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# Design and Working of Hydrophones Used In Sonobuoys and Under Water Vehicles

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**ABSTRACT:** A Sonobuoy is an expendable sonar system that is dropped/ejected from aircraft or ships conducting anti-submarine warfare or underwater acoustic research. The hydrophones play an important role in Sonobuoys by listening or recording the acoustical sound. Hydrophones are based on the piezoelectric transducer which generates electricity when subjected to the pressure change. The existing hydrophones use Lead Zirconate Titanate (PZT) as piezoceramic materials for transducer. PZT hydrophones are used in the applications of Sonobuoys and some under water vehicles. This project reveals about the Polyvinylidene Fluoride (PVDF) hydrophones. Compared with PZT ceramics, the low density and high compliance of the PVDF films make them a more suitable choice in modal testing, especially for detecting high-frequency modes in flexible or inflatable structures. The synthesis of PZT and PVDF thin films are mentioned. PZT can be synthesized by hydrothermal method and Sol-Gel process and PVDF can be synthesis from roll hot press method. PVDF hydrophones sense only high frequencies. In order to sense both low and high frequencies one face of metal plate is fixed with PZT and other face is fixed with PVDF.

**KEYWORDS:** Sonobuoy, Hydrophones, Lead Zirconate Titanate (PZT), Polyvinylidene Fluoride (PVDF), Sol-gel process, Roll hot press machine

## 1. INTRODUCTION

Sonobuoys use a transducer and a radio transmitter to record and transmit underwater sounds. There are three types of Sonobuoys:

- Passive Sonobuoys
- Active Sonobuoys
- Special purpose buoys.

Passive Sonobuoys use a hydrophone to listen for sound energy from a target. Active Sonobuoys use a transducer to send an acoustic signal and then listen for the return echo off an object. Special purpose buoys provide additional information about the environment such as water temperature, wave height, etc. Airplanes can drop these instruments into the water from altitudes as high as 30,000 feet. A pattern of Sonobuoys can be deployed and used to determine the exact location of a target. Hydrophones use the piezo ceramic materials for the transducers. Usually Hydrophones use Lead Zirconate Titanate (PZT) for its sensitive character. Among piezo ceramic materials it has good sensitivity and its mechanical properties prove its sensitivity but it is not flexible. In this thesis Polyvinylidene Fluoride is replaced in place of Lead Zirconate Titanate. Because PVDF thin films have piezo ceramic properties so that it can be used in hydrophones. PVDF thin films have the flexible character which has more advantage than PZT thin films. This thesis explains about the synthesis of PZT and PVDF thin films. Synthesis of PZT thin films are occurred by hydrothermal method and Sol-Gel method. Various methods are discussed for the synthesis PVDF thin films such that solvent painting, extrusion and spin coating.

## II. HYDROPHONE

A hydrophone is a microphone designed to be used underwater for recording or listening to underwater sound. Most hydrophones are based on a piezoelectric transducer that generates electricity when subjected to a pressure change. Such piezoelectric materials or transducers can convert a sound signal into an electrical signal since sound is a pressure wave. Some transducers can also serve as a projector, but not all have this capability, and may be destroyed if used in such a manner. A hydrophone can "listen" to sound in air, but will be less sensitive due to its design as having a

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good acoustic impedance match to water, which is a denser fluid than air. Likewise, a microphone can be buried in the ground, or immersed in water if it is put in a waterproof container, but will give similarly poor performance due to the similarly bad acoustic impedance match.

## III. PIEZOELECTRIC EFFECT

Hydrophones work on the basic principle of piezoelectric effect. Hydrophones are embedded with piezoelectric transducers. These transducer converts changes in water pressure into an electrical form. The conversion of mechanical vibrations into electrical energy and vice-versa is called piezoelectric effect. The nature of the piezoelectric effect is closely related to the occurrence of electric dipole moments in solids. The latter may either be induced for ions on crystal lattice sites with asymmetric charge surroundings (as in BaTiO<sub>3</sub> and PZTs or PVDFs) or may directly be carried by molecular groups. The dipole density or polarization (dimensionality [Cm/m<sup>3</sup>]) may easily be calculated for crystals by summing up the dipole moments per volume of the crystallographic unit cell.

As every dipole is a vector, the dipole density  $\mathbf{P}$  is a vector field. Dipoles near each other tend to be aligned in regions called Weiss domains. The domains are usually randomly oriented, but can be aligned using the process of *poling* (not the same as magnetic poling), a process by which a strong electric field is applied across the material, usually at elevated temperatures. Not all piezoelectric materials can be poled.

- Piezoelectricity is the combined effect of the electrical behaviour of the material:

$$\mathbf{D} = \epsilon \mathbf{E} \quad \Rightarrow \quad D_i = \epsilon_{ij} E_j$$

where  $D$  is the electric charge density displacement (electric displacement),  $\epsilon$  is permittivity and  $E$  is electric field strength, and Hooke's Law:

$$\mathbf{S} = \mathbf{s} \mathbf{T} \quad \Rightarrow \quad S_{ij} = s_{ijkl} T_{kl}$$

where  $S$  is strain,  $s$  is compliance and  $T$  is stress.

These may be combined into so-called *coupled equations*, of which the strain-charge form is:

$$\mathbf{S} = \mathbf{s} \mathbf{T} + \mathbf{d}^t \mathbf{E} \quad \Rightarrow \quad S_{ij} = s_{ijkl} T_{kl} + d_{kij} E_k$$

$$\mathbf{D} = \mathbf{d} \mathbf{T} + \epsilon \mathbf{E} \quad \Rightarrow \quad D_i = d_{ijk} T_{jk} + \epsilon_{ij} E_j.$$

- In matrix form,

$$\begin{aligned} \{S\} &= [s^E] \{T\} + [d^t] \{E\} \\ \{D\} &= [d] \{T\} + [\epsilon^T] \{E\}, \end{aligned}$$

where  $[d]$  is the matrix for the direct piezoelectric effect and  $[d^t]$  is the matrix for the converse piezoelectric effect. The superscript  $E$  indicates a zero, or constant, electric field; the superscript  $T$  indicates a zero, or constant, stress field; and the superscript  $t$  stands for transposition of a matrix.

- In total, there are 4 piezoelectric coefficients,  $d_{ij}$ ,  $e_{ij}$ ,  $g_{ij}$ , and  $h_{ij}$  defined as follows:

$$d_{ij} = \left( \frac{\partial D_i}{\partial T_j} \right)^E = \left( \frac{\partial S_j}{\partial E_i} \right)^T$$

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$$e_{ij} = \left( \frac{\partial D_i}{\partial S_j} \right)^E = - \left( \frac{\partial T_j}{\partial E_i} \right)^S$$

$$g_{ij} = - \left( \frac{\partial E_i}{\partial T_j} \right)^D = \left( \frac{\partial S_j}{\partial D_i} \right)^T$$

$$h_{ij} = - \left( \frac{\partial E_i}{\partial S_j} \right)^D = - \left( \frac{\partial T_j}{\partial D_i} \right)^S$$

Where the first set of 4 terms correspond to the direct piezoelectric effect and the second set of 4 terms corresponds to the converse piezoelectric effect.

## IV. HOW DOES IT WORKS

Hydrophone device that receives underwater sound waves and converts them to electrical energy. There are special computer programs that analyze these signals. Further this signal can be read on a meter or played through a loudspeaker. Hydrophones are generally two types. They are i) Omnidirectional Hydrophones ii) Directional Hydrophones. Omnidirectional Hydrophones are which records sounds from all directions with equal sensitivity. Directional Hydrophones are which have a higher sensitivity to signals from a particular direction. It increase the sensitivity and the receiving end must be spherical. The advantage of directivity spheres is that the hydrophone can be moved within the water, ridding it of the interferences produced by a conical-shaped element. Multiple hydrophones can be arranged in an array so that it will add the signals from the desired direction while subtracting signals from other directions. The array may be steered using a beam former. Most commonly, hydrophones are arranged in a "line array" but may be in two- or three-dimensional arrangements.

## V. LEAD ZIRCONATE TITANATE

Lead zirconium Titanate is an intermetallic inorganic compound with the chemical formula  $\text{Pb} [\text{Zr}_x\text{Ti}_{1-x}] \text{O}_3$  ( $0 \leq x \leq 1$ ). Also called PZT, it is a ceramic perovskite material that shows a marked piezoelectric effect, which finds practical applications in the area of electro ceramics. It is a white solid that is insoluble in all solvents.

Uses:

PZT-based materials are components of ultrasound transducers and ceramic capacitors, STM/AFM actuators (tubes). PZT is used to make ultrasound transducers and other sensors and actuators, as well as high-value ceramic capacitors and FRAM chips. PZT is also used in the manufacture of ceramic resonators for reference timing in electronic circuitry. In 1975 Sandia National Laboratories was working on anti-flash goggles to protect air crew from burns and blindness in case of a nuclear explosion. The PLZT lenses could turn opaque in less than 150 microseconds.

Commercially, it is usually not used in its pure form, rather it is doped with either acceptors, which create oxygen (anion) vacancies, or donors, which create metal (cation) vacancies and facilitate domain wall motion in the material. In general, acceptor doping creates hard PZT while donor doping creates soft PZT. Hard and soft PZT's generally differ in their piezoelectric constants. Piezoelectric constants are proportional to the polarization or to the electrical field generated per unit of mechanical stress, or alternatively is the mechanical strain produced by per unit of electric field applied. In general, Soft PZT has higher piezoelectric constant, but larger losses in the material due to internal friction. In hard PZT, domain wall motion is pinned by the impurities there by lowering the losses in the material, but at the expense of a reduced piezoelectric constant.

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## VI. POLYVINYLIDENE FLUORIDE

Polyvinylidene fluoride or Polyvinylidene fluoride (PVDF) is a highly non-reactive and pure thermoplastic fluoro polymer produced by the polymerization of vinylidene fluoride. PVDF is a specialty plastic material in the fluoro polymer family. It is used generally in applications requiring the highest purity, strength, and resistance to solvents, acids, bases and heat and low smoke generation during a fire event. Compared to other fluoro polymers, it has an easier melt process because of its relatively low melting point of around 177 °C. It has a low density (1.78 g/cm<sup>3</sup>) compared to the other fluoro polymers. It is available as piping products, sheet, tubing, films, plate and an insulator for premium wire. It can be injected, molded or welded and is commonly used in the chemical, semiconductor, medical and defense industries, as well as in lithium ion batteries. It is also available as a cross linked closed cell foam, used increasingly in aviation and aerospace applications. A fine powder grade, KYNAR 500 PVDF or HYLAR5000 PVDF, is also used as the principal ingredient of high-end paints for metals. These PVDF paints have extremely good gloss and color retention, and they are in use on many prominent buildings around the world, e.g. the Petronas Towers in Malaysia and Taipei 101 in Taiwan, as well as on commercial and residential metal roofing. PVDF membranes are used for western blots for immobilization of proteins, due to its non-specific affinity for amino acids. PVDF is sold under a variety of brand names including KF (Kureha), Hylar (Solvay), Kynar (Arkema) and Solef (Solvay).

### Properties:

PVDF is commonly used as insulation on electrical wires, because of its combination of flexibility, low weight, low thermal conductivity, high chemical corrosion resistance, and heat resistance. Most of the narrow 30-gauge wire used in wire wraps circuit assembly and printed circuit board rework is PVDF-insulated. In this use the wire is generally referred to as “Kynar wire”, from the trade name.

The piezoelectric properties of PVDF are used to advantage to manufacture tactile sensor arrays, inexpensive strain gauges and lightweight audio transducers. Piezoelectric panels made of PVDF are used on the Venetia Burney Student Dust Counter, a scientific instrument of the New Horizons space probe that measures dust density in the outer solar system. PVDF is the standard binder material used in the production of composite electrodes for lithium ion batteries. 1-2% weight solution of PVDF dissolved in *N*-methyl- 2-pyrrolidone (NMP) is mixed with an active lithium storage material such as graphite, silicon, tin, LiCoO<sub>2</sub>, LiMn<sub>2</sub>O<sub>4</sub>, or LiFePO<sub>4</sub> and a conductive additive such as carbon black or carbon Nano fibers. This slurry is cast on to a metallic current collector and the NMP is evaporated to form a composite or paste electrode. PVDF is used because it is chemically inert over the potential range used and does not react with the electrolyte or lithium.

In the biomedical sciences PVDF is used in immune blotting as an artificial membrane, usually with 0.22 or 0.45 micrometres pore sizes, on which proteins are transferred using electricity. PVDF is resistant to solvents and, therefore, these membranes can be easily stripped and reused to look at other proteins, making it very convenient. PVDF membranes may be used in other biomedical applications as part of a membrane filtration device, often in the form of a syringe filter, or wheel filter. The various properties of this material such as heat resistance, resistance to chemicals, corrosion and low protein binding properties make this material valuable in the biomedical sciences for preparation of medications as a sterilizing filter, and as a filter to prepare samples for High Performance Liquid Chromatography and other advanced analytical techniques in which small amounts of particulate can damage sensitive and expensive equipment.

PVDF is used for specialty monofilament fishing lines, sold as fluorocarbon replacements for nylon monofilament. Optical density is lower than nylon, which makes the line less discernible. The surface is harder, so it is more resistant to abrasion and sharp fish teeth. It is also denser than nylon, making it sink faster.

PVDF transducers have the advantage of being dynamically more suitable for modal testing applications than semi-conductor piezo resistive transducers, and more compliant for structural integration than piezo ceramic transducers. For those reasons, the use of PVDF active sensors is a keystone for the development of future structural health monitoring methods, due to their low cost and compliance.

In 1969, strong piezoelectricity was observed in PVDF, with the piezoelectric coefficient of poled (placed under a strong electric field to induce a net dipole moment) thin films as large as 6–7 pC/N: 10 times larger than that

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observed in any other polymer. PVDF has a glass transition temperature ( $T$ ) of about  $-35^{\circ}\text{C}$  and is typically 50–60% crystalline. To give the material its piezoelectric properties, it is mechanically stretched to orient the molecular chains and then poled under tension. PVDF exists in several forms: alpha (TGTG'), beta (TTTT), and gamma (TTTGTTG') phases, depending on the chain conformations as Trans (T) or gauche (G) linkages

## VII. SYNTHESIS

PZT can be synthesis by the Sol-Gel process. The sol-gel process may be described as: "Formation of an oxide network through polycondensation reactions of a molecular precursor in a liquid." A sol is a stable dispersion of colloidal particles or polymers in a solvent. The particles may be amorphous or crystalline. An aerosol is particles in a gas phase, while a sol is particles in a liquid, A gel consists of a three dimensional continuous network, which encloses a liquid phase, In a colloidal gel, the network is built from agglomeration of colloidal particles.

In a polymer gel the particles have a polymeric sub-structure made by aggregates of sub-colloidal particles. Generally, the sol particles may interact by van der Waals forces or hydrogen bonds. A gel may also be formed from linking polymer chains. In most gel systems used for materials synthesis, the interactions are of a covalent nature and the gel process is irreversible. The gelation process may be reversible if other interactions are involved. The idea behind sol-gel synthesis is to "dissolve" the compound in a liquid in order to bring it back as a solid in a controlled manner.

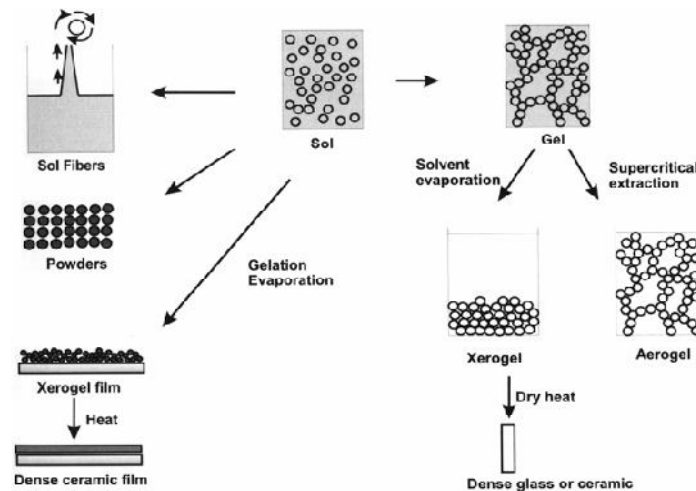


Figure 4-42. Sol-gel processing options.

Multi component compounds may be prepared with a controlled stoichiometry by mixing sols of different compounds. The sol-gel method prevents the problems with co-precipitation, which may be inhomogeneous, be a gelation reaction. Enables mixing at an atomic level. Results in small particles, which are easily sinterable. The sol-gel method was developed in the 1960s mainly due to the need of new synthesis methods in the nuclear industry. A method was needed where dust was reduced (compared to the ceramic method) and which needed a lower sintering temperature. In addition, it should be possible to do the synthesis by remote control. One of the well known examples of a sol-gel system often cited is quick clay. Clay may form a sol (quick clay) if it is washed sufficiently to remove the counter ions. Quick clay may be gelled if enough counter ions are added, so that the colloidal particles aggregate.

Sol-gel synthesis may be used to prepare materials with a variety of shapes, such as porous structures, thin fibers, dense powders and thin films. If the gel is dried by evaporation, then the capillary forces will result in shrinkage, the gel network will collapse, and a xerogel is formed. If drying is performed under supercritical conditions, the network structure may be retained and a gel with large pores may be formed. This is called an aerogel, and the density will be very low. A record is  $< 0.005 \text{ g/cm}^3$ .

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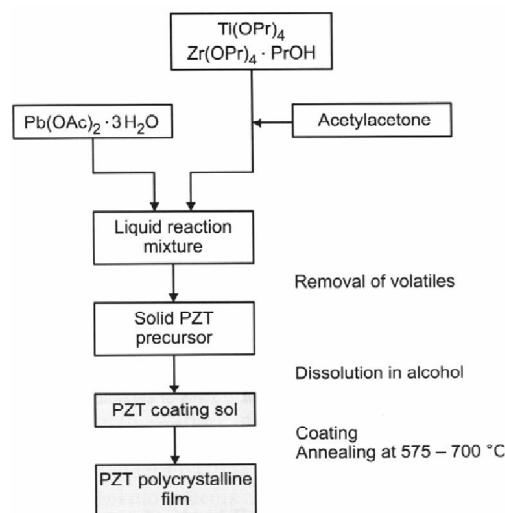


Figure 4-43. Processing steps for the preparation of polycrystalline PZT films.

In this experiments we performed and characterization of PVDF film using such equipment; Roll Hot Press machine. The operating system of the roll hot press machine is very simple compared other methods. Initially, the PVDF samples in powder form were placed on the cylinder engine and then heated until it melts furthermore roll hot press machine is operated to obtain a thin film. The PVDF thin film is perform for several different temperatures and various thicknesses. Film thickness was measured with a micro meter screw, the surface resistivity of film obtained by four point probes, and to determine the crystalline phase is determined from FTIR spectrum and pattern X-Ray Diffraction.

## VIII. RESULT AND DISCUSSION

From the experimental results obtained some pieces sample of PVDF films with various thicknesses for three different temperatures are measured.. XRD pattern of PVDF film with various film thickness, for roll hot press temperature; 140°C, 150°C 160°C are shown in Fig. 1.

As we can see in Fig 1, for fixed temperature the film thickness influence the amount of  $\beta$  fraction, this is caused by the PVDF thin films, will cause the dipole-dipole more properly oriented so that a larger of  $\beta$  fraction .

Theoretically, it is known that the film thickness effect on the surface resistivity of the PVDF films where with increasing PVDF thin films, the smaller the resistivity or otherwise. The lower the resistivity indicates that the greater the of  $\beta$  fraction

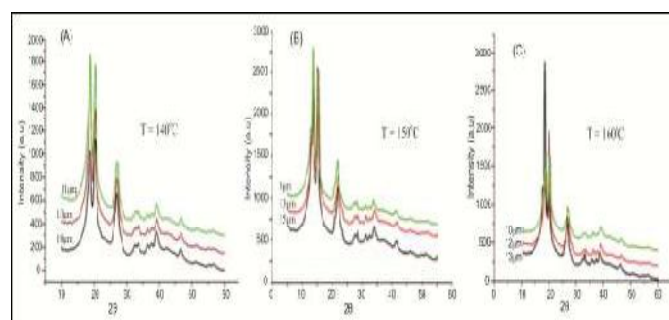


Fig 1: XRD pattern of PVDF film with various thickness for roll hot press temperature: (A). 140°C, (B).150°C (C) 160°C.



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IR spectrum for the PVDF film at a thickness of 13  $\mu\text{m}$  with the variation of temperature 140 $^{\circ}\text{C}$ , 150 $^{\circ}\text{C}$  and 160 $^{\circ}\text{C}$  are shown in Fig. 5. IR spectrum showed an increase of  $\beta$  fraction with increasing temperature, at wave number region of 600  $\text{cm}^{-1}$ . These results are consistent with the results of XRD measurements that have been described previously

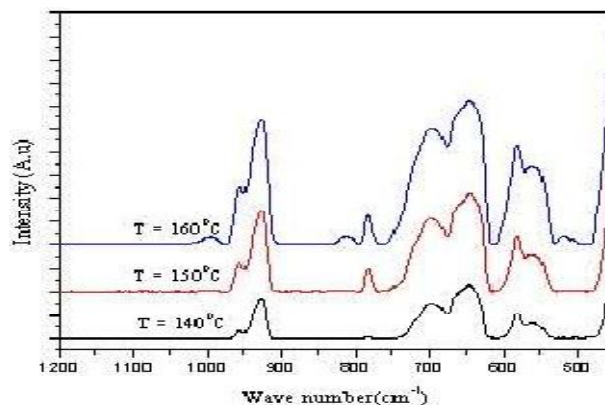


Fig.5. Graph of IR spectrum for sample at film thickness of 13 $\mu\text{m}$  with the variation of temperature 140 $^{\circ}\text{C}$ , 150 $^{\circ}\text{C}$  and 160 $^{\circ}\text{C}$ .

## IX. CONCLUSION

The PVDF thin films have been successfully prepared by Roll Hot Press machine. The increase in temperature causes an increase in polarity due to the dipole orientation resulting in the transformation of the structure occurs. It is characterized by the increase of  $\beta$  fraction. While the temperature increase causes a decrease in the surface resistivity value, which indicates that the properties of piezoelectric PVDF films is improving.

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