FABRICATION AND CHARACTERIZATION OF PIEZOELECTRIC THICK FILM ELEMENTS AND ARRAYS

Sergio Gwirc[*], Salvador Tropea
Instituto Nacional de Tecnología Industrial-CITEI, ARGENTINA
Carlos Negreira[**], Nicolas Perez
Laboratorio de Acústica Ultrasonora, Instituto de Física, URUGUAY
Francisco Montero de Espinosa
Instituto de Acústica, CSIC, Madrid, ESPAÑA

Abstract - PZT thick film discs have been produced in the range of 100-200 μm using screen printing technology and suitable new ink prepared with piezoelectric powder as main active component. After poling, characterization of electrical impedance was made and an acoustic spectroscopy technique used to analyze the vibrating behavior of PZT discs over different substrates in order to know typical parameters of the film. Also a dark field Schlieren technique was employed to evaluate emission field in water. It has been found that thick film piezoelectric layer of this material has a lower piezoelectric charge constant d_{33} and remanent polarization than the bulk one. Electrical impedance and acoustic emission analysis shows two main resonance modes, one of the PZT layer itself and other with the substrate and PZT vibrating as a whole. We also show some results evaluating a manufactured array structure with this technology and coupling modes through the substrate.

I. INTRODUCTION

In ultrasound transducer technology for medical imaging and non destructive testing is more and more important to improve resolution, contrast and detection of small discontinuities. Conventional diagnostic ultrasound is running to use 2-D array transducers to implement dynamic focusing, better resolution and 3D images. These improvements need a reduction in size of transducer elements and consequently arise limiting factors like increasing mismatch in electrical impedance with transmitter and receiver electronic, multiplying manufacture difficulties and the traditional acoustical impedance difference between PZT based transducer and water or human body. The choice of materials has been restricted by the need to produce a piezoelectric material of the thickness to resonate at the desired frequency. For this reason, ceramic transducers have been limited in their range of useful frequencies, even though they are stronger than polymers as piezoelectric.

In this paper we investigate a different approach to prepare PZT material and transducer itself, using thick film technology that is a mature and well-known one to perform hybrid circuits employing inks for screen printing and sintering. Because of reliability, low cost of small series and great geometrical flexibility, research and applications of this technology are growing to make sensors and transducers, mostly using commercial inks and lately developing new inks with specific properties [1]. The interest in PZT inks for this purpose was stimulated by the ability of this technology to produce films 30-250 μm thick with good acoustic properties to bridge the gap between thickness achieved with bulk and thin film ceramics.

With the aim to make ultrasonic arrays with complex geometry, small size transducer elements and better electric and acoustic properties and also the manufacturing flexibility, in this work we present a new composite based on a PZT ink to be used with thick film technology that we think is a step ahead in solving some of these problems.

II. TRANSDUCER FABRICATION

The small thickness required for film operation in 1-10 MHz range and the technology itself [2] point out the use of a mechanical support like a thin backing layer for PZT films. We start from an ink prepared as slurry of PZT powder with organic binders, plasticizers and solvents to manufacture transducer elements. Ceramic elements were screen printed through a finely woven mesh of stainless steel coated with an UV sensitive emulsion onto which pattern array can be formed. Ink is placed on the screen and a squeegee traverses it under pressure, forcing ink through mesh open areas, printing over an alumina substrate. Before PZT ink was applied on substrate, a lower gold electrode with Heraeus C5789 ink is printed and after PZT, an upper one is performed.

PZT ink has been prepared with a 3 μm mean size diameter PZ27 powder from Ferroperm Ltd. as active material. Powder is mixed with a small amount of glass frit (about 3-5%) in a ball mill, and then dispersed in a vehicle to get suitable rehological properties in the ink. A commercial vehicle ESL 400 was used as liquid carrier. The glass frit is necessary in order to bind powder particles together and to the substrate, using standard thick film technology process parameters, firing temperature of 850 °C. Others binders like PbO were evaluated but no improvement was found and sometimes appear a low dielectric constant interface that cancels ferroelectric properties of the sintered ink.

PZT discs with 8 mm diameter gold electrodes were screen-printed as samples on ceramic and stainless steel substrates. Multiple layers were printed to reach 100-200 μm range, because a single layer was between 30-50 μm, depending of ink viscosity and printing conditions. Samples were poled with an electric field of 3000 V/cm at 85 °C during 40 minutes

III. TRANSDUCER CHARACTERIZATION

Once PZT has been poled the d_{33} piezoelectric constant was measured with a Berlincourt tester, and impedance response [measured with a HP 4194A Impedance Analyzer] of the sample has been used to evaluate piezoelectric characteristics of the film. A multilayer KLM model with three layers: substrate, PZT and electrode, was used to calculate impedance on range frequency of 1-10 MHz and get piezoelectric and acoustical parameters adjusting measurements with model. Such techniques are generally used with bulk materials, where thin electrodes do not load the piezoelectric. As can be seen in this case from Figure 1, the PZT is thin enough to be affected, on its higher resonance frequency, by the electrode thickness (~ 5 μm thick) that must be take in account for the KLM model. It follows some characteristics parameters of the film:

Measured Values	*Calculated Values from KLM*
ρ : 6,2 g/cm^3	**C** : 2650 m/s
$\mathbf{K_{33}}$: 340-450	$\mathbf{k_t}$: 0,31
$\mathbf{d_{33}}$: $106 \cdot 10^{-12}$ C/N	$\mathbf{Q_m}$: 42

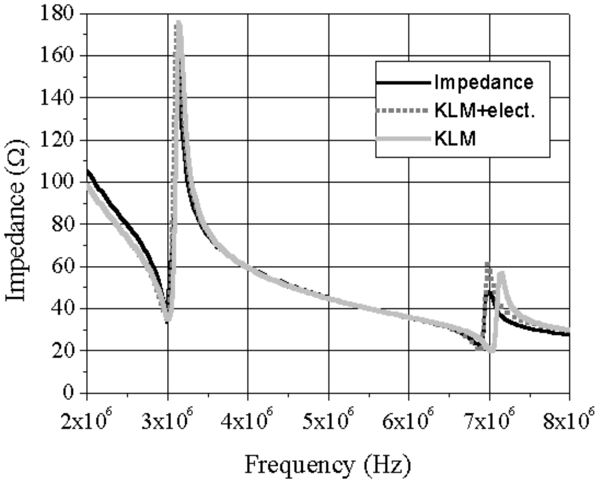

Figure 1: Impedance measurements and KLM model

Each element has two thickness resonance modes, the lower one correspond to the situation in which PZT and substrate vibrates as a whole, and the upper one where the PZT disc vibrates alone.

The acoustic response using acoustic spectroscopy was made exciting PZT film with a continuos signal and measuring pressure amplitude, every 0.2 mm along the sample diameter, with an PVDF hydrophone of 0.4 mm in aperture. Three substrates were basically employed to make test samples: alumina (thickness: 1, 0.635 and 0.235 mm), stainless steel (1 and 0.25 mm) and "Green Tape". On Figures 2 and 3 it can be seen graphics with normalized amplitude response of samples performed over 0.6 and 1 mm thick alumina substrates and 0.25 mm thick stainless steel substrate. It is important to make clear how these elements vibrate because the structure is really a sandwich, very different from bulk transducers.

Acoustic spectroscopy measurements with samples over alumina show that vibration and emission is in thickness mode, with a soft falling at sample electrode edge and outside it because there is non polarized border, also anchored to substrate, used to avoid shortcuts during polarization. Just at the edge can be seen a small emission peak from substrate induced by PZT disc radial movement (Poisson effect). On stainless steel, induced vibration is much more important own to compliance of substrate. This emission was not observed when Schlieren technique in water was used, probably because substrate vibration is strongly dumped by aqueous medium and longitudinal waves generated by thickness mode, far away from the source, are more relevant than the others. We work now in a deeper study of this effect to detect traces of radial waves.

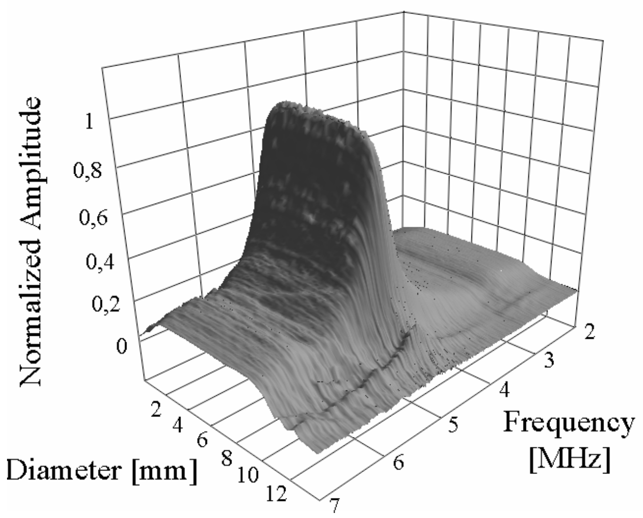

Figure 2: PZT on alumina substrate

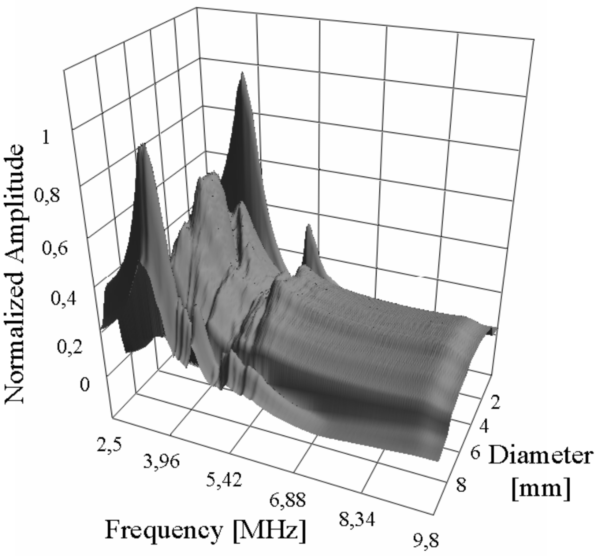

Figure 3: PZT on stainless steel 0.25 thick

Transducer thick film acoustic field in water has been studied by Schlieren. Samples were excited with a 6 Vpp sinusoidal voltage. As can be seen from Figures 4-6, acoustic emission is of high intensity, uniform and with very low divergence.

Acoustic field emitted by a thick film transducer printed on stainless steel can be seen in Figure 4. The curvature of near field fringes shows that it has focalization characteristics, own to electrodes of different size because one of them is the substrate.

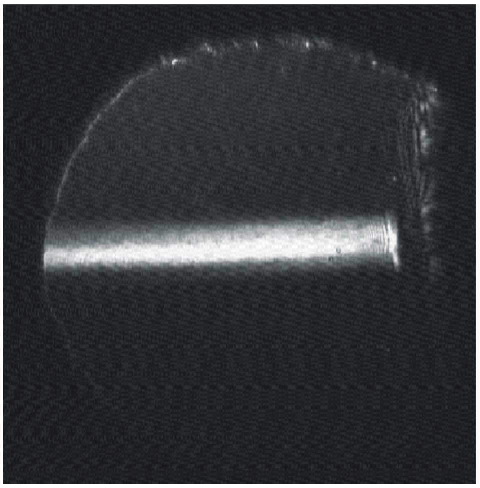

Figure 4: Schlieren image of stainless steel substrate transducer

IV. THICK FILM ARRAY

With the same PZT ink, an array with 16x15 elements was manufactured, each one of which is of 1.5 by 1.5 mm, and a thickness of about 100 μm. Down and top electrodes were performed as orthogonal lines with termination ends at right angles. Each element has a capacity of about 400 pF.

As a low-density structure the acoustic impedance is about half the bulky one. This structure was performed as a first design to test technology possibilities. The size of individual elements can be greatly reduced to use it in imaging instrumentation.

Schlieren Figures 5 and 6 show one element excited of the array, but each picture is for a different resonant frequency. At the lower one, piezoelectric and substrate vibrates as a whole, so there is a strong coupling between elements through the substrate, exciting other array elements. The way to decoupling elements is a problem to be solved. Upper frequency shows a very clean Schlieren figure because only the PZT vibrates.

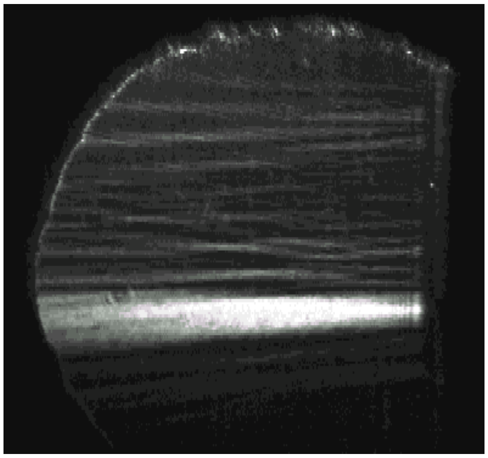

Figure 5: Single element at 4.6 MHz

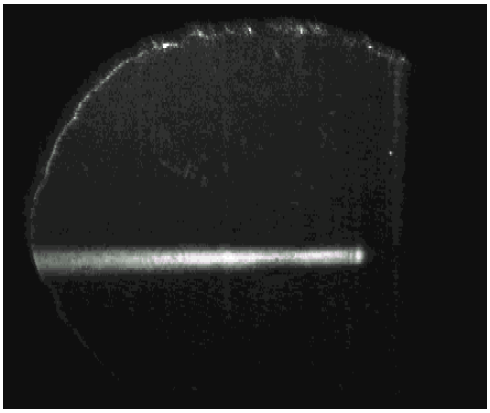

Figure 6: Single element at 7.6 MHz

V. CONCLUSIONS

Thick film PZT elements have many advantages respect bulk ceramics. These technologies allow us to make small elements with high diverse geometry. For the same thickness resonance frequency the film is thinner, so we have lower electrical impedance and, at the same time, lower acoustical impedance own to its porous structure [5]. To take advantage of these properties is important to obtain a composition with higher dielectric constant. The work in this way is ongoing.

The adhesion to different substrates is very good, and increase coupling problems between elements in arrays. It is important to point out that the emission field is powerful compared with bulk ceramics in spite of is less active as piezoelectric.

V. REFERENCES

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Footnote materials:
* Sergio Gwirc e-mail: sng@inti.gov.ar
** Carlos Negreira e-mail: can@fisica.edu.uy