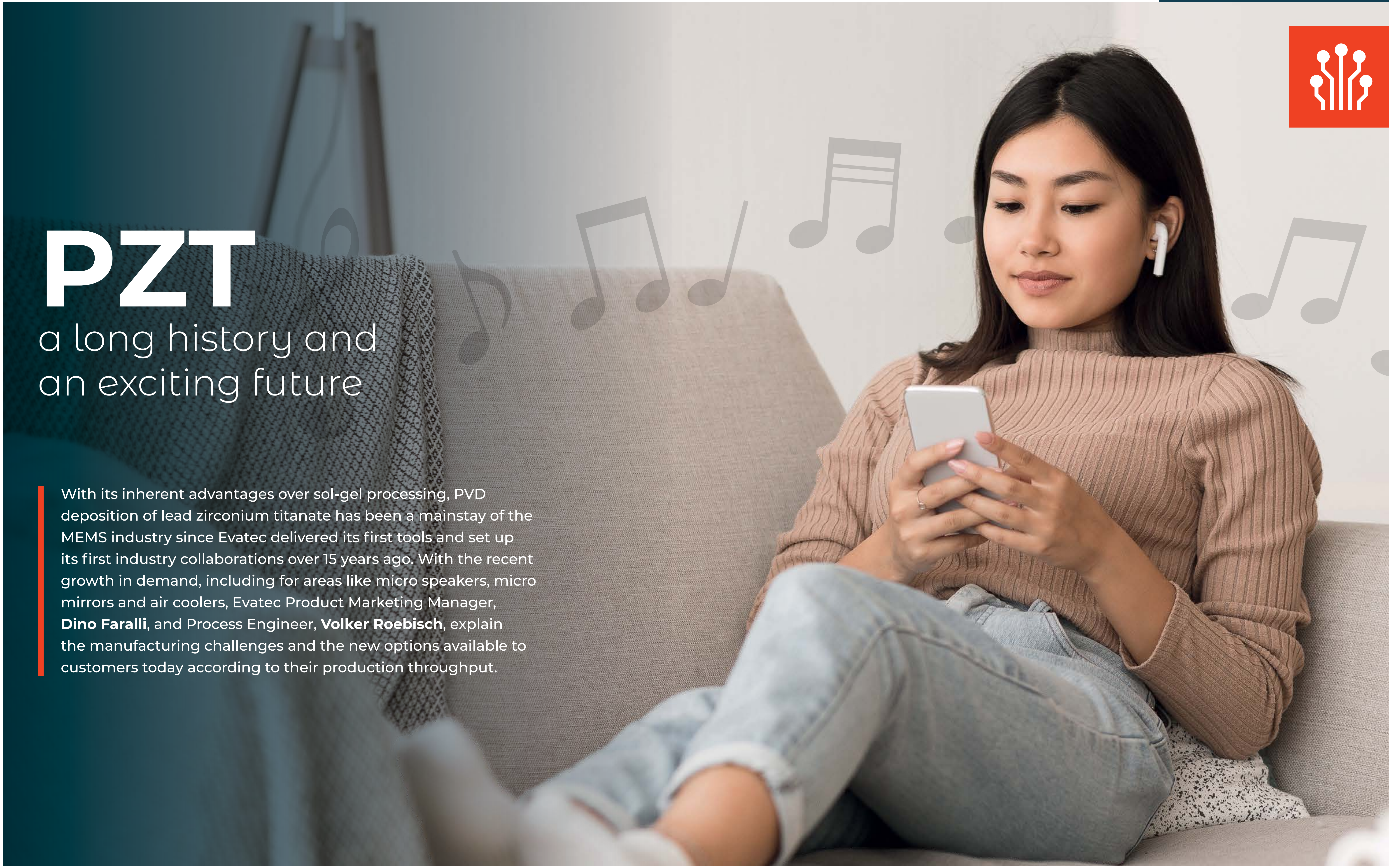

PZT
a long history and an exciting future

With its inherent advantages over sol-gel processing, PVD deposition of lead zirconium titanate has been a mainstay of the MEMS industry since Evatec delivered its first tools and set up its first industry collaborations over 15 years ago. With the recent growth in demand, including for areas like micro speakers, micro mirrors and air coolers, Evatec Product Marketing Manager, **Dino Faralli**, and Process Engineer, **Volker Roebisch**, explain the manufacturing challenges and the new options available to customers today according to their production throughput.

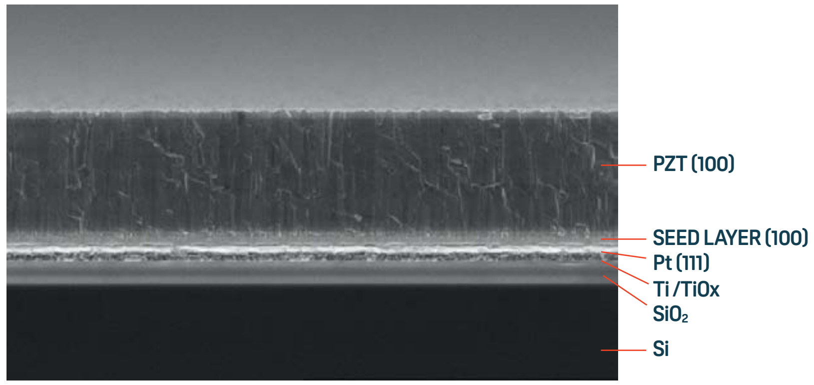

Figure 1: Typical PZT layer stack comprising adhesion layer, diffusion barrier, conductive electrode, and seed layer for film growth in perovskite crystal structure.

Figure 2: New RF process module for 400 mm targets integrating Very Hot Chuck and substrate bias tuning technology.

Figure 3: Picture of CLUSTERLINE® 200.

It's a complex process

The deposition of the PZT layer is just one part. A sequence of layers is needed to enable the PZT to grow with the correct stoichiometry and the needed crystal structure and orientation.

The stack

Figure 1 shows a typical stack comprising a metal / metal oxide stack for good adhesion and as diffusion barrier, a platinum electrode for electrical contact, and an oriented seedlayer to serve as template for the crystal structure prior to deposition of the PZT, for which deposition process and layer properties must all be first optimized to ensure best end-layer performance.

Process specifications on 200 mm call for high dielectric polarization and large piezoelectric response, but also typically for low wafer stress < ± 250 MPa (to ensure low wafer bow), low leakage current, high fatigue resistance less than 5% at 1e10 cycles, and tanΔ less than 5%.

The Evatec PZT process kit

The $Pb[Zr_xTi_{1-x}]O_3$ ceramic target composition with a dopant at low concentration is carefully chosen to improve the dielectric properties. RF sources for large targets of 400 mm diameter (Figure 2) are specified for competitive film uniformity. A dedicated magnet pack and new RF shield design are combined with a "Very Hot Chuck" for reliable operation at temperatures beyond 500°C in daily production. A newly integrated matching unit with autotuning allows adjustment of film properties and precise process control.

CLUSTERLINE® 200 – A proven workhorse for PZT production

In its largest configuration, today's CLUSTERLINE® 200 (Figure 3) can be equipped with up to 6 process modules for etch and deposition, plus three additional stations for integration of additional capabilities like degassing and cooling.

However, platform design flexibility now enables customers to choose from a range of options according to their PZT throughput requirements.

High-volume manufacturing

Here, it still makes sense to have dedicated single process modules for each process step, with the option for a second module dedicated to PZT for even higher throughputs (Figure 4).

The enlarged ARQ 320RF process sources used especially for this application deliver the wafer-in-wafer (WiW) uniformities required and a dedicated matching unit allows controlled ion bombardment of the substrate for process tuning.

Development / low volume production

Where demand is lower or budget constraints apply for R&D or low volume production, CLUSTERLINE® 200 can be delivered incorporating Evatec's proven Multi-Source technology for deposition of the metal / metal oxide and seed layers.

- **Option 1:** Using the same 8-sided VTM8 as the high-volume manufacturing platform at its core, the number of process modules could be reduced to 3, leaving room for later expansion.
- **Option 2:** A smaller 5-sided VTM5 platform can also be configured with single and multisources to enable the complete process (Figure 5).

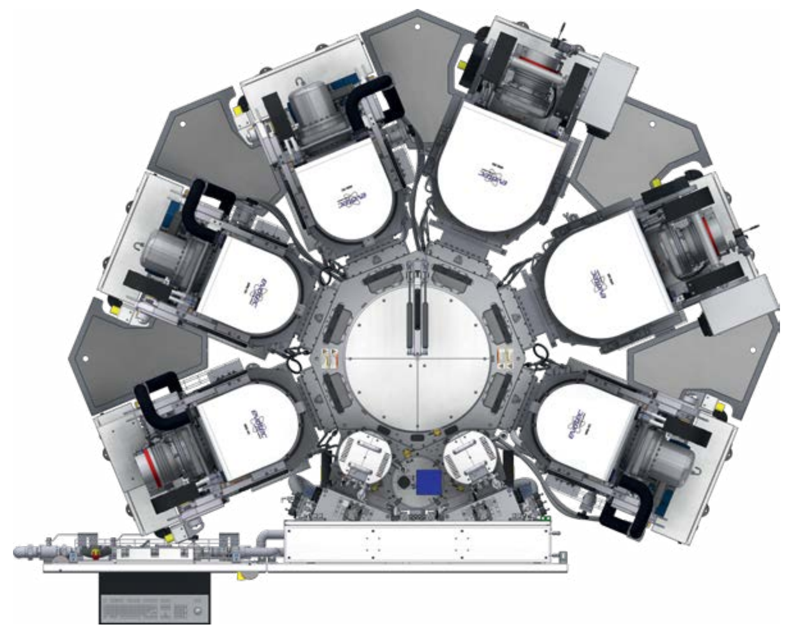

Figure 4: Fully equipped CLUSTERLINE® 200 for volume production of electrode, seed and PZT layers. Optionally a second PZT module can be configured for higher throughput.

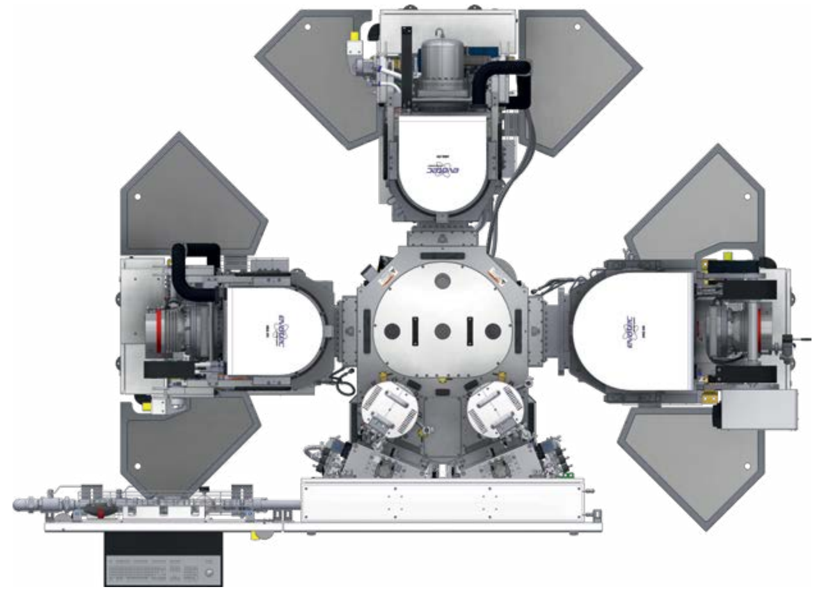

Figure 5: Budget configuration of a CLUSTERLINE® 200 for R&D and production. 3 SPM including 1 Multi-Source (MSQ) for depositions of electrode, seed and PZT layers.

Take a look at the results

1. Process and piezo-electric performance

Figure 6 illustrates the typical process performance achieved for PZT films. The film stress can be tuned by process parameters with good WiW uniformity, the permittivity is lower than that obtained for sol-gel films, polarization P_{max} is high with low coercive field, breakdown field, and piezoelectric coefficients are aligned to state-of-the-art values but are also a matter of ongoing optimization work. Short-term goals for further process development are also indicated in Figure 6. We are working on them together with partners.

Some of the parameters listed in Figure 6 are reported in more detail in Figure 7. Measurements were done at Silicon Austria Labs in Villach, using a DBLI system from AixACCT, on PZT 1 µm thick, with Pt top electrodes at diameter 1 mm.

2. Crystallinity

Figure 8 confirms the perovskite texture of the prerequisite seed layer with 100 orientation, measured at different radii on 200 mm wafers (Note: result at radius 30 mm is shown).

For PZT, the trace in Figure 9 shows XRD results at different radii on a 200 mm wafer deposited at 550°C and confirms the successful promotion of (100)-textured film growth from seed layer to PZT film.

3. PZT film composition

Figures 10 and 11 show lead and zirconium content as a function of radius on a 200 mm substrate as measured by X-ray Fluorescence (XRF) for a doped target and illustrate how composition can be controlled successfully.

Item	Demonstrated Properties (PZT on Seed layer)
PZT film	200 mm wafer, up to 2 µm, (100) texture
Thickness uniformity 1σ EE6	3.5% (Goal is <3%)
Residual stress	75 MPa (average), Range 50 MPa
Relative permittivity ε_r	800
Breakdown field	500 KV/cm (50 V/µm)
Polarization P_{max}	60 µC/cm²
Remanent polarization $2P_r$	40 µC/cm²
Coercive field	50-60 KV/cm
Leakage	50-60 nA/cm² @ 1V
e31,f	14 C/cm² (Goal is 16C/cm²)
d33,f	100-120 pm/V (Goal is 120 pm/V)
Fatigue	>10¹⁰ cycles at 5 Hz

Figure 6: Typical values for PZT film properties.

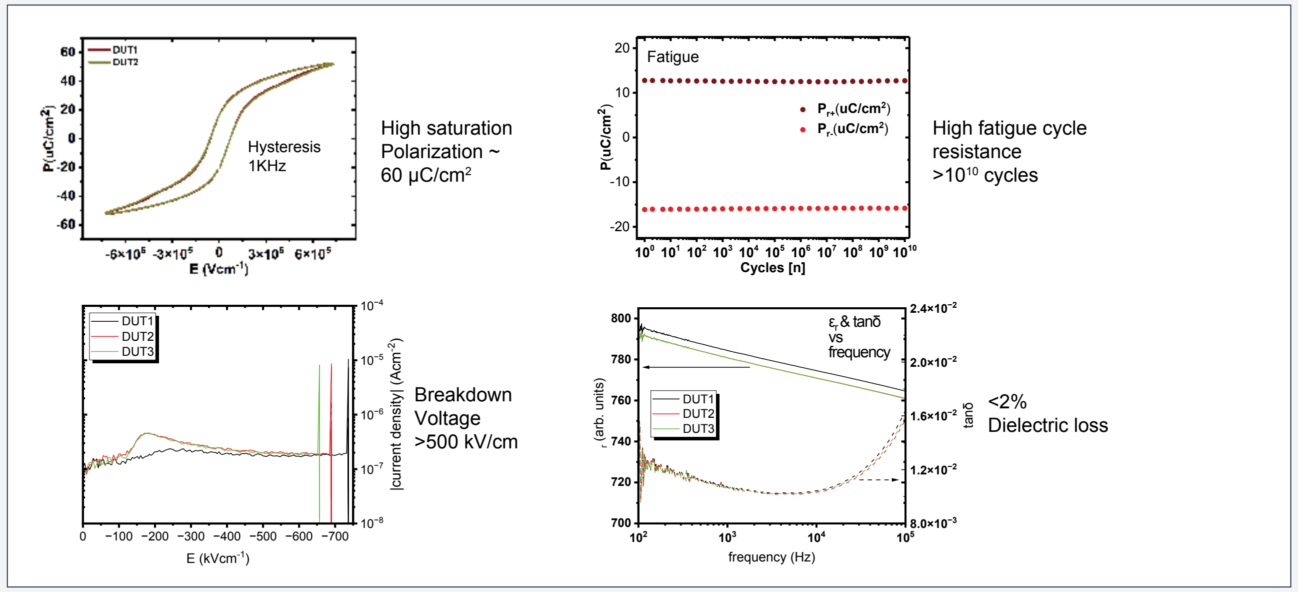

Figure 7: High saturation polarization and breakdown voltage paired with low dielectric losses and very low fatigue best describe the PZT films produced in Evatec's new RF module.

The work continues

As interest grows in improving know-how and processes for PZT, Evatec is continuing to work with partners in optimizing industrial-scale production.

From higher deposition rates to increase wph throughput, to maximizing tool uptimes by reducing target change over times and maximizing shield lives, we are working with our partners in test and qualification. If you would like to learn more about our PZT program, contact your local Evatec sales and service organization today.

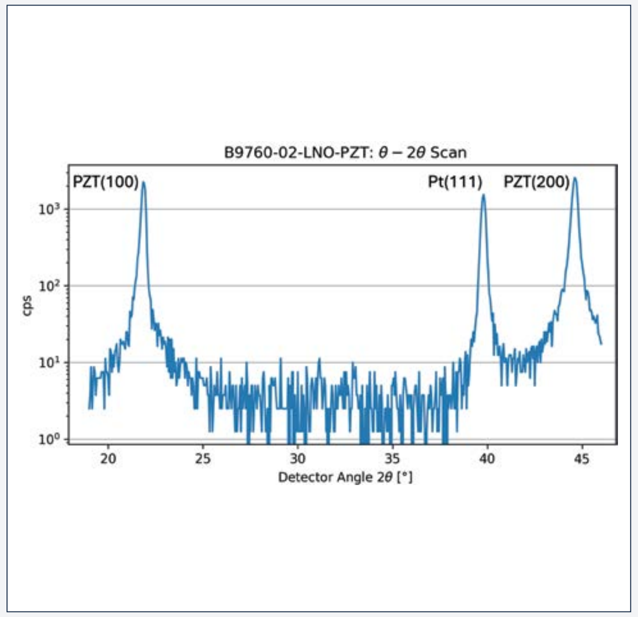

Figure 8: The XRD diffractogram shows a highly oriented perovskite crystal structure in (100)-direction for the deposited PZT on the seed layer.

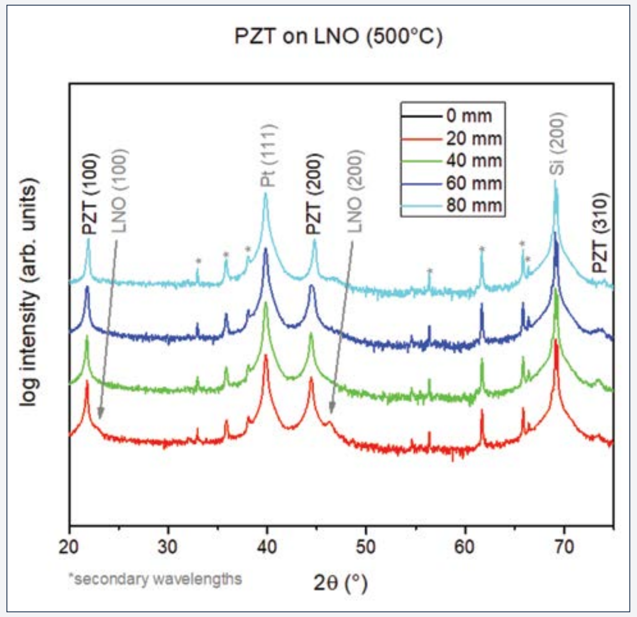

Figure 9: XRD diffractogram indicating highly textured PZT growth out-of-plane in (100)-orientation.

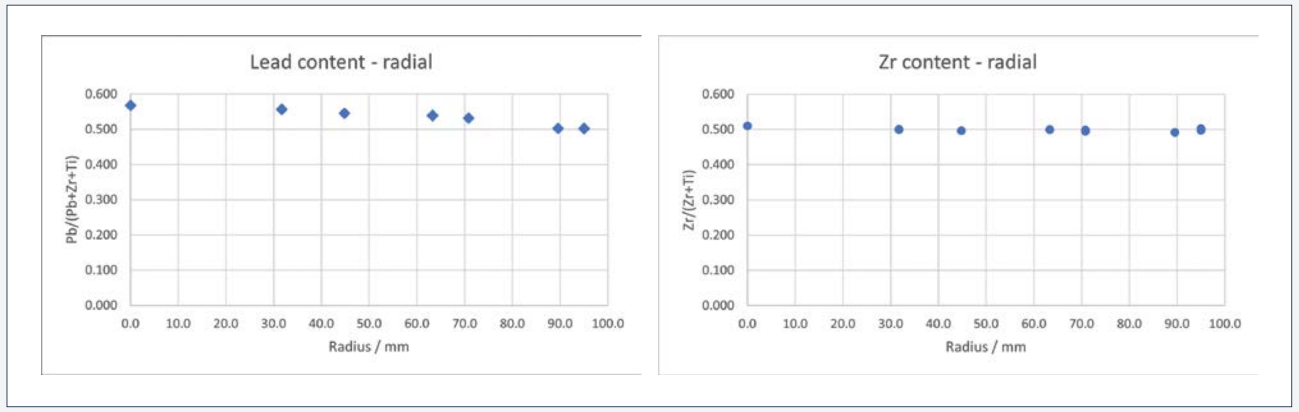

Figure 10 and 11: Radial distribution of Pb and Zr contents in at.-%.