Acoustics'08 Paris
June 29-July 4, 2008
www.acoustics08-paris.org

Integrated transducers for marine animal tags using thick film PZT

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The technology of printing PZT ceramic layers onto curved substrates using pad printing is demonstrated by the application of a transmitter/receiver system printed on alumina cylinders. The cylinder is used as housing for a Data Storage Tag (DST) for marine animals. DST´s are used for monitoring the behaviour and lifecycle of animals, providing valuable knowledge for marine biologists and researchers. Electrodes and PZT ceramic is printed directly onto the alumina housing using the pad printing technique, which eliminates the need for complex assembly procedures and other post processing steps. Since the PZT is situated on the external surface of the housing, direct contact between the acoustic elements and the marine animal is ensured and the elements do not take up valuable space inside the tag. The manufacturing of the active elements and the technology of pad printing PZT thick film is presented. The piezoelectric properties of the film and the acoustic properties have been tested under laboratory conditions. According to the obtained results one can conclude that the transmitter/receiver system was able to assure sufficient sensitivity in the required distance keeping the power consumption at an extremely low level. Second generation devices will be ready for commercialisation in the near future.

1 Introduction

Lately the technology of printing piezoelectric thick film onto various substrates has gained increasing interest because of the possibilities of integrating active structures into micro systems. The material used to accomplish this is Lead Zirkonate Titanate (PZT) which is formulated into a paste suitable for screen printing. In the open literature a few demonstrators have been published where the PZT layer is deposited on a complex structure and the combination constitutes a device [1,2], such as accelerometers, resonators etc. PZT thick film has also been used in the production of high frequency ultrasonic transducers where the thickness resonance of the film is used in imaging systems which operates at frequencies from 20 MHz to 60 MHz [3,4]. The benefit of these devices is higher functionality, smaller size, higher operating frequency, lower production cost etc. In this paper the technology is used in the manufacturing of a device which is complicated to manufacture using conventional production processes.

The Islandic company Star-Oddi develops, produces and markets Data Storage Tags (DTS), which is a micro system intended for use in a marine environment. The system is small in size, it contains several sensors and it has a lifetime of a few years. The DST is used to tag marine fauna, and thereby using the fauna as a mobile measuring station gathering information for researchers. The ultimate coal of this research is to facilitate sustainable utilization of marine resources. The use of a PZT thick film sensor gives researchers an additional tool as will be shown in this paper.

2 Preparation of the test structure

The PZT is printed using a paste formulated from Ferroperm Pz26 powder modified for thick film production. Originally, the paste was formulated for screen printing, but screen printing is not well suited for cylindrical substrates. Instead, the technology of pad printing is used. The paste formulated for screen printing can be used in pad printing with slight modification of the rheological properties. An illustration of the technique is given in Fig. 2.

The paste is filled into an etched pattern in a cliché and excess paste is removed by a doctor blade. Hereafter, the paste is transferred to the substrate by a silicon pad. Since the pad is flexible, the thick film can be deposited onto curved substrates. However, because of this flexibility the pattern will be distorted. For simple structures such as circles this distortion can easily be compensated for, but for more complicated structures and structures where patterns have to be aligned on the substrate the distortion must be taken into consideration.

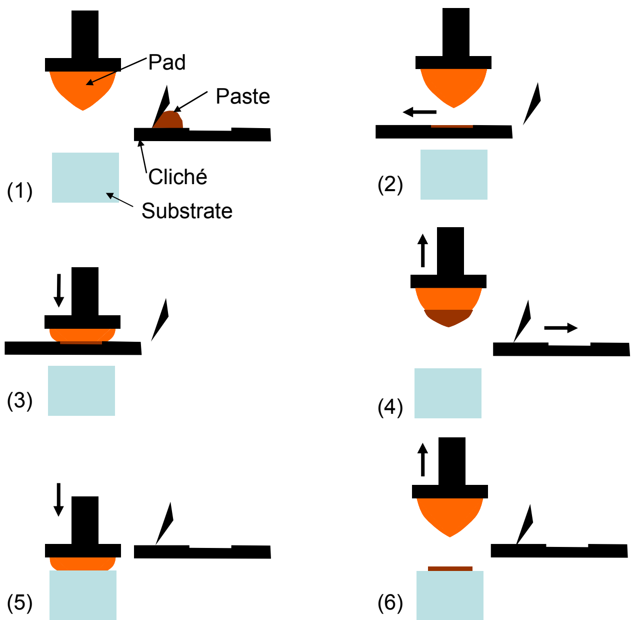

Fig. 1. Illustration of the technology of pad printing.

After printing, the paste is dried in a ventilated oven at about 100 °C. Each pad-printed layer has a thickness of about 1 µm and consequently, several layers are printed in order to achieve the desired thickness. First the gold electrode is printed using a commercially available electrode paste (ESL8880) after which the PZT layer is printed. After printing, the PZT is sintered at 850 °C in a box furnace. For a fired thickness of 50 µm, 70 layers of PZT are printed. Finally the top electrode is printed using a commercially available silver electrode ESL???.

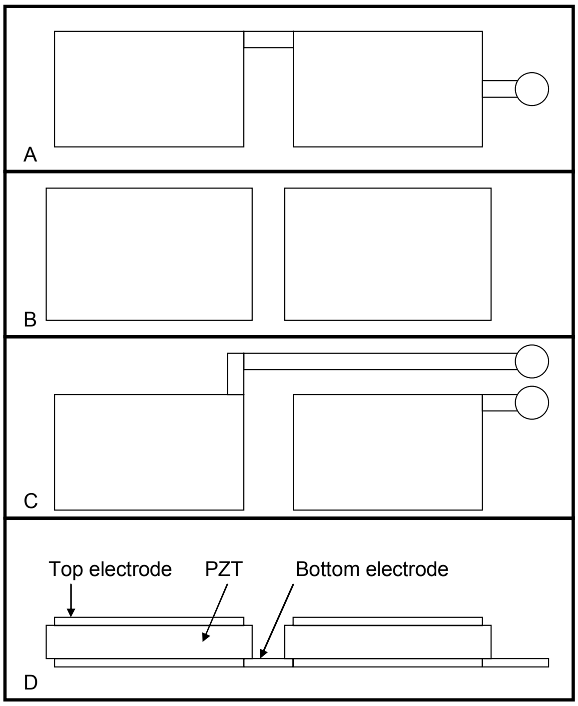

Fig. 2. The layouts of the various layers in the printed structure, A. bottom gold electrode with both elements connected, B. PZT layer, C. top electrode where the two elements are separated and D. which is a cross section of all the layers after printing.

In Fig. 2. the layout of the individual layers are shown. The final structure is divided into two active areas which are electrically connected via the bottom electrode but are electrically separated via the top electrode. Consequently there is one sending and one receiving part of the structure. The two elements are contacted with three contacting pads. One for common ground and one for each of the two elements. The final result can be seen in Fig. 3.

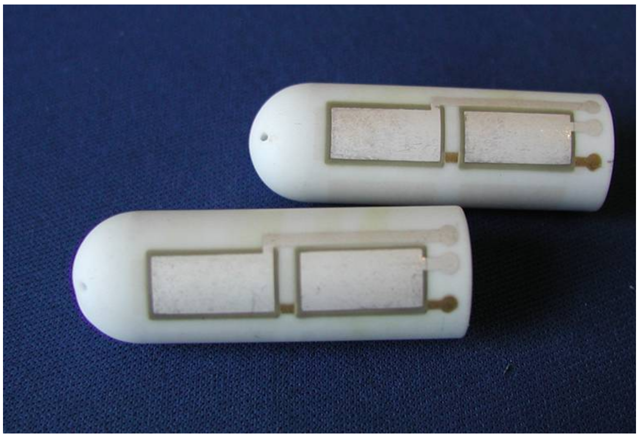

Fig. 3. Picture of the tag with printed PZT thick film elements. The size of the tag is about 30 mm.

When the layered structure is finalised the PZT is polarised in air at 150 °C, for 10 minutes applying a field of 10 kV/mm.

3 Experimental

The characterisation of the device has been performed on two levels. The PZT thick film is quite sensitive to the production process and consequently it is being characterised individually. The characterisation of the final device performance is described in the next section. There are no standard characterisation methods for PZT thick film, but in order to compare the PZT thick film with bulk PZT, two characterisation methods where utilised in this study. This includes impedance spectrum and characterisation of the complex dielectric permittivity at low frequency.

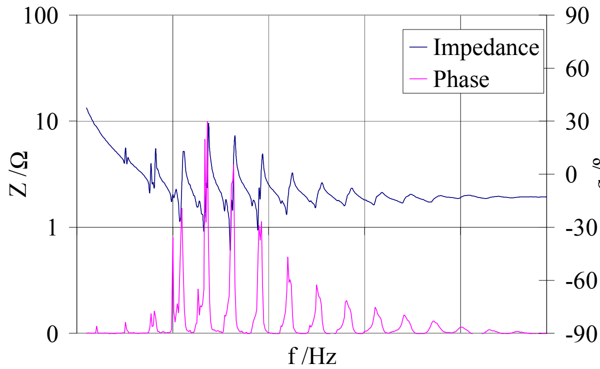

Fig 4. Impedance spectrum of the pads on the device. The scale in the frequency axis is 10 MHz/division.

In Fig 4. The impedance spectrum of the device measured using an Agilent HP4194A impedance analyzer with a high frequency probe is depicted. The response from a capacitor would be a straight line in double logarithmic plot, but here resonances are clearly seen. Each resonance in the impedance spectrum corresponds to a mechanical resonance in the device. The resonances are related to the harmonics in the thickness of the alumina house wall and consequently they are equidistantly spaced. The window from approximately 10 to 25 MHz where the resonances are particularly pronounced is related to the bandwidth of the PZT thick film.

The relative permittivity of the film was also calculated from the measured capacitance. The capacitance of the film after polarisation was measured using an Agilent HP4278A capacitance meter. The measured capacitance was approximately 6.5 nF for one elemnt. With a thickness of 50 micrometers and a surface area of 78 mm^2, this gives a relative permittivity of about 460 which corresponds well with the previously observed permittivity. The dielectric loss, $\tan\delta$ was measured to be 1.7 %. This also corresponds well with the previously observed value.

4 Characterisation of final device

The function of the tag is to record feeding behaviour of fish by measuring the size of the stomach. The DST is placed in the body cavity of fish, positioned between the stomach and the swimming bladder. The swimming bladder is filled with air which gives a good acoustic reflection. The PZT thick film acts as a transducer transmitting an ultrasonic signal and receives the echo reflected from the other side of the stomach. By measuring the time lag between transmitted and received signal the size of the stomach can be calculated.

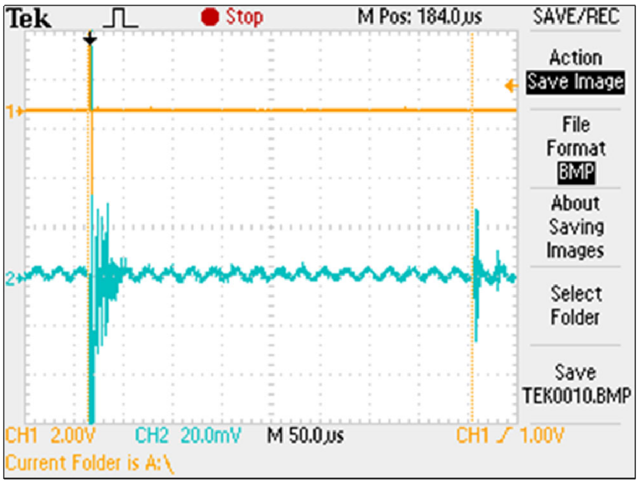

Fig. 5. Time domain plot of the sent and received signal from a PZT thick film transducer printed on a fish tag.

In Fig. 5 the sent and received pulse from the transducer is depicted, indicating the time lag between the two.
The DST is be able to transmit a pulse (< 1W) and receive the low power echo and measure the travelled distance. The sensor was tested on a fish with an intact swimming bladder and the echo was received from the transmitted signal 390 µsec later, assuming that the speed of sound is about 1500 m/s the travelled distance can be calculated. The results are shown in table 1.

Measured distance	Time lag	Calculated distance
20 cm ± 0.5 cm	290µsek±15µsek	21,75cm±1,4cm
30 cm ± 0.5 cm	390µsek±15µsek	29,25cm±1,5cm

Table 1. Measurement results from the test with two different distances. The calculated distance is obtained using a 1500 m/s as the speed of sound in water.

The calculated results from Table 1 correspond well with the measured ones.

5 Results and conclusion

It has proven to be possible to use the pad printing technology to deposit piezoelectric layers on an alumina cylinder used for housing in a DTS, adding functionality to the device. According to the characterisation methods used the film exhibits expected piezoelectric performance compared previous results.

The results from the first sensor prototype show that this method is feasible for the intended application in principle. The design of the sensor geometry can be improved to optimise the utilisation of the transmitted power and increase the sensitivity of the receiver. Modification of the design which will be introduced in the next prototype. The good results from this prototype has given motivation to design and produce a complete experimental DST for use on fish in captivity, as a next step towards developing tags for free swimming fish in nature. It is our believe that this technique will extend the possibilities of monitoring the behaviour and lifecycle of marine animals in the near future.

6 References

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