Hydrophone based on 3D printed polypropylene (PP) piezoelectret

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Every year, different areas of knowledge are becoming more interested in 3D-printing technology. Recently, this technology was also proved to be feasible for creating sensitive materials such as piezoelectrets. This Letter extends the concept of a 3D printed piezoelectret to produce a pressure sensitive film that can be employed as an ultrasonic transducer for underwater applications, such as hydrophones. In order to achieve this, a two-layer polypropylene film was printed using a filament-based 3D printer. Afterwards, adhesive electrodes were attached on both sides of the film and electrical charging was applied. Later, the 3D printed film was mounted in a metal housing specially designed to keep the film in direct contact with the water and to isolate the electronic amplification. The validation was performed using a piezoelectric ceramic made of lead zirconate titanate (PZT), immersed in a water tank, to produce ultrasonic sweeps to be sensed by the 3D printed transducer. These tests revealed sensor sensitivities up to 600 mV and promote a precise detection of the acoustic resonance frequency of the PZT at 43.7 kHz.

Introduction: 3D printing, also known as additive manufacturing process, gained wide prominence in prototyping markets and customised products due to its simplicity in reproducing a computer-aided design model [1, 2]. Nowadays, the usage of 3D printing is extended to electronics [2], medical and dental prostheses [3, 4]. Quite recently, it has been demonstrated that this technology could also be used to produce smart-materials, i.e. materials with additional functionality, such as electro-mechanical response, as it happens with the piezoelectrets [5]. These have proved to be a good alternative for piezo- and ferroelectric films, such as polyvinylidene fluoride mainly because of their polling simplicity, reduced cost and high electro-mechanical activity [6]. Piezoelectrets are also known as ferroelectrets and are materials that consist of films made from electret polymers with internal cavities that are electrically charged [6–8]. The voids, necessary for creating macroscopic electrical dipoles, can be made from foaming processes or thermal moulding methods [6, 9–12]. Normally, this last method is employed when there is a desire for producing piezoelectrets with regular cavities and at the same time, with further advantages such as homogeneous electrical charging and resonance frequency control [12, 13]. Regarding controlled voids, the first 3D printed piezoelectrets were made with very complex structure designs, requiring an additional assembling process after the 3D printing [5]. This Letter presents an improvement, simply by replacing the complex structures with a simple 3D printing process that leaves air gaps between the extruded filaments. Another improvement in the presented 3D printed piezoelectrets concerns the material itself since previously the employed polymer was the acrylonitrile butadiene styrene and this was replaced by polypropylene (PP), which is a much more conventional polymer employed in ferroelectrets. Therefore, it is described as the usage of the 3D printing method for producing piezoelectrets using PP and a functional application of this material as an acoustic sensor for a hydrophone device.

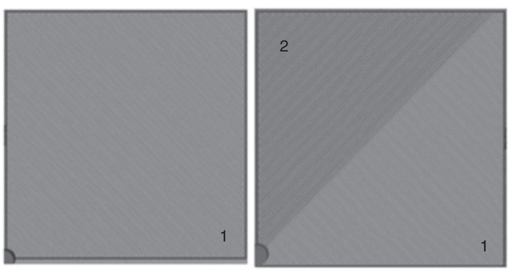

Fig. 1 *3D printing pattern with (1) first and (2) second layers*

Experimental details: 3D printed polypropylene piezoelectrets were produced by printing two layers of extruded filaments being one on top of other in the opposite direction, forming a chess pattern as shown in Fig. 1. After printing, adhesive copper cut in circular shapes was glued on both sides of the film and an electrical charging was applied directly to the electrodes during 10 s using a DC voltage with amplitude of 2.5 kV. The chess pattern adopted in the printing process was responsible for producing air cavities between the layers, which are necessary to form the electrical dipoles of piezoelectrets. Once the piezoelectret was formed, it was mounted inside an aluminium case, containing an electronic amplifier with a gain of 100×, a backing material to improve impedance matching and a sealing ring with an opening of 25 mm of diameter. Fig. 2*a* shows an exploded view of the final device, which was tested in a water environment to operate as a hydrophone. The experimental test was performed according to the schematic setup presented in Fig. 2*b*. The setup was mounted with a function generator (Tektronix AFG3022C) to stimulate a lead zirconate titanate (PZT) piezoelectric ceramic with an acoustic resonance of 40 kHz. The PZT ceramic was placed on one side of an 8 mm-thick acrylic box (with a length, width, and height of 216, 116, and 108 mm, respectively) filled with distilled water. The piezoelectret hydrophone was placed in the opposite direction directly in contact with the water and connected to an oscilloscope (Keysight DSOX 2002A).

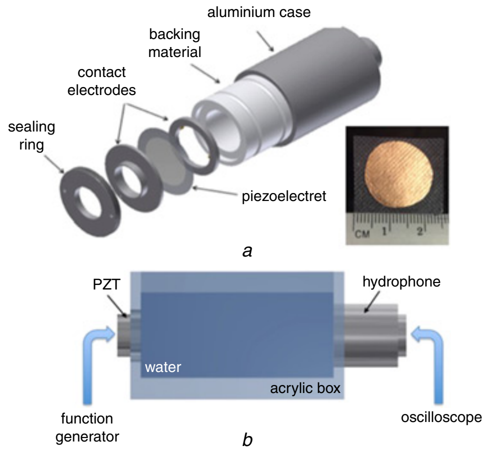

Fig. 2 *Hydrophone based on 3D printed polypropylene piezoelectric and measuring setup*

a Details of hydrophone and 3D printed PP piezoelectret
b Schematic of setup with acoustic emitter (PZT ceramic) and signal detector (piezoelectret hydrophone)

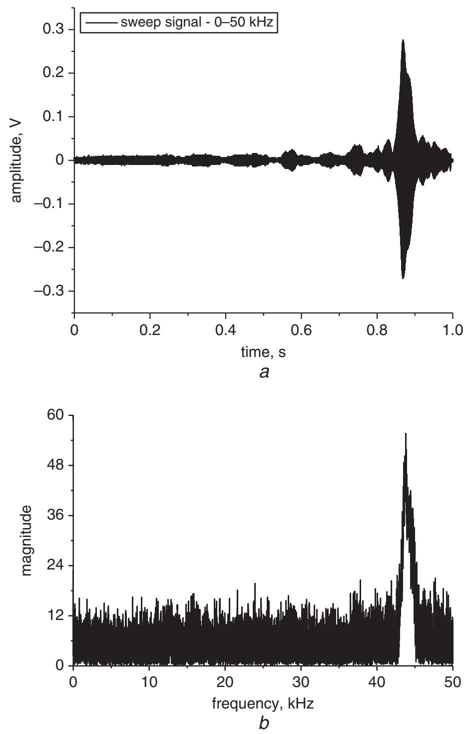

Fig. 3 *Signal recorded with piezoelectret hydrophone during sweep of 1 s. Results in*

a Time
b Frequency domains

After assembling the setup, the function generator was settled in the sweep mode to provide sinusoidal waves of 10 V_{pp} with frequencies from 1 μHz up to 50 kHz during 1 s. Five measurements were performed in this mode to verify the reproducibility. From this, it was found that the piezoceramic presents a resonance at 43.7 kHz. This frequency was used as a reference to determine the maximum sensitivity of the hydrophone in a direct measurement, stimulating the PZT with a 10 V_{pp} sinusoidal wave.

Results and discussion: Figs. 3*a* and *b* present the average results from five measurements in the sweep mode, in the time domain and in the frequency domain, respectively. Fig. 4 presents the signal detected by the hydrophone, using the 43.7 kHz stimulation, where it is possible to observe the maximum sensitivity of the hydrophone.

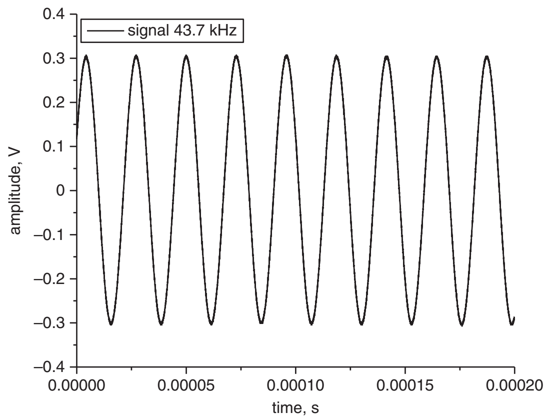

Fig. 4 *Signal detected by piezoelectret hydrophone when stimulated with PZT at resonance frequency (43.7 kHz)*

Conclusion: This Letter presented a functional application using 3D printed piezoelectrets. In general, it consists of a hydrophone, which is composed by its electronics and a polypropylene piezoelectret that was fully printed in a 3D printer. The measurements revealed a final device with a sensitivity of 600 mV and able to precisely detect the acoustic resonance of a PZT ceramic, which according to the manufacture was around 40 kHz. The main conclusion of this Letter is the viability of producing functional piezoelectrets through 3D printing technology using a very simple structure's design.

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One or more of the Figures in this Letter are available in colour online.

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