]	3	15
Stiffness [N/μm]	195	200
Blocking Force [N]	585	3600
Curie Temperature [K]	1423	623
Density ρ [g/cm^{-3}]	5	7.80
Relative Permittivity ϵ_{33}/ϵ_0	28.7	1750

- $LiNbO_3$ produces 0.3 % of heat dissipation of PZT but has a stroke of 8.3 % of PZT at room temperature, see Table 1 for properties of both
- From literature it is known that $LiNbO_3$ doesn't decrease the displacement stroke as drastically compared to PZT
- An SRF cavity was used to measure the piezo stroke due to its extreme sensitivity to longitudinal deformation

Cavity Frequency Tuner

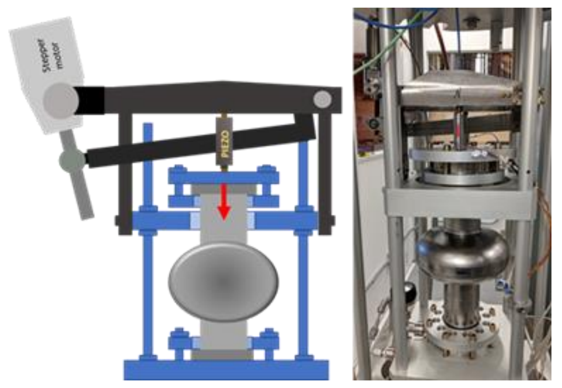

Figure 1: Left: schematic of one cell 1.3 GHz cavity with tuner installed. Right: Picture of cavity.

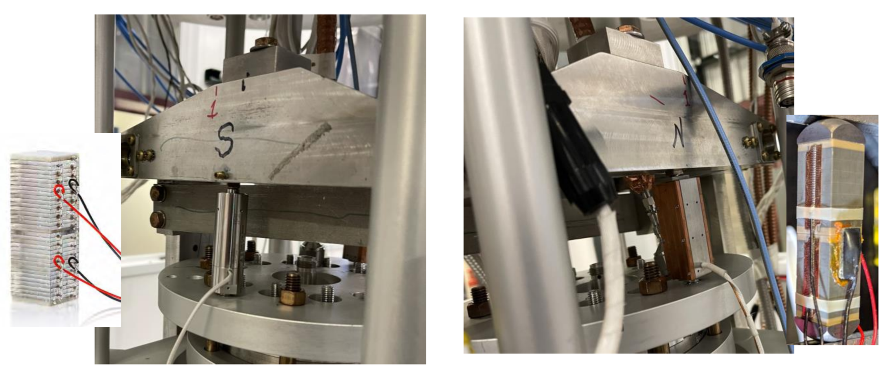

Figure 2 : Close-up look at the location of the piezos on the cavity tuner. Left is the $LiNbO_3$ and right is the PZT.

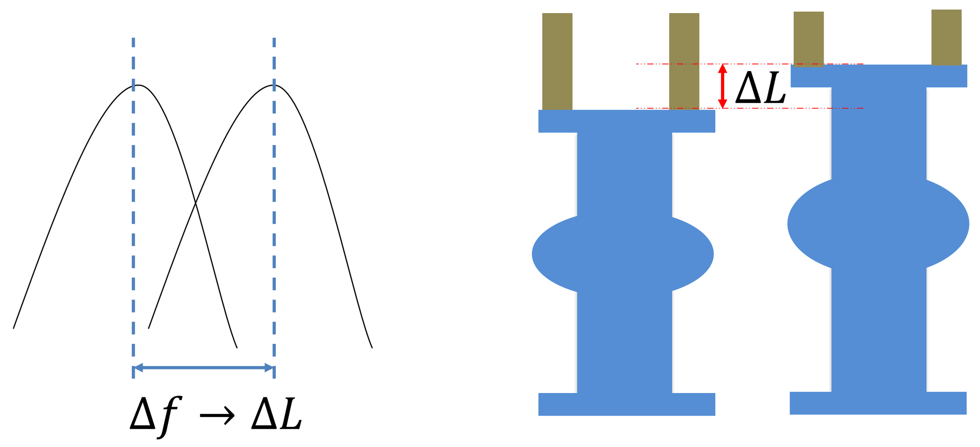

Figure 3 : Left: Depiction of cavity resonance when the cavity is compressed, this frequency shift is related compression. Right: Schematic of cavity compression by the piezos.

- The LCLS-II tuner is used, it consist of a stepper motor and piezos
- The cavity-tuner system is supported by an aluminum frame
- There are two piezos capsules which are used to control the frequency, in this case a PZT and $LiNbO_3$ capsules were used (See Figs. 1 and 2)
- The PZT capsule has a Cernox RTD attached to the PZT body, this is used to monitor the temperature
- The piezos are preloaded with the tuner to prevent any slack once cooled down
- The whole setup is inserted in a Dewar which is filled with liquid helium
- The frequency sensitivity of the cavity to longitudinal deformation is 2.3 kHz/μm and the cavity stiffness is 23 kN/mm
- The efficiency of the tuner is 40 % when both piezos are used, 20 % when only one piezo is used
- The method of the piezo stroke measurement is illustrated in Fig. 3 where the frequency shift of the cavity is related to the piezo stroke

Measurement at 4 K

- After cooling down to 4 K the stainless-steel frame becomes stiffer by 5% compared to room temperature, this improve the tuner efficiency by the same amount
- This effect is taking into consideration for the stroke calculations

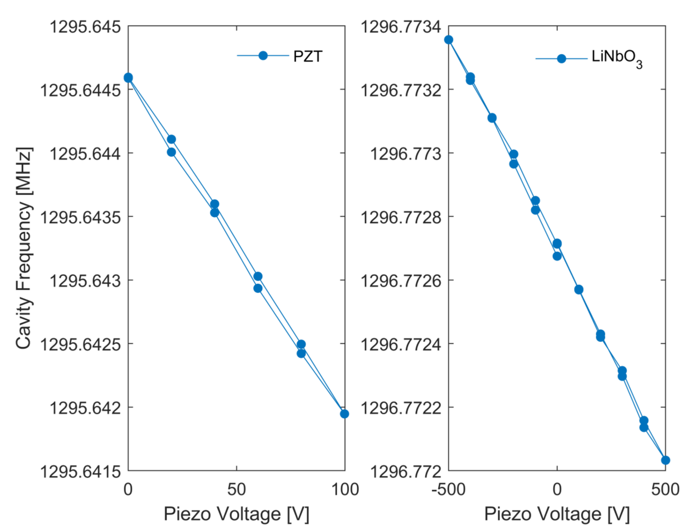

Figure 4: Piezo hysteresis plot on the cavity at 4 K. Left plot is for PZT and right plot is for $LiNbO_3$.

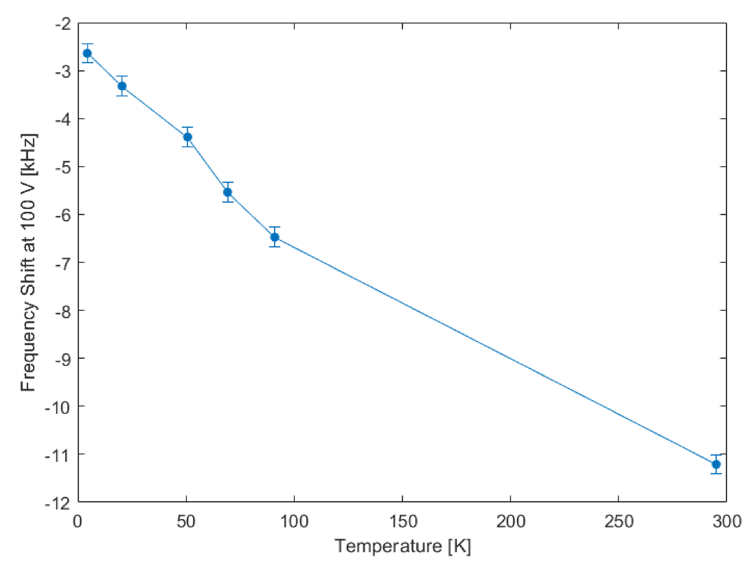

Figure 5: PZT stroke during warm up, voltage used was 0 to 100 V.

- Fig. 4 shows the hysteresis from both piezos, the hysteresis of the $LiNbO_3$ is smaller than that of PZT
- The hysteresis is correlated with the loss tangent thus showing that the loss tangent of $LiNbO_3$ is still smaller than the PZT

- Fig. 5 shows the data for PZT during warmup, the measurements stopped after 91 K because the frequency of the cavity was changing drastically due to thermal effects
- The measurements could not be done for $LiNbO_3$ due to larger frequency shifts caused by the temperature drifts
- The stroke of the piezo is calculated with the equation

$$D = \frac{\Delta f}{E * S}$$

- Where Δf is the frequency shift, E is the efficiency of the tuner at 20 % for a single piezo, and S Is the cavity sensitivity at 2.3 kHz/um
- Each of these parameters carries an uncertainty, the error for the stroke is given by

$$\frac{\delta D}{D} = \sqrt{\left(\frac{\delta S}{S}\right)^2 + \left(\frac{\delta E}{E}\right)^2 + \left(\frac{\delta \Delta f}{\Delta f}\right)^2}$$

- The calculated stroke is shown in Table 2

Table 2: The piezo sensitivity for 293 K is from 0 to 100 V. At 4 K it is from 0 V to 100 V. For $LiNbO_3$ it is from -500 V to 500 V at room temperature and at 4 K.

Piezo Type	Capacitance [μF]		Piezo Sensitivity [Hz/V]		Calculated Stroke [μm]		Stroke Ratio 4 K/300 K [%]
	293 K	4 K	293 K	4 K	293 K	4 K	
PZT	14	4	-112	-26.4	24.3±1.7	5.4 ±0.4	22.4 ± 2.2
$LiNbO_3$	.0013	.00125	-1.393	-1.323	3.0±0.3	2.7 ±0.2	90.4±11.2

Conclusion

- **The results show that PZT stroke is reduced to 22.4 % of the value at room temperature which is larger than the 10 % previously reported in the literature**
- **The stroke of $LiNbO_3$ was measured for the first time with an SRF cavity and it is 90.4 % of the room temperature value**

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