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Value from Innovation

Dimatix

Why Great MEMS Printheads Use Sputtered PZT

BY FUJIFILM DIMATIX

WHAT THIS PAPER WILL EXPLAIN

This paper will explain why FUJIFILM Dimatix uses sputtered PZT in its SAMBA® and SKYFIRE® printheads and compare sputtered PZT to alternative piezo technologies. It will answer questions you may have about the advantages of thin film technologies compared with bulk PZT used in other printheads. It will explain some of the innovations in sputtered PZT compared to piezo technologies that use conventional Lead (Pb), Zirconate (Z) and Titanate (T). You will come away with a designer's perspective on PZT from a leading inkjet printhead developer and an appreciation of why great MEMS printheads use sputtered PZT.

INTRODUCTION

In a piezoelectric inkjet, the process of generating an ejected droplet begins with the application of a voltage to a piezoelectric element, activating it. This produces a traveling pressure wave that propagates through the fluidic structure of the printhead's jet to the nozzle where it is converted into fluid flow. This flow, then, ejects a drop.

A voltage can activate a piezoelectric inkjet because the piezoelectric material has a physical property causing it to change shape when an electric field is applied. There are numerous materials that have this property to varying degrees. Due to its strong response to an electric field, the most widely used piezoelectric material in most industrial applications is a ceramic called PZT. This is a crystalline form of Lead (Pb), Zirconate (Z) and Titanate (T) used in a wide range of applications from ultrasound devices to gas grill ignitors. Its use is common in the inkjet industry and it is the piezoelectric material that FUJIFILM Dimatix uses in its printheads.

BULK PZT AND POLING

For its STARFIRE® SG1024, and earlier printheads, Fujifilm Dimatix uses PZT in the form of what we call, "Bulk PZT." Bulk PZT is formed by compressing finely milled ceramic $(PbZr_{\sim.52}Ti_{\sim.48}O_3)$ into 5-10 inch diameter pucks that are then fired in a furnace. In the furnace, the ceramic powders sinter to form small crystal grains of random orientation as shown in Figure 1 below.

Though each of the many crystalline grains

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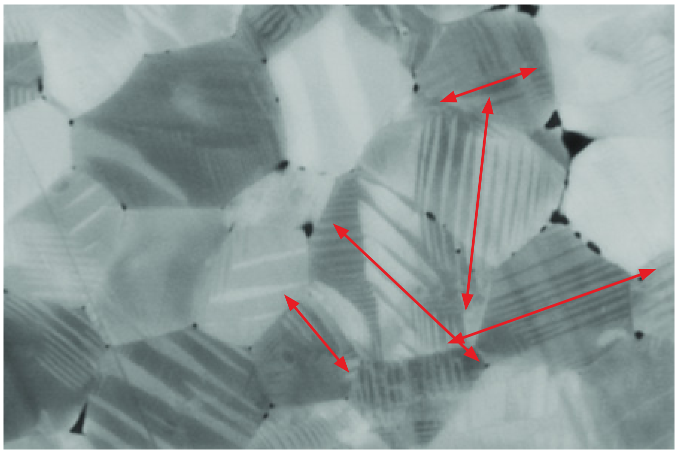
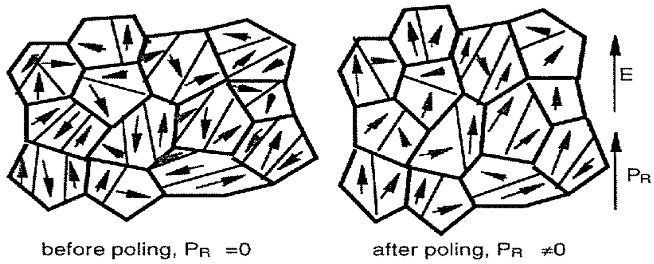


Source: https://www.researchgate.net/figure/Micrograph-of-striped-domain-patterns-forming-within-grains-of-ferroelectric-PZT_fig2_338655334

Figure 1: SEM image of polished un-poled PZT. The grains are visible. The arrows show the random orientation of various grains.

by themselves will exhibit the piezoelectric response to a voltage, a piece large enough for use in a printhead will not. This is because the many directions of the randomly oriented grains cause the various forces resulting from the voltage to cancel each other out. This is like ten people lifting a table and each of them trying to move the table in a different direction; a lot of force may go into that table, but it



Source: https://www.researchgate.net/figure/A-polycrystalline-ferroelectric-with-random-orientation-of-grains-before-and-after_fig15_37437490

Figure 2: The left-hand image shows the grain structure and orientation of un-poled PZT. The right-hand image shows the more consistently aligned grain structure and orientation of post poling PZT.

won't go far! Much of the randomness in grain direction can be removed in a process called poling, whereby a strong electric field (~10V/µm) is applied, partially rearranging the grains.

Figure 2 shows that after poling, although not perfectly aligned, the overall grain alignment is now trending enough in one direction to exhibit a net force when a voltage is applied. This is like five of those ten people holding the table agreeing to move towards the front door. There's still some wasted force going into that table from the other five people pulling in other

Figure 3: In the image on the left, every person is pulling in different directions; the table's overall position does not change. In the image on the right, many of the people are pulling or pushing in the same direction, so that the table changes positions.

directions, but there's enough people pulling towards the same direction, that the table will move closer to the front door.

This poling process, so important to the operation of the piezo itself, also has a downside. Over time, a poled piezo piece tends to lose this enforced alignment. This can be seen as entropy expressing itself to reduce the order of the piezo. This is especially prominent when temperatures and stresses are experienced such as during manufacturing, and later during use in the printhead. This can be overcome by bonding the crystal to something in the printhead as part of the manufacturing process and thereby fixing alignment in place. The crystals will then be prevented from moving back towards a random orientation, but the downside is that their propensity to revert to a random orientation can instead manifest as the buildup of stresses in the printhead if the manufacturing process requires the crystals to be poled after they are bonded. This is like holding open a spring-loaded door designed to close on its own. You can feel the stress on your arm when holding open the door, especially if it's a heavy door. Through careful design and manufacturing, bulk PZT printheads such as Dimatix's STARFIRE® design, have an operating specification that does not suffer from PZT deteriorations during normal operation within, or even sometimes beyond, its specification. However, for different applications requiring different specifications, other technologies come into consideration.

MEMS AND THIN FILM PZT

There are two main processes for the creation of thin film PZT in printheads: sputtering and sol-gel.

In sol-gel, piezo powder is suspended in a volatile fluid to make a thin slurry. The slurry is then applied to the wafer in a very thin layer (~1/10 to 1/100th µm) with a spin coater. Since the layer is too thin for practical use in making functional features, the process is repeated to build up a larger film thickness. Between layer applications, the volatile fluid is driven off. Finally, after the desired layer thickness is achieved, sintering in a furnace creates the randomly oriented crystal grain structure in the film. A poling step is then used to align the grains. Since the piezo film is attached to the substrate as part of the fabrication process, the poling step will generate stress as the piezo is forced into alignment by poling; remember that the crystals will tend to revert toward their initial orientation, especially when subjected to higher temperatures or stress. The internal stresses resulting from poling can present challenges to thin films during the intense manufacturing operations needed to create the intricate features for piezo inkjet designs.

For its SAMBA® and SKYFIRE® printheads, FUJIFILM Dimatix uses a very different method of creating thin film PZT that combines Micro Electro Mechanical Systems (MEMS) manufacturing with sputtered PZT. MEMS are tiny electrical and mechanical components. MEMS allows for the selection of certain nozzle patterns and configurations optimized for the printhead architecture. In SAMBA® for example, an overlapping strategy is used while minimizing cross-process nozzle density. To accomplish this layout of electrical and fluid connections in conventional printheads (i.e., non-MEMS) would be impossible. In sputtering, a target of PZT is bombarded with a plasma, freeing target material that is subsequently deposited onto a heated wafer. Importantly, the material onto which the PZT is deposited, typically a metal electrode material,

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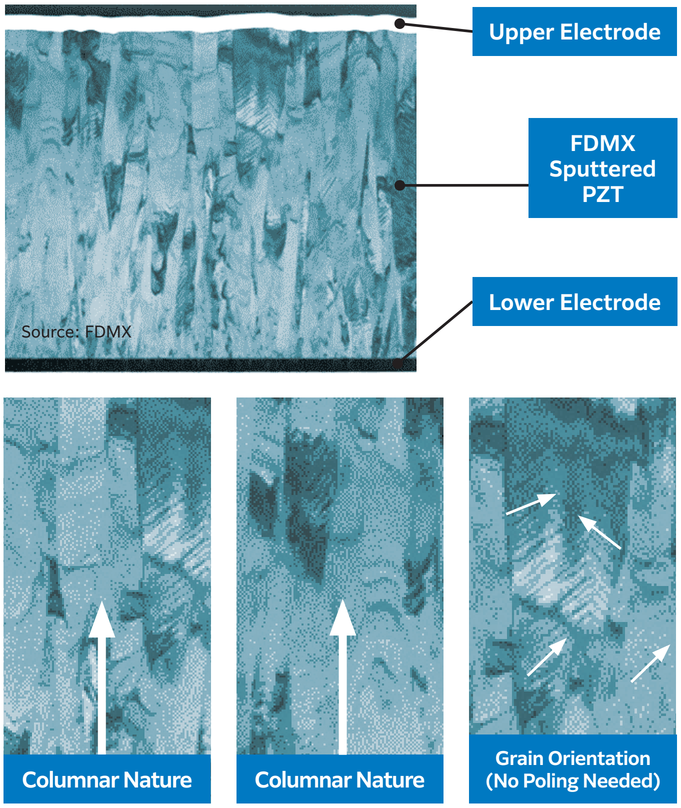

Figure 4: SEM image showing columnar grain structure of FDMX sputtered PZT.

will be specifically selected to have an atomic spacing consistent with the desired crystalline size of PZT. Hence, as the PZT is deposited, it forms into a well-aligned crystal by "stacking" multiple, substantially aligned grains on top of each other. The result is a "poled-as-deposited" columnar crystalline structure. Figure 4 above shows this structure. Compare this with the random nature of the grains previously shown in Figure 1.

ADVANTAGES OF MEMS SPUTTERED PZT

This "poled-as-deposited" sputtered PZT has multiple advantages:

1. The films are very stable and hold their poling orientation better than poled bulk PZT. The crystals are deposited in their final desired orientation because of how the metal electrode they were placed upon was chosen at the outset.
2. Because sputtered PZT is "poled-as-deposited," there is no separate poling operation to add stress. This low stress is beneficial for longevity in its own right, and in that it allows thicker layers to be deposited. Thicker layers allow a stiffer silicon structure and hence a higher resonance jet. Additionally, thicker silicon is stronger which contributes significantly to the robustness of the jets.
3. Sputtered PZT films are very heat resistant, which allows high temperatures to be used during manufacturing with less risk of scrap losses. Low scrap rates help make this technology affordable. Higher heat tolerance also allows the use of protective films, which are applied at high temperatures. This further extends printhead life by keeping out the moisture and other contaminants that can foster chemical reactions impacting product lifetime.
4. Since the PZT is not formed from compression and sintering as in bulk PZT, it is less susceptible to the formation of voids, which can concentrate stress (Voids are the black spots that can be seen in Figure 1 above.). This enables sputtered PZT to tolerate higher voltages when necessary. Nevertheless, the fact that MEMs PZT is a thin film means that it functions well at low voltages. Combining these factors means that FUJIFILM Dimatix sputtered PZT can typically tolerate about five to ten times the volts that can be accommodated within a film compared to bulk PZT or some other PZT technologies.

Why Great MEMS Printheads Use Sputtered PZT

FUJIFILM Dimatix has refined its sputtered PZT by developing innovations that build onto the foundation of this technology.

FUJIFILM Dimatix's Niobium doping adds about 13% Nb in the PZT, which results in an approximate 70% increase in the piezoelectric coefficient increasing its responsiveness. FUJIFILM Dimatix has also refined its sputtering process to achieve a high degree of uniformity across the wafer. This consistency directly supports jet-to-jet uniformity for consistent print quality.

COMPARISONS TO SOL-GEL

In comparison to FUJIFILM Dimatix sputtered PZT, the very thin membranes produced by using the sol-gel process are difficult to work with in tight jetting arrays. This is because the intertwining fluidic and electrical connections in a high performance, high resolution printhead require many complex manufacturing steps. Consequently, very thin membranes have a difficult time surviving such complex manufacturing. FUJIFILM Dimatix's sputtered PZT is substantially thicker than membranes produced using sol-gel, enabling dense jetting arrays and high jetting frequency at relatively low voltage. Such thickness on top of the heat resistance mentioned earlier allows sputtered PZT to safely survive intense manufacturing operations. Without such survivability, it might be necessary to forego some of the more innovative manufacturing techniques used, which could ultimately drive down product quality or performance.

Another problem that can occur when sol-gel is used to produce highly stressed poled thin films in some printheads is that the added stress can directly impact printing. In high drop-density print regions (e.g. solid color fill artwork) transient de-poling can occur in the piezo as the piezo reverts to a more random configuration under stress. This can slow the drop velocity and reduce drop size as the solid fill extends, which can appear as a fading color density in the print.

DISADVANTAGES OF SPUTTERED PZT

The only disadvantage of MEMS sputtered PZT for high-performance printheads that we've seen is that it is incredibly difficult and time consuming to develop this technology. Fortunately, that's behind us!

FUJIFILM Dimatix SAMBA® 1200 dpi printheads are leading the world in industrial high-performance printing for the world's most demanding printing applications. FUJIFILM Dimatix SKYFIRE® opens new possibilities for printer developers seeking the performance of sputtered PZT for ultra-high speed, high laydown, and high standoff 600 dpi applications.

Produced by FUJIFILM Dimatix

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