Capacitance, Quality Factor, and Magnetic Field Influence on Magneto-Piezoelectret Thermoformed

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Abstract—This integrated study presents a thorough investigation into a novel class of electrets known as Magneto-Piezoelectret Thermoformed (MPT) devices. The research focuses on evaluating capacitance, quality factor, and the impact of magnetic fields on these devices. Fabricated by fusing fluoroethylene propylene (FEP) films and integrating magnetic strips, the MPT devices exhibit both magnetostrictive and piezoelectric effects in response to external magnetic fields. The study encompasses the latest advancements in material synthesis, fabrication techniques, characterization methods, and potential device applications. Measurements conducted under various electric currents and frequencies revealed that higher capacitance values are associated with increased electric charge storage in MPT devices. The devices demonstrated exceptional quality factors, particularly in the MHz range, suggesting their potential as efficient electric charge storage devices. Further investigation focused on the influence of magnetic fields on the magneto-piezoelectric response of MPTs. Thermoformed piezoelectrets, featuring open tubular channels and an additional magnetic layer, were explored for their potential as sensors for detecting magnetic fields. While the magneto-piezoelectric response exhibited linearity in the presence of magnetic fields, a decrease in charge storage capacity was observed due to mechanical stress on the tubular channels. The MPTs displayed a maximum resistance of approximately 0.75 T against magnetic fields, reaching complete saturation at a magnetic field strength of 0.8 T. Beyond this point, the relationship between variables became nonlinear, resulting in a null magneto-piezoelectric response. This comprehensive study contributes to a deeper understanding of the capacitance, quality factor, and magnetic field influence on Magneto-Piezoelectret sensors. The insights gained from this research have significant implications for potential applications in advanced technologies that demand high-frequency operation and magnetic field detection.

Index Terms—Electrets, Polymers, Piezoelectricity, Magnetrects.

I. INTRODUCTION

In 1885, Oliver Heaviside introduced the term “electret” to characterize dielectric materials that maintain an electric moment subsequent to the removal of an externally applied electric field. In 1919, Mototaro Eguchi made significant strides in the comprehension by successfully creating the first electret. This groundbreaking achievement involved subjecting a thermally heated blend of carnauba and beeswax to an electric field. Eguchi’s formal acknowledgment of electrets, coupled with subsequent observations, unveiled the enduring property of specific dielectric materials. Notably, certain crystals and ceramics were found to retain a permanent electric charge even after exposure to an electric field [1].

Several studies have highlighted the importance of two critical variables in electret production: an activation energy source and a polarization field. An activation energy source refers to the external energy input required to induce specific changes or reactions within a material. The polarization field refers to the applied electric field that aligns or reorients the electric dipoles present in a material. When this material cools, it causes the trapped charges and oriented dipoles to freeze, resulting in permanent polarization [2], [3].

In the early 20th century, advancements in material science and engineering led to further exploration and applications of electrets. The development of synthetic dielectric materials, such as polymers, expanded the possibilities for creating and utilizing electrets in various devices and applications, for example, the piezoelectrets and magnetoelectrets, these materials exhibit a combination of piezoelectric and ferroelectric properties [1], [4].

Porous polymers or polymeric foams, which possess piezoelectric properties, are commonly utilized to produce electrical responses and efficient charge trapping when mechanically stimulated. The designed fabrication processes often include techniques such as foaming, thermally induced phase separation, or solvent evaporation, which create a porous network within the polymer matrix. The porosity is crucial, as it provides an interconnected pathway for charge carriers and allows for efficient charge trapping, affecting the overall electromechanical response [5], [6].

Studies have shown that combining two different polymers...
can enhance the retention efficiency of electrical charges. Advancements in technology, including the development of new materials and techniques and the improvement of equipment, have established a relationship between apparent piezoelectricity and the material’s elasticity. The thermoforming technique, which involves creating an electric field at high temperatures and maintaining it while cooling, is currently employed to trap charges [7], [8].

Cellular polymeric films, such as polytetrafluoroethylene (PTFE) and its copolymer fluoroethylene propylene (FEP), possess inherent properties that enable the formation of microscopic cavities during the lamination process. PTFE is known for its excellent chemical resistance and low friction properties, while FEP exhibits microscopic cavities that enhance its dielectric and thermal stability. These qualities make them suitable for applications in electrical insulation, wire coatings, and biomedical devices [9], [10].

An approach proposed by Altafim (2010) [11] created an FEP matrix with tubular air channels. This piezoelectrics design allows for the construction of structures with multiple layers in an orderly fashion. With this change, it becomes possible to tailor the geometry of the air channels and cavities to meet specific requirements for different applications.

When subjected to such forces, the nanoparticles undergo structural changes or vibrations, which generate an electric potential across their surfaces. Overall, the piezoelectric effects of nanoparticles offer a promising avenue for the development of advanced technologies, including nanoscale sensors, energy harvesting devices, and biomedical applications [12].

Recent research has studied the ability to convert magnetic energy into electrical energy, opening up possibilities for advanced technologies and devices. Defined as a magneto-piezoelectret (MPT) are electrets with both magnetostrictive and piezoelectric properties. When a magneto-piezoelectric material is subjected to a magnetic field, it not only experiences mechanical deformation (magnetostriction) but also generates an electric charge (piezoelectricity), named as magneto-piezoelectric effect (E-ME) [13], [14].

Like the piezoelectric effect, the magneto-piezoelectric effect can be direct or reverse. In direct E-ME, the application of a magnetic field to a magnetostrictive material induces polarization. This mechanical stress interacts with the piezoelectric material, resulting in deformation and the generation of an electric field. With inverse E-ME, magnetization occurs in the magnetostrictive material when an electric field applies to a piezoelectric material [15]–[17].

In recent years, significant progress has been made in the synthesis, characterization, and application of piezoelectrets and magnetoelectrets. Researchers have focused on developing new materials and fabrication techniques to enhance their performance, stability, and reliability. Additionally, investigations into the fundamental mechanisms underlying their unique properties have contributed to a deeper understanding of these materials and paved the way for further advancements [11], [18].

This paper constitutes an extension of previous research endeavors, focusing on the analysis of a novel class of electrets developed by the authors, denoted as Thermomolded Magneto-Piezelectrets (MPTs). Within this study, we delve into the investigation of capacitance, quality factor, and the influence of magnetic fields with varying intensities on the magneto-piezoelectric response of MPTs. Our objective is to explore recent advancements in material synthesis, fabrication techniques, characterization methodologies, and potential device applications.

Through the systematic analysis of data derived from these experiments, our aim is to attain a comprehensive understanding of the behavior and properties of MPTs under diverse magnetic field conditions. Furthermore, this article endeavors to elucidate the challenges and prospects entailed in harnessing the full potential of these materials for advanced technologies. It significantly contributes to our comprehension of the intricate relationship between magnetic fields and magneto-piezoelectric responses, thereby paving the way for potential applications in fields such as sensing and energy harvesting.

II. MATERIALS AND METHODS

A. Materials and characterization of Magneto-piezoelectrets Thermoformed (MPTs)

The materials and methods employed in the fabrication of the Magneto-Piezoelectret Thermoformed (MPT) devices are elucidated herein. Two fluoroethylene propylene (FEP) films, each possessing a thickness of 50 µm, are subjected to fusion through a lamination machine to configure a multilayer structure.

Preceding the lamination process, a polytetrafluoroethylene (PTFE) template featuring rectangular perforations is interposed between the FEP layers. This template is strategically designed to create four uniformly spaced channels, each measuring 2.0 mm in width and 100 µm in thickness.

The rectangular apertures in the PTFE template facilitate the fusion of the FEP films. Subsequent to the completion of lamination, the template can be readily removed, yielding precisely defined tubular channels. This removal is feasible due to the higher melting point of PTFE compared to FEP.

Subsequently, each channel undergoes a covering process with a magnetic layer, a laminated product by Fermag-BR primarily composed of magnetic ferrite and vinyl rubber, possessing a thickness of 0.3 mm. The magnetic layer is precisely cut to dimensions of 1.5 mm x 15 mm. To ensure thorough coverage, a third FEP film is overlaid on the magnetic stripes and subsequently laminated at 280°C. Following the removal of the PTFE template, the insertion of aluminum electrodes is performed. For a better understanding of the characterization, Figure I(a) exemplifies the schematic design of each material layer in the MPT, and Figure I(b) depicts the actual MPT used in the measurements.

The MPTs were then charged electrically for 10 seconds using a DC voltage of 3.5 kV. By applying an external magnetic field, the magnetic coating on the MPTs shape electrically charged channels, generating an electrical signal. The external force applied is now in the shape of a magnetic field generated by an electromagnet, rather than a mechanical force. Therefore, not possible to use the term the piezoelectric coefficient, or piezoelectric response, describes the relationship between the applied mechanical stress and the resulting
electrical charge. In this analysis, we focus on the MPT’s ability to convert the magnetic field into electrical energy. Hence, the term magneto-piezoelectric coefficient or magneto-piezoelectric response is used to enhance the comprehension of the findings.

The MPTs underwent an electrical charging process for a duration of 10 seconds, employing a direct current (DC) voltage of 3.5 kV. Subsequently, upon the application of an external magnetic field, the magnetic coating on the MPTs configured electrically charged channels, thereby generating an electrical signal. It is noteworthy that the external force applied in this context assumes the form of a magnetic field produced by an electromagnet, as opposed to a mechanical force. Consequently, the utilization of terms such as the piezoelectric coefficient or piezoelectric response, which typically characterize the relationship between applied mechanical stress and resulting electrical charge, is not appropriate.

In the course of this analysis, our emphasis is directed towards evaluating the MPT’s capacity to convert a magnetic field into electrical energy. Therefore, the term “magneto-piezoelectric coefficient” or “magneto-piezoelectric response” is employed to accurately characterize and enhance the comprehension of the observed phenomena and findings.

III. ANALYSIS OF CAPACITANCE, QUALITY FACTOR, AND THE IMPACT OF MAGNETIC FIELDS ON THE MAGNETO-PIEZOELECTRIC RESPONSE

A. Capacitance and Quality Factor

Capacitance is a fundamental electrical property of dielectric materials, including electrets. It is defined as the ability of a material to store electrical charge when subjected to an applied voltage. Capacitance is directly related to the amount of charge that can be stored per unit voltage applied across the material [19].

The capacitance of a dielectric material, including electrets, is determined by various factors such as the material’s permittivity, geometric properties, and the distance between the conductive surfaces. Higher permittivity values generally lead to higher capacitance, as the material can store more charge for a voltage [19].

The quality factor is another important parameter used to quantify the energy losses in the material and represents the efficiency with which the material can store and release electrical energy. A higher quality factor indicates lower energy losses and better energy storage capabilities. The quality factor is commonly used in resonant systems, where energy is stored and released in oscillatory cycles. It determines the sharpness of resonance and the selectivity of the system [20].

In dielectric materials, factors such as dielectric losses, internal resistance, and leakage currents contribute to energy dissipation and affect the quality factor. Lower dielectric losses and reduced energy dissipation result in higher quality factors and more efficient energy storage [21], [22].

Understanding the capacitance and quality factor of dielectric materials, including electrets, is crucial for designing and optimizing various electronic devices and systems. By characterizing and manipulating these properties, researchers can explore the full potential of electrets in applications such as sensors, actuators, energy harvesters, and telecommunications devices [23].

To analyze the Capacitance and Quality Factor, the HP LCR Meter Precision 4284A was utilized. This instrument offers a frequency range of 20 Hz to 1 MHz.

Initially, the instrument was calibrated, and then the test probes were connected to the positive and negative terminals of the MPT device. The MPT was exposed to magnetic fields produced by AC electric currents of 10 A, 50 A, and 80 A.

The corresponding magnetic fields to the applied currents were also measured, with frequencies of 20 Hz, 1 kHz, and 1 MHz.

B. Influence of Magnetic Field on the Magneto-piezoelectric Response

The experimental setup for analyzing the influence of high magnetic fields on the magneto-piezoelectric response of the MPT began with a measurement of the magnetic field generated by the MPT’s own magnetic layer. This measurement was conducted using the Gaussmeter F. W. Model BELL 4048 and probe 1917.

Next, an electromagnet was used to generate a magnetic field by passing an electric current through it. The electromagnet comprises a coil of wire wrapped around a core material, typically made of iron or another ferromagnetic material. When an electric current flows through the coil, it creates a magnetic field around it. The schematic drawing of the measurement system is shown in the Fig. 3.

Electromagnet operating ranges were shown in Tab. I.

To determine the electric current applied to the electromagnet coils, a multimeter with a voltage range of 200 mV was utilized. The multimeter was connected in series with a shunt resistance of 0.001 Ω and the voltage measured was across this resistor.

In this experiment, a magnetic field variation of 1.2 T was applied. The MPT was carefully inserted between the Cenco
Fig. 2. Schematic drawing of the measurement system.

TABLE I

<table>
<thead>
<tr>
<th>Voltage (mV)</th>
<th>Electric Current (µA)</th>
<th>Magnetic Field (T)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.15</td>
<td>1.50</td>
<td>0.10</td>
</tr>
<tr>
<td>2.43</td>
<td>2.40</td>
<td>0.20</td>
</tr>
<tr>
<td>6.04</td>
<td>6.04</td>
<td>0.50</td>
</tr>
<tr>
<td>8.99</td>
<td>8.99</td>
<td>0.75</td>
</tr>
<tr>
<td>9.73</td>
<td>9.73</td>
<td>0.80</td>
</tr>
</tbody>
</table>

The air inside the channels acted as the insulating material between the FEP layers. Air has a dielectric strength of $3 \times 10^6$ V/m, which means that this is the maximum value it can withstand without becoming a conducting medium inside the MPT channels, thus preserving the ability of the MPT to store electric charges.

The capacitances and quality factors were measured when the MPT terminals were connected to the RLC Meter at a specific voltage ($V_m$) given in Volts ($V$), an electric current ($I_m$) given in Amperes ($A$), and a frequency ($F$) given in Hertz ($Hz$). The results obtained for the first experimental trial, where the MPT was already connected to the RLC Meter and positioned near the secondary wire of the Current Transformer with variable current flow at 10 A, are presented in Table III.

The results obtained for the second experimental trial, where the MPT was already connected to the RLC Meter and positioned near the secondary wire of the Current Transformer with variable current flow at 50 A, are presented in Table IV.

The results obtained for the third experimental trial, where the MPT was already connected to the RLC Meter and positioned near the secondary wire of the Current Transformer with variable current flow at 80 A, are presented in Table V.

When subjected to a potential difference, the MPT created an electric field, which consequently caused the FEP layers separated by the channels to be charged with the same magnitude of charge but with opposite directions, one negatively charged and the other positively charged.

IV. Results and Discussion

A. Capacitance and Quality Factor Analysis

The values of electric charges and magnetic fields obtained for each selected electric current are exemplified in Table II where the electric current is given in Amperes ($A$), the magnetic field in Gauss ($G$), and the electric charge in Coulombs ($C$):

TABLE II

<table>
<thead>
<tr>
<th>No.</th>
<th>Electric Current (µA)</th>
<th>Magnetic Field (G)</th>
<th>Electric Charge (pC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st</td>
<td>10</td>
<td>2.20</td>
<td>68.64</td>
</tr>
<tr>
<td>2nd</td>
<td>50</td>
<td>9.50</td>
<td>11.27</td>
</tr>
<tr>
<td>3rd</td>
<td>80</td>
<td>15.20</td>
<td>15.32</td>
</tr>
</tbody>
</table>

Bringing the MPT device close to the magnetic field produced by AC electric current was necessary for the compression and expansion of the channels. In this context, the 10 A current was chosen as the minimum value to meet the sensitivity of the MPT, while the 80 A current was selected as the maximum supported by the MPT without compromising linearity. The choice of a 50 A current was made randomly to assess the MPT’s response at an intermediate point between the minimum and maximum applied currents. The magnetic field and electric charge values were measured in proportion to the applied current.
According to the results, it is confirmed that the higher the capacitance, the greater the electric charge stored in the MPT. This experimental trial confirmed that the MPT, in the developed configuration, is an excellent device for storing electric charges, and at high frequencies, in this case, in MHz, it exhibits an outstanding quality factor.

B. Influence of Magnetic Field on the Magneto-piezoelectric Response Analysis

The MPT was manufactured, and samples were assembled before undergoing a second lamination process. In this process, an additional layer of FEP and a magnetic layer were added to create a unified structure.

After these measurements, the MPT with a magnetic field strength of 0.19 T was used in tests. The MPT was connected to the electrometer and then carefully inserted between the coils of the electromagnet.

Electrical charges in the MPT had linear behaviour, where the highest value got was 13.57 μC for a magnetic field of 0.75 T. But, after the magnetic field was applied at 0.80 T, the MPT became deformed, and the electrometer could not detect any electrical charge.

When a stronger magnetic field was applied, the forces and resulting displacements of piezoelectric cavities exceeded the Hookean limits, also known as elastic limits, which refer to the range of deformation within a material where it exhibits linear elastic behaviour. In this range, the material follows Hooke’s law, which states that the stress applied to a material is directly proportional to the strain it undergoes.

Within the Hookean limits, the material will return to its original shape and size once the applied stress is removed. This behaviour is characterized by a linear relationship between stress and strain, allowing for the calculation of Young’s modulus, which represents the material’s stiffness.

Here, Young’s modulus, suffers an increase in numbers, causing hardening in the FEP and deformations in the geometry of the channels. When the thickness of the channels decreases, the mechanical stress that acts mainly on the structure of the already strongly stretched FEP, instead of compressing the channels creates additional stress that is strongly reducing, bringing on the drastic decrease of the magnetic-piezoelectric response.

Thus, the forces and displacements exerted on the MPTs exceeded Hookean limits, and caused them to undergo plastic deformation, which means it will undergo permanent changes in shape or size even after the stress is removed. The linear relationship between stress and strain no longer holds, and the material exhibits non-linear behavior, as shown in Table VI.

Therefore, the MPT loses its electrical charge storage properties when exposed to a magnetic field greater than 0.75 T, as a magnetic field of 0.80 T causes saturation or collapse of the open-tubular channels.

To enhance the description of the relationship between variations in electrical charge in ferroelectrets and the external magnetic field, we introduce a piezoelectric-magnetic coefficient (d\textsubscript{p-m}). This coefficient is derived from observations in traditional piezoelectric materials, where polarization can be detected along different orthogonal axes, represented by a three-dimensional tensor (d\textsubscript{ij}) [14], [24].

In ferroelectrets, electric polarization \( \vec{P} \) arises from electrical charging, occurring in the direction of the external electrical field, specifically in the out-plane direction, referred to as the third axis. Since mechanical deformation or electrical stimulation is applied in this direction, the d\textsubscript{33} tensor is commonly used to define the piezoelectric coefficient in ferroelectrets [3].

The d\textsubscript{33} coefficient is expressed in (1), representing the relationship between a mechanical stress variation (\( \Delta\sigma \)) applied perpendicular to the ferroelectret thickness (out-of-plane direction) and the variation in electrical charge densities (\( \Delta p \)) induced on the ferroelectret electrodes [14], [24].

\[
d_{33} = \frac{\Delta\sigma}{\Delta p} \tag{1}
\]

In thermoformed magnetic-piezoelectrets, the same concept is applied, but the mechanical stress now results from the presence of an external magnetic field. It is redefined in (2) as the variation in the external magnetic field (\( \Delta m \)), providing the magnetic-piezoelectric effect (d\textsubscript{p-m}).

\[
d_{p-m} = \frac{\Delta m}{\Delta p} \tag{2}
\]

The magnetic layer attached to the open-tubular channels, when subjected to an external magnetic field, electrically overloaded the channels, thus creating the magnetic-piezoelectric response. The mechanical tension exerted by the magnetic field, when high, causes a decrease in linearity in the MPTs. As described in [25], for higher compression levels, the magnetic-piezoelectric coefficient, instead of increasing, decreases.

TABLE VI

<table>
<thead>
<tr>
<th>Magnetic Fields</th>
<th>Electrical Charges</th>
<th>Magnetic-piezoelectric Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.10 T</td>
<td>1620 μC</td>
<td>16200 pC/T</td>
</tr>
<tr>
<td>0.20 T</td>
<td>3720 μC</td>
<td>184600 pC/T</td>
</tr>
<tr>
<td>0.50 T</td>
<td>9060 μC</td>
<td>181200 pC/T</td>
</tr>
<tr>
<td>0.75 T</td>
<td>13570 μC</td>
<td>180933 pC/T</td>
</tr>
<tr>
<td>0.80 T</td>
<td>0 pC</td>
<td>0 pC/T</td>
</tr>
</tbody>
</table>

V. Conclusions

This paper presented a highly innovative approach to investigating and understanding the optimization and the physical operating principles of the MPT developed by the authors. The construction technique employed channels with five layers, which effectively explored the magnetostrictive and piezoelectric responses of the materials to their maximum potential.

The magnetic layer, when subjected to an external magnetic field, electrically overloaded the channels, thus creating a response. The combination of piezoelectric and magnetic effects led to the proposition of the name: magnetic-piezoelectric coefficient. The deformation experienced by the magnetostrictive phase, induced by the magnetic field, was elastically transmitted to the piezoelectric phase through their coupling. Consequently, the mechanical load was then transmitted through oscillations.
However, it is important to note that this effect differs from the traditional magnetoelectric behaviour, since no magnetic field was applied during the polarization of the MPT. Instead, the polarization was achieved through direct electrical charging (dielectric barrier discharges), and the additional magnetic layer attached to the channels resulted in the electromagnetic response.

Through experimental measurements using an LCR Meter, the capacitance and quality factor of the MPT devices were evaluated under different electric currents and frequencies. The results demonstrated that higher capacitance values corresponded to increased electric charge storage in the MPT. Furthermore, the MPT devices showed excellent quality factors at high frequencies, particularly in the MHz range.

The findings of this study confirm that the developed MPT configuration serves as a promising device for the efficient storage of electric charges. These materials hold great potential for advanced technologies, especially in applications that require high-frequency operation. Further research and development are warranted to explore the full capabilities of these electrets and address challenges that arise in their practical implementation.

The maximum magnetic field the MPTs could withstand was determined to be approximately 0.75 T. However, total saturation was observed at a magnetic field of 0.80 T. Beyond this point, the relationship ceased to be linear, and the magnetic-piezoelectric coefficient became zero.

The developed MPT showed its capability to detect the electromagnetic field generated by an electromagnet. This magnetic effect induced an electrical charge in the piezoelectric layer, thus validating the MPT response. As a result, the additional magnetostrictive material layer not only optimized the piezoelectricity in the MPT, but also enabled them to exhibit optimal magnetic-piezoelectric coefficient in response to external magnetic fields.

The results from experimental tests, which aimed to characterize the sensitivity of the MPTs, revealed that the electromagnetic charge in this configuration exhibited a linear relationship with the observed magnetic fields. However, when exposed to high magnetic fields generated by the electromagnet, this linear relationship diminished.

During the experimental investigation, typical challenges were encountered, such as interference from materials and measuring equipment. To mitigate these interferences to the greatest extent possible, all electrical and magnetic components were shielded with thin aluminum and PVC films. Furthermore, rigorous calibrations were conducted for all measurement instruments, ensuring the accuracy and reliability of the obtained results.

In conclusion, this study contributes to the understanding of electrets and opens avenues for further exploration and utilization of their unique properties in various technological applications, such as monitoring energy distribution in off-grid systems and providing a robust assessment of distribution conditions. Additionally, these sensors can play a pivotal role in magnetic energy harvesting, contributing to the development of low-power energy devices. The successful fabrication and characterization of the MPT devices provide a solid foundation for future research and development in the field of electrets and related materials.

REFERENCES


R. A. S. Moreira completed his Ph.D. in Mechanical Engineering in 2005 at the University of Porto, Faculty of Engineering. He also holds a Ph.D. in Mechanical Engineering in 1997 from the University of Porto, Faculty of Engineering. In addition, he earned a Master's degree in Mechanical Engineering with a specialization in Structures in 1997 and another Master's degree in Mechanical Engineering in 2005, both from the University of Porto, Faculty of Engineering. Dr. Moreira obtained his Bachelor's degree in Mechanical Engineering in 1995 and another Bachelor's degree in Mechanical Engineering in 1994, both from the University of Porto, Faculty of Engineering. He is currently an Associate Professor at the University of Aveiro, Department of Mechanical Engineering. Dr. Moreira has authored 9 books and has supervised 1 doctoral thesis and 9 master's dissertations. He has received 2 awards and honors for his work. In his professional activities, he has collaborated with 2 colleagues on co-authored scientific papers. In his Curriculum Vitae, the most frequent terms in the context of his scientific, technological, and artistic-cultural production are Engineering and technology.

R. A. P. Altafim was born in Ribeirão Preto—SP, Brazil in 1982. He received a B.Sc. degree in informatics in 2003, from the Computer Science and Mathematical Institute (ICMC), University of São Paulo (USP). In 2006, he received his master degree in electrical engineering from the Electrical Engineering Department of USP, working on the development of measurement systems for thin piezoelectric films, such as ferroelectrets. In 2010, he obtained a Ph.D. degree in electrical engineering also from USP, where he worked on the development of piezoelectrets with well-controlled voids made from fused polymer films. He also worked for one year (2009) at the Applied Condensed-Matter Physics at University of Potsdam, Germany, improving his research. After his Ph.D. (October 2010) he performed a post-doc again in Potsdam, working on piezoelectrets. Since 2012, Altafim is Adjunct Professor at the Computer System Department from Federal University of Paraíba – PB, Brazil, where he was one of those responsible for creating the Laboratory of Measurements and Instrumentation (LMI). In 2018, he worked as post-doc researcher at the Electrical and Computer Engineering Department at the University of São Paulo, Brazil, doing research on 3D printed piezoelectrets and applications.

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