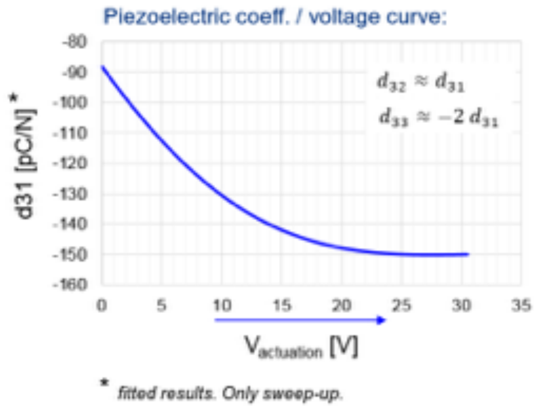
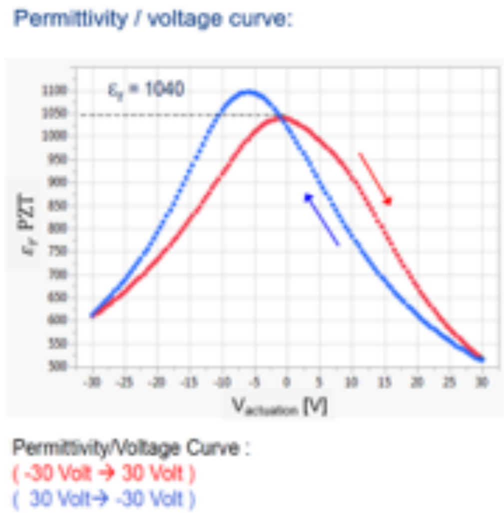
MEMS micro loudspeaker: characterization and optimization of PZT MEMS actuators for improved linearity and acoustic distortions (THD)

A. Rusconi-Clerici[1], J. Spötl[1], C. Novotny[1]
[1] USound GmbH, Vienna Austria

USound GmbH develops and markets Piezo MEMS based audio systems in the field of micro-acoustics; examples of our applications are earphones, headphones and hand free portable applications for the consumer market. Compared to voice coil based technologies, Piezo MEMS can achieve higher level of miniaturization (small footprint depending on application and thickness down to 1mm) and integration with modern electronic systems; Piezo MEMS allow for fabrication of high force, high displacement actuators which are fast in response thus generating crisp and clear sound; their efficiency allows for a 50% improvement in power consumption. Further advantages in using silicon and microelectronics assembly production infrastructures are bottom line gains in term of yields, scalability, cost reduction roadmaps, device performances repeatability and reliability.

USound is using PZT deposited on silicon wafer by a sol gel process; the design is based on a system of cantilevers and springs that traduces the piezoelectric effect in to a vertical movement. For generating the high end quality sound we are targeting, the transducer must be highly linear with acoustic harmonic distortions (THD) below 1% in the whole bandwidth (20Hz to 20kHz) at high Sound Pressure Levels. Distortions are generated from various electrical and mechanical non linearities; with ferroelectric materials one source of non linearity is the hysteresis of the polarization loop during loading and unloading cycles. A second source on non linearity is the dependency of d33 to the applied voltage. Thanks to its characteristic, the d33 non linearity can be easily compensated by a proper design of the transducer. The hysteresis non linearity is hardly affected by design and must be optimized by process.

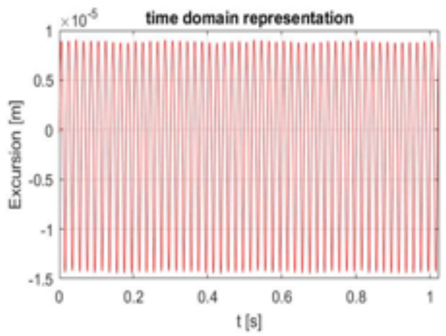


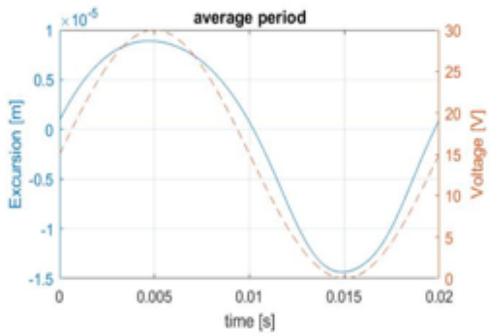


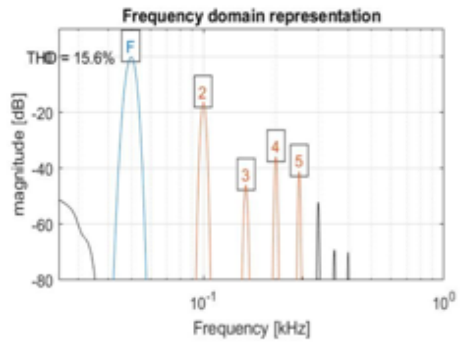
In this presentation we show our work in order to characterize and optimize the material using a hot poling process and a temporary poling induced by the driving principle during operation; the characterization is done on piezo coefficients, dynamic displacement of the actuator and acoustic distortions measurements of the speaker. The hot poling experiments include following parameters: Temperature 80°C to 120°C; DC Voltage 10V to 30V; Duration 1min to 10min. The effect of the polarization is tested directly after poling, then repeated after 1day, 1week and 1month; durability of the polarization with stress tests (i.e. temperature and humidity tests) is still under evaluation. The temporary poling is achieved through a DC signal variation between 2V and 20V.

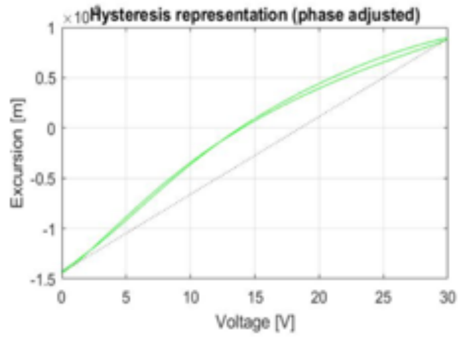
The mechanical measurements are done with a Polytec500 Laser Doppler Vibrometer for measuring elongation at given frequencies below *fres* both in static (step of DC voltages applied) and dynamic (time domain, DC+AC sinus signal) conditions. The static measurement points are interpolated and give a picture of the linearity of the elongation. The time domain data are translated to frequency domain through PSD (power spectral density) which returns all the harmonic distortion components, THD is calculated via the ratio of the sum of harmonics k2 till k5 compared to k1 (the fundamental frequency). The algorithm has been validated by generating an artificially distorted signal with known THD and comparing this to the calculated results; the resulting difference is below 0.1%.

In a parallel analysis, the acquired time-data are averaged to calculate an 'average period' of the signal and compared to a sinus or another reference signal. This helps to visualize the deviation of the mechanical response from an ideal sinusoidal movement and secondly to obtain the characteristic curve, which shows the input (voltage) to output (excursion) relationship during loading and unloading cycles.









The acoustical measurements are done with an artificial ear (711 Coupler, a standard for in-ear headphones characterization), in this stage the MEMS parts are assembled in the final package and mounted in a earphone shell. The measurement system acquires acoustic SPL and THD form 20Hz to 20kHz.

The results show a remarkable impact of both hot poling and driving induced poling improving the linearity of the displacement and reducing acoustic THD; additionally, poling is improving the elongation performance of the actuator at lower driving voltages. In particular, an optimized hot poling process reduces THD by 30% to 50% depending on driving conditions.