Ultrasonic Array of Thick Film Transducers for Biological Tissue Characterization

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***Abstract*— The initial motivation for this work was to accomplish an easy way to manufacture different geometries of ultrasonic transducers and arrays using a PZT powder, combined with a standard process to have repetitive series of them. The piezoelectric thick film was obtained using a PZT paste and applying it by screen printing on an alumina substrate. Then, the film was drying and sintered with a temperature-time profile determined by the paste characteristics. Each transducer is composed by three layers, one by PZT and two acting as electrodes.**

The active element of the paste is a PZT powder which is dispersed in a commercial vehicle to obtain rheological properties suitable for use the screen printing process. The connection between PZT particles is improved by adding a lead borosilicate frit glass that also helps to attach the film to the substrate due to the relatively low temperature of sintered that has been used in this process. The PZT film has low density that is generated by internal porosity, so its acoustic impedance is lower than for a bulk ceramic transducer and so is well adapted to testing human tissues. At the same time the thick film technology is well suited to make medium size transducers and also arrays performed with tiny ultrasonic transducers.

I. Introduction

THE use of ultrasound as diagnostic tool includes both, the ability to detect failures in industrial materials and identification of biological structures by several techniques that go from the classical ultrasound through the use of high frequency scanning in either A or B modes, arriving to ultrasonic tomography. In all cases it requires high frequency transducers, high reliability and good coupling with the medium under study, allowing the display of deep structures. A good example of the advantages in the use of these techniques in medical applications are advanced atherosclerotic lesions, that are detected by clinical tests such as angiography, exploration of computed tomography, surgical inspection and pathology. These procedures cannot be applied widely in asymptomatic population because they are invasive, or they require the use of ionizing radiations. Arterial images with a not invasive method can be performed via high frequency B-mode ultrasound and can be applied repeatedly to the same subjects to monitor the development of atherosclerosis. It is important in this case the ultrasound methods, to allow the direct assessment of the role of the arterial wall. Both, the wall thickness and diameter of lumen, that are essential to assess the severity of the atherosclerotic process and its progress, can be measured.

Bidimensional MUT (Micromachined Ultrasonic Transducers) arrays can be easily made with excellent reproducibility by using micromachining techniques and were investigated intensively for the last 10 years. They offer advantages of improved bandwidth, easy fabrication of large arrays with compact designs and integration with support electronics, but they already have to probe its utility and reliability with frequencies used for medical diagnostic [1], [2]. On the other hand, making arrays of PZT transducers by dicing and connecting individual piezoelectric elements is full of difficulties and is expensive, not to mention the large input impedance mismatch problem that such elements present to transmit/receiving electronics. Adapt the acoustic and electric impedance must be done almost individually on each transducer, for the emission and reception. An alternative developed in this work is the use of thick film transducers using a piezoelectric PZT layer printed on an alumina substrate [3]. The aim is to use the hybrid thick film technology, that have been used for many years in electronic devices and it is well matured, to make the array and its adaptations for the whole piezoelectric array. In this work, we present the properties for this type of transducers that make possible the achievement of a better image due to its low acoustic impedance, wide bandwidth and better properties of emission and reception that are characterized by an improved use of the energy available in the individual signals and easy assembly of arrays to get ultrasound imaging.

II. Thick Film Transducers

The thick film ultrasound transducer consists essentially of two layers, PZT ceramic, which has significant porosity, and the inert substrate, alumina in this case, over which the film is sintered. Also an internal electrode is added between the film and the substrate, which structurally is part of the latter, together with a top electrode. The PZT layer that forms the transducer element is printed by screen printing using a paste of suitable viscosity, with powder of PZT embedded and a small proportion of 3% in weigh or less of glass in it. The paste is applied using a stainless steel mesh stretched, covered with a UV sensitive emulsion on which the design of the transducer is made [4]. The assembly is sintered at 850 °C, where the PZT paste achieves its final solid structure, and after that an electrode of Ag / Pt (Heraeus C1218) is placed on top. The PZT is polarized over a heating plate at 110 ° C and with an electric field of 3000 V/mm applied on it [3]. With using screen printing is obtained a homogeneous layer of 160 µm in thickness deposited on the alumina substrate. This set is a thin structure that functions as ultrasonic transducer. The thickness of PZT can vary by using several layers of paste, sintered each one separately, between 80 and 250 µm.

The PZT film sintered is a composite material consisting in a matrix of particles of PZT grouped and partially covered by a thin film of glass. T The structure that is obtained using this process has a high degree of internal porosity and its density is approximately 20% lower than for the same type of PZT in traditional bulk ceramic [5]. The method produces a porous structure because from the beginning the PZT particles are not compressed in the vehicle. Drying of the film and then the sintering eliminate the vehicle from the film, but there is no process to compact the powder like in the classic sintered in which a high-pressure is applied previously. The low density in the film itself modifies not only mechanical features such as longitudinal wave velocity, but also its electrical and piezoelectric properties [6]. As a result the acoustic impedance of the transducer is of about 16 MRayl, much lower than in the bulk ceramic used in systems images.

In the same way that in a transducer with traditional bulk ceramic, a backing has to be added to the transducer to reduce or eliminate the waves reflected in the rear face of alumina. There it is placed the absorbent backing performed with epoxy and 45% by volume of ferro-tungsten load, for approximate the acoustic impedance of the substrate. Finally, the electrical behavior of the transducer is adjusted so that its electrical impedance at resonance is equal to the electrical generator, usually 50Ω.

The construction itself of thick-film transducers implies the existence of two resonant frequencies in thickness mode. Roughly, one of them is of the classic ceramic plate with acoustic symmetric load on both sides, in which the acoustic power is emitted in odd multiples of half wavelength. On the other hand, the substrate acts as rear load of PZT disk and therefore their emission nearly refers to a plate that has an infinite load on one side and very low the other one, enabling frequencies given by odd multiples of $\lambda/4$. However, the substrate is not absolutely rigid and its thickness is finite, only a little larger than the piezoelectric film under consideration and the emission, in odd multiples of half wavelength, remains visible but its value is approximate. This is an integrated multi-layer system, which differs somewhat of the oscillating piston type considered basic in the classic case of PZT ceramic disk [7], [8].

III. Acoustic Pulsed Response

The acoustic and electric impedance is always important in the pulsed behavior of an ultrasonic piezoelectric transducer. For thick film transducers, the acoustic impedance is about one half of that for a PZT bulk ceramic that is about 34 MRayl and the electric impedance at the resonance frequency is very near to the generator impedance, which contributes to the rapid attenuation of the mechanical oscillations. We have got a spectral response with two major resonant frequencies, 3.8 (BW: 6 dB to 0.6 MHz) and 7.8 MHz, clearly defined. The lower frequency in the spectrum coincides with resonance mode of the film in a quarter of wavelength, considering the substrate completely rigid. The resonance at 7.8 MHz is roughly the thickness mode for half wavelength of the thick film material with symmetrical load. This feature, that excites modes of the film in the two types of behavior, is because the limited thickness or lack of rigidity of the substrate gives the possibility to deform it slightly.

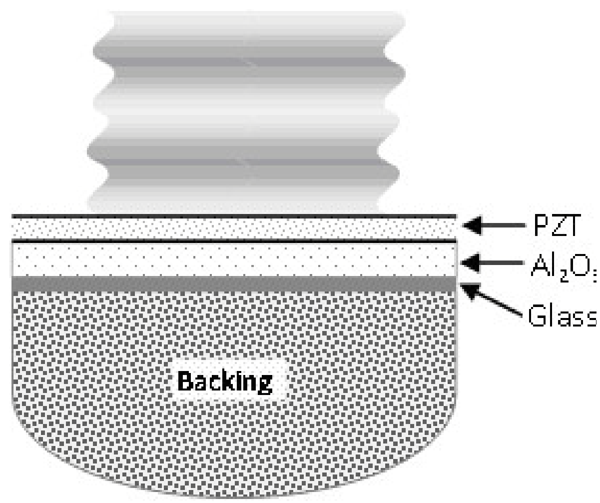

Fig. 1. Structure of a screen printed thick film transducer

The existence of two resonance frequencies in thickness mode which are near between them, it is not the usual behavior of bulk PZT ceramic. The ability to have two well-defined frequencies and near between them, enable to use it as multifrequency transducer. This fact helps to achieve a wide bandwidth when you add the backing and also improves the axial resolution of the transducer.

To achieve significant damping in the transducer, it adds an extra layer of paste glass, very thin, the type used in hybrid technology as protective enamel ("*overglaze*") on the free surface of alumina. This last layer is applied during the manufacturing process, before polarizing the film. We used a commercial glass paste, IP9025 from

Cermalloy Heraeus, which was baked at 600 ° C [9]. Over this thin glass layer we placed a traditional backing, with the usual procedure. The glass layer bonded to the alumina is calculated so thin that its thickness does not substantially alter the resonance frequency (Fig. 1). Glass has an acoustic impedance of about 12-15 MRayl, allowing the adaptation of a backing easy to implement. In this way we obtain a bandwidth of almost 2 MHz (50%) with a signal drop of 6 dB for a transducer with central frequency of 3.9 MHz [10].

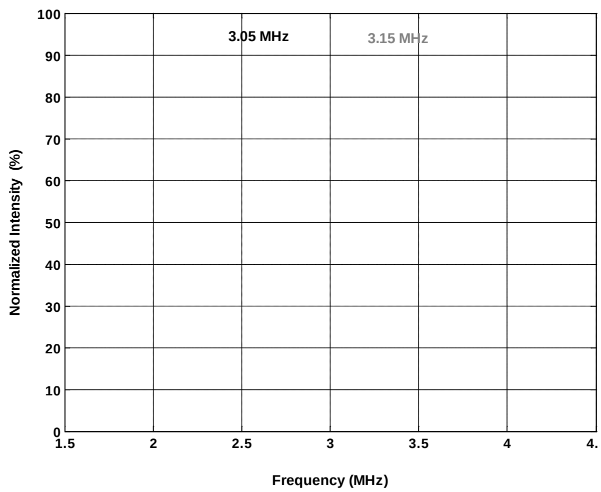

Fig. 2. Comparison of intensity bandwidth, of emission for thick film and bulk ceramic transducers with 3 MHz central frequency.

The bandwidth in intensity was optically estimated using a "schlieren" technique. Figure 2 shows the graph that result from the measurements comparing thick film with the bulk ceramic, both of them without backing. The resonance frequencies are 3.05 MHz for the thick film and 3.15 MHz for the bulk ceramic. This shows that for the same emission frequency, if we consider a 50% fall in intensity, bandwidth in acoustic intensity is notoriously wider for the thick film disk than for the bulk ceramic disk. The value of BW for thick film is 0.76 MHz and the transducer response for bulk ceramic is 0.31 MHz, almost 2.5 times less.

IV. Arrays of Transducers

Using screen printing technology, that is one of the traditional methods used in thick film to print transducers on a given substrate, it is achieved great versatility in the geometry of the transducer but, what is even more important is the possibility to perform two-dimensional arrays of multiple transducers almost with the same facility that for only one transducer, varying also its location into the array quite easily. Because there is a limit in the definition of the thinnest line that can be printed, approximately 100 µm for conductive lines but much higher for other materials, is fairly delicate to make, with PZT, small transducers whose width were less than 1 mm and its borders well defined. However this limitation can be overcome using a laser cut adjusted for this job, for an adequate definition of the limits of the transducer.

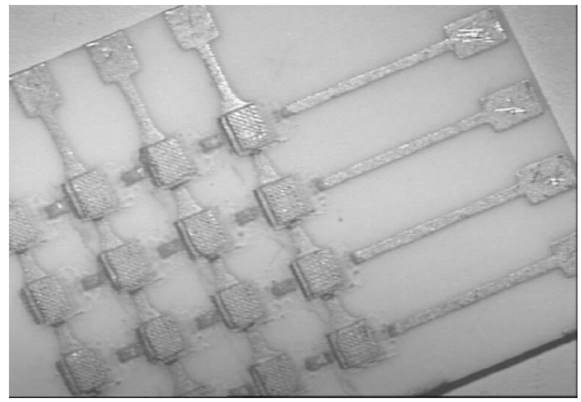

Fig. 3. Image of a 4x4 array and 160 µm thicknesses each element.

The figures 3 and 4 show some alternatives for design of arrays that make use of screen printing. As an example is the application of square elements of 1.5 mm in side, with gold electrodes and very good definition. It is clear that an important factor to make the various layers of the array adjust each other is the alignment for the three layers that make up each elementary transducer, so the register for printing each layer must be very accurate.

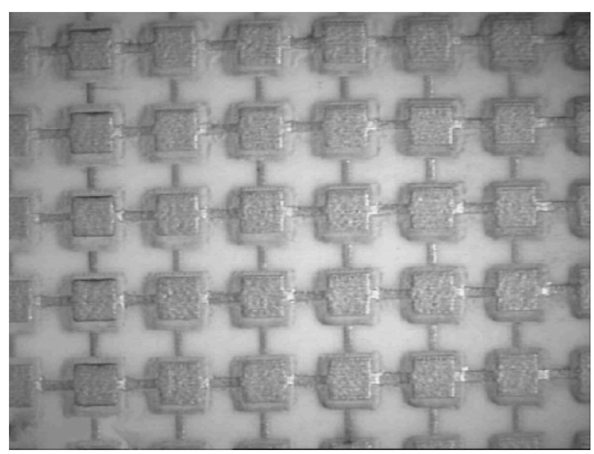

Fig. 4. Image of a section from a 16x15 array. The thickness of each element is about 130 µm.

To highlight the ability of thick-film transducers to generate images of good quality, we prepare a phantom mimicking the acoustic properties of human tissue using agar. It contains two inclusions of 2 mm diameter each one with different density, simulating internal structures, like small tumors. The inclusion located between 35 and 40 mm depth, is about 20% more dense than the medium surrounded , and the closest to the surface, at about 25 mm

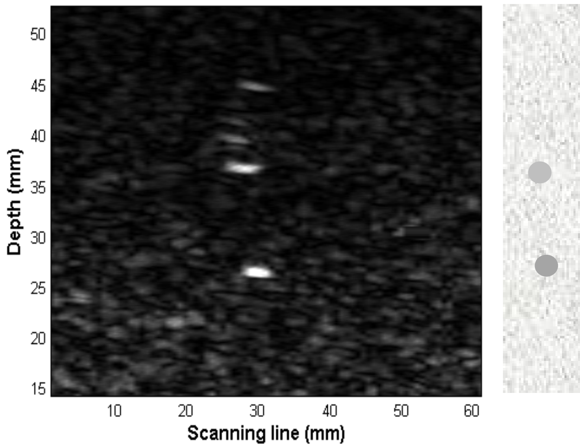

Fig. 5. Image of a phantom mimicking human tissue with tumors.

depth, is 30% denser than the previous one. The gel matrix includes little density variations that simulate real background noise in the medium. On the right side of the figure 5 shows a scheme of the phantom with the location of the two inclusions. By scanning the phantom with the screen printed thick film transducers we have obtained the image of the left side in figure 5. The near field range that contains no reliable information is not shown in the figure [11]. In this case we got an A scan each 0.75 mm. Each sweep is processed with the amplitude of the signal envelope.

The two inclusions are perfectly detected on the noisy background of the gel, as well as the density difference between the two. The size of the inclusions are in good agreement with the central part of the inclusion in the image for the one of higher density, while in the other is somewhat diffuse, but it shows good resolution in both cases taking into account transducers are not optimized.

The assembly of a linear arrangement prepared to perform the measurements listed above can be seen in figure 6.

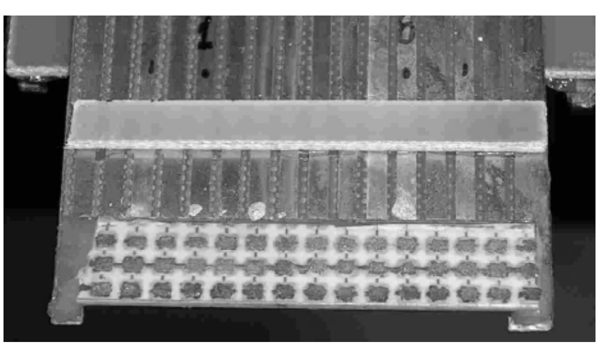

Fig. 6. Picture of the initial sample of a thick film linear array.

V. Conclusion

A new piezoelectric transducer that has:

- Important bandwidth, which may be increased due to the double resonance frequency.
- Good sensitivity due to better impedance matching to biological tissue
- Ability to be used in two frequencies.
- Ability to design different geometries
- Compatibility with hybrid thick film technology to adapt electrical and acoustic impedance.
- Easy interface with electronic in the same substrate.

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